Annals of Silvicultural Research
49(2), 2024: 44-52
https://creajournals.crea.gov.it/asr/

Research paper

Species Richness and Diversity of Klawalu Mangrove, Doberai Peninsula, Indonesian New Guinea

Anike Asmuruf[1], Yolanda Holle[2], Agustinus Murdjoko[3]*, Nithanel M.H. Benu[4], Dony A. Djitmau[3]

Received: 3/03/2023 *Accepted: 23/01/2024* *Published online: 29/03/2024*

ABSTRACT Mangrove plays an important role in the coastal area in particular as an ecological service, yet ecosystem cover has been declining for decades. This research was designed to find out the vegetation diversity of mangroves in Klawalu, Doberai Peninsula, Indonesian New Guinea. The 30 nested plots were located in three locations as the representation of mangrove fringe, intermediate, and landward zone, consecutively. This study revealed that mangrove forest consists of 21 species classified as the main structure and 9 species as mangrove associates. In general, the mangrove forest is able to regenerate naturally where fecundity establishment can be seen by the number of small individuals. The species diversity and the number of individuals from the edge to the inland increase resulting from tidal factors affecting the seed dispersal and sapling establishment. Practically, government intervention is needed to strengthen the status of the area as a protected area by means of regional regulations to manage sustainably the mangrove.

KEYWORDS: Coastline, mangrove, propagule, Shannon-Weiner Index, tropical forest, viviparous.

Introduction

The latitudinal diversity gradient of vegetation refers to the pattern of plant species richness and diversity changing with latitude characterized by higher species richness in tropical regions near the equator and decreasing diversity towards the poles (Hofhansl et al. 2020, Liang et al. 2022). Specifically, the richest vegetation based on taxonomy for the species level is in mainland New Guinea with lifeform distribution ranging from lowlands to highlands (Cámara-Leret et al. 2020, Murdjoko, Djitmau et al. 2021, Tawer et al. 2021). In the lowland areas themselves, many types of ecosystems and sub-ecosystems are formed, especially in areas bordering marine or aquatic ecosystems (Cámara–Leret and Dennehy 2019, Canty et al. 2022). The mangrove ecosystem is one of the structures of the lowland biome with the adaptation to survive using anatomical and morphological ability to tidal movements. Moreover, the vegetation of mangrove forests can adapt to salinity caused by seawater. The process of this adaptation can be seen morphologically in the form of modified roots as aerial roots and anatomical tissues that can tolerate salinity by seawater and evaporation resulting in salt crystals on the surface of the stems and especially the leaves. These conditions have made the ecological characteristics of the vegetation of mangroves able to survive in the transitional areas (ecotone) of waters, especially seawater, and land (Kathiresan and Bingham 2001, Matthijs et al. 1999). Consequently, the taxonomic number in mangrove forests is mostly lower than in primary or secondary forest areas on the mainland which have high species richness with lifeform variations. Ecologically, the mangrove area functions as an ecosystem for other organisms, especially aquatic organisms such as a place to live and reproduce for some fish and crabs (Feller et al. 2010, Field 1999, Polidoro et al. 2010). In addition, the shape of the roots that appear on the surface can be a support for the accumulation of sediment from litter and other organic materials, so the role of mangrove areas is currently being considered as carbon sequestration commonly known as "blue carbon" (Safwan Azman et al. 2023, Sarker et al. 2019, Sasmito et al. 2020). Anthropologically, the existence of the mangrove forest supports the activities of local communities who already live around the mangrove area. Many studies showed that mangrove forests have become an important part of contributing to the livelihood of local communities such as finding food sources viz. fish, shellfish, and crabs. Some local communities have used wood for house construction as well as community needs such as firewood and traditional medicinal materials for generations (Arbiastutie et al. 2021, Gnansounou et al. 2021, Islam et al. 2022, Liebezeit and Rau 2006).

The Vogelkop of Papua Island has coastal areas consisting of mangrove forests where some are in Doberai Peninsula located in the western part (administratively included in Sorong Regency, Sorong City, South Sorong Regency, and Tambrauw Regency) and south, especially the Bintuni Bay area. For this reason, scientific observations are needed to reveal the biodiversity of mangrove vegetation. It is crucial to study mangrove vegetation as some publication results indicated that the mangrove area has decreased a lot in the area due mainly to human activities (anthropological factor). Some studies showed that mangrove areas have been decreased resulting mainly

1 – Universitas Papua - Program Magister Ilmu Lingkungan Manokwari, Papua Barat – Indonesia

2 – Universitas Papua - Fakultas Pertanian Manokwari, Papua Barat – Indonesia

3 - Universitas Papua – Fakultas Kehutanan Manokwari, Papua Barat – Indonesia

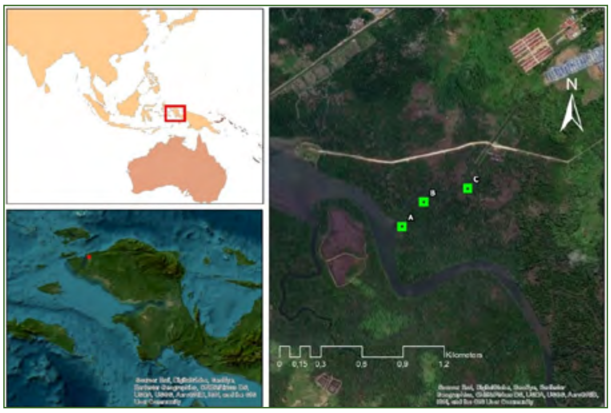
4 - Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia, Balai Penetapan Standar Instrumen Lingkungan Hidup dan Kehutanan (BPSILHK) Manokwari, Papua Barat – Indonesia

*Corresponding author: agustinus.murdjoko.papua@gmail.com

http://dx.doi.org/10.12899/asr-2483

from the conversion to other functions in a very massive area, and also in some places, there has been partial reclamation of mangrove areas (Hagger et al. 2022, Sasmito et al. 2023). Hence, the need for research to reveal one of them biodiversity for vegetation is of very crucial interest.

Figure 1 - The location of research for mangroves in Klawalu with the fringing zone (A), the intermediate zone (B), and the landward zone (C) which is given a green box symbol.



