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Floristic richness and diversity of Bintuni mangrove, Bird's Head Peninsula, West Papua, Indonesia

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Abstract. *Kasihiw P, Bawole R, Marwa J, Murdjoko A, Wihyawari A, Heipon Y, Cabuy RL, Benu NMH, Hematang F. 2023. Floristic richness and diversity of Bintuni mangrove, Bird's Head Peninsula, West Papua, Indonesia. Biodiversitas 24: 2887-2897.* Mangrove ecosystems play an important role in the functions of coastal protection, fish and other living-organism habitats, carbon storage, and the livelihood of local people. Yet, mangrove forests generally face ecological threats like anthropogenic pressures. However, fewer studies were carried out in this area, so this research aimed to reveal the vegetation diversity and richness in Bintuni, not only the *true mangroves* but also the *mangroves associates* with three different conditions, namely sandy areas called protection forests, disturbed forests called production forests, and delta called nature reserve. The results showed that species vegetation in the Bintuni Mangrove could be differentiated as *true mangroves* (29.82%) and *mangrove associates* (70.18%) of the total species richness of mangrove vegetation where in terms of taxonomic composition, the three forests encompassed 25 families, 47 genera, and 57 species clustered into 9 lifeforms. Then, the vegetation diversity and richness were highest in the nature reserve, and 34 (59.65% of total species number) species of vegetation in common share in three forest types. Consequently, frequent checking of vegetation richness is important since the Bintuni mangrove does not seem to have a significant threat like massive conversion of mangrove.

Keywords: Intertidal zone, Rhizophoraceae, salt-tolerant, tropical forest, vivipary

INTRODUCTION

Indonesian New Guinea (Papua) is part of New Guinea, the largest tropical island providing the most floristic area (Cámara-Leret et al. 2020; Murdjoko et al. 2021b, 2022). This island's latitudinal position increases vegetation richness, especially trees (Liang et al. 2022). Biogeographically, the island harbors vegetation spreading from coastlines to alpine tundra with various ecosystems (Cámara-Leret et al. 2019; Cámara–Leret and Dennehy 2019; Fatem et al. 2020; Murdjoko et al. 2020, 2021a; Trethowan et al. 2023). Some taxonomic studies still revealed the revisions of vegetation species, such as some species and genera had been revised based on the vegetation classification in palms, shrubs, and pandanus (Barfod and Heatubun 2009, 2022; Hughes et al. 2015). Particularly in the coastline ecosystems, the mangrove forest has played an important role in ecosystem services such as coastal protection, carbon stock known as part of blue carbon, fishery product, and habitats for other organisms (Bryan-Brown et al. 2020; Worthington et al. 2020). In Papua, the mangroves are distributed almost in shoreline ecosystems as the main structure of the wet forest. The mangrove forest is floristically dominated by species belonging to the Rhizophoraceae family, about more than 70%. The distribution of mangrove forests takes place such as in estuaries, along rivers, coastlines, and deltas (Sillanpää et al. 2017; Yudha et al. 2021; Sraun et al. 2022). The mangrove ecosystem has benefited local people, whether directly using organisms in mangroves or indirectly, such as through the compensation earned from forest concession (Wahyudi et al. 2014; Sasmito et al. 2023). The mangrove vegetation is salt-tolerant with salinity, inundation, and ocean current, so the mangrove naturally survive on shorelines. The intertidal zones are distributed depending on the sea level during high and low tides, the topographic condition, and the number of rivers (Liu et al. 2018; Sreelekshmi et al. 2018). Moreover, the intertidal areas affect the ecological mechanisms such as seed dispersal to allow the natural regeneration of mangrove vegetation and the floristic composition in shoreline ecosystems (Sarker et al. 2019).

Bintuni Gulf is a major part of the mangrove distribution in Bird's Head Peninsula of New Guinea, consisting of dense vegetation. The mangrove vegetation appears from mangrove fringes, mangroves in delta, estuary, and coast with numerous sediment (Sillanpää et al. 2017; Yudha et al.

2021, 2022; Sraun et al. 2022). The mangrove vegetation contains the *true mangroves* and *mangrove associates*, whereas some studies in Bintuni focused more on the *true mangroves*. However, in the mangrove forest, plenty of vegetation was classified as *mangrove associates* that are part of vegetation diversity in the mangrove ecosystem (Wang et al. 2011; Chanda et al. 2016). The mangrove forest is more dynamic regarding substrates and sediments resulting from tidal activity. Hence, it can lead to the vegetation structures such as species distribution and mangrove zonation shaping, fringing zone, intermediate zone, and landward zone (Matthijs et al. 1999; Feller et al. 2010; Sreelekshmi et al. 2018). The true mangrove vegetation provides different species compositions causing certain *mangrove associates*. As defined by some research, mangroves allow other vegetation to grow along with the composition of the mangrove creating vegetation assembly (Otero et al. 2020).

Much research in Bintuni focused on the "true mangrove" and the recovery of logged mangrove (Sillanpää et al. 2017; Yudha et al. 2021, 2022). On the contrary, the study of vegetation diversity and species richness of mangroves shaping the vegetation community was poorly understood. As a result, the aims of the study was intended to examine scientifically the vegetation diversity and species richness of vegetation and whether *true mangroves* and *mangrove associates* with three conditions in Bintuni mangroves ranging from sandy coast, disturbed mangrove, and deltas. Furthermore, we analyzed the vegetation cohort resulting from the composition of the mangrove forests. We hypothesized that the diversity and species richness differed among the three mangrove conditions causing the variation of *mangrove associates*. This study was important since we provided biodiversity, especially vegetation, to understand the coastline ecosystem in sharing the habitat for vegetation.

