INDO PAC J OCEAN LIFE
Volume 8, Number 2, December 2024
Pages: 84-93

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o080203

Species diversity of mangrove at tree and pole level in Sampang and Pamekasan Districts, Madura Island, Indonesia

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Manuscript received: 31 December 2023. Revision accepted: 14 November 2024.

Abstract. *Lathifah MN, Muazulfa TI, Nisa WK, Raharjo YAA, Arta YPA, Setyawan AD. 2024. Species diversity of mangrove at tree and pole level in Sampang and Pamekasan Districts, Madura Island, Indonesia. Indo Pac J Ocean Life 8: 84-93.* Madura Island, Indonesia, located northeast of Java Island, features naturally occurring mangrove vegetation along its coastline. Mangrove forests encompass approximately 75% of the coastlines in tropical and subtropical regions. The diversity of mangrove species needs to be assessed to determine the current situation and provide an evaluation of biodiversity conservation. In this research, the mangrove species diversity at both tree and pole level in the coast of Taddan Village, Sampang District (7°13'7.53"S, 113°16'15.93"E), Song Osong Beach, Sampang District (7°13'19.55"S, 113°12'10.63"E), Branta Tinggi Village, Pamekasan District (7°13'19.53"S, 113°27'12.45"E) and Tlanakan Village, Pamekasan District (7°13'16.24"S, 113°26'11.68"E), Madura Island, East Java, Indonesia were determined. A 150 m long transect plot was established at each station, yielding 40 plots for 4 stations. Abiotic factors, including temperature, salinity, pH, and soil moisture at the study location, were also measured. The Shannon-Wiener Index (H') is used to analyze the species diversity index; Pielou's Evenness and Margalef's Richness index analysis are also calculated in this research. The results indicated that there are 3 species consisting of *Rhizophora stylosa, Avicennia marina,* and *Sonneratia alba.* The diversity analysis showed a moderate category (H' range: 1.85-2.56), with the highest values at both tree and pole levels recorded at Song Osong Beach (H' tree: 2.56, H' pole: 2.19). Meanwhile, the lowest value at the tree level was recorded at Taddan Village (H': 1.99), and the pole level is at Branta Tinggi Village (H': 1.85). The Margalef's richness values obtained range from D: 39.34-95.58 (high) at the tree level and D: 13.61-98.00 (high) at the pole level. The results of Pielou's evenness calculations indicate low evenness at all stations (J' tree: 0.05-0.27: J' pole: 0.02-0.48. In an ecosystem with a medium-level diversity index, vegetation can grow with sufficient support but also faces significant threats. In this instance, the threats arise from anthropogenic activities, such as illegal logging and land conversion for aquaculture purposes. The implementation of mangrove maintenance efforts can be achieved through protection and rehabilitation initiatives that collaborate with local governments and engage indigenous communities.

Keywords: Diversity index, Madura Island, mangrove, Shannon-Wiener Index

Abbreviations: DBH: Diameter at Breast Height

INTRODUCTION

Mangrove forests encompass approximately 75% of the coastline in tropical and subtropical regions. Indonesia is the habitat of almost 30% of the total mangrove area in the world. Until 2014, Indonesia was recorded as a country with the world's largest mangrove forest (Hamilton and Casey 2016). Mangrove forests protect coastal areas from abrasion, wind, storms, and other natural disasters (Rafael and Calumpong 2018). Mangrove trees can adapt to strong waves and high salinity (Amalia et al. 2016). Various types of mangrove species have diverse ways of adapting to various types of soil and geographical location. Thus, mangrove communities have different vegetation zones (Mojiol and Salleh 2017). Mangrove forests have a variety of plant species, but what dominates are some trees and shrubs that can absorb carbon and are resistant to high salinity (Afifudin 2019). Several factors affect mangrove forest species structure and characteristics, such as climate, tidal wave distance, coastal landform, soil type, and freshwater availability (Koswara et al. 2017). Therefore, to adapt to extreme environments, mangroves exhibit both morphological and physiological adaptations. Notably, these species possess unique mechanisms, including the adjustment of salt glands in their leaves for salt excretion and respiratory roots to assist respiration in oxygen-poor sediment conditions (Maiti and Chowduri 2013).

Species diversity indicates the different types of organisms that live in an area, which includes variations in genetics, species, and ecosystems. Species diversity is necessary to measure and evaluate biodiversity conservation (Morris et al. 2014). Species diversity is measured using a mathematical function in general (Daly et al. 2018), referred to as the species diversity index. The diversity index is used to compare different communities in an area, especially to observe the impact of disturbances on the community (Rochmady 2015). The high level of mangrove species diversity is valuable and must be maintained (Nawar et al. 2021).

