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Diversity, composition, structure and canopy cover of mangrove trees in six locations along Bintuni riverbank, Bintuni Bay, West Papua, Indonesia

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Abstract. *Srau M, Bawole R, Marwa J, Sinery AS, Cabuy RL. 2022. Diversity, composition, structure and canopy cover of mangrove trees in six locations along Bintuni riverbank, Bintuni Bay, West Papua, Indonesia. Biodiversitas 23: 5835-5843.* Mangroves provide various benefits of ecological and socio-economic aspects. Such benefits could be delivered if mangrove vegetation is in good condition, indicated by several ecological parameters. This study was conducted to investigate the diversity, composition, structure, and canopy cover of mangrove trees along Bintuni riverbank, Bintuni Bay, West Papua, Indonesia. There were six different locations representing biotic and abiotic conditions. The study only focused on the mangrove tree stage with a total of 175 plots established, of which each plot had a size of 10 × 10 m. The name of mangrove species, tree diameter, total height, and canopy cover percentage was recorded and measured. The result showed that the diversity and composition of mangrove trees varied among the six locations indicated by the importance value index (IVI) parameter. The estuary and sub-estuary areas were dominated by *Rhizophora mucronata*, while in the further area from the estuary toward the land, the dominant mangrove species was *Avicennia* sp. The highest number of mangrove trees was found in Kampung Lama 1 with 989 trees/ha (593 trees in 60 plots) with an average diameter of 18.8077 cm (SD±7.0279) and an average height of 8.9477 m (SD±2.2814). The lowest tree distribution was found in Kampung Masuhi with 940 trees/ha (94 trees in 10 plots) with an average diameter of 15.4787 m (SD±3.8205). The highest average of canopy covers was noted in the sub-river estuary with a percentage of 86.97% (SD±85) and the lowest percentage was in Kampung Masina with 59.89% (SD±124.85). Statistical analysis of variance (ANOVA) showed that there was a significant difference in terms of average tree diameter and height among the six locations with a p-value of 0.00021 < 0.05 at 95% CI. There was a strong positive correlation between tree diameter and height, as indicated by R^2 of 0.69. In addition, a statistical test of analysis of variance from each location was significantly different among these six locations.

Keywords: Bintuni Bay, canopy coverage mangrove forest, structure and composition

INTRODUCTION

Mangroves are unique coastal ecosystems with a total coverage area of 13,776,000 ha globally and are distributed in 118 countries along the equator (Arifanti et al. 2021). Indonesia has the largest extent of mangroves in the world with an estimated 3.2 million hectares or about 25% of the total world's mangrove area (Murdiyarso et al. 2015). Despite the large extent, mangroves in Indonesia also have high diversity with 202 species, consisting of 89 species of tree, 19 species of liana, 5 species of palm, 4 species of epiphyte, 44 species of soil herbs, and 1 species of fern (Kusmana and Sukristijiono 2016), of which 43 species are classified to be true mangrove while the rest are identified as associate mangrove.

Mangrove ecosystems play pivotal ecological roles as the habitat of various flora and fauna living in this ecosystem (Srikanth et al. 2015; Kusmana and Sukristijiono 2016; Carugati et al. 2018). From a socio-economic perspective, mangroves provide various sources of livelihood to communities living around it, from fisheries, building materials, firewood, charcoal products, foods, and medicines to handicraft products (Vo et al. 2012; Suharti et al. 2016). Mangrove forest with high biological diversity is likely to be more productive not only in providing multiple forest products but more than that, in maintaining estuarian water quality which plays an important environmental aspect of living fauna, which in many cases being consumed by humans (Yuliana et al. 2019; Arifanti et al. 2022). Mangroves are also considered important in preventing abrasion and natural disasters, such as tsunamis and storms, as well as capable of absorbing large sea waves. Mangroves forest are also able to protect wetland crops and other coastal vegetation from damage due to storms and salination through a filtration process.

In recent decades, there is an increasing scientific understanding that mangroves are also recognized as one of the key elements in climate change mitigation. Mangroves ecosystem are considered among the largest carbon pools by sequestering more CO_2 in mangrove vegetation and soil than any other terrestrial marine ecosystems (Chen et al. 2016; Alongi 2022; Chatting et al. 2022). In line with

Indonesian government's pledge to reduce emissions by 29% by 2030, mangrove forests are expected to have a major contribution to help the government in achieving that promise (Murdiyarso et al. 2015). This is because Indonesian mangrove forests store 3.14 Pg of carbon (Richards et al. 2015; Roe et al. 2019).

Despite the high biodiversity and vital role in delivering various ecosystem services, a large extent of mangrove forests in Indonesia has been deforested and degraded, including in Papua (Tindit et al. 2017; Murdiyarso et al. 2021; Yudha et al. 2022). The primary drivers of the loss and degradation of Indonesian mangroves include timber extraction, conversion from mangrove forests into aquaculture ponds and salt farming, and infrastructure development, such as for ports, industrial areas and settlements (Iman et al. 2011; Cahyaningsih et al. 2022). The deforestation and degradation of mangrove forest has contributed to the release of greenhouse gas (GHG) emissions of about 0.07-0.21 Pg CO2e, despite it only constituting around 6% of Indonesian total annual deforestation loss (Murdiyarso et al. 2015).