MATERIALS AND METHODS

Study area

The study was conducted in the Bintuni mangroves in the Gulf of Bird's Head Peninsula in West Papua, Indonesia, part of New Guinea Island. The Bintuni mangrove is a wide tract of vegetation from the shorelines to the landward, accounting for approximately one-tenth of the Indonesian mangrove forests. The mangrove forests are flanked by lowland tropical woods that rise 300 meters above sea level. This study concentrated on locations in the northern, southern, and eastern parts of the gulf representing the sandy area known as protection forest (133°27'14.06"E 2°13'40.88"S), disturbed mangroves known as production forest (133°48'56.97"E 2°33'12.55"S), and delta dominance with undisturbed mangrove known as a nature reserve (133°38'28.21"E 2°13'27.43"S) (Figure 1). The mangrove vegetation was dominated by Rhizophora and Bruguiera genera belonging to the Rhizophoraceae family (Sillanpää et al. 2017; Yudha et al. 2021). Some studies mentioned that family was the main structure of the mangrove forest in Bintuni, along with the ability of natural regeneration creating the high abundance of individuals distributing from small to large individuals assumed as putative parent trees.

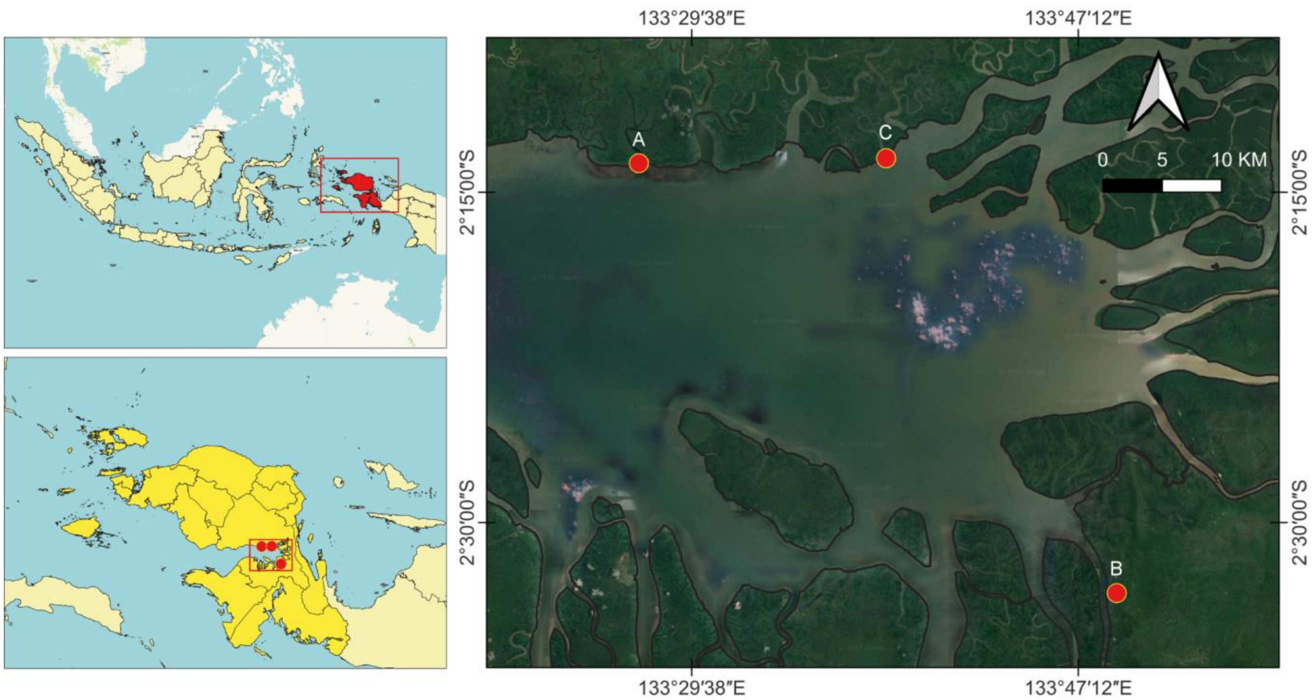


Figure 1. Location of plotting areas in the Bintuni mangroves, West Papua, Indonesia. Note: A. Protection forest, B. Production forest, C. Nature reserve

Field data collection

This study sampled the vegetation based on the lifeforms: Bamboo, Climber, Epiphyte, Fern, Orchid, Palm, Pandanus, Shrub, and Tree (small, intermediate, and large). The sample was designed using the circular plots with 10 m as the radius (A), and two subplots were inside plot A with 4 m in radius (B) and 1 m in radius (C). We applied the modified circular plot as used in a previous study in Bintuni (Sillanpää et al. 2017). Plot A was to collect the large individuals categorized with a diameter of at least 10 m, the plot B was to record the intermediate individual with a diameter below 10 m and height of at least 1.5 m, and plot C was to enumerate the small individuals, regarded as the height below 1.5 m. The plotting was perpendicular from the mangrove fringe to landward, and we conducted the three transects at each location (nature reserve, protection forest, and production) with 20 plots per transect with the distance between plots at least 30 m, so 60 plots were placed per location and in total there were 180 plots in this study. The data collection was performed in low tide to cover small individuals, and the information on tidal time was obtained from local people we validated using a tidal table online on Tideschart (https://www.tideschart.com /Indonesia/West-Papua/Bintuni accessed on 2 February 2023). The data were taxonomic information from family to species level, and the scientific name followed The World Flora Online (http://www.worldfloraonline.org accessed on 20 March 2023) and Plants of the World Online (https://powo.science.kew.org/ accessed on 20 March 2023). The identification of taxonomic information was conducted directly in the field. At the same time, undescribed vegetation was sent as a voucher to *Herbarium Manokwariense (MAN) Pusat Penelitian Keanekaragaman Hayati Universitas Papua (PPKH-UNIPA),* Manokwari. The information on conservation status and population trend was obtained from The International Union for Conservation of Nature's Red List of Threatened Species (https://www.iucnredlist.org/ accessed on 20 March 2023). Moreover, data of individual numbers were recorded in each plot, and diameter (dbh) was carried out for the large individual (Sillanpää et al. 2017; Yudha et al. 2021).