Madura Island is one of the islands in East Java Province, Indonesia. This island is located in the northeastern part of Java Island, separated from Java by the Madura Strait. Geographically, Madura is located between 6°00'-7°10' south latitude and 113°15'-114°20' east longitude. Madura Island has mangrove vegetation along its coast and has a coastline of about 985 km, but this may change due to the influence of coastal accretion (Sukandar et al. 2016; Agustin and Achmad 2020). Mangrove vegetation occupies various types of land and water areas, known as 'geomorphologies'. These include mudflats, estuaries, and riverbanks. The mangrove forests on Madura Island are forests that form naturally. According to Rosadi et al. (2018), two types of mangroves dominate the Sampang District area, Madura, namely *Rhizophora apiculata* and *Sonneratia alba*. The density of vegetation in mangrove forests in Sampang District is relatively dense and has trees that are not too tall. Mangrove ecosystems in the Sampang District can generally be found in coastal areas that form a green belt (Rosadi et al. 2018). The research focuses on the Sampang and Pamekasan Districts, as both areas are situated in the southern coastal region traversed by the Jalan Lintas Selatan (Southern Cross Road). This road frequently experiences tidal flooding; therefore, the study aims to evaluate the presence of mangroves in these areas. Additionally, the results are expected to offer insights into the potential for reforestation efforts to mitigate the impact of tidal floods. Based on the description above, it is important to know the diversity of mangroves to support the sustainability of mangrove ecosystems. This study aims to determine the diversity of mangrove species at the tree and pole level on the coast of Sampang and Pamekasan Districts, Madura Island, Indonesia.

MATERIALS AND METHODS

Study area

This research was conducted from 9 to 10 December 2023 in Sampang and Pamekasan Districts located on Madura Island, East Java, Indonesia (Figures 1 and 2). Based on BMKG station data, Madura Island has an annual rainfall of 1,314.67 mm with an average monthly air temperature of 27.9°C and an average length of solar radiation of 2149,673 hours/year (Latifah and Siregar 2021). Sampang District is located at coordinates 6°05'-7°13'S and 113°08'-113°39'E, while Pamekasan District is located at coordinates 6°51'-7°31' S and 113°19'-113°58' E. There are 4 sampling points for mangrove diversity on the Sampang and Pamekasan coasts: Taddan Village (Station 1), Tlanakan Village (Station 2), Branta Tinggi Village (Station 3), and Song Osong Beach (Station 4). The coordinates of each sampling point and the differences in substrate characteristics in the four study areas can be seen in Table 1.

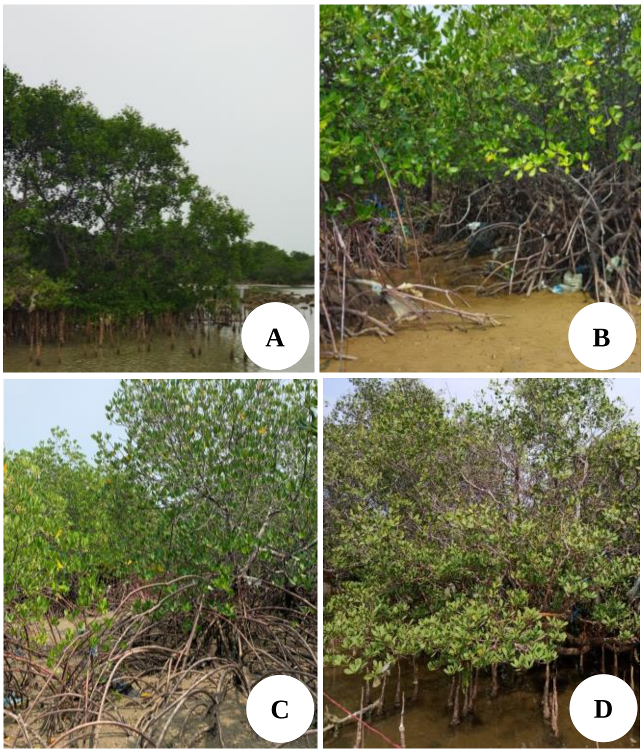

Figure 1. Mangrove ecosystem in Madura Island, East Java, Indonesia: A. Song Osong Beach, B. Taddan Village, C. Tlanakan Village, and D. Branta Tinggi Village