Bintuni area in West Papua Province is considered the second largest extent of mangroves in the world after Bangladesh in which most of the mangrove forests are located as production forests (Murdiyaso et al. 2021). The mangroves in Bintuni area are estimated to have a total extent of 250,000 ha, which are dominantly distributed around the bay area with ± 82,120 ha. There are five true mangrove species considered to be dominant species in the area (Yudha et al. 2021). Timber extraction in the mangrove forests in Bintuni was initiated in the 1980s, occupying a wide range of management areas (Murdiyarso et al. 2021). Due to the high timber potential, a number of logging concession permits have been issued by the government to operate in the bay area of Bintuni (Yudha et al. 2022). Several development agendas are also ongoing in the Bintuni area, adding pressure to the existing mangrove forest. Such anthropogenic activities have changed mangrove forest structure, composition, and zonation along the riverbank area.

Therefore, this study aimed to investigate mangrove tree diversity, composition, structure, and canopy cover along the Bintuni riverbank. This study is important to obtain ecological context and academic perspective of the current state of mangroves in the riverbank of Bintuni. We expected the results of this study might serve as baseline information for monitoring the dynamics of mangrove forests in the area to inform the ecological and socio-economic importance of underpinning sustainability in the Bintuni municipal area.

MATERIALS AND METHODS

Study area

This study took place in Bintuni District, West Papua Province, Indonesia (Figure 1). Data collection was conducted for two weeks in March 2022 along Bintuni riverbank, which was covered with mangrove species. The study area is a lowland tropical forest with a dominant alluvial soil, particularly along the riverbank with substrate sediment rich in deep organic soils (Sasmito et al. 2020). There were six locations for data collection, namely Bintuni river estuary, sub-river estuary, Kampung Lama 1, Kampung lama 2, Kampung Masina, and Kampung Masuhi. The six locations were selected based on mangrove status, the distribution of mangrove covers, tree canopy coverage, and the similarity of ecological attributes (i.e., soil characteristics, relative humidity, temperature, and annual precipitation).

Data collection

A transect line was created to acquire mangrove data with azimuth designed to be perpendicular toward the contour, meaning that data were acquired from the river bank to the mainland. Along the transect, observation plots were established. There was a total of 175 sampling plots established of which each plot had a size of 10 × 10 m intended only to measure vegetation at the tree stage, while other growth stages were not completely covered. The plot was determined based on location characteristics and accessibilities; therefore, plots were not always linear and perpendicular to azimuth.

Within each plot, all mangrove species at the tree stage were recorded and measured. A mangrove key identification book (Mangrove Guidebook for Southeast Asia) was used to identify species names, which then being confirmed by botanists (Giesen et al. 2006). Mangrove tree data and structural tree distributions were acquired by measuring diameter tree breast height using Phi Band and total height using Suunto Clinometer. In addition, the canopy cover (in percentage) at each plot was using Fuji Film X-7 Digital Camera with a perpendicular angle (90°). There were four (4) images taken at each selected plot with four different quadrants (diagonal direction). The images were then analyzed using *Hemispherical Photography Image-J* software in order to acquire the percentage of tree canopy coverage based on the output of color differentiations (Purnama et al. 2020). There was a total of 13 different hemispherical photography images from six different locations.

Table 1. Location and number of plots for data collection along the Bintuni riverbanks, Bintuni District, West Papua Province, Indonesia

Name of location	Location code	Coordinates	Number of plots
River estuary	Location01	2°12'47"S, 133°33'45"E 2°12'55"S, 133°34'43"E	20
Sub-river estuary	Location02	2°11'04"S, 133°34'50"E	10
Kamp. Lama 1	Location03	2°08'04"S, 133°33'03"E	60
Kamp. Lama 2	Location04	2°07'49"S, 133°32'29"E	50
Kamp. Masuhi	Location05	2°06'43"S, 133°31'19"E	25
Kamp. Masina	Location06	2°06'58"S, 133°31'31"E	10
Total			175