The development programs in developing regions such as Sorong City are requiring areas to fulfill them. In coastal areas, the areas are mainly dominated by mangrove forests, but the use of mangroves must be conducted wisely since the mangrove has an ecological function. Currently, some of the mangrove areas have been developed as tourist areas. Ecologically, this area provides a barrier and supports the diversity of organisms. However, the biodiversity of vegetation in the Klawalu mangrove area has not been scientifically revealed. Therefore, the purpose of this research was to study the species richness and diversity of the Klawalu mangrove forest. The study was crucial to provide scientific and valid information for vegetation diversity.

Materials and Methods

Study area

The location of research was carried out in the Kawalu Mangrove Forest area of the Doberai Peninsula which is administratively part of Sorong City (Fig. 1). This area has several parts of mangrove forests which are designated as Areas for Other Uses (APL) on the mainland and there are Convertible Production Forests (HPK) functions around the west and east, while in the outer areas such as the islands to the west designated as Protected Forest (HL). The data collection was carried out in the APL area which is the main structure of the tourist area managed by the Sorong City government through the Tourism Office and has been running officially since 2019. Data collection was carried out in the area around the estuary or fringing which represents the fringing zone of the mangrove (A), intermediate zone - the middle area which represents the middle part of the mangrove vegetation (B), and landward - the area considered as the boundary between mangrove vegetation and terrestrial vegetation (C). Geographically, the positions of the three locations are location A (0°55'4.80"S, 131°18'4.45"E), location B (0°54'58.98"S, 131°18'9.60"E), and location C (0°54'55.81"S, 131°18'19.94"E). The consideration for dividing the location is to observe the gradient of vegetation biodiversity from areas adjacent to waters where there are influences from tides to land areas that were not much affected by tides.

Vegetation Sampling and Data Collection

We performed nested-circular plots in which each plot consisted of a plot with a radius of 7 m. The plot was to collect vegetation categorized as large individuals with criteria having a diameter greater than 5 cm. Then, within the plot, a subplot with a radius of 2 m was set to collect vegetation categorized as saplings with a diameter of less than 1 cm and a height of less than 1.5 m while small individuals with a diameter between 1 – 5 cm and a height taller than 1.5 m. Furthermore, the number of plots for each location was 20 plots and they were placed parallel to the coastline, so there were a total of 60 plots. The minimum distance for each plot at each location was a minimum of 30 m to minimize the pseudo-replication effect (Cannon et al. 1998, Sillanpää et al. 2017). From each plot, all individual in the plot was recorded for taxonomic information at the species level and diameter measurements for small and large individuals along with the number of individuals present (Sillanpää et al. 2017). Information regarding the scientific nomenclature system for vegetation followed Plants of the World Online (https://powo.science.kew.org/, accessed on 2 February 2023) and World Flora Online (http://www.worldfloraonline.org/, accessed on 2 February 2023).

Data Analysis

To know the dominant and rare species in the mangrove area, we executed the Importance Value Index (%) for the growth stages of saplings, small individuals, and large individuals (Cottam and Curtis 1956, Murdjoko et al. 2021). The use of the formula for calculating the analysis is as follows $IVI_i = RFr_i + RDe_i + RDo_i$ where IVIi = Importance value index of species *i*; RFri = Relative Frequency of individual species I; RDei = Relative Density of individual species I; and RDoi = Relative Dominance of individual species *i*. In particular, for species at the sapling level, we only applied frequency and density to obtain the Importance Value Index (%).

Species diversity was calculated using the Shannon-Weiner Index, while evenness was analyzed through the diversity index. The two indices were calculated using the following formula of $H' = -\sum p_i \ln(p_i)$ where H'= Shannon-Weiner for diversity index and p_i = the number of samples where tree species i is present. The value of the evenness index was measured using $E' = \frac{H'}{\ln(S)}$ where S is the number of species for each location (Murdjoko, Ungirwalu et al. 2021, Spellerberg and Fedor 2003). Calculation of these two indices was carried out: to compare the three growth phases of saplings, small individuals and large individuals; to compare the three locations of the fringing zone (A), the intermediate zone (B), and the landward zone (C). The analysis of the two indices was performed using the software PALeontological Statistics (PAST) version 4.03 (Hammer et al. 2001).

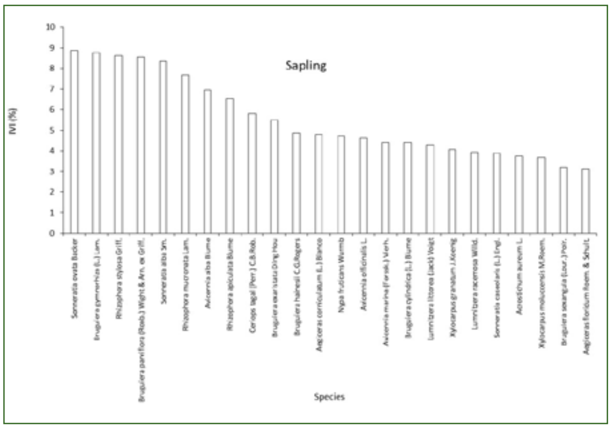
Results

Taxonomic Composition and Diversity of Mangrove Forest

We found 30 species in the Klawalu mangrove area consisting of 21 species categorized as true mangroves and 9 species grouped as mangrove associates. Furthermore, the component species in sapling level, small individuals, and large individuals are displayed with a graph showing the Importance Value Index (%) for each structure species below.