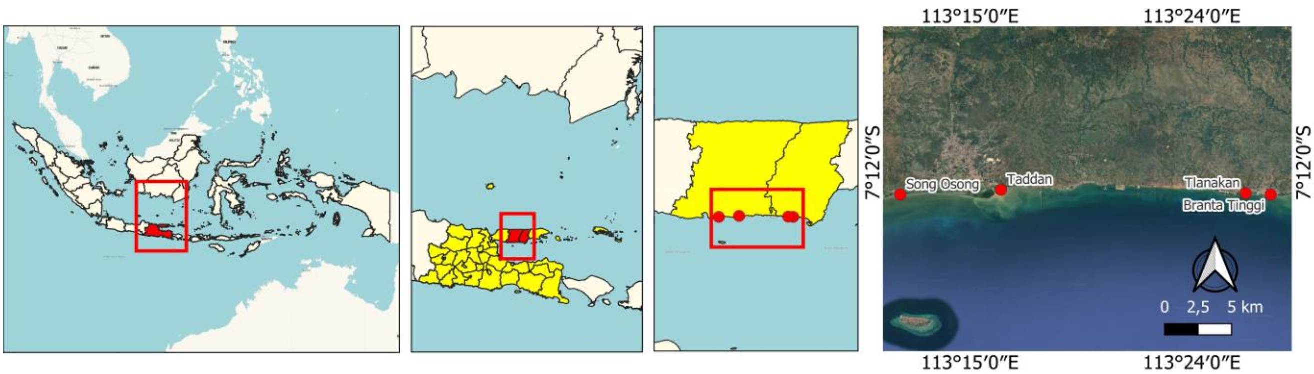

Figure 2. Location of 4 mangrove diversity sampling points: Song Osong Beach, Taddan Village, Tlanakan Village, and Branta Tinggi Village of Madura Island, East Java, Indonesia

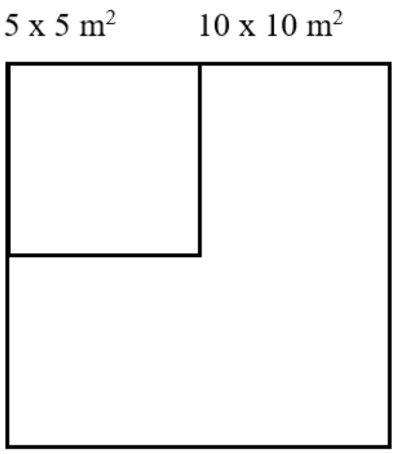

Figure 3. Square plot quadrate for sampling mangrove stand

Procedures

Mangrove sampling was conducted at 4 research stations with ten square plots of 10×10 m^2 size at each station for tree species identification and 5×5 m^2 for pole type identification (Figure 3). This methodology, in accordance with Sholiqin et al. (2021), builds on their use of three-square plot sizes for sampling at the seedling, pole, and tree levels. We have refined this approach, using only two square plot sizes were used to sample mangroves at the pole and tree levels following the predetermined research objectives. The mangrove stand is categorized as plants when the diameter is above 20 cm and is included in the category of plants with a Diameter at Breast Height (DBH) of 10-20 cm (Wijana et al. 2022). Observations include identifying the type of mangrove species in a square plot and counting the total number of species of each mangrove stand (trees and poles), considering the height and diameter of plants following Sholiqin et al. (2021).

At each observation station, measurements were also made on several abiotic factors with three repetitions. Abiotic factors measured include temperature, salinity, pH, and soil moisture. Rainfall and air temperature data were obtained through BMKG data. Abiotic factor measurements were carried out thrice in the morning until noon in each research station to verify the repeatability of measurement results (Yu et al. 2014). Samples of unidentified species were identified by analyzing photographs of samples. Key morphological characters used for the identification of mangrove plants were leaf shape, flower color, and fruit (Dahibhate et al. 2020; Mwakha et al. 2020).

Data analysis

Mangrove diversity was calculated using the Shannon-Wiener index (H') (Asuk et al. 2018; Suwanto et al. 2021).

$$H' = -\sum Pi \ln Pi$$

$$Pi = \frac{ni}{N}$$

Where:

H': Shannon-Wiener Diversity Index

Pi: Number of individuals of a species divided by the total number of species found.

H' values range from 0 (low diversity) to 1 (high diversity). The criteria for the diversity index are as follows: (i) H'<1.5: low diversity; (ii) 1.5≤H'≤3.5: moderate diversity; (iii) H'>3.5: high diversity (Krebs 1989).