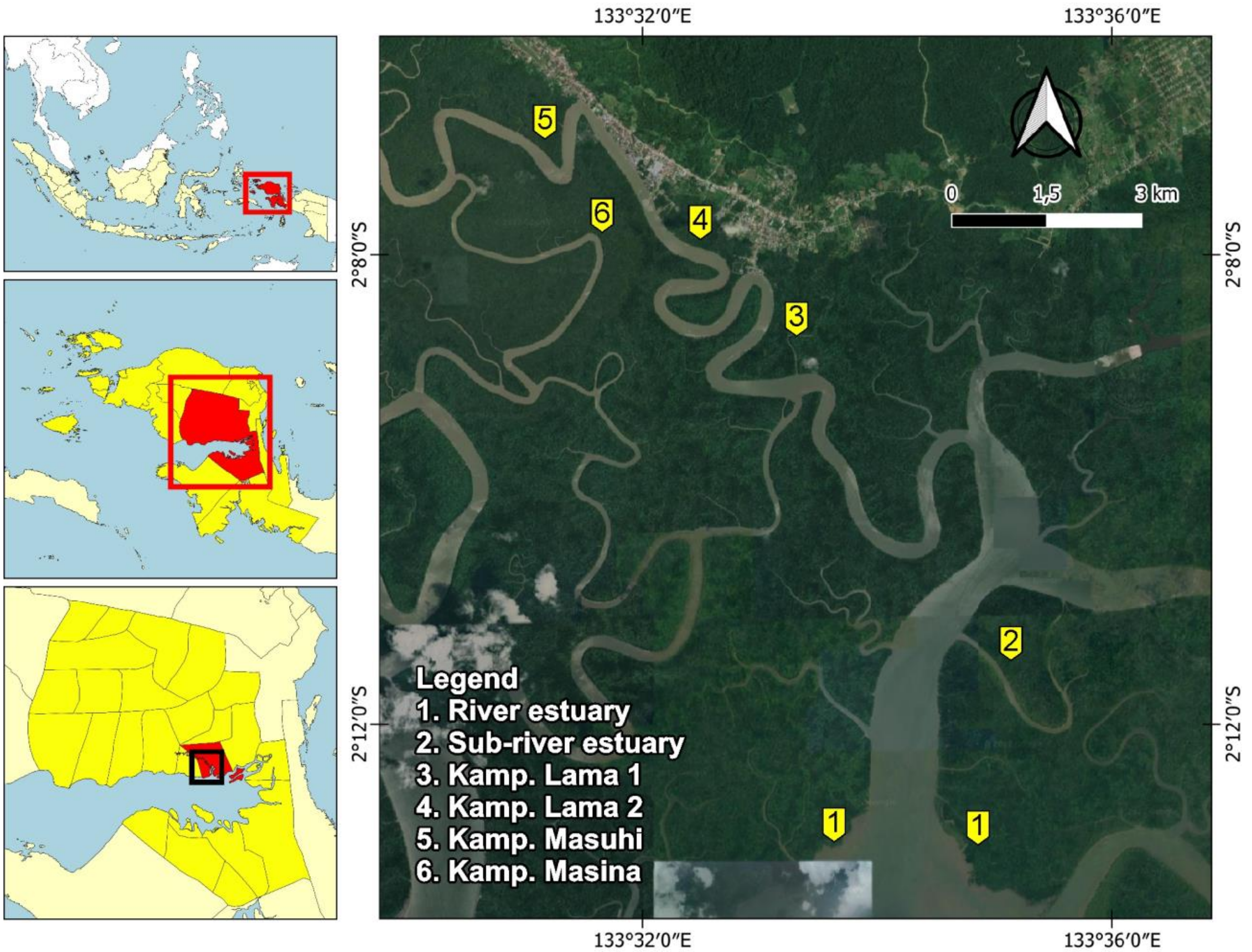

Figure 1. Map of research locations in Bintuni riverbank area, West Papua Province, Indonesia

Data analysis

Tree diameter and total height were recorded into the *tally sheet* and input into MS. Excel for further data analyses and visualization. Mangrove tree dominance at each location was calculated as the Importance Value Index by summing up the relative density (RD), relative frequency (RF) and relative dominance (RDo). A statistical test of ANOVA was performed to test the differences in mangrove tree diameter (cm) and total height (m) among the six different locations. Tukey post hoc test of ANOVA was applied to investigate the most significant difference among the locations using '*multcomView*' and '*dplyer*' packages. In order to see the correlation between the diameter and the total height of mangrove trees in six different locations, multiple linear models were performed using '*tidyverse*' and '*ggplot2*' packages. Data variance distributions among the six locations were also highlighted in individuals-principal component analysis (PCA) using '*FactoMineR*' package (Figure 4). Tree canopy coverages (%) were analyzed using *Image-J* free software by contrasting the color of the mangrove canopy cover and the color of the sky in a pixeled base (Chianucci et al. 2014). ANOVA test was also used to see the most significant correlation among basal area (m^2 ha^{-1}), stem density (tree ha^{-1}), total tree height (m), and tree diameter (cm) on mangrove canopy coverage (%). All statistical analyses were performed using R statistical software (R Core Team 2022).