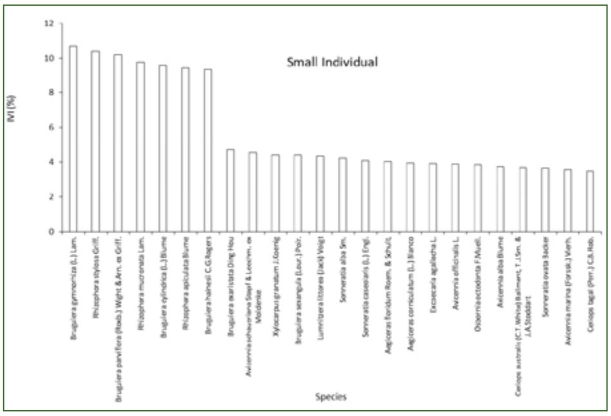
There are 24 species of saplings in the growth phase of mangroves in this area in which the results of the Importance Value Index (%) show the dominant species such as *Sonneratia ovata* Backer, *Bruguiera gymnorhiza* (L.) Lam., *Rhizophora stylosa* Griff., *Bruguiera parviflora* (Roxb.) Wight & Arn. ex Griff., *Sonneratia alba* Sm., *Rhizophora mucronata* Lam., *Avicennia alba* Blume, *Rhizophora apiculata* Blume, *Ceriops tagal* (Perr.) C.B.Rob., and *Bruguiera exaristata* Ding Hou. On the other hand, several species at this sapling growth stage are categorized as very rare, namely *Lumnitzera racemosa* Willd., *Sonneratia caseolaris* (L.) Engl., *Acrostichum aureum* L., *Xylocarpus moluccensis* M.Roem., *Bruguiera sexangula* (Lour.) Poir., and *Aegiceras floridum* Roem. & Schult.

Figure 2 - Importance Value Index (%) of vegetation species making up mangrove areas for saplings.



In the distribution of the vegetation, 24 species of small individuals are distributed showing the dominant species based on IVI (%) namely *Bruguiera gymnorhiza* (L.) Lam., *Rhizophora stylosa* Griff., *Bruguiera parviflora* (Roxb.) Wight & Arn. ex Griff., *Rhizophora mucronata* Lam., *Bruguiera cylindrica* (L.) Blume, *Rhizophora apiculata Blume*, and *Bruguiera hainesii* C.G.Rogers. In addition, the species indicating a rare category are *Aegiceras corniculatum* (L.) Blanco, *Excoecaria agallocha* L., *Avicennia officinalis* L., *Osbornia octodonta* F.Muell., *Avicennia* alba Blume, *Ceriops australis* (C.T.White) Ballment, T.J.Sm. & J.A.Stoddart, *Sonneratia ovata* Backer, *Avicennia marina* (Forssk.) Vierh., and *Ceriops tagal* (Perr.) C.B.Rob.

Figure 3 - Importance value index (%) of vegetation species making up the mangrove area for small individuals.



The structures of the mangrove forest in the Kawalu area identified 24 species in the growth phase at the large individual level. Furthermore, the Importance Value Index (%) shows that many species dominate in this area, namely *Bruguiera gymnorhiza* (L.) Lam., *Bruguiera cylindrica* (L.) Blume, *Rhizophora apiculata* Blume, *Rhizophora stylosa* Griff., *Xylocarpus granatum* J.Koenig, *Rhizophora mucronata* Lam., *Bruguiera hainesii* C.G.Rogers, and *Bruguiera parviflora* (Roxb.) Wight & Arn. ex Griff. In addition, some species are identified as non-dominant categories in this area viz. *Sonneratia caseolaris* (L.) Engl., *Sonneratia ovata* Backer, and *Aegiceras corniculatum* (L.) Blanco. Overall the vegetation of the mangroves in the Klawalu area is divided into three, namely the fringing zone directly adjacent to the sea (A), the central area (B), and the landward zone (C). Furthermore, the vegetation structure is separated into three phases, saplings - individuals that have just germinated, small individuals - vegetation that has grown from saplings with a height of more than 1.5 m, and large individuals with a category of vegetation above 5 cm in diameter.

For the sapling phase, the highest number of species is in the fringing area and the middle part with the number of species being 24 each, while the number of individuals constituting the area is the fringing zone with 178 individuals followed by the intermediate zone with 87 individuals and areas that bordering the mainland vegetation with 85 individuals. The diversity value for areas on the waterfront and adjacent to terrestrial vegetation shows higher diversity with values A = 2.99 and C = 3.06 compared to the intermediate zone with H' value for B = 2.96. Then, the evenness of the species is more varied in the fringing zone with a value of E' = 0.97 compared to the central area and adjacent to mainland vegetation with a value of E' is B = 0.96 and C = 0.97.

In the small individual, the number of taxa composing each area is different as found in the intermediate zone (B) with the number of species 23, and then the area bordering the mainland vegetation with 24 species, while the fringing zone is 22 species. The same model also occurs for the number of individuals, namely the central area (B) has the highest number of individual distributions with a value of 345 individuals and is followed by the landward zone (C) with a total of 338 individuals, while the fringing zone (A) is the area with the least number of individuals in the small individual phase with 177. The diversity indices show that the landward zone (C) with an H' value of 3.00, and then coastal areas (A) and the middle region (B) with A=3.06 and B=2.98, respectively. The evenness index has variations from the three locations which are indicated by the highest diversity value in the fringing zone A with a value of 0.97 and the intermediate zone (B) along with the landward zone have the same E' value of 0.86 (Tab. 1).

Figure 4 - Importance value index (%) of vegetation species making up the mangrove area for large individuals.

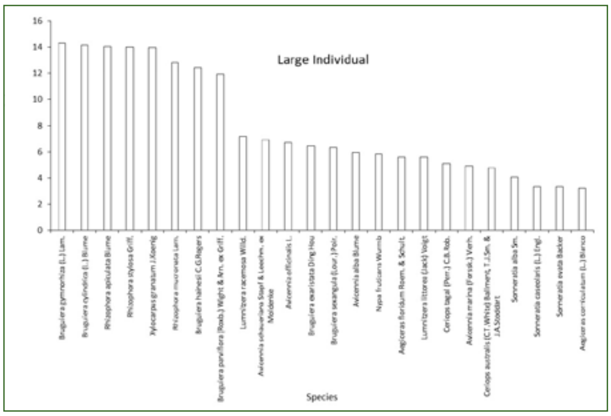


Table 1 - Structure of mangroves distributing from fringing zone (A), intermediate zone (B) to landward zone (C) along with the number of species (Taxa_S), number of individuals (n), the diversity index (H'), and evenness index (E').