Data analysis

Therefore, to describe the species richness of mangrove vegetation, we performed the sample rarefaction (Mao's tau) by plotting the number of plots in the x-axis (horizontal line) as opposed to the number of taxa (species) in the y-axis (vertical line) (Colwell et al. 2004; Murdjoko et al. 2021c). Moreover, the Whittaker plot for each location was executed in which the abundance of vegetation species was log-transformed in the y-axis (vertical line) versus species rank by descending order in the x-axis (horizontal line) (de Maçaneiro et al. 2016; Murdjoko et al. 2022). Next, vegetation diversity was explained by calculating the Shannon-Wiener index and Pielou's evenness as follows $H' = -\sum_{i=1}^{S} p_i \ln\ (p_i)$ where H' is the Shannon-Wiener index, p_i is the proportional number of individuals of species i obtained from the number of species I divided by the total number of species, and $E' = H'/\ln(S)$, where S is the total number of species for each location. Next, we presented the vegetation species per lifeform using density (individual number per plot size). Then, the dominant species of vegetation was analyzed using Importance Value Index (IVI) by adding relative frequency, relative density, and relative dominance as follows $IVI_i = RFr_i + RDe_i + RDo_i$ for large individuals, while the small individuals followed $IVI_i = RFr_i + RDe_i$ (Bray and Curtis 1957; Tawer et al. 2021). Finally, the Dendrogram and Correspondence Analysis (CA) were implemented to describe vegetation assembly. The computation analysis was executed by running software of PAST (PAleontological STatistics) version 4.03 (Hammer et al. 2001).

RESULTS AND DISCUSSION

Vegetation richness and diversity of Bintuni mangrove

In this research, we explored using the systematic plots in the three forest types: nature reserve, protection forest, and production forest. Then, we recorded the total number of individuals was 2,844 in a 2.21 ha sampling area, consisting of 493 small individuals per 0.02 ha, 518 intermediate individuals per 0.30 ha, and 1,833 large individuals per 1.89 ha. Regarding taxonomic composition, the three forests encompassed 25 families, 47 genera, and 57 species. Moreover, the individuals were grouped into 9 lifeforms, namely bamboo (1 species), climber (6 species), epiphyte (7 species), fern (3 species), orchid (2 species), palm (3 species), pandanus (1 species), shrub (2 species), and tree (32 species).

Then, we applied sample rarefaction (Mao's tau) to describe the species number against the plot number (Figure 2). The species richness distribution varied among the forest types in which nature reserve contained 54 species, protection forest comprised 37 species, and production forest consisted of 39 species. The nature reserve was the home of 24 families and 44 genera, the protection forest had 28 genera and 15 families, and 31 genera and 19 families covered the production forest. As explained in the method, we grouped the individuals in the three forests into small, intermediate, and large individuals to show the mangrove vegetation structure (Table 1). So, the number of species, genera, and families showed that the highest number for the small individual was in the nature reserve, where 12 families, 18 genera, and 41 species were found compared to the other forest types. On the other hand, the protection forest covered the lowest number of families, genera, and species, where there were 11, 20, and 27, respectively. In intermediate individuals, the highest number of the family, genus, and species was recorded in the nature reserve as the numbers were 12, 18, and 25 correspondingly. In contrast, the number of families, genera, and species in protection and production forest was more or less similar. The comparable condition occurred in the large individual category where the highest number of families, genera, and species were in the nature reserve compared to the protection and production forests.

Table 1. The number of families, genera, species, Shannon-Wiener index (H'), and the Evenness index (E') of small, intermediate, and large individuals in Nature Reserves, Protection Forests, and Production Forest

Ecological parameters	Nature reserve	Protection forest	Production forest
All individual			
Number of Families	24	15	19
Number of Genera	44	28	31
Number of Species	54	37	39
Small individual			
Number of Families	20	11	14
Number of Genera	34	20	24
Number of Species	41	27	32
Shannon-Wiener index (H')	2.84	1.98	2.30
Evenness index (E')	0.41	0.26	0.31
Intermediate individual			
Number of Families	12	8	8
Number of Genera	18	11	10
Number of Species	25	17	16
Shannon–Wiener index (H')	2.57	2.13	2.02
Evenness index (E')	0.52	0.49	0.47
Large individual			
Number of Families	11	5	8
Number of Genera	16	7	11
Number of Species	23	13	17
Shannon–Wiener index (H')	2.39	1.87	1.66
Evenness index (E')	0.47	0.50	0.30