RESULTS AND DISCUSSION

Mangrove composition and structure

The composition of mangrove trees along Bintuni riverbank varied among the six observation locations based on the importance value index (Table 2). The mangrove forest in the river estuary (Location01) was dominated by *Rhizophora mucronata* (IVI 133.99), while the least dominant species was *Xylocarpus granatum* (IVI 2.39). In the sub-river estuary (Location02), th most dominant mangrove species found was *R. mucronata* (IVI 93.24) and the least dominant species was *Heritiera littoralis* (IVI 2.39). In the Kamp. Lama 1 (Location03), *R. mucronata* had the highest IVI with 107.52, while *Avicennia alba* had the lowest with 0.93. In the Kamp. Lama 2, *Bruguiera gymnorrhiza* (IVI 67.07) turned out to be the most dominant species while the least dominant mangrove species was *Rhizophora stylosa* (IVI 3.40). In the Kamp. Masuhi, *Avicennia marina* had the highest IVI with 103.51, while *Bruguiera sexangula* had the lowest with 1.86. In the

Kamp. Masina, the most dominant mangrove species was *Avicenna alba* (IVI 157.01), while the least dominant species were *Ceriops tagal* and *Xylocarpus moluccensis* (IVI 5.34).

From the six observation locations, there were variations in tree species structure and density among these locations. The highest number of mangrove trees was found in Kamp. Lama 1 with 989 tree/ha (593 trees in 60 plots), an average diameter of 18.8077 cm (SD±7.0279) and an average height of 8.9477 m (SD±2.2814). The lowest tree structure and density were found in Kamp. Masuhi with 940 tree/ha (94 trees in 10 plots), and the average diameter was 15.4787 m (SD±3.8205) and an average total height of 9.0319 m (SD±1.4987). Of these total six locations, the highest diameter was in Kamp. Lama 1 (18.8077 cm) and the lowest average tree diameter found in Kamp. Lama 1 (8.9477 m).

There is a significant positive correlation between diameter as an explanatory variable and height as a response variable, as indicated with designated a positive correlation R squared of 0.69 (Figure 3). There is a significant difference in tree diameter and height among the six locations with a *p*-value of 0.00021 < 0.05 at 95% of confidence interval (CI) (Figure 2). In addition, the statistical test of ANOVA from each location was significantly different among these six. River estuary (Location01) indicated a significant difference with *a p*-value of 0.00002 < 0.05 and a relatively positive coefficient correlation (R^2) of 0.61 in terms of tree diameter in each location, sub-river estuary (Location02) showed a significant difference with *p*-value of 0.00003 < 0.05 and a coefficient of correlation (R^2) of 0.41, Kamp. Lama 1 (Location03) pointed out a significant difference with *p*-value of 0.00005 < 0.05 and a relatively low coefficient of correlation (R^2) of 0.09, Kamp. Lama 2 (Location04) noticed a significant difference with *p*-value of 0.00002 < 0.05 and a relatively positive coefficient of correlation (R^2) of 0.64, Kamp. Masina (Location05) designated a significant difference with *p*-value of 0.00008 < 0.05 and a relatively positive coefficient of correlation (R^2) of 0.45, and Kamp. Masuhi (Location06) specified a significant difference with *p*-value of 0.00002 < 0.05 and a relatively positive coefficient of correlation (R^2) of 0.53.

The highest average mangrove tree diameter and total height were recorded in Kamp. Lama 2 (Location04) due to the highest tree basal area of species per hectare (25.804 m^2 ha^{-1}) compared to other locations, even though tree density per hectare in Kamp. Lama 2 (11,840 trees ha^{-1}) was relatively lower than in the estuary area (12,250 trees ha^{-1}).

Canopy coverage (%)

The canopy cover of mangrove trees was measured from the six different locations represented by 13 plots. These data were then grouped into six groups representing each study location. The study found the highest average of canopy coverage was noted in the sub-river estuary (Location02) with a percentage of 86.97% (SD±85), then followed by Kamp. Lama 1 with the percentage of canopy covers 86.81% (SD±84.5), then Kamp. Masuhi with a percentage canopy cover of 83.71% (SD±92.5), the fourth high percentage was performed by Kamp. Lama 2 with a canopy percentage cover of 80.32% (SD±98.04), the fifth high percentage of canopy cover as indicated in the river estuary area by 67.19% (SD±117.11) and the lowest percentage of canopy cover was specified in Kamp. Masina by 59,89% (SD±124.85).

One-way analysis of variance (ANOVA) indicated no correlation either between average diameter (cm) and percentage of canopy coverage (%) and between average height (m) and percentage of canopy coverage (%) among the six different locations. No significant difference was noticed between an average diameter (cm) and percentage of canopy coverage (%) with *p*-value 0.755 > 0.05, R^2 of 0.02 and between the average height (m) and percentage of canopy coverage (%) with *p*-value 0.831 > 0.05, R^2 of 0.01 at 95 percent of CI.

