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Mangrove Diversity and Community Structure in Savu Sea Marine National Park - East Nusa Tenggara, Indonesia

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ABSTRACT

Mangroves are vital coastal ecosystems, notably present in the Savu Sea Marine National Park (SSMNP) in East Nusa Tenggara. This study evaluated sea environmental conditions (temperature, pH, salinity, dissolved oxygen, biochemical oxygen demand, and total suspended solids), alongside mangrove community structure and diversity. Using transect sampling, data were collected from 15 mangrove areas (45 plots) across the islands of Timor, Rote, Sabu, and Sumba, with plots sized for trees (10x10m), saplings (5x5m), and seedlings (2x2 m). Results identified eight mangrove species, including *Rhizophora mucronata*, which showed the highest importance value index for trees (165) and saplings/seedlings (200). A total of 513 individuals were recorded: 210 trees, 68 saplings, and 235 seedlings. Diversity indices ranged from 0.47 to 2.31 for trees and 0 to 1.55 for saplings/seedlings, indicating low-to-medium diversity and richness. Water conditions were found suitable for mangrove growth. This study provides a comprehensive baseline on mangrove diversity and environmental conditions, supporting conservation aligned with SDGs 13 (climate action), 14 (Life Below Water), 15 (Life on Land), and 8 (decent work and economic growth).

INTRODUCTION

Indonesia has great natural resource potential and is a country with the fifth largest natural resources in the world after China, America, the European Union, and India **(Soeprobowati *et al.*, 2012)**. Indonesia has the Savu Sea Marine National Park (SSMNP) with an area of ±3,355,352.82 hectares covering 4 large islands in NTT (Timor, Rote, Sabu, and Sumba Island). The SSMNP has natural resource potential, which plays an important role in the sustainability of the ecosystem since it contains a variety of flora and fauna that inhabit or act as river channels (especially marine mammals) **(Indonesian Governmental Regulation PP No. 22, 2021)**. Given its significant role and potential for developing national conservation areas, it needs to be studied more thoroughly and comprehensively.

One of the potential natural resources in the SSMNP area are mangroves. The mangrove ecosystem is a unique plant community that can survive in the mangrove ecosystem consists of areas that are periodically submerged in water and are tolerant of high salinity. It provides essential environmental services, such as serving as a breeding ground for various species of crustaceans and helping to resist coastal erosion. Additionally, when properly maintained and managed, it offers economic services by supporting mangrove-based ecological tourism (ecotourism). The ecological role of the mangrove ecosystem is crucial as a buffer for coastal areas, helping to maintain the stability of the marine environment **(Schaduw, 2018a)**. Furthermore, it serves as a vital habitat for fish and shrimp, playing a key role in preserving ecosystem quality **(Indrayanti *et al.*, 2015)**.

The mangrove ecosystem as an ecological unit, apart from influencing its environment, is influenced by the environmental conditions in which it inhabits, such as water quality (temperature, pH, salinity, DO, BOD, and TSS), substrate, as well as anthropogenic activities. In this case, an ecosystem can be viewed from the flora and fauna composition angle and the environmental factors that influence it. The mangrove ecosystem can also serve as an indicator of the health of coastal ecosystems because it is sensitive to environmental changes **(Singh, 2020)**. Apart from being influenced by the environment, the mangrove ecosystem influences environmental quality, at least qualitative and quantitative changes to the flora **(Kim *et al.*, 2002)**; in turn, this ecosystem influences nature-based recreational landscapes **(Dramstad *et al.*, 2006)**.

The research on the Savu Sea Marine National Park (SSMNP) mangrove ecosystem is groundbreaking due to its comprehensive assessment of diverse environmental parameters and mangrove community structure across multiple islands. Unlike previous studies that often focus on isolated parameters or smaller regions, this study provides a holistic view by examining temperature, pH, salinity, dissolved oxygen, biochemical oxygen demand, and total suspended solids, and correlating these with mangrove species abundance and diversity. This multifaceted approach offers new insights into the intricate relationships between environmental conditions and mangrove ecosystems, making a significant contribution to marine conservation science.

This research aimed to determine water quality (temperature, pH, salinity, DO, BOD, and TSS) and to analyze community structure and mangrove diversity in the SSMNP as a reference for developing coastal areas in the SSMNP.

MATERIALS AND METHODS

The area of the SSMNP is $\pm$ 3 x 10^{10} m^2, while the area of mangroves is $\pm$ 6 x 10^7 m^2, or around 0.17% of the total area. Data were collected on mangrove vegetation in the SSMNP area, including Timor Island (Pariti, Paradiso, Tesabela, Salupu, and Semau), Rote Island (Papela, Baudale, Oelaba, and Oeseli), Sabu Island (Mebba and Lederaga), and Sumba Island (Kambuomang, Warambadi, Lumbukore, and Hambapraing) (Fig. 1) from August to November 2022. Research sampling was carried out on 15 mangrove vegetation (3 plots in each vegetation), producing 45 plots with sample plot sizes for tree habitus: 10x10m, saplings: 5x5m, and seedlings: 2x2m, to obtain data on the types and quantity of mangrove individuals in the SSMNP area. Sampling locations in the SSMNP area were determined subjectively (purposive sampling). The environmental parameters in the SSMNP area taken *in situ* (in each plot) were temperature, pH, salinity, and dissolved oxygen (DO), and those analyzed *ex-situ* were biochemical oxygen demand (BOD5) and total suspended solids (TSS).