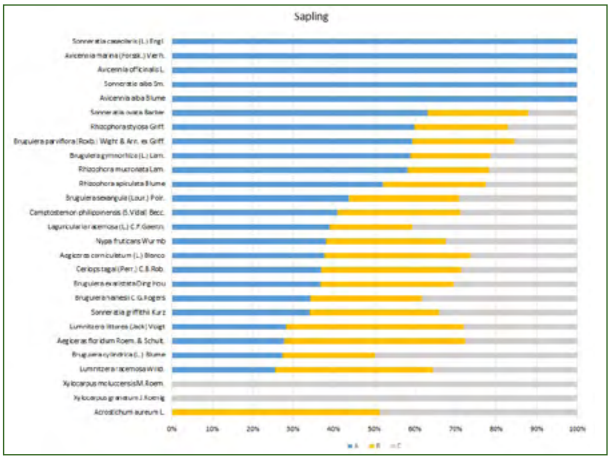
Mangrove structures	Ecological Parameters	A	B	C
Saplings	Taxa_S (spp. / 62.8 m²)	24	20	22
	Individuals (n / 62.8 m²)	178	87	85
	H'	2.99	2.96	3.06
	E'	0.83	0.96	0.97
Small Individuals	Taxa_S (spp. / 1,005.8 m²)	22	23	24
	Individuals (n / 1,005.8 m²)	177	345	338
	H'	3.06	2.98	3.00
	E'	0.97	0.86	0.83
Large Individuals	Taxa_S (spp. / 6,285.8 m²)	25	25	24
	Individuals (n / 6,285.8 m²)	250	425	411
	H'	3.16	3.02	2.99
	E'	0.94	0.82	0.83

The species composition in the three areas for large individuals show that the distribution of the highest number of species is in the intermediate zone (B) with some species 25 and the fringing zone with 31 species, then the next is the landward zone (C) with the number of species being 24. The diversity of vegetation present in the three locations also shows high variation in the fringing zone (A) with an H' value of 3.16, the intermediate zone with 3.02, and the landward zone (C) with an H' value of 2.99. In the proportion of species and the number of individuals, the fringing zone (A) with a value of E' is 0.94, and the central area (B) and the area bordering the mainland (C) vegetation with 0.82 and 0.83, respectively.

For analysis of the distribution of species in the fringing zone (A), the intermediate zone (B), and the landward zone (C) are shown graphically in Figures 5, 6, and 7 below. The composition of the vegetation structure is analyzed with the proportion of the number of species and the number of individuals in the three areas so that it can visualize the distribution of each species in the three areas.

Mangrove areas are naturally composed of the main component (true mangroves) and vegetation that is classified as an additional component or (minor component). The saplings in the fringing zone (A) are dominated by species *Rhizophora apiculate, Rhizophora mucronata, Bruguiera gymnorhiza, Bruguiera parviflora, Rhizophora stylosa, Sonneratia ovata, Avicennia alba, Sonneratia alba, Avicennia officinalis, Avicennia marina,* and *Sonneratia caseolaris* while the landward zone (C) is dominated by the species *Xylocarpus granatum* and *Xylocarpus moluccensis*.

Figure 5 - The composition of the mangrove vegetation species in the three locations A=fringing zone, B=intermediate zone, C=landward zone for saplings.



For the growth phase at the small individual, the fringing zone (A) is massively overgrown by species such as *Sonneratia ovata.* In the intermediate zone (B) is dominated by *Aegiceras corniculatum* while the area adjacent to terrestrial vegetation (C) shows the dominant species viz. *Aegiceras floridum* and *Xylocarpus granatum*.

There are many *Avicennia schaueriana, Avicennia officinalis,* and *Sonneratia alba* found in the species of large individuals in the fringing zone (A). The intermediate zone (B) is composed predominantly of *Bruguiera parviflora*. Finally, areas adjacent to terrestrial vegetation (C) are mostly dominated by *Nypa fruticans* and *Xylocarpus granatum*.

Figure 6 - The composition of the mangrove vegetation species in the three locations A=fringing zone, B=intermediate zone, C=landward zone for small individuals.

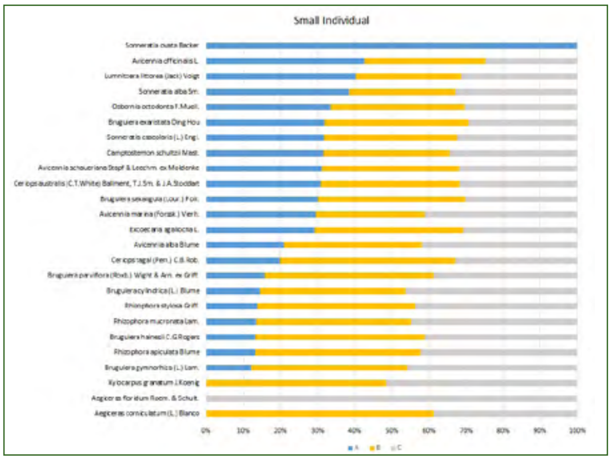
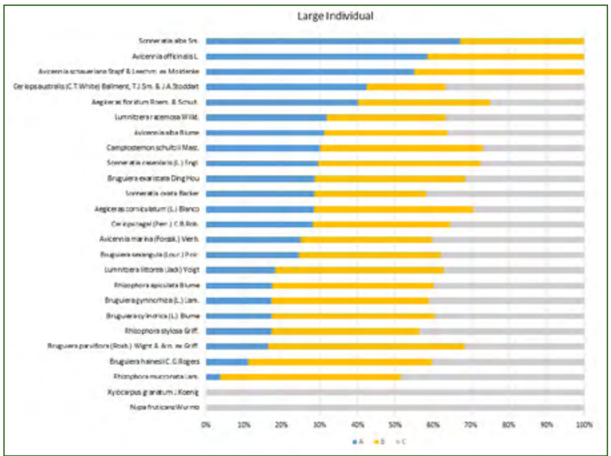


Figure 7 - The composition of the mangrove vegetation species in the three locations A=fringing zone, B=intermediate zone, C=landward zone for large individuals.