The Index of Evennes was determined using Pielou's (J) (Heip et al. 1998)

$$J' = \frac{H'}{H'max}$$

$$H' \max = -\sum_{i=1}^{S} S^2 \ln \frac{1}{S} = \ln S$$

Where:

J': Pielou’s Evenness Index

H': Shannon-Wiener Diversity Index

H'max: Maximum Shannon-Wiener Diversity Index

S: Number of species.

The value of J ranges from 0 to 1. A value closer to 1 indicates a higher level of evenness.

For the species richness index, the Margalef Index (D) was used (Subhan et al. 2021)

$$D = \frac{S-1}{\ln N}$$

Where:

D: Margalef Richness Index

S: Number of species present in the community

N: Number of individuals in the community.

The criteria for the richness index are as follows: (i) D<3.5: low species richness; (ii) 3.5<D<5: moderate species richness; (iv) D>5: high species richness.

Data analysis was performed quantitatively using Microsoft Office Excel software.

RESULT AND DISCUSSION

Environment condition of study area

The observations result from four points have varied soil types: Taddan has muddy, quite thick type of soil; Tlanakan and Branta Tinggi have muddy and sandy soil; Song Osong Beach has a sandy type of soil. The results of measurements and observations can be seen in Table 1. Measurement of abiotic factors in mangrove ecosystems was also carried out in the research of Irsadi et al. (2019) in the coastal area of Semarang-Demak in 2018 to determine the environmental factors supporting mangrove ecosystems. Abiotic factors measured in Irsadi et al. (2019) research include salinity, air temperature, water pH, soil pH, rainfall, and light intensity. In his research, salinity, water pH, soil pH, and light intensity were observed directly in the field.

Table 1. Abiotic factors measured at 4 sampling points

Location/Station	Soil temp. (°C)	Water temp. (°C)	Air temp. (°C)	Soil pH	Water pH	Salinity (ppt)	Soil moisture (θ)	Substrate characteristics
Taddan/1 (7°13'7.53"S, 113°16'15.93"E)	30.34±0.72	30.67±0.72	31.70±0.57	6.170±0.62	7.60±0.05	28.30±1.36	>10	Muddy
Branta Tinggi/2 (7°13'19.53"S, 113°27'12.45"E)	34.30±0.58	34.30±0.75	37.17±0.59	6.80±0.08	7.37±0.03	28.30±1.36	>10	Muddy, Sandy
Tlanakan/3 (7°13'16.24"S, 113°26'11.68"E)	35.00±0.00	36.00±0.47	36.30±0.33	7.10±0.08	8.03±0.15	32.67±0.98	>10	Muddy, Sandy
Song Osong/4 (7°13'19.55"S, 113°12'10.63"E)	34.70±0.33	35.70±0.75	36.30±0.33	6.97±0.03	7.53±0.07	19.67±1.19	>10	Sandy

Note: Temp.: Temperature

The soil temperature measured in this study ranged from 30.34°C to 35.00°C. Increasing soil temperature can stimulate microflora metabolic activities to accelerate the pace of the mineralization process (Efendi et al. 2018). Soil pH ranged from 6.17 to 7.10, which is suitable for mangrove growth. Based on Badu et al. (2022), the soil pH for mangrove sediment ranges from 6 to 7. All four sampling sites have a humidity of more than 10 on soil moisture parameters. High soil moisture also affects germination rates (Hidayah et al. 2022).

Water temperature ranged from 30.67°C to 36.00°C. This variation is influenced by several factors, such as the differences in the intensity of sunlight hitting the water, and several factors, such as the geographical location of the waters, circulation of ocean currents, wind, and seasons (Widiawati et al. 2023). Metabolic activity and geographical distribution of aquatic organisms are much influenced by water temperature (Dallas and Ross-Gillespie 2015). Water pH in this study ranged from 7.37 to 8.03. The pH value of water in the Sampang and Pamekasan coastal areas is still following the threshold of seawater quality standards based on Kepmen LH No. 51 of 2004 for biota health in the range of normal limits up to a pH value of 8.5 (Widiawati et al. 2023). Salinity ranged from 19.67 ppt to 32.67 ppt. Mangrove can grow well with salinity levels of 10-30 ppt (Khawarizmi et al. 2021). In addition, the salinity levels in Tlanakan village exceed the optimal salinity levels but can still be tolerated.