Table 2. Distribution of basal area, tree density, frequency, dominance, and importance value index of the mangrove trees along the Bintuni riverbank, West Papua, Indonesia

Species	∑	Basal area/ species	D	RD	F	RF	D	RDo	IVI
River Estuary (Location 01)									
Avicennia alba	2	0.10	100	0.82	0.10	3.39	0.01	1.42	5.63
Avicennia marina	8	0.30	400	3.27	0.15	5.08	0.04	4.42	12.77
Avicennia officinalis	1	0.01	50	0.41	0.05	1.69	0.00	0.11	2.22
Bruguiera gymnorrhiza	10	0.32	500	4.08	0.15	5.08	0.05	4.62	13.79
Bruguiera parviflora	21	0.52	1050	8.57	0.40	13.56	0.08	7.50	29.63
Bruguiera sexangula	8	0.27	400	3.27	0.20	6.78	0.04	3.89	13.93
Heritiera littolaris	2	0.06	100	0.82	0.10	3.39	0.01	0.91	5.12
Rhizophora apiculata	19	0.93	950	7.76	0.40	13.56	0.14	13.53	34.85
Rhizophora mucronata	143	3.11	7150	58.37	0.90	30.51	0.45	45.12	133.99
Sonneratia alba	24	1.19	1200	9.80	0.15	5.08	0.17	17.24	32.12
Xylocarpus granatum	1	0.02	50	0.41	0.05	1.69	0.00	0.29	2.39
Xylocarpus moluccensis	6	0.06	300	2.45	0.30	10.17	0.01	0.94	13.56
	245	6.89	12250	100	2.95	100	1	100	300.00

Sub-river Estuary (Locaition 02)									
Avicennia marina	11	0.40	1100	9.32	0.40	12.50	0.12	12.41	34.24
Bruguiera gymnorrhiza	11	0.17	1100	9.32	0.30	9.375	0.05	5.39	24.08
Bruguiera parviflora	17	0.76	1700	14.41	0.60	18.75	0.23	23.30	56.45
Bruguiera sexangula	2	0.03	200	1.69	0.10	3.125	0.01	0.95	5.77
Diospyros sp.	4	0.05	400	3.39	0.10	3.125	0.01	1.44	7.95
Heritiera littolaris	1	0.04	100	0.85	0.10	3.125	0.01	1.17	5.14
Rhizophora apiculata	21	0.74	2100	17.80	0.60	18.75	0.23	22.79	59.33
Rhizophora mucronata	33	0.74	3300	27.97	0.40	12.50	0.23	22.77	63.24
Rhizophora stylosa	10	0.12	1000	8.47	0.20	6.25	0.04	3.79	18.51
Xylocarpus moluccensis	8	0.19	800	6.78	0.40	12.50	0.06	6.00	25.28
	118	3.24	11800	100	3.20	100	1.00	100.00	300.00
Kamp. Lama1 (Location 03)									
Avicennia alba	1	0.05	16.67	0.169	0.017	0.503	0.003	0.26	0.933
Avicennia marina	57	2.80	950.00	9.612	0.383	11.558	0.149	14.95	36.117
Bruguiera gymnorrhiza	119	3.32	1983.33	20.067	0.683	20.603	0.177	17.70	58.374
Bruguiera parviflora	73	2.04	1216.67	12.310	0.583	17.588	0.109	10.89	40.790
Bruguiera sexangula	12	0.44	200.00	2.024	0.067	2.010	0.024	2.36	6.398
Ceriops tagal	4	0.04	66.67	0.675	0.033	1.005	0.002	0.20	1.883
Diospyros sp.	4	0.05	66.67	0.675	0.017	0.503	0.002	0.25	1.426
Heritiera littolaris	5	0.28	83.33	0.843	0.083	2.513	0.015	1.50	4.855
Rhizophora apiculata	28	1.25	466.67	4.722	0.133	4.020	0.067	6.65	15.393
Rhizophora mucronata	248	7.33	4133.33	41.821	0.883	26.633	0.391	39.07	107.523
Xylocarpus granatum	20	0.59	333.33	3.373	0.233	7.035	0.032	3.16	13.568
Xylocarpus moluccensis	22	0.56	366.67	3.710	0.200	6.030	0.030	3.00	12.741
	593	18.76	9883.33	100.000	3.317	100.000	1.000	100.00	300.000
Kamp. Lama2 (Location 04)									
Avicennia alba	17	0.58	0.029	2.872	0.34	8.252	0.022	2.250	13.374
Avicennia marina	138	5.38	0.233	23.311	0.78	18.932	0.209	20.860	63.103
Bruguiera gymnorrhiza	140	6.70	0.236	23.649	0.72	17.476	0.260	25.955	67.079
Bruguiera parviflora	108	4.35	0.182	18.243	0.52	12.621	0.168	16.840	47.705
Bruguiera sexangula	8	0.40	0.014	1.351	0.16	3.883	0.015	1.543	6.778
Diospyros sp.	34	1.01	0.057	5.743	0.26	6.311	0.039	3.906	15.960
Heritiera littolaris	10	0.26	0.017	1.689	0.1	2.427	0.010	1.024	5.140
Maniltoa rhombifolia	8	0.25	0.014	1.351	0.12	2.913	0.010	0.973	5.237
Rhizophora apiculata	73	4.60	0.123	12.331	0.64	15.534	0.178	17.808	45.673
Rhizophora mucronata	20	0.91	0.034	3.378	0.16	3.883	0.035	3.517	10.779
Rhizophora stylosa	8	0.28	0.014	1.351	0.04	0.971	0.011	1.082	3.404
Sonneratia alba	16	0.70	0.027	2.703	0.04	0.971	0.027	2.716	6.390
Xylocarpus granatum	12	0.39	0.020	2.027	0.24	5.825	0.015	1.526	9.378
	592	25.80	1.000	100.000	4.12	100.000	1.000	100.000	300.000
Kamp. Masina (Location 06)									
Avicennia alba	61	1.0573	0.65	64.89	1	35.71	0.56	56.41	157.01
Avicennia marina	12	0.3753	0.13	12.77	0.5	17.86	0.20	20.02	50.64
Bruguiera parviflora	7	0.1468	0.07	7.45	0.3	10.71	0.08	7.83	25.99
Ceriops tagal	1	0.0133	0.01	1.06	0.1	3.57	0.01	0.71	5.34
Rhizophora mucronata	7	0.1316	0.07	7.45	0.4	14.29	0.07	7.02	28.76
Sonneratia alba	4	0.1215	0.04	4.26	0.3	10.71	0.06	6.48	21.45
Xylocarpus granatum	1	0.0154	0.01	1.06	0.1	3.57	0.01	0.82	5.46
Xylocarpus moluccensis	1	0.0133	0.01	1.06	0.1	3.57	0.01	0.71	5.34
	94	1.8745	1.00	100.00	2.8	100.00	1.00	100.00	300.00
Kamp. Masuhi (Location 05)									
Avicennia alba	6	0.3184	0.02	2.22	0.24	6.12	0.03	3.05	11.39
Avicennia marina	112	4.2402	0.41	41.48	0.84	21.43	0.41	40.60	103.51
Bruguiera parviflora	19	0.4906	0.07	7.04	0.52	13.27	0.05	4.70	25.00
Bruguiera sexangula	1	0.0491	0.00	0.37	0.04	1.02	0.00	0.47	1.86
Rhizophora apiculata	5	0.1570	0.02	1.85	0.2	5.10	0.02	1.50	8.46
Rhizophora mucronata	59	2.8140	0.22	21.85	0.28	7.14	0.27	26.94	55.94
Rhizophora stylosa	10	0.2155	0.04	3.70	0.2	5.10	0.02	2.06	10.87
Sonneratia alba	36	1.5662	0.13	13.33	0.72	18.37	0.15	15.00	46.70
Xylocarpus granatum	22	0.5936	0.08	8.15	0.88	22.45	0.06	5.68	36.28
	270	10.4445	1.00	100.00	3.92	100.00	1.00	100.00	300.00