Vertical Stratification of Mangrove Forest

In terms of vertical structure, the vegetation in the Kawalu area can be analyzed by the number of individuals in the saplings, small individuals, and large individuals. This information can be used to see the growth process, especially the regeneration of each structure of species. The results of the analysis in the graph above indicate that not all species are present in all growth phases. Species such as *X. moluccensis* and *A. aureum* are present only in the form of saplings with conditions where small and large individuals are absent or not found in this area. The opposite phenomenon is species such as *Ceriops australis* (C.T.White) Ballment, T.J.Sm. & J.A. Stoddart, *Osbornia octodonta* F. Muell., *Excoecaria agallocha* and *Avicennia schaueriana* can be found in this area as small and large individuals without any sapling phase being encountered. In addition to the species mentioned in these two categories, the presence of these species is found in the sapling phase, small individuals, and large individuals (Tab. 2).

Discussion

Biodiversity of Vegetation in Mangrove Ecosystem

Vegetation analysis indicated the number of species in each growth phase, namely saplings, small individuals, and large individuals, is still in a good condition. Some of the dominant species in each of these phases are species included in the true mangroves. As many published studies stated species from genera viz. *Sonneratia*, *Avicennia*, *Bruguiera*, and *Rhizophora* are key species in the composition of mangrove forest vegetation (Baloloy et al. 2021, Kasihiw et al. 2023, Matthijs et al. 1999). Particularly for species of the two genera like *Bruguiera* and *Rhizophora*, they have a unique ability to regenerate categorized as viviparous regeneration in which germination has started since the propagules are still attached in the parent individual (Kathiresan and Bingham 2001). This condition is the main factor that individuals from the two genera show in large numbers in each growth phase (saplings, small individuals, and large individuals). Moreover, these species are annual plants and evergreen vegetation, so the reproduction process occurs all the time leading to the production of propagules continuously.

On the contrary, other species such as *C. australis, O. octodonta, E. agallocha,* and *A. schaueriana* are found in the form of saplings at this location. The seeds are produced at any time, but the seeds take time to germinate at this location, then they are most likely carried by tidal currents from the sea (Correa et al. 2022, Polidoro et al. 2010). In addition, species from the lifeform group classified as palm also reproduce a lot of vegetative through shoots or suckers viz. *N. fruticans* which are also present in abundance on the edge of the land area bordering the mainland vegetation (Murdjoko et al. 2016). This situation results in regeneration for some of these species to experience displacement because this seed dispersal model is counting on the hydrochory model (Correa et al. 2022). The location of the mangrove in this area is directly opposite an estuary whose flow and water level are affected by tidal phenomena from the sea. Therefore, when the seeds fall during the high tide to be carried away by the flow in the estuary, or at the time of falling when the water recedes but the seeds cannot germinate, and then when the water level rises due to the tide the seeds are carried away by the water. This is one of the main reasons for the low density of the sapling phase in many species in this location.

In the analysis of species diversity based on the number of species and the number of individuals, there is a tendency for the species number to be greater in the fringing zone except for the sapling growth phase. This event can be explained that this mangrove forest is strongly influenced by the presence of rivers or estuaries which are affected by tides. The more landward it is, the less affected it is by sur-

Table 2 - Number of individuals in each mangrove structure, i.e. saplings (n / 62.8 m²), small individuals (n / 1,005.8 m²), and large individuals (n / 6,285.8 m²) for true mangroves and mangrove associates.

Structure	Species	Saplings	Small Individuals	Large Individuals
True Mangroves	*Avicennia alba* Blume	20.8	24.8	34.8
	Avicennia officinalis L.	13.8	25.8	39
	Avicennia schaueriana Stapf & Leechm. ex Moldenke	0	30.2	40.4
	Avicennia marina (Forssk.) Vierh.	13.2	23.8	28.8
	Bruguiera cylindrica (L.) Blume	13.2	63.6	82.6
	Bruguiera exaristata Ding Hou	16.4	31.4	37.6
	Bruguiera gymnorhiza (L.) Lam.	26.2	70.8	83.4
	Bruguiera hainesii C.G.Rogers	14.6	62	72.4
	Bruguiera parviflora (Roxb.) Wight & Arn. ex Griff.	25.6	67.6	69.6
	Bruguiera sexangula (Lour.) Poir.	9.6	29.2	36.8
	Ceriops australis (C.T.White) Ballment, T.J.Sm. & J.A.Stoddart	0	24.6	27.8
	Ceriops tagal (Perr.) C.B.Rob.	17.4	23.2	29.8
	Lumnitzera littorea (Jack) Voigt	12.8	28.8	32.8
	Lumnitzera racemosa Willd.	11.8	0	42
	Nypa fruticans Wurmb	14.2	0	34
	Rhizophora apiculata Blume	19.6	62.6	81.8
	Rhizophora mucronata Lam.	23	64.8	74.6
	Rhizophora stylosa Griff.	25.8	69	81.6
	Sonneratia alba Sm.	25	28	23.8
	Sonneratia caseolaris (L.) Engl.	11.6	27.2	19.6
	Sonneratia ovata Backer	26.6	24.4	19.6
Mangrove associates	*Acrostichum aureum* L.	11.2	0	0
	Aegiceras corniculatum (L.) Blanco	14.4	26.2	19
	Aegiceras floridum Roem. & Schult.	9.4	26.8	32.8
	Camptostemon philippinensis (S.Vidal) Becc.	11.6	0	0
	Camptostemon schultzii Mast.	14.2	0	0
	Excoecaria agallocha L.	0	26	0
	Osbornia octodonta F.Muell.	0	25.6	0
	Xylocarpus granatum J.Koenig	12.2	29.2	81.4
	Xylocarpus moluccensis M.Roem.	11	0	0

face water flow where the seeds that fall do not experience displacement due to water flow (Kathiresan and Bingham 2001). Especially viviparous seeds, they can immediately establish saplings and develop an increasing number of sapling phases. Similarly, for seeds that need time to germinate or dormant, these seeds are static and collect in locations close to the parent individuals which later when they germinate also shape cohorts or groups in that location. Furthermore, most of the mangrove species have morphological characters of fruit or seeds that are large in size so that when they fall from the parent individuals they are not mechanically affected by the morphological form of the parent individuals. Another explanation is that most of the seeds from this mangrove species are not a food source for some animals belonging to the browser. However, the absence or low population of crabs as propagule predation could be another reason why those species grow abundantly (Ferreira and Ganade 2015). The germination ability leads to a high number of sapling establishments mostly because of the non-dormant condition of seeds. This also occurs in several species of mangrove vegetation whose lifeform includes ferns such as those from the genus *Acrostichum* whose reproductive organs are in the form of spores which can also grow into new individuals when scattered around their parent vegetation.