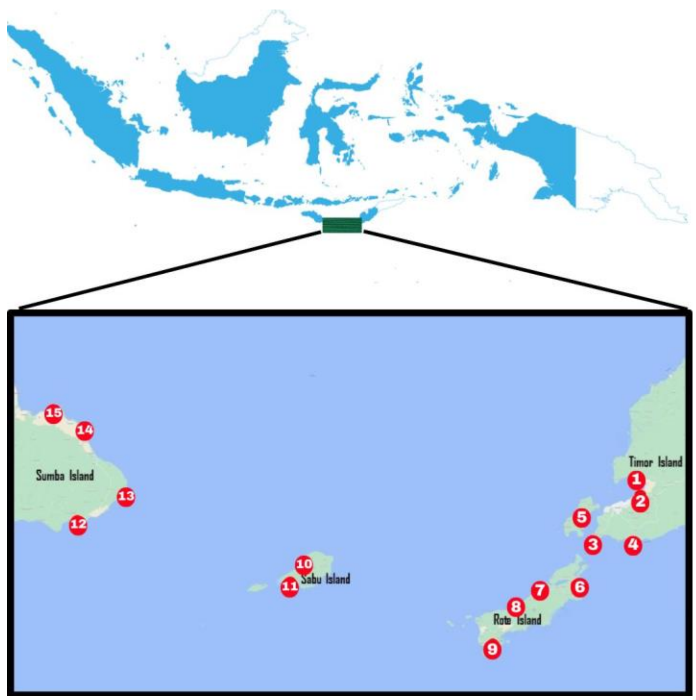


Fig. 1. Map of research setting in the Savu Sea Marine National Park (1. Pariti, 2. Paradiso, 3. Tesabela, 4. Salupu, 5. Semau, 6. Papela, 7. Baudale, 8. Oelaba, 9. Oeseli, 10. Mebba, 11. Lederaga, 12. Kambuomang, 13. Warambadi, 14. Lumbukore, 15. Hambapraing)

Quantitative analysis was carried out on plant diversity in the mangrove ecosystem in the SSMNP area, as shown in Table (1).

Table 1. The formula used for mangrove diversity analysis

No	Parameter	Formula	Unit	Notes
1	Total density	$D = \frac{\sum ni}{N}$		D = Density ∑ni = Total number of mangroves N = Total sampling area
2	Taxa richness	$D\ mg = \frac{S-1}{in\ N}$		D = Margalef taxa richness index S = Number of species found N = Total individual
3	Shannon-Weiner's diversity index	$H' = -\sum(pi)\ x \log(pi)$		H' = Shannon-Weiner index Pi = Constanta
		$pi = \frac{ni}{N}$		ni = number of stand species I N = total number of stand in plot
4	Dominance index	$C = \sum(pi)^2$		C = Dominance index
5	Evenness index	$E = \frac{H'}{\log(pi)}$		E = Evenness index H' = diversity index Pi = Constanta
6	Importance value index	$IVI = RA + RF + RD$	%	**Trees** RA (relative abundance) = ni/N *100 RF (relative frequency) = Fi/total F*100 RD (relative dominance) = diameter at breast height (DBH) species i/total DBH*100
		$IVI = RA + RF$	%	**Sapling and Seedling**

The diversity index is a quantitative measure to obtain information or data about the number of species and density in a community. The greater the number of species that live in a region or ecosystem, the higher the level of species diversity in that area. Species diversity is in the high category if the diversity index value is >3, the medium category if the diversity index value is >1- <3, and the low category if the diversity index value is <1 **(Martuti, 2013)**.

The dominance index was obtained by calculating the species of mangroves in an ecosystem/vegetation. Meanwhile, the evenness index was used to analyze the distribution of mangrove species in an ecosystem or vegetation. If the dominance and evenness index values are close to 1 (one), it indicates that there are mangroves that dominate the ecosystem. Meanwhile, if the dominance index value is close to 0 (zero), it indicates no dominant mangroves. The importance value index (IVI) is an index value obtained from the sum of density, frequency, and cover expressed in percentages (%).

RESULTS

Environmental parameters

The environmental parameters, including temperature, pH, salinity, DO, BOD, and TSS, were analyzed in this study. Based on this study, all the environmental parameters in the SSMNP area showed quite diverse values (Table 2).

Table 2. Environmental parameters of the mangrove ecosystem in the SSMNP

Location	Average environmental parameters*					
	Temperature (°C)	pH	Salinity (‰)	DO (mg/l)	BOD (mg/l)	TSS (mg/l)
Pariti	29.00 – 30.00[abc]	8.20 – 8.40[c]	3.50 – 3.90[a]	8.12 – 8.55[a]	5.10 – 6.25[a]	0.90 – 1.48[a]
Paradiso	28.50 – 31.20[bcd]	8.20 – 8.45[c]	3.20 – 3.50[a]	8.05 – 8.75[a]	7.90 – 8.43[a]	1.25 – 1.45[a]
Tesabela	29.05 – 32.90[bcde]	7.90 – 8.10[abc]	3.70 – 3.80[a]	7.25 – 7.80[a]	4.11 – 5.60[a]	2.22 – 1.90[a]
Salupu	32.34 -34.60[ef]	8.00 – 8.20[abc]	3.70 – 3.80[a]	7.00 – 7.50[a]	5.90 – 6.35[a]	1.11 – 1.82[a]
Semau	30.00 – 31.50[bcde]	7.90 – 8.00[abc]	3.60 – 3.70[a]	7.88 – 8.10[a]	4.22 – 5.59[a]	1.25 – 1.67[a]
Papela	32.76 – 33.90[ef]	8.00 – 8.10[bc]	3.70 – 3.90[a]	7.36 – 7.90[a]	4.21 – 5.12[a]	1.11 – 1.90[a]
Baudale	31.00[bcd]	7.55 – 7.70[a]	3.70 – 3.90[a]	7.75 – 8.10[a]	4.11 – 5.35[a]	0.27 – 1.10[a]
Oelaba	27.70 – 29.75[a]	7.60 – 8.00[ab]	3.60 – 3.80[a]	5.50 – 6.92[a]	4.08 – 4.90[a]	0.22 – 0.90[a]
Oeseli	28.70 – 30.00[abc]	7.50 – 7.90[ab]	2.50 – 2.80[a]	7.90 – 8.23[a]	4.11 – 4.25[a]	1.96 – 5.70[a]
Mebba	30.30 – 31.25[bcde]	7.90 – 8.20[abc]	3.60 – 3.80[a]	7.56 – 7.95[a]	4.11 – 4.80[a]	0.05 – 1.00[a]
Lederaga	31.90 – 32.70[def]	7.70 – 8.00[abc]	3.30 – 3.40[a]	7.23 – 7.67[a]	4.22 – 4.90[a]	0.90 – 1.12[a]
Kambuomang	32.67 – 34.00[f]	8.00 – 8.30[abc]	3.50 – 3.60[a]	7.36 – 7.85[a]	4.11 – 4.90[a]	1.00 – 1.56[a]
Warambadi	31.65 – 32.30[cde]	7.90 – 8.10[abc]	3.60 – 3.90[a]	7.50 – 8.00[a]	4.10 – 4.59[a]	1.02 – 1.56[a]
Lumbukore	28.90 – 29.50[ab]	8.00[abc]	1.90 – 2.90[a]	7.80 – 8.32[a]	4.11 – 4.22[a]	0.82 – 1.90[a]
Hambapraing	29.75 – 31.38[bcde]	8.10 – 8.60[c]	3.00 – 3.40[a]	7.34 – 7.50[a]	4.08 – 4.50[a]	0.90 – 1.56[a]