The air temperature ranged from 31.70°C to 37.17°C. The temperature at 4 mangrove observation points on the Sampang and Pamekasan coasts is quite high. This condition is still conducive for mangrove growth, as mangroves thrive at temperatures ranging from 4.5°C to 36°C (Hidayah et al. 2022), unless Branta Tinggi was recorded at 37.17°C. However, this does not significantly affect mangrove growth. According to Asbridge et al. (2015), species that grow near the equator exhibit greater tolerance to air temperatures than those that inhabit higher latitudes. Temperature is one of the factors that determines the growth, development, reproduction, and survival of plants. It is also important in physiological processes (Hardiansyah and Noorhidayati 2020).

Mangrove species in Madura coastal areas

Three species of mangroves, namely *Rhizophora stylosa* (Figure 5), *S. alba* (Figure 4), and *Avicennia marina* (Figure 6), were found in the present study area. The *R. stylosa* a type of mangrove that impressively inhabits both muddy and sandy substrates (Giesen et al. 2007), showcases its adaptability. According to Kint (1934), *R. stylosa* and *S. alba* mangroves usually live on sandy and rocky beaches in Indonesia. The *R. stylosa* mangroves have a fruit length of 20-30 cm, but sometimes it can be more than 54 cm (Giesen et al. 2007). The *S. alba* tends to inhabit sandy substrates. The characteristics for identification of *S. alba* are breath roots, open white, an average tree height is 15 m, unique round-shaped fruits, and oblong or round leaf shapes forming love. The *A. marina* mangrove species is a mangrove that is more often found on muddy substrates and has a high tolerance in saline conditions (Noor et al. 1999). The *A. marina* possesses a type of breathing root known as a pneumatophore. This root exhibits a pencil or cone-shaped morphology, protrudes above the substrate, and is characterized by numerous air-filled gaps that allow gas exchange. It is typically brown and reaches an average height of approximately 30 cm, with a diameter of about 1 cm (Tumangger and Fitriani 2019).

Taddan, Sampang District

This station has muddy characteristics because it is directly facing the beach. At station one, namely in the Taddan Village, Sampang District, three species were found, namely *S. alba* and *A. marina*, which consisted of trees and poles, also *R. stylosa* only at pole level. The mangroves found have a DBH ranging from 3.18 to 52.23 cm. The *S. alba* dominated 9 of 10 plots. The *R. stylosa*, at this station, there are only 35 individual poles. The number of *S. alba* at station one was 66 trees and 1 pole. In this site, *S. alba* is found at the pole level in limited abundance due to frequent displacement and transport of mangrove seedlings by tides. This phenomenon can be attributed to *S. alba* being the outermost species in this area, directly exposed to the sea. The *A. marina* species was found with 10 trees and 6 poles.

The *S. alba* likes waterlogged and muddy coastal areas, which is the character of the Taddan Village mangrove area. The mangrove type *A. marina* is a mangrove that has tolerance for high salinity of seawater because the higher the salinity, the faster the stimulation of growth *of A. marina* seeds, and vice versa if the salinity value is low; it will have an impact on plant growth and development (Cheng et al. 2020). In addition, *A. marina* mangroves also have good tolerance to metal content in the soil (Sholiqin et al. 2021). The *A. marina* mangrove can tolerate salt content in seawater; therefore, *A. marina* can be used as a phytoremediation agent, but based on Sholiqin et al. (2021) reports, it should not be used because it is only temporary and is considered ineffective. The *A. marina* mangrove has roots that are almost the same as the *S. alba* type, namely respiratory roots that come out of the soil surface (Pan et al. 2022).

Branta Tinggi, Pamekasan District

A sandy substrate characterizes this station; the species found in the 10 plots are all *R. stylosa* mangrove species, which consist of trees and poles with DBH ranging from 3.18 to 11.15 cm. The number of individuals at this station is 226 trees and 233 poles, and all are *R. stylosa* mangrove species. At the research location, the density of each individual is quite dense and they grow well in sandy areas. At the research location, 5 *R. stylosa* were taken, which were used to determine the type of mangrove being studied. The length of each Propagule is 35.2, 30.1, 29.8, 25.6, and 25.5 cm. The *R. stylosa* grows well in sandy areas and even in rocky areas. The stems of this type of mangrove can be used for charcoal production. The shape of this type of mangrove fruit is long and brown, and the flowers are yellowish white, usually consisting of 5-8 stems. The *R. stylosa* is a type of mangrove with a supporting root shape, like a brown chicken claw with more than two branches (Tumangger and Fitriani 2019). Mangrove plants that have roots usually live in sandy substrates or swamps; the sturdy roots of mangroves are useful for resisting waves and mud, protecting beaches from erosion and tidal waves (Tumangger and Fitriani 2019)