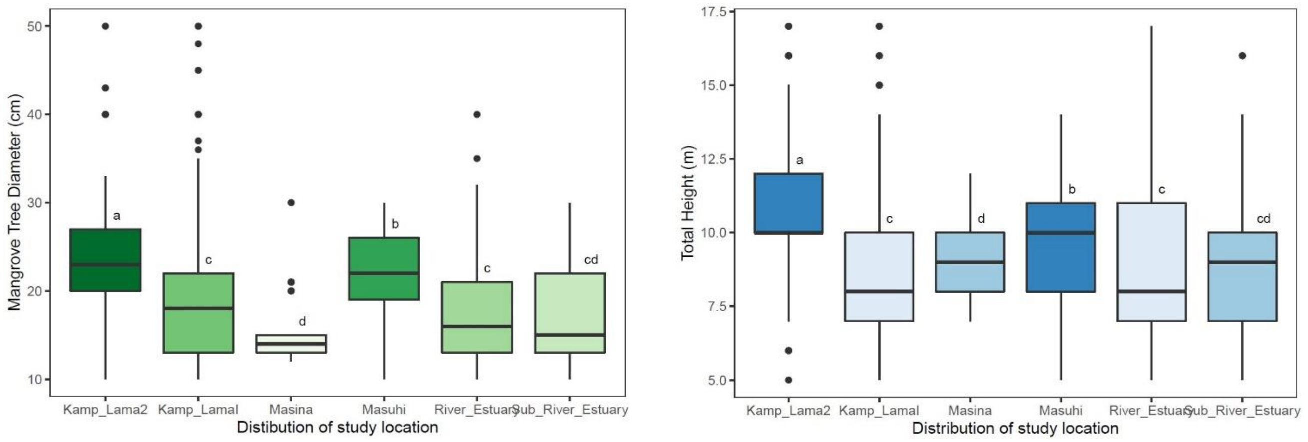

Figure 2. Average diameter (cm) and total height (m) of mangrove trees in six observation locations. There was a very significant difference in average diameter (p-value of $0.0002 < 0.05$) and total height (p-value of $0.000216 < 0.05$) among the six established locations. Differences in gradient color indicated different median levels among boxplots from dark to light color