*: The same notation of each parameter showed no significant difference based on the ANOVA test, which continued with the Tukey test (α= 0.05).

The environmental parameters of the mangrove ecosystem in the SSMNP (Table 2) show that water temperature ranged from 27.20 to 34.60°C, pH from 7.50 to 8.60, and salinity from 1.90 to 3.90‰, with the lowest salinity observed at Lumbukore (1.90‰). The dissolved oxygen (DO) ranged from 5.50 to 8.92mg/ L, and biochemical oxygen demand (BOD) values ranged from 4.08 to 8.43mg/ L. Total suspended solids (TSS) values ranged from 0.05 to 5.70 mg/L. The water conditions in the Sawu Sea National Park are generally in good condition and support mangrove growth. All environmental parameters measured in this study (temperature, pH, salinity, dissolved oxygen (DO), biochemical oxygen demand (BOD), and total suspended solids (TSS)) are within the tolerance limits necessary for the growth and development of the mangrove ecosystem.

Mangrove vegetation community structure

The total mangrove vegetation at the research location was 513, consisting of 210 tree habitus, 68 sapling habitus, and 235 seedling habitus. The number of individual mangroves obtained at each research location is presented in Fig. (2)

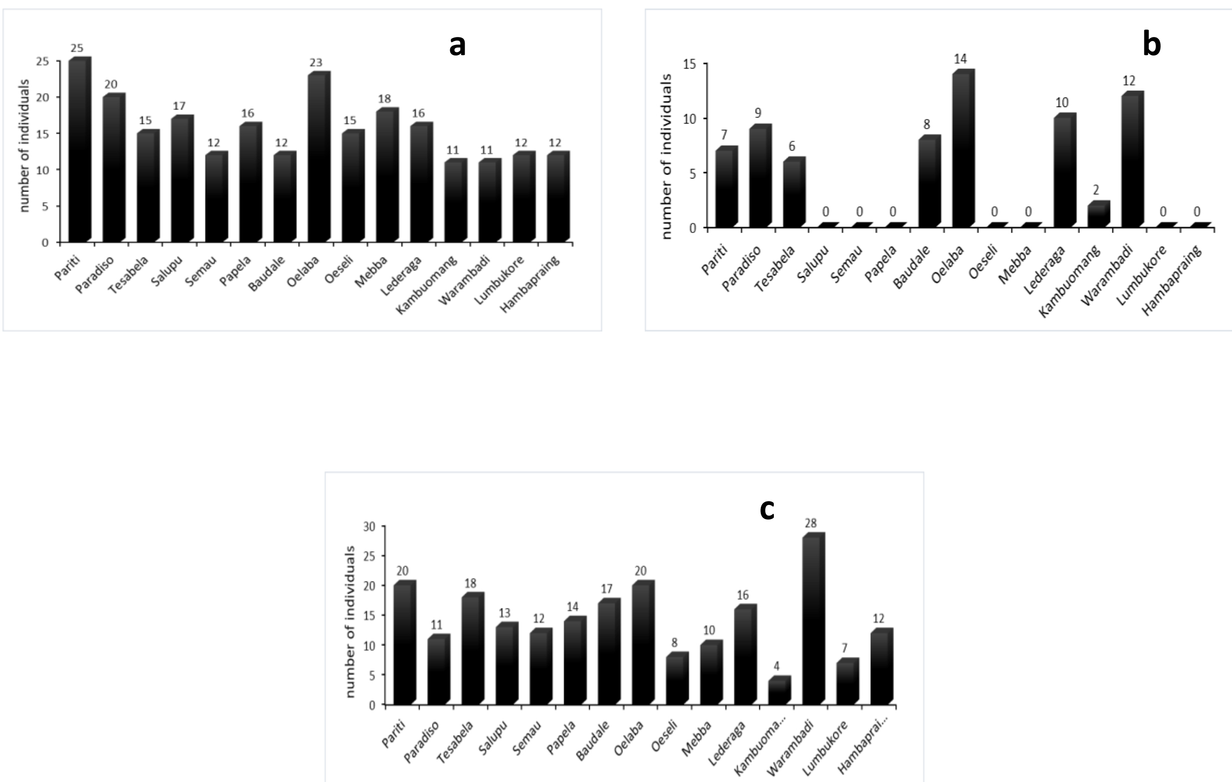


Fig. 2. Number of individuals of mangrove in Savu Sea National Park, **a.** Tree, **b.** Sapling, and **c.** Seedling

Mangroves' density and taxa richness show varying results between locations in the SSMNP area (Fig. 3). Taxa richness is the simplest and most general measure of biodiversity to determine the number of taxa present in a particular area or ecosystem **(McCarthy & Magurran, 2008)**. The lowest density for habitus trees was 1.90/m^2 (4 of 210 individuals) with 0 saplings and 4.68/m^2 seedlings (11 of 235 individuals). Meanwhile, the highest density for habitus trees was 13.33/m^2 (28 of 210 individuals), 20.59/m^2 saplings (14 of 68 individuals), and 10.63/m^2 seedlings (25 of 235 individuals).