Tlanakan, Pamekasan District

This station has the characteristics of a sandy substrate and much plastic waste disposed of by the surrounding community. At this station, several dead mangrove plants were also found which were cut down by the community and which are characteristic of a beachside location. At the third station, mangrove species were identified, namely *R. stylosa, S. alba, and A. marina*, consisting of trees and poles with a DBH ranging from 3.50 to 25.48 cm. The most frequently encountered species was *R. stylosa,* with a presence of 146 at the tree level and 11 at the pole level. The second most common species was *A. marina*, recorded at 14 at the tree level and 1 at the pole level. The *S. alba* was exclusively found at the pole level, with a total of 11 poles. The *A. marina* in this station has a different character from other stations because the color of the leaves on the individuals found is greenish yellow. Generally, the *A. marina* leaves are green (Giesen et al. 2007). The difference in color on the leaves of *A. marina* at station 3 is caused by a lack of nutrition. According to Cheng et al. (2020), *A. marina* is a mangrove with a high tolerance to seawater salinity. However, this site may not be suitable for *A. marina,* resulting in nutritional deficiencies. According to Sholiqin et al. (2021), *A. marina* is more suited to living on sandy substrates; its flowers are yellow, and its fruit resembles nuts.

Song Osong, Sampang District

This station has characteristics of sandy and muddy substrates. The species types found were *R. stylosa, S. alba*, and *A. marina*, which consisted of trees and poles. The most dominant mangrove at this station is *R. stylosa,* totaling 145 trees and 21 poles; the muddy character of this station is suitable for *R. stylosa*. Other mangrove species were found at this location, namely *S. alba* by 9 and *A. marina* by 32, but the numbers were not as numerous as *R. stylosa*. This happens because the environmental character is not suitable for those three mangroves. The *S. alba* mangrove dominates the frontmost habitat zone or conservation zone between sea and land due to its ability to adapt to sandy and muddy environmental conditions (Haya et al. 2015). Not only does it dominate in the zone directly adjacent to the sea, but *S. alba* can also live in the middle zone. Just like *S. alba*, the habitat of *A. marina* is almost the same, dominating the muddy zone.

Species diversity of tree and pole-level mangroves

The species diversity index is used to measure the diversity of species in a vegetation community (Cavieres et al. 2014). The Shannon-Wiener Index (H') is used to analyze the species diversity index in this study. The mangrove diversity index value in this study refers to the categorization by Krebs (1989), where H'<1.5 indicates low diversity, 1.5≤H'≤3.5 indicates moderate diversity, and H'>3.5 for high diversity. According to Kim et al. (2017), the diversity index is strongly influenced by the number of individuals and species in an ecosystem. The higher the vegetation diversity index value, the more stable and mature the environmental conditions are (Jucker et al. 2014). The mangrove diversity index in this study is differentiated according to the identification of mangrove growth rates, divided into tree and pole species. Mangrove diversity index data at the tree and pole level at four research stations along the coast of Sampang and Pamekasan, Madura, are presented in Table 2.

The species diversity index is primarily influenced by species richness and evenness indices. According to Farista and Arben (2021), population unevenness and the dominance of certain species can result in a low diversity index value. An evenness index approaching 1 (J'=1) suggests that the number of individuals across different mangrove species is relatively uniform. In this research, the evenness values observed at all stations were significantly below 1, indicating an imbalance in individual numbers and the dominance of certain species within the community. At the tree level, the highest value was recorded at Taddan (0.27), followed by Tlanakan (0.23), Song Osong (0.21), and Branta Tinggi (0.05). At the pole level, the highest evenness values were found at Song Osong (0.48), followed by Taddan and Tlanakan (0.28), and the lowest value was Branta Tinggi (0.01). In Branta Tinggi, there is a very wide difference in the evenness index due to the presence of only one species, *R. stylosa*, despite the presence of a large number of species.

The species richness index revealed high species richness across the research stations. The highest richness index at the tree level was found at Branta Tinggi (95.58), followed by Tlanakan (71.68), Song Osong (65.70), and Taddan (39.34); at the pole level, the highest richness value was also observed at Branta Tinggi (98.00), followed by Taddan (24.03), Tlanakan (14.69), and Song Osong (13.61).