From the results of diversity in the context of population dynamics, namely, the number of individuals present in the area is higher in landward than in the fringing zone. This, as explained above, is owing to the influence of water flow as a result of the tides leading to some newly formed saplings being carried away as the shape of their roots is not yet strong enough to withstand the movement of water flow. This condition results in the number of individuals that survive and become a process of fecundity or sapling establishment being much less compared to land areas where the influence of water flow due to tides is very small. In this situation, it can be estimated that the process of sapling establishment in the fringing zone is very low due to the process of mobilization or movement of seeds or even saplings that have just germinated due to the water flow (Nasrin et al. 2020, Sreelekshmi et al. 2018).

Applications of Sustainably Management Based on Ecological and Economical Aspects

The vegetation area in the Klawalu is still classified as a state of vegetation that has a species richness and good diversity level whereas the vegetation structures still contain groups of true mangroves and mangrove associates. Under natural conditions, mangrove vegetation can regenerate and survive in rivers, estuaries, and coastal areas as well. This is supported by the theory that mangroves can tolerate salinity through root and leaf morphological modifications. This is the basis for the theory that naturally inter-species competition will only occur with mangrove vegetation compared to the condition of terrestrial or mountain forest ecosystems which have biodiversity in the form of a very high number of species and lifeforms (Sillanpää et al. 2017). Therefore, the scientifically optimistic opinion that this mangrove vegetation has regeneration, especially one of the supporters of the sustainability of mangrove ecosystems, is very possible. In contrast, degradation and deforestation in mangrove areas is a result of anthropological factor. This is supported by several studies on changes in mangrove areas in several places caused by anthropological actions. This situation is a form of dilemma in area management where on the one hand development requires area size, while from the other side, from a conservation perspective, action is needed to maintain the area and the level of existing biodiversity (Cosyns et al. 2020).

Recently, the mangrove area has been programmed as a tourist area managed by the local government currently handled by the Sorong City Government through the local Tourism Office where facilities have been built to be used by tourists. The purpose of developing this tourist area is a form of management that maintains the condition of the mangrove forest by offering views of mangrove vegetation which is classified as still natural. However, from the determination of the functional status of the area based on the central government through SK.783/Menhut-II/2014 dated 22 September 2014, namely as an Area for Other Uses (APL) which legally will easily be converted into other functions. In regional settings, this mangrove vegetation has the potential to be developed into other functions such as settlements and other economic areas. Therefore, it is recommended that the management of existing tourist areas be strengthened with the local government through regulations in the form of area designations so that they are not converted for other purposes. This can be done by setting zones not to be converted and strengthening management as an ecosystem-based tourism area without changing the area massively. The zones of mangrove management must be made based on future studies regarding both the ecological and economic benefits and this activity must involve local communities. Furthermore, the local government could set the conservation programs using a combination of traditional knowledge and science. The program must be stated legally in the planning and development of the district as a roadmap for the government (Bryan-Brown et al. 2020, Manuputty 2022). Furthermore, it is hoped that the local government can strengthen the position of this mangrove area by formulating policies, especially for the western part which is bordered by rivers and estuaries, so that this area will not be converted to other functions. In this condition, the authority of the local government can be used to support the status of the area with the aim of conservation which can be utilized without reducing the mangrove area. For example, regional policies have been implemented by several districts to support conservation or sustainable development programs in Tanah Papua – Indonesian New Guinea (Cámara-Leret et al. 2019, Sreelekshmi et al. 2018). In this condition, considerations for management, especially in Klawalu, as an example, are that local government intervention is needed to legally delineate the zones of mangrove management using regional regulations (Manuputty 2022). Moreover, there is also a need for scientific exploration of biodiversity for other organisms as ecosystem processes such as animals, and investigative topics that support the scientific basis for future research.

This study underlined that the Klawalu mangrove forest consists of 21 species which are classified as the main structure (true mangroves) and 9 species of mangrove associates. In general, the regeneration process for the sustainability of mangroves naturally is taking place in this area. This can be seen that almost all species are present in the form of saplings, small individuals, and mature individuals. Then, the diversity of species and the number of individuals from the edge to the land indicates an increase caused by tidal factors that affect the process of seed dispersal and sapling establishment (Sreelekshmi et al. 2018). Mangroves play an important role in the coastal ecosystem providing numerous economic and ecological benefits. Hence, effective management of mangroves is crucial to ensure long-term sustainability and resilience. In general, sustainable harvesting of resources, habitat restoration, ecotourism development, and education and community engagement are highly recommended by prioritizing the conservation of the mangrove ecosystem. Further investigation focusing on ecological functions will support the strengthening of this area as a conservation of mangrove area which is a source of biodiversity, but it would be also managed to support economic functions.

Acknowledgments

We thank Pemerintah Kota Sorong for giving the permit during data collection. We are also extremely grateful to the anonymous reviewer(s) for giving useful inputs in this manuscript.

References

Arbiastutie Y., Diba F., Masriani 2021 - *Ethnobotanical and ecological studies of medicinal plants in a mangrove forest in mempawah district, west kalimantan, indonesia.* Biodiversitas 22 (6): 3164–3170. doi:10.13057/biodiv/d220619

Baloloy A. B., Blanco A. C., Sharma S., Nadaoka K. 2021 - *Development of a Rapid Mangrove Zonation Mapping Workflow Using Sentinel 2-Derived Indices and Biophysical Dataset.* Frontiers in Remote Sensing 2 (September): 1–18. doi:10.3389/frsen.2021.730238

Bryan-Brown D. N., Connolly R. M., Richards D. R., Adame F., Friess D. A., Brown C. J. 2020 - *Global trends in mangrove forest fragmentation.* Scientific Reports 10 (1): 1–8. doi:10.1038/s41598-020-63880-1