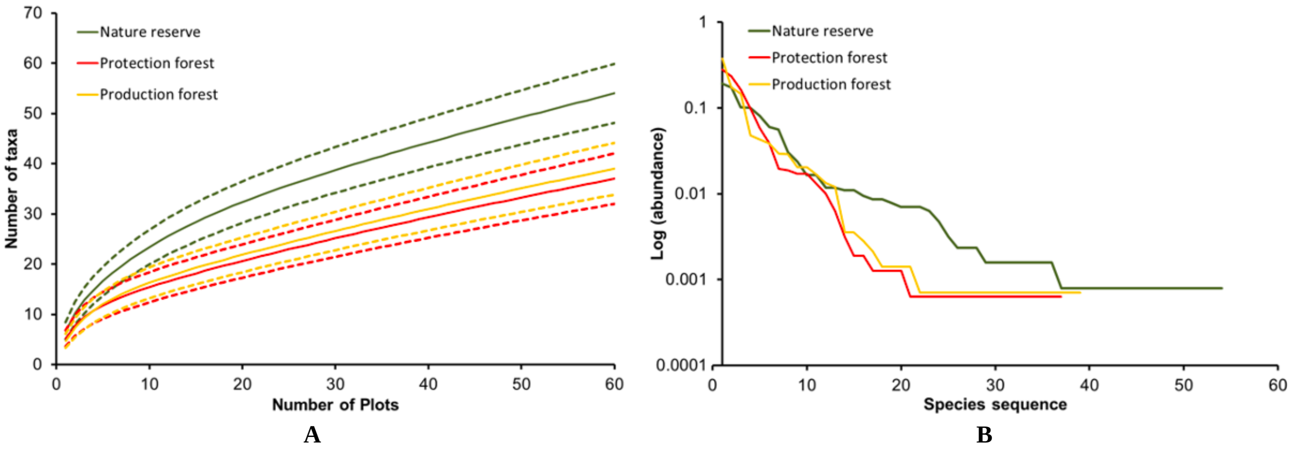


Figure 2. The species accumulation over the number of the plot using sample rarefaction (Mao's tau). The solid green line is the nature reserve; the solid red line is the protection forest; the solid yellow line is the production forest. The dashed lines above the solid line are the upper limit, and the dashed lines below the solid lines are the lower limit. A. The upper and lower limits explain the 95 % of confidence interval. B. The Whittaker plots for each location are log-transformed on the y-axis versus species rank in descending order on the x-axis

The species diversity of mangrove vegetation differed among the three forest types, as shown by the variation of the Shannon-Wiener index (H') and the Evenness index (E') for small, intermediate, and large individuals. The diversity was highest in the nature reserve for small, intermediate, and large individuals as the H' of each group of mangrove vegetation was 2.84, 2.57, and 2.39, correspondingly. In the production forest, the diversity was the lowest for intermediate and large individuals, in which the H' indices were 2.02 and 1.66, respectively, while for the small individuals were less diverse as the H' index was 1.98. The Evenness index (E') value revealed that vegetation species were distributed disproportionately in the three forest types. The small individuals in the nature reserve had the highest value of the E' index (0.41), while the protection forest showed the lowest value of the E' index (0.26). Furthermore, the intermediate individuals in the nature reserve indicated the highest E index (0.52) compared to protection and production forests (0.49 and 0.47, respectively). The large individuals in the protection forest showed the highest value of the E' index (0.50) rather than in the natural reserve and the production forest (0.47 and 0.30, respectively). The vertical structure of mangrove forests in the three forest types indicated that small, intermediate, and large individuals grew since the stock of individuals was generally available.

We presented Table 2 to show the density of vegetation species in the nature reserve, protection forest, and production forest. To describe the dominant vegetation species, we implemented the Importance Value Index (IVI), then the dominant vegetation species were labeled as an asterisk (*) in the Table. We differentiated the group of individuals as small, intermediate, and large, where we only included the lifeform of the tree in the IVI analysis. The threshold of IVI value was above 20 for small, intermediate, and large individuals. We displayed the analysis of the Importance of Value Indices (IVIs) for individuals categorized as small, intermediate, and large in three different forests in Figure 3. In the nature reserve, small individuals were dominated by *B. parviflora* (IVI=40.62 %), *B. gymnorhiza* (L.) Lam. (IVI=32.96 %), and *R. mucronata* Poir. (IVI=28.26 %). Particularly, B. *parviflora* and *B. gymnorhiza* were distributed in half of the mangrove forest (F=0.56 and F=0.46, respectively). Intermediate individuals of *B.* gymnorhiza (IVI=42.68 %), *Avicennia marina* (Forssk.) Vierh. (IVI=24.26 %), *X. moluccensis* M.Roem. (IVI=24.15 %), and *B. parviflora* (IVI=23.35 %) were the most frequent vegetation species. The large individuals were dominated by *B. gymnorhiza* (IVI=57.34 %), *B. parviflora* (IVI=54.63 %), *A. marina* (IVI=36.13 %), R. *mucronata* (IVI=35.22 %), *R. apiculata* Blume (IVI=26.94 %), and *X. moluccensis* (IVI=25.39 %). In the protection forest, vegetation such as *A. marina* (IVI=56.06 %), *R. mucronata* (IVI=55.61 %), and *B. parviflora* (IVI=33.10 %) abundantly grew in the category of small individuals. In the intermediate individuals, the dominant species were *R. mucronata* (IVI=51.75 %), *B. parviflora* (IVI=34.92 %), and *A. marina* (IVI=30.41 %), while the species of *R. mucronata* (IVI=76.84 %), *A. marina* (IVI=60.38 %), B. gymnorhiza (IVI=44.55 %), *B. parviflora* (IVI=41.91 %), and *S. alba* (IVI=25.82 %) grew abundantly as a group of large individuals. In the production forest, species such as *R. mucronata* (IVI=55 %), *B. gymnorhiza* (IVI=41.40 %), and *B. parviflora* (IVI=20.57 %) grew dominantly. In the intermediate individuals, we found that *R. mucronata* (IVI=54.05 %), *B. parviflora* (IVI=37.63 %), and *B. gymnorhiza* (IVI=33.17 %) were the leading species, while in large individuals the species namely *R. mucronata* (IVI=140.66 %), *B. gymnorhiza* (IVI=44.38 %), *R. apiculata* (IVI=28.93 %), and *B. parviflora* (IVI=27.61 %) were dominant.

Conservation status of mangrove vegetation

We described the conservation status of each species of vegetation using The International Union for Conservation of Nature (IUCN) Red List, which groups the conservation status into nine categories. However, in this study, the species were categorized into four (DD - Data Deficient; LC - Least Concern; NT - Near Threatened; and VU – Vulnerable), and the rest species were Not Available (Table 3). Of the three forest types, the nature reserve is home to the larger number of conservation status as Least Concern (29 species), while the protection and production forest consisted of 22 and 23 species, respectively. Furthermore, the nature reserve indicated that this forest type harbored the two species with the conservation status as Near Threatened, namely *C. decandra* and *I.palembanica*. At the same time, this mangrove forest was the place for one species categorized as Vulnerable. *P. dalbergioides* The species of *C. decandra* is a mangrove plant that grows as either shrub or small tree with a height that could reach more or less 15 meters in aquatic intertidal associated with other mangrove vegetation. On the other hand, both species of *I. palembanica* and *P. dalbergioides* most of the time grew behind the mangrove fringe, not in intertidal zones.