Table 2 shows the tree-level mangrove diversity index at all four study sites. The data presented in the table indicate the mangrove diversity index at the highest tree level in the study site, Song Osong, Tlanakan, Branta Tinggi, and Taddan, are 2.56, 2.32, 2.09, and 1.99, respectively. This value shows that the diversity of tree-level mangroves in the study site is grouped in the medium category. The tree-level mangrove that dominates the Taddan area is the *S. alba* species, with 66 individuals. Branta Tinggi is dominated by the mangrove species *R. stylosa,* with a total number of individuals of 226. Tlanakan is dominated by the mangrove species *R. stylosa* with 146 individuals. Song Osong's research site is also dominated by the mangrove species *R. stylosa*, with individuals 117. The table also provides the mangrove diversity index at the pole level for the four research locations. The highest values recorded were 2.19 in Song Osong, followed by 1.86 in both Tlanakan and Taddan and 1.85 in Branta Tinggi. These values suggest that the mangrove diversity within the study site is categorized as moderate.

Shannon-Wiener Diversity Index

The mangrove diversity index along the coasts of Sampang and Pamekasan District at both tree and pole levels is categorized as moderate, with values ranging from 1.99 to 2.56. The results fall within the range of H' values: 1.5≤H'≤ 3.5 as a moderate level. This moderate diversity index suggests that the mangroves prefer a relatively stable ecosystem, benefiting from the existing vegetation in the area. The stability of these ecosystems, as evidenced by the moderate diversity index, is a testament to the resilience of mangrove forests. Consequently, this stability enhances the ecosystem's capacity to support further vegetation (Hardiansyah and Noorhidayati 2020). The results align with those of Akhrianti and Gustomi (2021), who examined the coastal area of Pangkalpinang City, Bangka Belitung Island Province, where the mangrove diversity index was categorized as low to moderate. Their research identified substrates predominantly composed of mud, sandy mud, sand, rocks, and coral fragments, indicating that the stability of mangrove vegetation communities in coastal areas is dependent on environmental parameters and substrate composition that facilitate mangrove growth.

Table 2. Tree and pole mangrove Shannon's Diversity Index, Margalef's Species Richness, and Pielou's Evenness Index

Species name	Amount	H'	Categories	D_{mg}	Categories	J'	Categories
Tree level mangrove							
Taddan Village							
Sonneratia alba J.E. Smith	66	1.99	Moderate	39.34	High	0.27	Low
Avicennia marina (Forsk.) Vierh.	10						
Branta Tinggi Village							
Rhizophora stylosa Griff.	226	2.09	Moderate	95.58	High	0.05	Low
Tlanakan Village							
Rhizophora stylosa Griff.	146	2.32	Moderate	71.68	High	0.23	Low
Avicennia marina (Forsk.) Vierh.	14						
Song Osong Beach							
Sonneratia alba J.E. Smith	25	2.56	Moderate	65.70	High	0.21	Low
Rhizophora stylosa Griff.	117						
Avicennia marina (Forsk.) Vierh.	3						
Pole level mangrove							
Taddan Village							
Rhizophora stylosa Griff.	35	1.86	Moderate	24.03	High	0.28	Low
Avicennia marina (Forsk.) Vierh.	6						
Sonneratia alba J.E. Smith	1						
Branta Tinggi Village							
Rhizophora stylosa Griff.	233	1.85	Moderate	98.00	High	0.01	Low
Tlanakan Village							
Rhizophora stylosa Griff.	11	1.86	Moderate	14.69	High	0.28	Low
Sonneratia alba J.E. Smith	11						
Avicennia marina (Forsk.) Vierh.	1						
Song Osong Beach							
Rhizophora stylosa Griff.	8	2.19	Moderate	13.61	High	0.48	Low
Sonneratia alba J.E. Smith	7						
Avicennia marina (Forsk.) Vierh.	6						

Note: H': Shanon's Diversity Index, D_{mg}: Margalef's Species Richness, J': Pielou's Evenness Index

Figure 4. Flowers and fruit of *Sinneratia alba* trees at Station 1 (Taddan Village) of Madura Coastal Beach, East Java, Indonesia

Figure 5. Flowers and fruit of *Rhizophora stylosa* trees at Stations 2, 3, and 4 (Branta Tinggi Village, Tlanakan Village, Song Osong Beach) on the Madura Coast, East Java, Indonesia