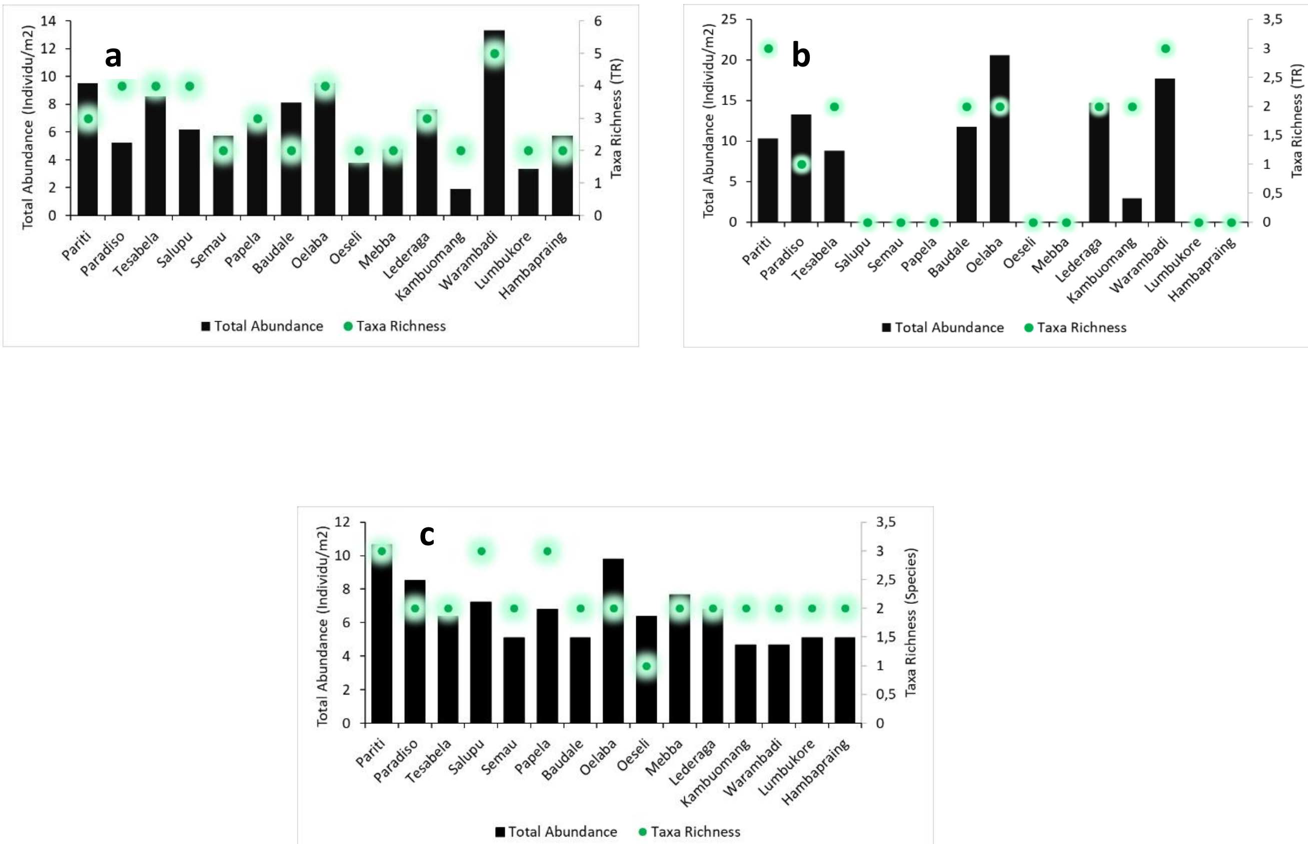
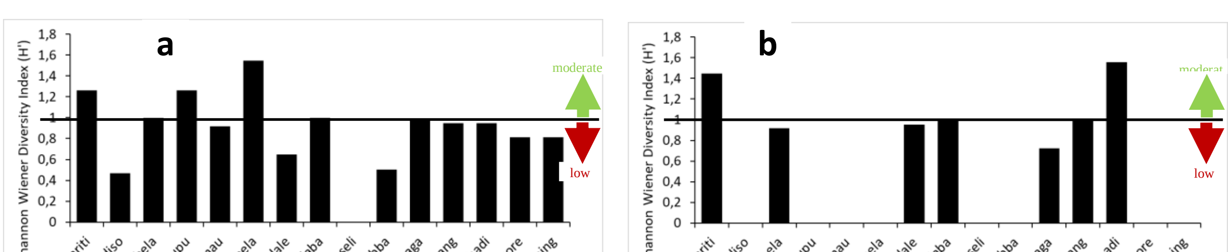


Fig. 3. Total abundance and taxa richness of mangrove vegetation in Savu Sea Marine.National Park, **a.** Tree; **b.** Sapling, and **c.** Seedling

Data on the taxa richness of mangroves (Fig. 3) in the SSMNP area showed that the lowest taxa richness were 2 tree habitus, 0 saplings, and 1 seedling. Meanwhile, taxa with the highest richness were 5 tree habitus, 3 saplings, and 3 seedlings.

Mangrove vegetation diversity in the SSMNP

The Shannon-Wiener diversity index values of mangroves in the SSMNP area (Fig. 4) for tree habitus range from 0.47 to 2.31, while stilt roots and seedlings range from 0 to 1.55. These data indicate that the mangrove diversity index at the research site was categorized as low or medium. The low values of the mangrove diversity index for stilt root and seedling habitus are due to the absence of stilt root and seedling mangrove habitus in some sampling locations (plots).