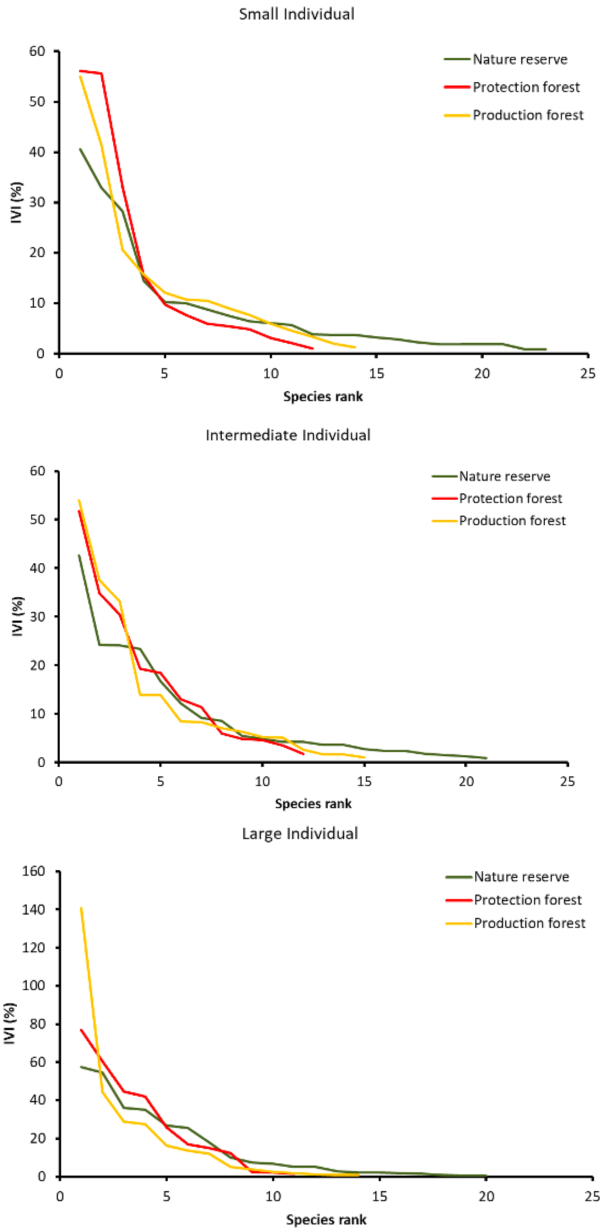


Figure 3. Importance Value Indices (IVIs) (y-axis) of tree species (x-axis) that are arranged in descending order against IVIs in Bintuni mangrove based on small, intermediate, and large individuals distributed in nature reserve (green lines), protection forest (red lines), and production forest (yellow lines)

Table 2. Density and dominancy (labeled as asterisk) of vegetation of species mangrove in Nature Reserve, Protection Forest, and Production Forest based on lifeform along with small (Sm), intermediate (In), and large individuals (La). The average density of vegetation is the number of small, intermediate, and large individuals per 3.14 m^2, 50.29 m^2, and 314.29 m^2, respectively. The conservation status is explained as Empty is Not Available, DD is Data Deficient, LC is Least Concern, NT is Near Threatened, and VU is Vulnerable. The population trend is described as Un is Unknown, D is Decreasing, and St is Stable