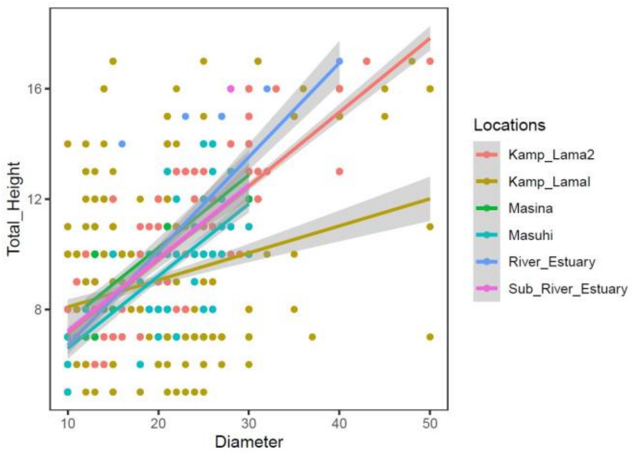

Figure 3. Correlation between tree diameter (cm) and height (m) in six locations. Colored symbols correspond to each location defined in this study

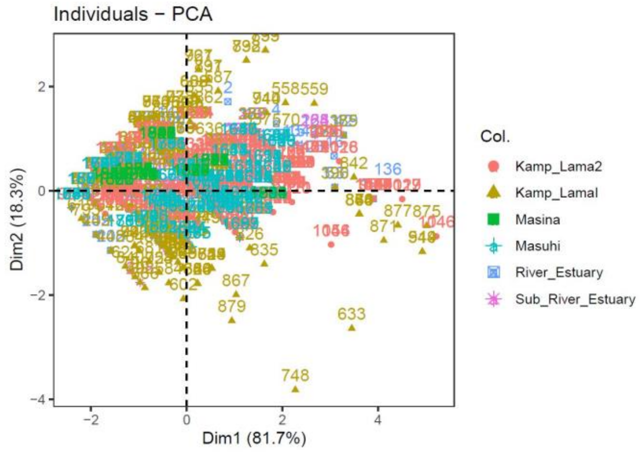

Figure 4. Principal Component Analysis (PCA) plot showing variation among six locations in terms of tree diameter and total height variables. Colored symbols correspond to each location defined in this study

Discussions

Mangrove diversity, composition and stand structure

Mangroves in Bintuni Bay are recognized as the second largest block in the world which is indicated by the distribution of mangrove tree species, mangrove tree density, and dominance in the area (Murdiyarso et al. 2021). In terms of species, this study found 16 species distributed across 6 different locations with slightly different dominance indicated by the IVI parameter. *R. mucronata* was dominant in the estuary (Location01), sub-estuary (Location02) due to its physical and physiological abilities to retain external disturbances such as waves, more tolerant to water salinity, the deep root system and higher root surface area (Batol et al. 2014; Baishya et al. 2020). Basyuni et al. (2020) indicated *R. mucronata* possesses a stilted root that underpins the plant to stand well in the ocean wave. On the other hand, a slightly different mangrove tree dominance, i.e., *Avicennia* sp. was pointed out in two locations, Kamp. Masuhi (Location05) and Kamp. Masina (Location06), which was relatively far from the estuary. There were a number of factors affecting the higher *Avicennia* sp., distribution in these two locations, one of which was the low rate of substrate sediment that increase the potential of life growth (Affandi et al. 2010). Therefore, even though the *Avicennia* sp., is known as a salt-tolerant species and tends to adapt to water fluctuation (Chen and Ye 2014), the species is unable to grow longer due to a low root penetration system and does not produce fibrous mud, poor ability to regenerate and susceptible to the extreme micro-climate attributes, in particular close to the estuary (Budiadi et al. 2022). Therefore, it can be assumed that there was a pattern of mangrove diversity zonation among the six locations which is obviously influenced by environmental factors, such as the ability to tolerate water salinity, the capability of growing with seawater inundation, etc (Irawan et al. 2021).

The high basal area is correlated to a large tree diameter of the accounted tree individuals (Verma et al. 2014; Chukwu et al. 2018). In general, the overall mangrove tree density along the Bintuni riverbank was considered as high, ranging from 9,400 trees ha^{-1} found in Kamp. Masina (Location06) to 12,250 tree ha^{-1} in the estuary (Location01) compared to other similar studies (e.g. Kurniawan et al. 2014; Buwono 2017; Sahami 2018).