Cámara-Leret R., Frodin D. G., Adema F., Anderson C., Appelhans M. S., Argent G., Guerrero S. A., Ashton P., Baker W. J., Barfod A. S., Barrington D., Borosova R., Bramley G. L. C., Briggs M., Buerki S., Cahen D., Callmander M. W., Cheek M., Chen C.-W. et al. 2020 - *New Guinea has the world's richest island flora.* Nature 584 (August): 579–583. doi:10.1038/s41586-020-2549-5

Cámara-Leret R., Schuiteman A., Utteridge T., Bramley G., Deverell R., Fisher L. A., McLeod J., Hannah L., Roehrdanz P., Laman T. G., Scholes E., de Fretes Y., Heatubun C. 2019 - *The Manokwari declaration: Challenges ahead in conserving 70% of Tanah Papua's forests.* Forest and Society 3 (1): 148–151. doi:10.24259/fs.v3i1.6067

Cámara–Leret R., Dennehy Z. 2019 - *Indigenous Knowledge of New Guinea's Useful Plants: A Review.* Economic Botany 73 (3): 405–415. doi:10.1007/s12231-019-09464-1

Cannon C. H., Peart D. R., Leighton M. 1998 - *Tree species diversity in commercially logged Bornean rainforest.* Science 281 (5381): 1366–1368. doi:10.1126/science.281.5381.1366

Canty S. W. J., Kennedy J. P., Fox G., Matterson K., González V. L., Núñez-Vallecillo M. L., Preziosi R. F., Rowntree J. K. 2022 - *Mangrove diversity is more than fringe deep.* Scientific Reports 12 (1): 1–10. doi:10.1038/s41598-022-05847-y

Correa D. F., Stevenson P. R., Umaña M. N., Coelho L. de S., Lima Filho D. de A., Salomão R. P., Amaral I. L. do, Wittmann F., Matos F. D. de A., Castilho C. V., Phillips O. L., Guevara J. E., Carim M. de J. V., Magnusson W. E., Sabatier D., Molino J., Irume M. V., Martins M. P., Guimarães J. R. da S. et al. 2022 - *Geographic patterns of tree dispersal modes in Amazonia and their ecological correlates.* Global Ecology and Biogeography (September): 1–21. doi:10.1111/geb.13596

Cosyns H., Joa B., Krumm F., Winkel G., Schulz T. 2020 - *Resolving the trade-off between production and biodiversity conservation in integrated forest management: comparing tree selection practices of foresters and conservationists.* Biodiversity and Conservation (September): 1–21. doi:10.1007/s10531-020-02046-x

Cottam G., Curtis J. T. 1956 - *The Use of Distance Measures in Phytosociological Sampling.* Ecology 37 (3): 451–460.

Feller I. C., Lovelock C. E., Berger U., McKee K. L., Joye S. B., Ball M. C. 2010 - *Biocomplexity in mangrove ecosystems.* Annual Review of Marine Science 2 (1): 395–417. doi:10.1146/annurev.marine.010908.163809

Ferreira A. C., Ganade G. 2015 - *Ocean & Coastal Management Restoration versus natural regeneration in a neotropical mangrove : Effects on plant biomass and crab communities.* Ocean & Coastal Management journal 110: 2002–2009. doi:10.1016/j.ocecoaman.2015.03.006

Field C. D. 1999 - *Rehabilitation of mangrove ecosystems: An overview.* Marine Pollution Bulletin 37 (8–12): 383–392. doi:10.1016/S0025-326X(99)00106-X

Gnansounou S. C., Toyi M., Salako K. V., Ahossou D. O., Akpona T. J. D., Gbedomon R. C., Assogbadjo A. E., Glèlè Kakaï R. 2021 - *Local uses of mangroves and perceived impacts of their degradation in Grand-Popo municipality, a hotspot of mangroves in Benin, West Africa.* Trees, Forests and People 4. doi:10.1016/j.tfp.2021.100080

Hagger V., Worthington T. A., Lovelock C. E., Adame M. F., Amano T., Brown B. M., Friess D. A., Landis E., Mumby P. J., Morrison T. H., O'Brien K. R., Wilson K. A., Zganjar C., Saunders M. I. 2022 - *Drivers of global mangrove loss and gain in social-ecological systems.* Nature Communications 13 (1): 1–16. doi:10.1038/s41467-022-33962-x

Hammer Ø., Harper D. A., Ryan P. D. 2001 - *PAST: paleontological statistics software package for education and data analysis.* Palaeontologia Electronica 4 (1). http://palaeo-electronica.org/2001_1/past/issue1_01.htm.

Hofhansl F., Chacón-Madrigal E., Fuchslueger L., Jenking D., Morera-Beita A., Plutzar C., Silla F., Andersen K. M., Buchs D. M., Dullinger S., Fiedler K., Franklin O., Hietz P., Huber W., Quesada C. A., Rammig A., Schrodt F., Vincent A. G., Weissenhofer A. et al. 2020 - *Climatic and edaphic controls over tropical forest diversity and vegetation carbon storage.* Scientific Reports 10 (1): 1–11. doi:10.1038/s41598-020-61868-5

Islam A. T. M. R., Hasan M. M., Islam M. T., Tanaka N. 2022 - *Ethnobotanical study of plants used by the Munda ethnic group living around the Sundarbans, the world's largest mangrove forest in southwestern Bangladesh.* Journal of Ethnopharmacology 285 (November 2021): 114853. doi:10.1016/j.jep.2021.114853

Kasihiw P., Bawole R., Marwa J., Murdjoko A., Wihyawari A., Heipon Y., Cabuy R. L., Benu N. M. H., Hematang F. 2023 - *Floristic richness and diversity of Bintuni mangrove, Bird's Head Peninsula, West Papua, Indonesia.* Biodiversitas Journal of Biological Diversity 24 (5): 2887–2897. doi:10.13057/biodiv/d240543

Kathiresan K., Bingham B. L. 2001 - *Biology of mangroves and mangrove ecosystems.* Advances in Marine Biology 40: 81–251. doi:10.1016/S0065-2881(01)40003-4

Liang J., Gamarra J. P., Picard N., Zhou M., Pijanowski B., Jacobs D., Reich P., Crowther T., Nabuurs G.-J., De-Miguel S., Fang J., Woodall C., Svenning J.-C., Jucker T., Bastin J.-F., Wiser S., Slik F., Hérault B., Alberti G. et al. 2022 - *Co-limitation towards lower latitudes shapes global forest diversity gradients.* Nature ecology & evolution doi:10.1038/s41559-022-01831-x

Liebezeit G., Rau M. T. 2006 - *New Guinean mangroves - Traditional usage and chemistry of natural products.* Senckenbergiana Maritima 36 (1): 1–10. doi:10.1007/BF03043698

Manuputty A. 2022 - *Sebaran Mangrove Dan Manajemen Konservasi Di Kabupaten Manokwari, Papua Barat: Analisis Pendekatan Pengindaraan Jauh.* Jurnal Kehutanan Papuasia 8 (2): 326–334.