Lifeform and species name	Abbreviation of species names	Conservation status	Population trend	Nature reserve			Protection forest			Production forest		
				Sm	In	La	Sm	In	La	Sm	In	La
Bamboo												
Schizostachyum brachycladum Kurz	Sc_bra				1			1			5	
Climber												
Abrus precatorius L.	Ab_pre			3			1			1		
Derris trifoliata Lour.	De_tri			2			1			1		
Dischidia sp.	Di_sp.			1			1			1		
Finlaysonia obovata Wall.	Fi_obo			2			1			1		
Hoya sp.	Ho_sp.			1			1			1		
Stenochlaena palustris (Burm.) Bedd.	St_pal			1			1			2		
Epiphyte												
Asplenium nidus L.	As_nid			1								
Bulbophyllum sp.	Bu_sp.			2								
Dendrobium antennatum Lindl.	De_ant	LC	Un	1			1			1		
Drynaria quercifolia (L.) J.Sm.	Dr_que			1			2			1		
Hydnophytum formicarum Jack	Hy_for			1			1			1		
Myrmecodia pendens Merr. & L.M.Perry	My_pen			1			1			1		
Pyrrosia novoguineae (Christ) M.G.Price	Py_nov			1			1			1		
Fern												
Acrostichum aureum L.	Ac_aur	LC	St	4			2			1		
Acrostichum speciosum Willd.	Ac_spe	LC	St	1			3			1		
Platycerium bifurcatum (Cav.) C.Chr.	Pl_bif			1								
Orchid												
Grammatophyllum scriptum Blume	Gr_scr			1			1			1		
Oxystophyllum sp.	Ox_sp.			1			1			1		
Palm												
Cocos nucifera L.	Co_nuc					3			1	2		
Metroxylon sagu Rottb.	Me_sag	LC	St			1			1			3
Nypa fruticans Wurmb	Ny_fru	LC	Un			10		5				1
Pandanus												
Pandanus polycephalus Lam.	Pa_pol				2			3				2
Shrub												
Acanthus ebracteatus Vahl	Ac_ebr	LC	D		2			1		1		
Acanthus ilicifolius Lour.	Ac_ili	LC	Un		3			1		1		
Tree												
Aegiceras corniculatum (L.) Blanco	Ae_cor	LC	D	12	3					11	18	
Avicennia alba Blume	Av_alb	LC	D			11	12		15	2	2	1
Avicennia marina (Forssk.) Vierh.	Av_mar	LC	D	9	36	83*	135*	79*	161*	14	4	23
Avicennia officinalis L.	Av_off	LC	D	4		8	16			34	14	20
Barringtonia racemosa (L.) Spreng.	Ba_rac	LC	St	8	16	6						
Brownlowia argentata Kurz	Br_arg	DD	Un	3	4	4						
Bruguiera gymnorhiza (L.) Lam.	Br_gym	LC	D	48*	74*	122*	21	35	101*	97*	93*	59*
Bruguiera parviflora Wight & Arn. ex W.Griffith	Br_par	LC	D	60*	35*	125*	72*	76*	109*	48*	109*	51*
Bruguiera sexangula (Lour.) Poir.	Br_sex	LC	D	5	6	10		9	18	7	8	14
Ceriops decandra (Griff.) W.Theob.	Ce_dec	NT	D		14							
Ceriops tagal C.B.Rob.	Ce_tag	LC	D	12	2		2			26	25	4
Diospyros maritima Blume	Di_mar	LC	St	4	4	1						4
Dolichandrone spathacea (L.f.) Baillon ex Schumann	Do_spa	LC	D							5	2	10
Excoecaria agallocha L.	Ex_aga	LC	D	2								
Ficus tinctoria G.Forst.	Fi_tin	LC	St	2								
Heritiera littoralis Aiton	He_lit	LC	D		6	2		2				
Hibiscus tilliaceus L.	Hi_til	LC	Un					10				
Inocarpus fagifer (Parkinson ex F.A.Zorn) Fosberg	In_fag	LC	St	10	6	23						
Intsia palembanica Miq.	In_pal	NT	D	6	2	7						
Leea rubra Blume ex Spreng.	Le_rub			1								
Mallotus sp.	Ma_sp.			2								
Premna corymbosa Rottler & Willd.	Pr_cor			6							2	
Pterocarpus dalbergioides Roxb.	Pt_dal	VU	D		1							
Rhizophora apiculata Blume	Rh_api	LC	D	12	16	43*	21	42	31	7	9	45*
Rhizophora mucronata Poir.	Rh_muc	LC	D	48*	8	74*	123	124*	199*	112*	149*	275*
Rhizophora stylosa Griff.	Rh_sty	LC	D	2	3	16	7*	9	5			
Schefflera actinophylla (Endl.) Harms	Sc_act	LC	St			1						
Sonneratia alba Sm.	So_alb	LC	D	1	4	4	1	7	54*	5	14	
Teijsmanniodendron hollrungii (Warb.) Kosterm.	Te_hol	LC	Un		8	1						
Thespesia populnea Sol. ex Corrêa	Th_pop	LC	St									1
Xylocarpus granatum J.Koenig	Xy_gra	LC	D	18	25	33	3	24	3	11	12	1
Xylocarpus moluccensis M.Roem.	Xy_mol	LC	D	16	45*	42*	8	20	3	15	25	2

Discussion

In general, the species richness of the mangrove forest in Bintuni consisted of many species found in the 57 species of vegetation distributed in many lifeforms. The lifeform of the tree was the most number of species since it constituted seedlings categorized as small individuals, saplings grouped as intermediate individuals, and large individuals assumed as reproductive individuals. The trees grew dominantly in the Bintuni mangrove, from fringe mangroves and intertidal zone to terrestrial areas. The species vegetation in the Bintuni Mangrove can be differentiated as *true mangroves* (29.82 percent) and *mangrove associates* (70.18 percent) of the total species richness of mangrove vegetation. The vegetation of the Bintuni mangrove in this study presented not only the terrestrial or intertidal zone but also epiphytic plants containing families of Aspleniaceae, Orchidaceae, Polypodiaceae, and Rubiaceae. The mangrove associates were higher in species richness, resulting from the Bintuni mangrove being surrounded by terrestrial forest grouped as a lowland tropical forest. Hence, the seedling establishment of the lowland tropical forest is distributed particularly in the ecotone between the coastline ecosystem and terrestrial vegetation. Therefore, families such as Pandanaceae, Ebenaceae, Fabaceae, Lamiaceae, Lecythidaceae, Malvaceae, Meliaceae, and Vitaceae are mostly found in the terrestrial zone. Still, they are associated with creating vegetation assembly and *true mangrove* vegetation. The vegetation of *mangrove associates* tended to be more abundant in the opposite direction to the shoreline in which the salt-tolerant condition is possibly a factor affecting the distribution of the "mangrove associates" vegetation (Kathiresan and Bingham 2001; Bai et al. 2021; Fatonah et al. 2021; Song et al. 2023).

The vegetation of *M. sagu* has established clusters of vegetation as the areas were frequently inundated with low salinity. The ability of this species to regenerate not only depends on a generative way but also through vegetative regeneration by suckering, producing multiple-stemmed individuals (Sillanpää et al. 2017; Yudha et al. 2021). This study underlined that the presence of *M. sagu* is the specific character of mangroves since *M. sagu* is the native vegetation of New Guinea. Another factor to explain that is flat areas dominate the topographic condition of the forest, so some areas are identified as repeatedly inundated zones generating more gallery forests. Moreover, the areas of Bintuni Mangroves also comprised riparian forests since there are many rivers. Hence, the hydrochory mechanism is imperative to affect seeds, spores, and fruits during seed dispersal (Polidoro et al. 2010; Correa et al. 2022). Thus, this can be the explanatory factor concerning the presence of species such as *I. palembanica* and *P. dalbergioides* as *mangrove associates* vegetation and the high number of species richness in the Bintuni mangrove. The edaphic condition of the Bintuni mangrove is mainly a result of the deposition of sediment by the rivers and tidal process, creating an alluvial plain, particularly in the nature reserve.

Therefore, this situation supports the hydrochory mechanism wherein the water movement, either sea or river, brings the floating seeds, spores, and fruits from the terrestrial forest around the mangrove forest. This condition strengthens the phenomenon that the Bintuni mangrove contained "mangrove associates" vegetation (Sillanpää et al. 2017; Yudha et al. 2021).