The lowest average tree diameter was found in Kamp. Masina with an average of 15.4787 cm and low stem density per hectare of 9,400 trees ha^{-1}. One factor affecting the lower average tree diameter and stem density compared to other locations were likely caused by anthropogenic factors since the surrounding area has experienced lots of community activities and revegetation program to recover the forest. Several standing trees incorporated in this study have been indicated as plantation mangroves from *Avicennia* sp. In addition, there was an indication of a significantly reduced survival and regeneration of mangrove trees when the structure of mangrove forests becomes lower in stem density and basal area (Sillanpää et al. 2017). The overall correlation between tree diameter and tree total height in the six locations was relatively positive specified by its coefficient of determination (R^2) value that ranged from 0.09 in Kamp. Lama1 (Location03) up to 0.64 in Kamp. Lama 2 (Location04) (Figure 3). It was an obvious indication of positive tree growth in a balanced ecological niche and micro-climate condition (Siregar et al. 2019).

Correlation of canopy cover and mangrove stand attributes

Mangrove canopy cover was analyzed by calculating the average percentage among the six plots ranging from 59.86% (±SD124.85) to 86.97% (±SD85.00). The highest canopy cover was found in the river estuary (Location01) and the lowest was seen in Kamp. Masina (Location06). There was no correlation between canopy cover and stem density (R^2 = 0.11; *p*-value of 0.507 > 0.05), canopy cover and basal area (R^2 = 0.04; *p*-value of 0.698 > 0.05) as well as canopy cover and total height (R^2 = 0.05; *p*-value of 0.666 > 0.05) among the six locations. It means, that the high and low stem density and basal area of mangrove trees do not provide a good indication of mangrove canopy cover along the Bintuni riverbank areas. However, a slightly positive correlation was indicated between canopy cover and tree diameter (R^2 = 0.31), despite no statistical significance of the result of analysis of variance (*p*-value of 0.234 > 0.05). Therefore, it can be inferred that stand parameter that affect the percentage of mangrove canopy cover along the Bintuni riverbank areas was tree diameter. Hence, the increase in mangrove tree diameter will increase the canopy cover percentage in the Bintuni River area, and vice versa. The result was similar to Brūmelis et al. (2020) who found a positive correlation between the increase of DBH and tree crown based on regression models. However, this study result was a bit in contrast with Wachid et al. (2017) highlighted that tree density influences mangrove canopy cover based on NSVI result from Sentinel-2A data in Jor bay area.

Mangrove role in Bintuni Municipal Area

The mangrove area in Bintuni Bay approximately occupy one-third of the total forest cover (~ 600,000 ha) and has been fundamental for the municipal area of Bintuni Bay. This study bestowed a promising benefit on ecological and socio-economic aspects of the mangrove forest along the Bintuni riverbank areas, of which the potency, structure, tree composition, and density level in the forest were noticeably high. Mangrove forest is able to generate income for local communities in Bintuni since the forest provides a large benefit, including stabilizing shorelines and reducing the dangerous impact of natural disasters, as well as providing food, fuelwood, medicines and construction materials (Prabhakaran and Kavitha 2012; Aye et al. 2019; Marlianingrum et al. 2021). Bawole et al. (2008) highlighted a high number of traditional fishery production/week from Sebyar and Wamesa indigenous groups around the bay area with the average production for fish ± 25.97 kg/trip, shrimp ± 4.58 kg/trip, crabs 230 kg, and lobster ± 11.30 kg. Mangrove forests are among the most carbon-rich habitats on the planet earth, and they have double the living biomass of tropical forests overall (Sasmito et al. 2020). Murdiyarso et al. (2021) pointed out the huge potency of mangrove carbon pools in the Bintuni Bay area to preserve and maintain around 70 - 75% of the total ecosystem carbon stocks. Their study also found that the mangrove around Bintuni Bay has the ability to recover and return to the new natural ecosystem between 15 - 25 years, even though, according to Sillanpää et al. (2017), the harvested rotation for mangrove timber was ideal for be cutting around 30 to 40 years. It was obvious that the mangrove in Bintuni Bay has been pivotal. However, some strategic policies and effective management should be taken well in order to preserve, protect and well-maintained the mangroves' potency in Bintuni.

It can be concluded that mangrove vegetation is widely distributed along the Bintuni riverbank with slightly different species dominating each study location indicated by the importance value index (IVI). The estuary and sub-estuary areas were dominated by *R. mucronata*, while in the further area from the estuary, the dominant mangrove species was *Avicennia* sp. The highest average of mangrove tree diameter and total height was found in Kamp. Lama 2 due to the highest tree basal area of species per hectare (25.804 m^2 ha^{-1}) compared to other locations. The lowest average tree diameter was in Kamp. Masina with an average of 15.4787 cm and low stem density per hectare of 9.400 tree ha^{-1}. Mangrove canopy cover ranged from 59.86% (±SD124.85) to 86.97% (±SD85.00). The highest canopy cover occurred in the river estuary and the lowest was seen in Kamp. Masina. The mangrove area in Bintuni Bay has been fundamental for the municipal area of Bintuni Bay, bestowing a promising benefit of ecological and socio-economic aspects.

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