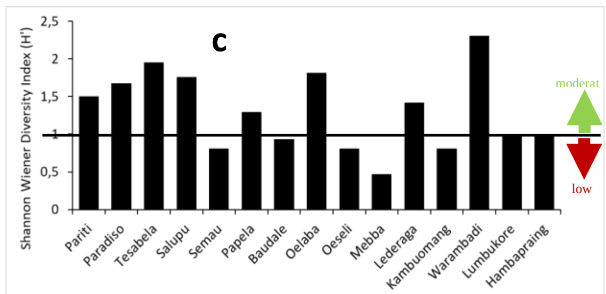


Fig. 4. Diversity index of mangrove vegetation in Savu Sea Marine National Park, **a.** Tree; **b.** Sapling; and **c.** Seedling

Evenness and mangrove vegetation dominance index in the SSMNP

The dominance index value is a parameter used in a community to express the level of centrality of a species **(Prastomo *et al.*, 2017)**. The results of the analysis of the mangrove evenness index in the SSMNP area (Fig. 5) show that the lowest evenness index value was 0.47 tree habitus, 0 saplings, and seedlings, while the highest evenness index was 0.99 tree habitus, 1 sapling, and seedling. Meanwhile, the index value shows the lowest dominance was 0.17 tree habitus, 0 sapling, and 0.31 seedling, while the highest dominance index was 0.80 tree habitus, 1 sapling, and seedling. Thus, the evenness and dominance index of mangroves in the SSMNP was in the high category.

Importance value index (IVI) of mangrove vegetation in the SSMNP

Based on this study, the species *Rhizophora mucronata* has the highest importance value index (IVI) for the tree level (165), stilt root or sapling level (200), and seedling level (200) (Fig. 6). The low IVI value in several locations is due to the absence of mangrove sapling habitus in these locations (Fig. 6b).

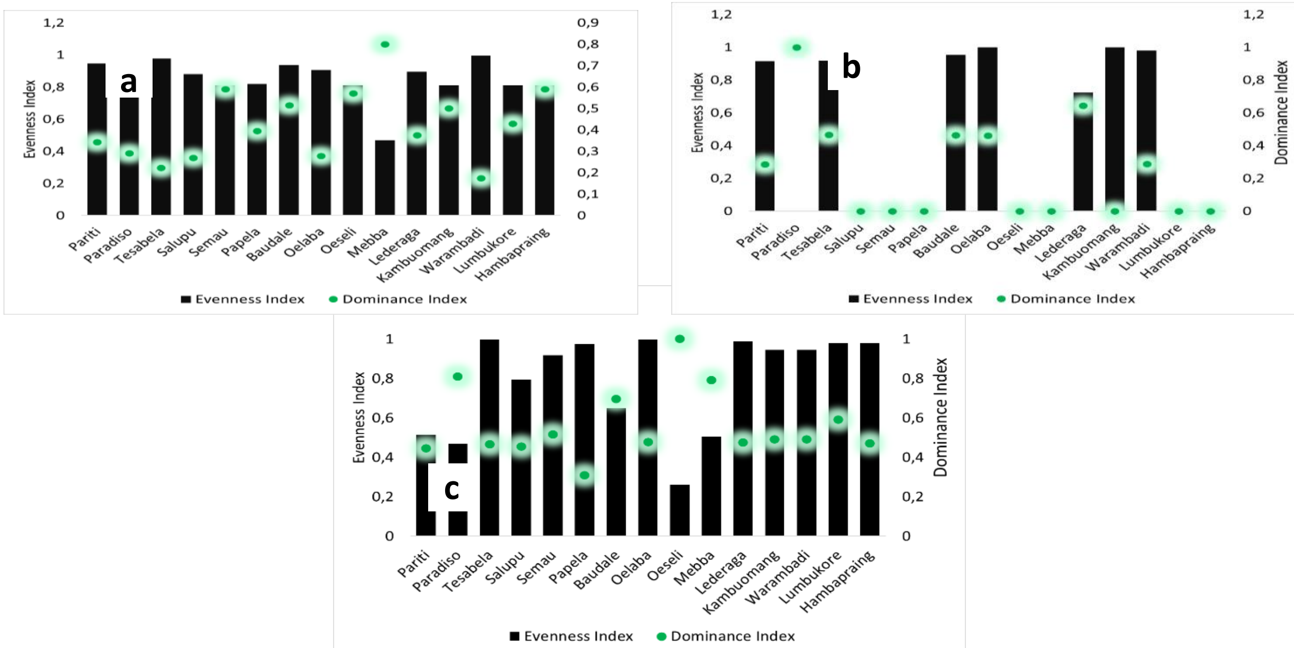


Fig. 5. Evenness index and dominance index of mangrove vegetation in the Savu Sea Marine National Park; **a.** Tree; **b.** Sapling; **c.** Seedling

Importance value index (IVI) of mangrove vegetation in the SSMNP

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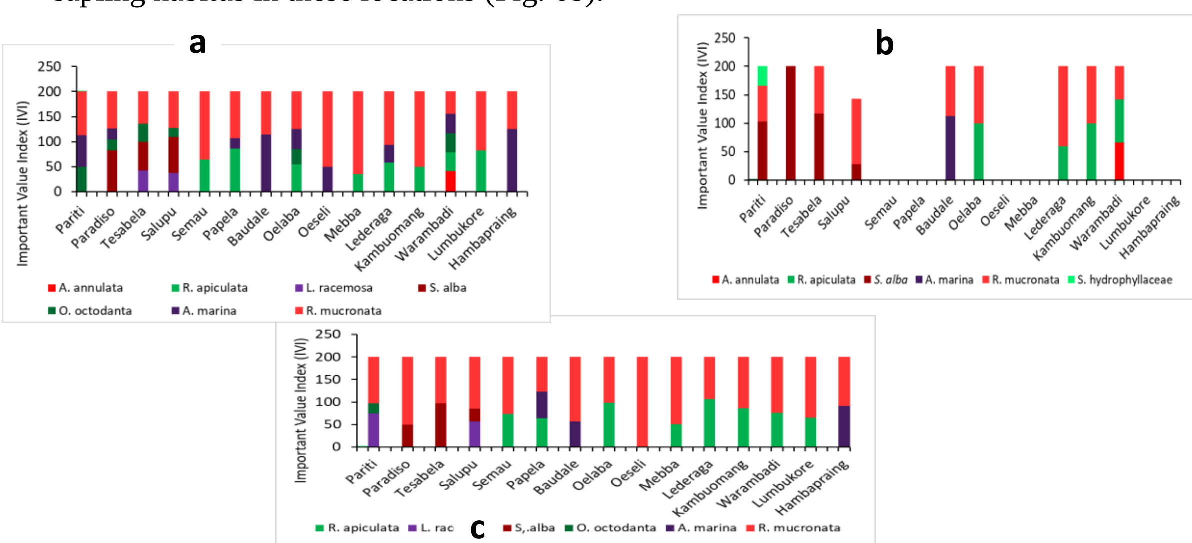