Figure 6. Flowers and fruit of *Avicennia marina* trees at Stations 1, 3, and 4 (Taddan Village, Tlanakan Village, Song Osong Beach) on Madura Coastal Beach, East Java, Indonesia

In this study, the substrate type identified at the research stations was predominantly muddy, with two stations exhibiting variations of sandy substrate. According to Salmo et al. (2013), the formation of mangrove stands is significantly influenced by soil characteristics. Research on the mangrove diversity index at the tree and pole level was also conducted by Akhmadi (2023) along the coast of Sampit Bay, Eas Kotawaringin. His study reported diversity index values of 0.64 for trees and 0.57 for poles, categorizing these indices as low. Akhmadi (2023) attributed the low species diversity index at both growth stages to the environmental conditions of the mangrove forest at the research site, which is characterized by a thick mud substrate that is frequently inundated and experiences low light intensity due to the dense canopy of mangrove trees.

Mangrove species threat

Based on the results obtained from the four stations, the diversity of tree and pole-level mangroves showed moderate diversity. According to Asadi et al. (2018), mangrove species with a moderate level of diversity are vulnerable to genetic differences and reduced genetic diversity, so they can affect the ability of mangroves to adapt to stressful conditions. Mangrove diversity is crucial in maintaining ecological balance and mangrove ecosystem services. However, mangrove diversity can face several threats, such as illegal logging and conversion of forest land to aquaculture areas. Mangrove trees cut down can directly cause changes in plant makeup and no longer function as a feeding ground and nursery ground suitable for various fish and shrimp of the economically important (Hidayah and Suharyo 2018). Threats caused by humans' excessive use of mangroves, mangrove habitat conversion, fisheries cultivation, and heavy metal pollution cause significant effects on mangrove ecosystems (Ashton 2022). According to Mughofar et al. (2018), mangrove forest vegetation in most areas has decreased in quality and quantity if it cannot be controlled, and the mangrove forests in the area will be damaged. According to Xie et al. (2020), the impacts of climate change, such as global warming, rising sea levels, and extreme weather patterns, are predicted to threaten mangrove ecosystems in the future. Climate change and sea level rise are also threats to mangrove species. Mangrove forests are vulnerable to changes in temperature, rainfall, salinity, and sea level. Climate change can affect the distribution, growth, and reproduction of mangrove flora and fauna and increase the effects of diseases, pests, and invasive species. Rising sea levels will slowly eliminate mangrove forest habitats, reducing the space used for mangrove forest expansion (Akram et al. 2023).

Efforts to protect mangrove forests

Mangrove forests play a crucial role in ecosystems, and their preservation should be ensured through various efforts, including conservation, restoration, and rehabilitation. According to Kiolol (2017), sustainable management can be achieved through two conceptual frameworks: strategic management and implementation, specifically focusing on the protection and rehabilitation of mangrove forests. These efforts should involve the indigenous community to ensure effective implementation (Sugiyanti and Hotimah 2020). The first aspect is protection, which can be implemented by establishing nursery centers, preservation of flora and fauna biodiversity along with their ecosystems, and promoting sustainable utilization practices. Protection efforts can be reinforced through the establishment of regulatory frameworks for designated areas. Rehabilitation initiatives can be implemented in collaboration with local government to enhance community knowledge of mangrove forest management. Active community involvement is essential to ensure that ecosystem maintenance is conducted routinely and sustainably (Dewi et al. 2023).

The conclusion that can be drawn from this study indicates that the mangrove diversity index along the coast of Sampang and Pamekasan District, at both tree and pole levels, falls within the medium category. The *R. stylosa, S. alba,* and *A. marina* were found in the study site. Specifically, the mangrove diversity index was highest at the research of Song Osong Beach (2.56), followed by Tlanakan (2.32), Branta Tinggi (2.09), and Taddan (1.99) at the tree level. For the pole-level mangrove diversity index, the highest values were recorded at Song Osong (2.19), Tlanakan and Taddan (1.86), and Branta Tinggi (1.85). The implementation of mangrove maintenance efforts can be achieved through protection and rehabilitation initiatives that collaborate with local governments and engage indigenous communities.

ACKNOWLEDGEMENTS

The researcher expressed his gratitude to the mangrove manager in Taddan Village, Tlanakan Village, Branta Tinggi Village, and Song Osong Beach and residents around the research area in Madura Island, Indonesia, who have given permission and the opportunity to conduct research in the mangrove area and thank all parties who participated both in the research and in the preparation of this article.

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