In this research, the forest types differentiated as nature reserve, protection forest, and production forest as we found that in the three forest types, there were 34 (59.65% of total species number) species of vegetation in common to share in three forest types. In terms of species richness, the nature reserve provided the highest number of species of vegetation. Even though the sample rarefaction (Mao's tau) curve showed an increasing trend of species number in the three locations, the number of vegetation species in the nature reserve was higher comparing to other mangrove forests. The vegetation species increased logistically as the number of sampling areas increased linearly. The tendency to increase vegetation richness could result from the uneven distribution of vegetation species, as shown by the Evenness index (E'), mostly below 0.5. Consequently, there is a probability of recruiting vegetation species during data collection as the character of tropical rainforest has a higher number of vegetation species (Murdjoko et al. 2021c, 2022). Moreover, in this research, we collected the *true mangrove* and the vegetation of *mangrove associates* tallied. The nature reserve and protection forest experienced less disturbance as a result of human activities unless, in the production forest, the company of forest concession has been conducting the harvest for decades (Wahyudi et al. 2014; Sillanpää et al. 2017; Yudha et al. 2021).

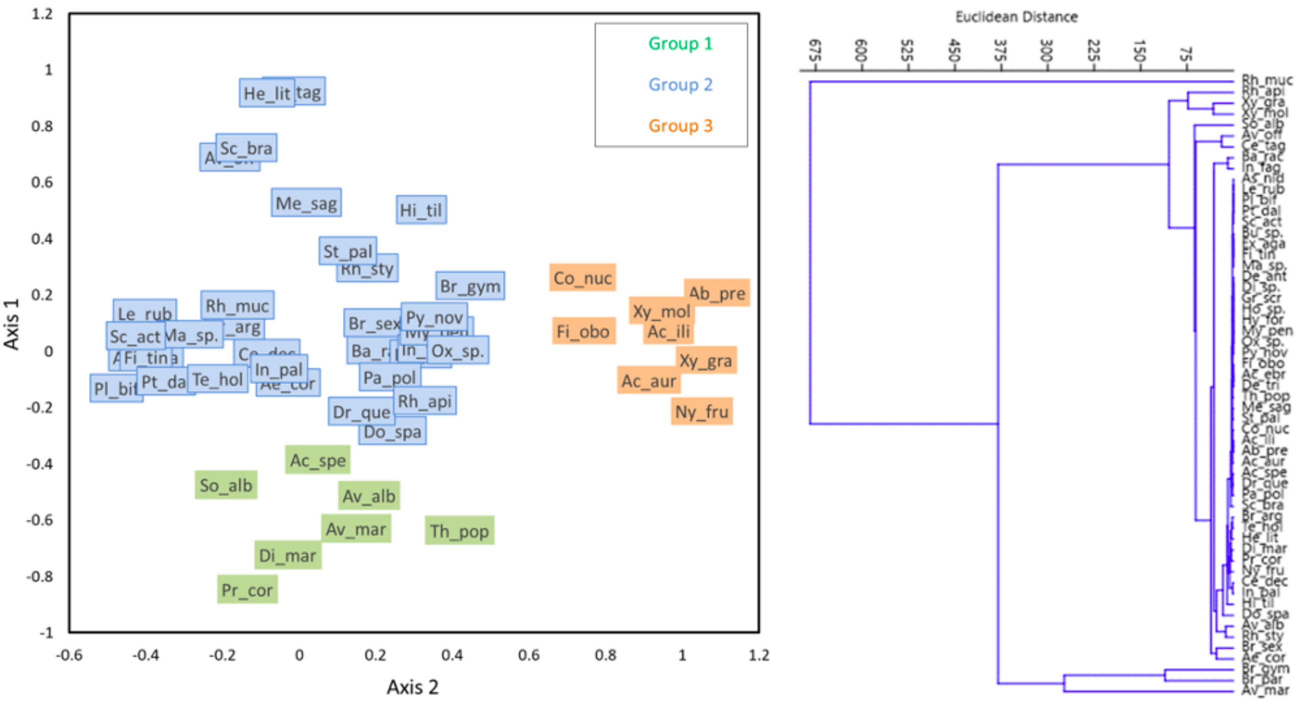
Particularly in the nature reserve, the species richness is higher not only in the true mangrove vegetation but also in the *mangrove associates* vegetation, where the natural forest can provide the place to maintain the biodiversity of vegetation. The protection forest is an undisturbed area, but the geographical position in this gulf is because mostly the protection forests are located in the outlier of the gulf. Thus, the seed dispersal process of whether *true mangroves* or *mangrove associates* counts on the hydrochory since the true mangrove provides the viviparous seeds as propagules (Kathiresan and Bingham 2001; Wang et al. 2011; Islam et al. 2022). The nature reserve is mainly located in the corner of the gulf, and the areas are shaped by the deposition of rivers creating many tide-dominated deltas in which vegetation, particularly *true mangroves*, grew (Fagherazzi 2008). The role of rivers is also imperative to support the vegetation establishment in nature reserves that carry the deposit and the reproductive organs of vegetation, such as seeds, spores, and fruits from terrestrial forests. The ocean current in the gulf produces water movement, so it impacts seed dispersal. The ocean current is not directly observed during the research, but we could assume that ocean current could result in the accumulation of reproductive organ that is available to germinate in delta rivers (Davis et al. 2004; Azman et al. 2021; Hagger et al. 2022; Azman et al. 2023).