Fig. 6. Important value index (IVI) of mangrove vegetation in the Savu Sea Marine National Park; **a.** Tree; **b.** Sapling; and **c.** Seedling

DISCUSSION

Environmental parameters

The SSMNP water temperature ranged from 27 to 34°C, which is not less than 20°C and is categorized as a good temperature for the growth of mangroves **(Kolehmainen *et al.*, 1974)**. According to **Lovelock *et al.* (2016)**, the low temperatures prevent mangroves from growing, and if they are exposed to freezing or extremely cold temperatures, they may die or suffer damage **(Osland *et al.*, 2017)**. Conversely, exposure to high temperatures (over 35 ºC) will negatively impact photosynthesis, seedling development, and root structure. Mangrove leaves have a maximum stomatal conductance and absorption rate between 25 and 30ºC. At temperatures beyond 35 degrees, these values rapidly decrease **(Alongi, 2009)**.

This study found the pH levels of SSMNP ranged from 7.50 to 8.60, which are in line with **Rizki *et al.* (2015)** which stated that the pH value of water in eastern Indonesia ranged from 7.9 to 8.1. pH levels are closely related to decomposer activity **(Koch, 2001)**, because fallen mangrove litter is decomposed by microorganisms, producing detritus causes the water to become more acidic, or because of the presence of microorganisms that break down organic matter (nitrates), which produce different organic acid compounds **(Tis'in, 2004; Adeleke *et al.*, 2016)**. Furthermore, **Poedjirahajoe *et al.* (2017)** noted that low pH levels result in very low deficient decomposer activity, so the decomposition of organic material into inorganic material becomes delayed, restricting mangrove growth owing to a lack of food and mineral delivery. Meanwhile, **Schaduw (2018b)** indicated that the oceanographic and geomorphological features of a given water location significantly impacted the variations in pH levels found there. This suggests that the oceanographic and geomorphological features of the study site differ from one another.

Salinity in the SSMNP area ranged from 1.90 to 3.90‰, with the lowest recorded at Lumbukore (1.90‰). Lumbukore, located at a river estuary, exhibited the lowest salinity due to the influence of freshwater inflow from the surrounding land. This observation aligns with the statement by **Geng *et al.* (2016)**, which notes that brackish water with fluctuating salinity is influenced by the mixing of seawater and freshwater.

Dissolved oxygen (DO) ranged from 5.50 to 8.92mg/ L. The high DO content indicates that the condition of the water is quite good. According to **Indonesian Governmental Regulation PP No. 22 (2021)**, which specifies that the dissolved oxygen (DO) concentration in waterways should be greater than 5mg/ L, the high DO levels observed in the SSMNP suggest that the water conditions are excellent. **Mattone and Sheaves (2017)** noted that DO levels are influenced by factors such as tidal height, sunlight intensity, and the phase of the tides. DO is essential for marine organisms in respiration and metabolism processes, which provide energy for reproduction **(Dubuc *et al.*, 2019)**.

Biochemical oxygen demand (BOD) refers to the amount of oxygen required by microorganisms to break down organic matter and nitrogen compounds in water. The BOD values in this study ranged from 4.08 to 8.43mg /L, indicating a moderately polluted status. According to **Tampo *et al.* (2021)**, water with a BOD value of 2mg/ L is considered clean, values between 2 and 8mg/ L are classified as moderately polluted, and values above 8mg/

L indicate heavy contamination. Despite being moderately polluted, the BOD remains below the threshold of 10 mg/L, which is the upper limit for mangrove growth, as specified in **Indonesian Governmental Regulation PP No. 22 (2021)**.

Total suspended solids (TSS) are substances suspended in water due to soil erosion, such as mud, fine sand, and microorganisms. High TSS values can degrade water quality, causing physical, chemical, and biological changes **(Bilotta & Brazier, 2008)**. Elevated TSS can reduce the availability of dissolved oxygen and disrupt marine life, potentially causing anaerobic conditions that kill aerobic organisms **(Rinawati *et al.*, 2016)**. The TSS values in the SSMNP ranged from 0.05 to 5.70mg/ L, indicating that the water is clean and conducive to mangrove survival, as it is well below the 80mg/ L maximum level set by **Indonesian Governmental Regulation PP No. 22 (2021)**.

Mangrove vegetation community structure

The research results showed eight species of mangroves found in SSMNP, including *Rhizophora mucronata, R. apiculata, Osbornia octodanta, Avicennia marina, Sonneratia alba*, *Lumnitzera racemosa, Aegalitis annulate*, and *Scyphiphora hydrophyllaceae*. These results are different from the data retrieved from **Kepmen (2014**), which stated that there were 15 (fifteen) species. Moreover, other research in the SSMNP area showed that Kupang Bay (Timor Island) had 11 (eleven) species **(Rusydi *et al.*, 2015)**, Rote Island and Ndana had 14 species **(Widiatmaka *et al.*, 2016)**, Aiama Rote Ndao Village had 11 species **(Ngoma *et al.*, 2020)**, and East Sumba Pakonjawai Protected Forest had 9 species **(Kahi *et al.*, 2022)**. The variation in environmental characteristics of the ecosystem, especially the temperature in Oelaba and Kambuomang, and the pH in Pariti, Paradiso, Baudale, and Hambapraing, which were significantly different from other areas or locations, might have caused differences in the number of mangrove species capable of growing in those areas. The species that can develop and adapt successfully in this situation will be influenced by various conditions **(Hidayatullah, 2017)**. These environments include the kind of soil (mud, sand, or peat), salinity, openness to waves, and tidal impacts **(Bunt & Williams, 1981)**.