Matthijs S., Tack J., van Speybroeck D., Koedam N. 1999 - *Mangrove species zonation and soil redox state, sulphide concentration and salinity in Gazi Bay (Kenya), a preliminary study.* Mangroves and Salt Marshes 3 (4): 243–249. doi:10.1023/A:1009971023277

Murdjoko A., Djitmau D. A., Ungirwalu A., Sinery A. S., Herlina R., Siburian S., Mardiyadi Z., Wanma A. O., Wanma J. F., Rumatora A., Mofu W. Y., Worabai D., May N. L., Jitmau M. M., Alexander G., Mentansan F., Krey K., Musaad I., Manaf M. et al. 2021 - *Pattern of tree diversity in lowland tropical forest in Nikiwar, West Papua, Indonesia.* Dendrobiology 85: 78–91. doi:https://doi.org/10.12657/denbio.085.008

Murdjoko A., Marsono D., Sadono R., Hadisusanto S. 2016 - *Plant Species Composition and Their Conspecific Association in Natural Tropical Rainforest, South Papua.* Biosaintifika: Journal of Biology & Biology Education 8 (1): 33. doi:10.15294/biosaintifika.v8i1.5217

Murdjoko A., Ungirwalu A., Mardiyadi Z., Tokede M. J., Djitmau D. A., Benu N. M. H. 2021 - *Floristic Composition of Buah Hitam Habitats in Lowland Tropical Mixed Forest of West Papua, Indonesia.* Floresta e Ambiente 28 (3). doi:https://doi.org/10.1590/2179-8087-FLORAM-2021-0042

Nasrin S., Mahmood H., Mrh S. 2020 - *Adaptive responses to salinity: seed germination traits of Sonneratia apetala along salinity gradient in sundarbans, Bangadlesh.* Journal of Tropical Forest Science 32(2): 179–186.

Polidoro B. A., Carpenter K. E., Collins L., Duke N. C., Ellison A. M., Ellison J. C., Farnsworth E. J., Fernando E. S., Kathiresan K., Koedam N. E., Livingstone S. R., Miyagi T., Moore G. E., Nam V. N., Ong J. E., Primavera J. H., Salmo S. G., Sanciangco J. C., Sukardjo S. et al. 2010 - *The loss of species: Mangrove extinction risk and geographic areas of global concern.* PLoS ONE 5 (4). doi:10.1371/journal.pone.0010095

Safwan Azman M., Sharma S., Liyana Hamzah M., Mohamad Zakaria R., Palaniveloo K., MacKenzie R. A. 2023 - *Total ecosystem blue carbon stocks and sequestration potential along a naturally regenerated mangrove forest chronosequence.* Forest Ecology and Management 527 (July 2022): 120611. doi:10.1016/j.foreco.2022.120611

Sarker S. K., Matthiopoulos J., Mitchell S. N., Ahmed Z. U., Mamun M. B. Al, Reeve R. 2019 - *1980s–2010s: The world's largest mangrove ecosystem is becoming homogenous.* Biological Conservation 236 (May): 79–91. doi:10.1016/j.biocon.2019.05.011

Sasmito S. D., Basyuni M., Kridalaksana A., Saragi-Sasmito M. F., Lovelock C. E., Murdiyarso D. 2023 - *Challenges and opportunities for achieving Sustainable Development Goals through restoration of Indonesia's mangroves.* Nature Ecology and Evolution 7 (1): 62–70. doi:10.1038/s41559-022-01926-5

Sasmito S. D., Sillanpää M., Hayes M. A., Bachri S., Saragi-Sasmito M. F., Sidik F., Hanggara B. B., Mofu W. Y., Rumbiak V. I., Hendri, Taberima S., Suhaemi, Nugroho J. D., Pattiasina T. F., Widagti N., Barakalla, Rahajoe J. S., Hartantri H., Nikijuluw V. et al. 2020 - *Mangrove blue carbon stocks and dynamics are controlled by hydrogeomorphic settings and land-use change.* Global Change Biology 26 (5): 3028–3039. doi:10.1111/gcb.15056

Sillanpää M., Vantellingen J., Friess D. A. 2017 - *Vegetation regeneration in a sustainably harvested mangrove forest in West Papua, Indonesia.* Forest Ecology and Management 390: 137–146. doi:10.1016/j.foreco.2017.01.022

Spellerberg I. F., Fedor P. J. 2003 - *A tribute to Claude-Shannon (1916-2001) and a plea for more rigorous use of species richness, species diversity and the "Shannon-Wiener" Index.* Global Ecology and Biogeography 12 (3): 177–179. doi:10.1046/j.1466-822X.2003.00015.x

Sreelekshmi S., Preethy C. M., Varghese R., Joseph P., Asha C. V., Bijoy Nandan S., Radhakrishnan C. K. 2018 - *Diversity, stand structure, and zonation pattern of mangroves in southwest coast of India.* Journal of Asia-Pacific Biodiversity 11 (4): 573–582. doi:10.1016/j.japb.2018.08.001

Tawer P., Maturbongs R., Murdjoko A., Jitmau M., Djitmau D., Siburian R., Ungirwalu A., Wanma A., Mardiyadi Z., Wanma J., Rumatora A., Mofu W., Sinery A., Fatem S., Benu N., Kuswandi R., Lekitoo K., Khayati L., Tambing J. 2021 - *Vegetation dynamic post-disturbance in tropical rain forest of bird's head peninsula of west papua, indonesia.* Annals of Silvicultural Research 46 (1): 48–58. doi:10.12899/ASR-214