The reproductive organs could come from another part of the terrestrial forest close to the shoreline; then, they reach the delta area to grow as vegetation establishments (Chen et al. 2020; Correa et al. 2022; Wendt et al. 2022). The tidal mechanism affects the distribution of reproductive organs predominantly to the inland area since the high tide in the nature reserve and owing to the flat area leading to the rising water river surface. This situation could spread river flow to the riverbank, causing water inundation in some forests. Another thing was that vegetation diversity also appears in mangrove trunks which provided a place for epiphytes and climbers since the trunks have a rough surface that allows seeds or spores to be placed probably by zoochorous species or anemochorous process (López-Martínez et al. 2013; Chen et al. 2020; Pedraza et al. 2021; Correa et al. 2022; Wendt et al. 2022). We accentuated that the species such as *M. pendens* and *P. novoguineae* (Christ) M.G.Price are native to New Guinea. Hence, it is interesting to observe that mangrove forests accommodated biodiversity and played a crucial role as the main structure of the ecotonal ecosystem between aquatic and terrestrial zones.

In contrast, protection forests are generally situated on shorelines with dominancy of the sandy area, as observed from aerial images. Then, we could explain that the ocean current carries the deposit and reproductive organs could not accumulate in protection forests. Thus, this condition can explain why species richness tended to be lower than in nature reserves. Most of the time, the species richness and diversity in protection forests were similar to the production forest. This results from silvicultural treatments conducted during the harvest (Sillanpää et al. 2017; Yudha et al. 2022). Besides, the availability of a family of Rhizophoraceae could germinate without dormancy and viviparous process (Kathiresan and Bingham 2001). Most of the species in this family has been used as tree target during mangrove concession in Bintuni. Moreover, afforestation was conducted to increase the number of vegetation recruitment, and also, remaining parent trees could supply the number of propagules. Hence, although this process takes decades, the logged mangrove forest could recuperate as closely as the undisturbed mangrove forest. Once the logged mangrove forest has been dense with many individuals and species richness specifically categorized as *true mangrove* vegetation, the *mangrove associates* vegetation could grow, such as epiphytic plants. So, this study's main finding is that *true mangrove* vegetation plays a crucial role in vegetation diversity and species richness.

The predominant vegetation in each forest type's small, intermediate, and large individuals was *B. parviflora*, while *B. gymnorhiza* and *R. mucronata* were predominant vegetation in large individuals in three forest types. This phenomenon can be explained that the family of Rhizophoraceae was the superior vegetation in mangroves as some publications mentioned that species belonging to this family grow dominantly in the mangrove forest (Lillo et al. 2019; Yudha et al. 2021; Canty et al. 2022). The character of reproductive mechanisms such as vivipary creating propagules of the vegetation leading to seedling establishment successfully occurring in mangroves (Kathiresan and Bingham 2001; Feller et al. 2010; Otero et al. 2020) (Fatonah et al. 2021). The shallow water is favorable to this recruitment process since the areas of the Bintuni mangrove, especially in the nature reserve, mainly located in the gulf corner, make it possible to be a seedling establishment zone. The salt-tolerant character of intermediate and large individuals, such as aerial root systems and wood anatomy, grows from fringe mangroves to gallery forests. The species of *A. marina* appeared in small, intermediate, and large individuals as dominant vegetation in protection forests because the shoreline is the sandy area where the *A. marina* is most favored. The species that belong to the genera of *Bruguiera* and *Rhizophora* are more adjustable with sediment conditions as they appear plentifully in mangrove forests. They are mostly considered the main structure of mangrove, as observed in many small individuals as the result of fast germination during viviparous development, and the morphological character of propagule support the natural regeneration. The species of large individuals like *S. alba* and *X. moluccensis* were distributed plentifully in protection forests and nature reserves, respectively.

This study described the vegetation assembly using Correspondence Analysis (CA), as shown in Figure 4, to show the vegetation cohort; as we obtained the result from the analysis, three vegetation groups were displayed in CA and Dendrogram. We applied the Euclidean distance to cluster the vegetation species; the lower Euclidean distance means the closer vegetation to grow side by side (Murdjoko et al. 2016a, 2016b). In this mangrove vegetation, we found three models of vegetation assembly as observed in the CA graph and dendrogram. *A. speciosum*, *A. alba*, *A. marina*, and *S. alba* groups were frequently found in the same area. They seemed to be in a fringing zone in the protection forest with a sandy shoreline area. In contrast, the nature reserve and production forest, in which the shorelines were mostly muddy sediment, resulted in *Bruguiera* and *Rhizophora* being dominant. The species such as *A. aureum*, *N. fruticans* Wurmb, *X. granatum*, *X. moluccensis*, and *D. trifoliata* appeared in the landward zone where the salinity and inundation were considerably low. The condition of edaphic variables such as sand and mud has significantly affected the formation of the zonation mangrove pattern. Furthermore, mangrove vegetation's physical and anatomical properties, notably its regenerative ability, influence its geographical distribution.



A B

Figure 4. A. Correspondence Analysis (CA) for vegetation assembly of the Bintuni mangrove shows the three clusters of green, blue, and brown boxes with the abbreviation of species names as seen in Table 1. B. The dendrogram uses Euclidean Distance as a similarity index

The Bintuni mangrove was a suitable ecosystem supporting the conservation program, particularly in the nature reserve, as the vegetation was classified as Near Threatened and Vulnerable. Furthermore, the number of species in three forest types was found in the Least Concern category, with the population trend decreasing. On the contrary, the Bintuni mangrove can maintain its structure and composition as some studies mentioned that regeneration of mangrove, particularly vegetation belonging to the family of Rhizophoraceae, is successfully established. For that reason, regular monitoring of vegetation richness is important since the Bintuni mangrove does not have a significant threat like massive conversion of mangrove (Richards and Friess 2016; Sarker et al. 2019; Hagger et al. 2022; Sasmito et al. 2023). The monitoring can be done through recent technology, such as online and unmanned-aerial vehicles, as done by some publications applying NDVI and other vegetation indexes (Hematang et al. 2021, 2022; Manuputty 2022). We proposed that future research not only focus on vegetation but also species richness and diversity of wildlife since the mangrove forest, especially the Bintuni mangrove, functions as the habitat of other organisms and is part of the food chain in the ecotone ecosystem.

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