Three mangrove species were consistently found in most research locations, such as *Rhizophora mucronata*, *R. apiculate,* and *Avicennia marina*. This is in line with **Ariani *et al.* (2016)** stating that *R. apiculata* is a mangrove that has a high level of dominance in Indonesian mangrove areas. Moreover, **Sofian *et al.* (2001)** stated that *Rhizophora mucronata* and *Avicennia marina* species have advantages in adapting to the sea environment. Meanwhile, **Souza and Sampaio (2011)** stated that low levels of propagule predation could be the reason for some species' dominance (Rhizophora), but there could be a positive or negative link between these two factors. **(Pribadi *et al.*, 2014)**. Furthermore, there are two mangrove species found only in specific sampling locations, such as *Aegalitis anulata* (Warambadi) and *Scyphiphora hydrophyllaceae* (Pariti), which is suspected to occur due to the adaptive ability of these mangrove species to the environment and other factors.

The density and taxa richness of mangroves indicated that the mangrove habitus with the highest density was the tree and sapling habitus (13.33 and 20.59). The high density of mangrove tree habitus showed many tree habitus in the area. The high density of the habitus of trees caused a reduction in the intensity of sunlight entering the mangrove forest, which results in a reduction in the light intensity obtained by the habitus of the seedlings for their growth. **Supardjo (2008)** stated that the low intensity of light entering the mangrove forest floor was due to obstruction by the habitus of trees and saplings and reduced the light supply needed by the habitus of seedlings for photosynthesis.

This study showed the number of individual tree habitus (Fig. 2a) and seedlings (Fig. 2c) was more dominant than the sapling habitus (Fig. 2b). This meant that mangrove regeneration in the SSMNP area was going well. **Shankar (2001)** and **Dewi *et al.* (2021)** stated that an ecosystem or forest runs well if the presence of seedling habitus is higher than that of other habitus. Apart from that, it was also supported by environmental factors such as light intensity, mangrove health, water, and substrate conditions **(Nurdiansah & Dharmawan, 2018; Dewi *et al.*, 2021)**. The low presence of sapling habitus in several research locations was due to the absence of sapling habitus within the sampling plots (Salupu, Semau, Papela, Oeseli, Mebba, Lumbukore, and Hambapraing).

The taxa richness (Fig. 3) was classified as high according to the criteria. **Margalef (1985)** stated that the taxa richness index is in the low category if the index value is <2.5, the medium category if the index value is 2.5 to 4, and the high category if index value is >4. According to **Gotelli and Colwell (2001)**, the taxa richness is strongly influenced by sampling effort. It is feared that there will be bias in decision-making, therefore **Walther and Martin (2001)** proposed that methods need to be developed to correct the influence of sampling effort on the richness of the taxa found. However, all of the assessed estimators' bias and precision, according to **Gwinn *et al.* (2016)**, are very sensitive to sample size.

Mangrove vegetation diversity in the SSMNP

The Shannon-Wiener diversity index (H') values of mangroves in the Savu Sea Marine National Park (Fig. 4) were categorized as low and medium, with H' values for tree habitus ranging from 0.47 to 2.31 and for stilt roots and seedlings ranging from 0 to 1.55. According to **Giesen *et al.* (2006)**, the low diversity of mangroves in an ecosystem is because not many species can adapt or survive the environmental conditions of that ecosystem. However, the environmental parameter data in the research location shows that the water conditions in the SSMNP support the growth of mangroves. Therefore, it is suspected that other factors influence the low mangrove diversity index, as found by **Setyawan *et al.* (2003)** and **Siringoringo *et al.* (2017)**, apart from being influenced by environmental factors, mangrove ecosystems are also influenced by other factors such as climate, anthropogenic activities, or other factors.

According to **Susanto *et al.* (2013)**, the low diversity of a species in a mangrove ecosystem indicates that the ecosystem is experiencing pressure or is experiencing a decline in condition. Furthermore, mangroves live in extreme environments, such as salt levels or substrates, so they must undergo extra tight selection and high adaptability to survive.

Apart from that, the low diversity index of the mangroves can be caused by human activities. Another factor is anthropogenic, as stated by **Setyawan *et al.* (2003)**, in which the influence of anthropogenic activities that change mangrove habitat for human purposes, such as ponds, land clearing, and settlements, causes a small number of mangrove species (low mangrove diversity).

If conditions like this continue to occur, it will cause damage to the mangrove ecosystem, which will have harmful consequences for human life. **Baderan (2017)** stated that damage to mangrove forests, apart from having an impact on the livelihoods of people around the mangrove area, results in the extinction of various flora species, certain fauna, and biota in the world, resulting in the destruction of the mangrove forest habitat itself.

Evenness and mangrove vegetation dominance index in the SSMNP

The mangrove evenness index in the SSMNP area (Fig. 5) showed that the lowest evenness index value was 0.47 for tree habitus and 0 for saplings and seedlings. In comparison, the highest evenness index was 0.99 for tree habitus and 1 for saplings and seedlings. Anthropogenic activities may have a positive effect on the mangrove ecosystem, as happened in the Mebba (Sabu) and Lumbukore (Sumba) communities, thereby increasing the area and cover of mangroves. This is in line with **Giri *et al.* (2015)**, who stated that the area and cover of mangroves in South Asia are influenced by anthropogenic activities. On the other hand, anthropogenic activities might have negative effects, such as a low dominance index of the mangrove ecosystem. **Sreelekshmi *et al.* (2020)** stated that the low diversity status of an ecosystem indicates an unstable condition caused by natural and anthropogenic stress. Anthropogenic activities include land clearing for cultivation and settlement **(Siringoringo *et al.*, 2017; Iswahyudi *et al.*, 2019)**. Meanwhile, the low evenness index value, according to **Sannigrahi *et al.* (2020)**, is caused by geological systems, anthropocentrism, weather, and sustainable conservation. It was further stated that the low evenness index value could also be caused by several species of mangroves, which tend to grow in clusters **(Sholiqin *et al.*, 2022)**.

Importance value index (IVI) of mangrove vegetation in the SSMNP

The importance value index (IVI) is a crucial metric in understanding the composition and structure of mangrove ecosystems. In the SSMNP area, the high IVI values for *Rhizophora mucronata* and *Sonneratia alba* can be attributed to community-led conservation efforts. Notably, in 2018, a significant collaboration involved students from SMAN 1 Sabu and the local community in Mebba, and a similar initiative took place in Lumbukore in 2015. These efforts align with those of **Setyawan *et al.* (2003)**, who reported that high IVI values in Indonesian mangroves are typical for genera like Rhizophora, Bruguiera, and Sonneratia. These genera are known for their robust regeneration capabilities, ensuring a steady population of mature trees and seedlings.

The findings from **Harahab and Raymond (2011)** further emphasize that species with high IVI are more efficient in resource utilization and better adapted to local environmental conditions. The results indicate that these species have a greater control over their habitat, which is consistent with the dominant presence of *Rhizophora mucronata* and *Sonneratia alba* in the SSMNP area. **Agustini *et al.* (2016)** also highlighted that dominant plant species in an ecosystem typically exhibit high IVI values, indicating their ecological significance and adaptability. The results of the IVI analysis of the mangrove ecosystem in the SSMNP area show the highest IVI was tree habitus 165%, saplings and seedlings 200%.

Recent studies support these observations. For instance, **Kauffman *et al.* (2020)** examined the role of community-based mangrove restoration projects in Southeast Asia and found that such initiatives significantly enhance the ecological health and biodiversity of mangrove forests. Similarly, a study by **Alongi (2022)** highlighted the resilience of mangrove ecosystems in the face of climate change, particularly those dominated by species with high IVI values.

The low IVI values for stilt root mangrove species in certain locations within the SSMNP area, such as Salupu, Semau, and others, are intriguing. Despite favorable water quality parameters (temperature: 28.90-33.90°C, pH: 7.50-8.60, salinity: 1.90-3.90‰, DO: 7.34-8.32mg/ L, BOD: 4.08-5.12mg/ L, TSS: 0.05-5.70mg/ L), these species are underrepresented. This discrepancy may be attributed to their inability to adapt to high disturbance pressures, as suggested by **Erenso *et al.* (2014)**. Moreover, local community activities and natural environmental factors might also play a significant role in their low presence.

Further research by **Friess *et al.* (2019)** underscores the importance of integrating local ecological knowledge with scientific research to better understand and manage mangrove ecosystems. By incorporating traditional practices and community engagement, conservation strategies can be more effective and sustainable. This approach is particularly relevant for areas like the SSMNP, where community involvement has already shown positive impacts on mangrove health.

In conclusion, the high IVI values for certain mangrove species in the SSMNP area reflect successful community-led conservation efforts and the ecological adaptability of these species. Continued research and community collaboration are essential for maintaining and enhancing the biodiversity and resilience of these vital ecosystems.

Implications/benefits for society and science development

Significant impacts of this research prevail for advances in science as well as for societal advantages. From a scientific standpoint, it improves our knowledge of how environmental factors impact the composition and productivity of mangrove ecosystems. Ecological models are improved by the thorough examination of water quality and its effects on mangrove variety, which can also direct future research in comparable maritime habitats. This study emphasizes the value of mangroves for society, especially in resource-dependent areas like Indonesia, where they protect coastlines, conserve biodiversity, and boost local economies through tourist and fishing. The results of this study can help conservationists and legislators create management plans that will effectively protect these important ecosystems, guaranteeing their long-term viability and the benefits they offer to nearby communities.

Relevance to sustainable development goals (SDGs)

Numerous UN Sustainable Development Goals (SDGs) are directly aligned with this research. First of all, it promotes the conservation and sustainable use of marine resources, especially through the preservation and research of mangrove habitats, which are essential for marine and coastal biodiversity. This helps achieve SDG 14: Life Below Water. Second, it supports SDG 13: Climate Action, since mangroves are important carbon sinks, and knowledge of their distribution and health can help with efforts to mitigate the effects of climate change. Furthermore, by highlighting the interdependence of terrestrial and marine ecosystems and the significance of preserving their health for overall biodiversity, the research contributes to SDG 15: Life on Land. Lastly, the study also addresses SDG 8: Decent Work and Economic Growth, assuring that economic development is in line with environmental sustainability by offering a perspective that might enhance local livelihoods and encourage sustainable economic activity like ecotourism.

CONCLUSION

The waters of the SSMNP in NTT exhibit favorable conditions for mangrove growth, including optimal levels of temperature, pH, salinity, dissolved oxygen (DO), biochemical oxygen demand (BOD), and total suspended solids (TSS). These conditions support the sustainability of the mangrove ecosystem. The mangrove vegetation in the area consists of eight species: *Rhizophora mucronata*, *R. apiculata*, *Avicennia marina*, *Sonneratia alba*, *Osbornia octodanta*, *Aegialitis annulata*, *Lumnitzera racemosa*, and *Scyphiphora hydrophyllacea*. Among these, *Rhizophora mucronata*, *R. apiculata*, and *Avicennia marina* are consistently dominant across key research locations. Mangrove diversity in the SSMNP includes a total of 513 individuals, comprising 210 trees, 68 saplings, and 235 seedlings. The indices for density, taxa richness, dominance, evenness, and importance are within the low to medium range, all supported by the area's favorable environmental conditions.

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