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Ecological Status and Community Structure of Mangroves in East Siantan, Anambas Marine Tourism Park: A Baseline Study for Sustainable Management

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ABSTRACT

Mangrove ecosystems are vital for maintaining ecological balance and supporting the economic resilience of coastal communities. This study investigated the community structure of mangroves, evaluated water environmental parameters, and reviewed current management practices in the Siantan Timur ubdistrict. Field surveys were conducted from August to October 2023 across three stations using the transect-quadrat method. Plot sizes were 10×10m for trees, 5×5m for saplings, and 2×2m for seedlings. Nine mangrove species from four families were identified: Rhizophoraceae (*Rhizophora stylosa*, *R. mucronata*, *R. apiculata*, *Bruguiera gymnorrhiza*, *B. cylindrica*, *Ceriops tagal*), Sonneratiaceae (*Sonneratia alba*), Myrsinaceae (*Aegiceras floridum*), and Meliaceae (*Xylocarpus granatum*). Tree density ranged from 2,482 to 2,890 individuals per hectare. Dominant species by Importance Value Index (IVI) were *R. mucronata* (143.23%) at Station 1, *R. stylosa* (105.34%) at Station 2, and *R. apiculata* (127.70%) at Station 3. Molluscs dominated the associated fauna. Water quality parameters indicated healthy conditions. The substrate consisted of muddy sand and sandy mud, with a single daily tidal cycle. Mangrove management follows Ministerial Decree No. 53/2014 on the zoning of the Anambas Marine Tourism Park. The study provides essential baseline data for sustainable mangrove conservation in small island regions.

INTRODUCTION

Mangrove ecosystems are among the most important biological systems in tropical coastal areas due to their interconnected ecological and economic functions. Ecologically, mangrove forests protect coastal regions from erosion, storms, and saltwater intrusion through their dense root structures and canopy **(Lovelock & Reef, 2020; Griscom *et al.*, 2022)**. Additionally, mangroves serve as breeding and nursery grounds for various aquatic organisms, including fish, shrimp, and molluscs **(Wahyuni *et al.*, 2016; Delgado**

***et al*., 2021)**. The presence of mangrove vegetation also contributes to maintaining water quality by filtering sediments and pollutants from land to sea **(Dookie *et al*., 2022)** and by absorbing significant amounts of blue carbon, which plays an important role in climate change mitigation efforts **(Murdiyarso *et al*., 2009; Hamza *et al*., 2024)**.

From an economic perspective, coastal communities utilize mangrove forests as sources of raw materials such as wood and charcoal, as well as for traditional medicine and fishing grounds **(Brander *et al*., 2012)**. In the context of sustainability, mangrove-based ecotourism development has been implemented in various regions, demonstrating significant potential to support local economies while minimizing environmental damage **(Gustria *et al*., 2018; Suardana *et al*., 2023)**.

Unfortunately, various anthropogenic pressures have made mangrove ecosystems increasingly vulnerable to structural damage and biodiversity loss. The conversion of mangrove land into fish ponds, residential areas, and port infrastructure is the leading cause of mangrove forest decline in Indonesia **(Dong *et al*., 2024)**. Uncontrolled illegal logging further exacerbates the degradation of vegetation cover, particularly for key mangrove species such as *Rhizophora* and *Avicennia* **(Utomo *et al*., 2018; Sunkur *et al*., 2024)**. Additionally, pollution from domestic waste, marine plastics, and potential oil spills from oil and gas operations adds further pressure to mangrove habitats **(Hou *et al*., 2020; Choi *et al*., 2021)**. These pressures not only lead to a reduction in mangrove area but also cause the loss of local species and disruption of vegetation community structure **(Damastuti *et al*., 2022; Wang *et al*., 2022)**. When only one or two species dominate, it indicates that the ecosystem is experiencing high ecological stress.

In mangrove ecology studies, community structure is a key parameter that reflects the stability and integrity of the ecosystem. This structure includes species composition, density, occurrence frequency, dominance, and the Importance Value Index (IVI), which assesses the relative ecological role of each species **(Irawan *et al*., 2017; Almasi *et al*., 2018)**. A healthy community structure is characterized by high species diversity, balanced distribution, and dominance by species typical of tidal zone zonation **(Damastuti *et al*., 2022)**. An imbalance in community structure indicates the presence of external disturbances, whether from environmental factors or human activities **(Sudjana *et al*., 2024)**. Therefore, analyzing community structure not only serves as a basis for vegetation inventories but also as a crucial tool in designing science-based conservation and rehabilitation strategies **(Wang *et al*., 2022; Suardana *et al*., 2023)**. Such studies are also essential for evaluating the effectiveness of conservation area management, especially in regions transitioning from ecological pressure to economic development.

Siantan Timur Subdistrict is part of the Anambas Archipelago Marine Tourism Park conservation area in Riau Archipelago Province. Geographically, the area features a sheltered bay morphology and mud-sand substrate, both of which support the growth of natural mangrove vegetation **(Ilham *et al*., 2018)**. The existing mangroves are critical to supporting traditional fishing activities and protecting the coastline from abrasion caused by inter-island currents **(Jayadi *et al*., 2024)**. However, infrastructure development—including roads, ports, and settlements, as well as ecotourism projects that exceed the area's environmental carrying capacity—poses direct threats to the mangrove ecosystem **(Sudjana *et al*., 2024)**. The subdistrict is also adjacent to the Oil and Gas Mining Work Area in northern Anambas, which presents risks of oil spills and seawater contamination that could harm coastal ecosystems **(Andrito *et al*., 2020; Hou *et al*., 2020)**.

Despite its ecological significance, few scientific studies have documented the condition of the mangrove community structure in East Siantan in detail and with quantitative analysis. Therefore, this study aimed to: (1) examine the structure of the mangrove community, including species composition, density, dominance, and importance value index; (2) analyze environmental parameters influencing the distribution and presence of mangrove species; and (3) develop recommendations for mangrove conservation management based on local ecological data.

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MATERIALS AND METHODS

Time and location

Research sampling and data collection were conducted from August 21 to October 12, 2023, in East Siantan Subdistrict, Anambas Islands Regency, Riau Archipelago. Three observation stations—Tanjung Kumbik, Batu Belah, and Temburun—were selected using purposive sampling to represent varying mangrove structures and levels of anthropogenic pressure, following the methodologies of **Sulistiyowati *et al*. (2025)** and **Syah *et al*. (2024)**. The sampling sites were chosen based on several factors, including proximity to tourist areas and distance from residential zones **(Ilham *et al*., 2018)**, as well as locations near moderately populated residential areas to assess ecological conditions, vegetation density, and site accessibility **(Tran *et al*., 2022; Winarso *et al*., 2023)**. A detailed breakdown of the site characteristics is provided in Table (1).

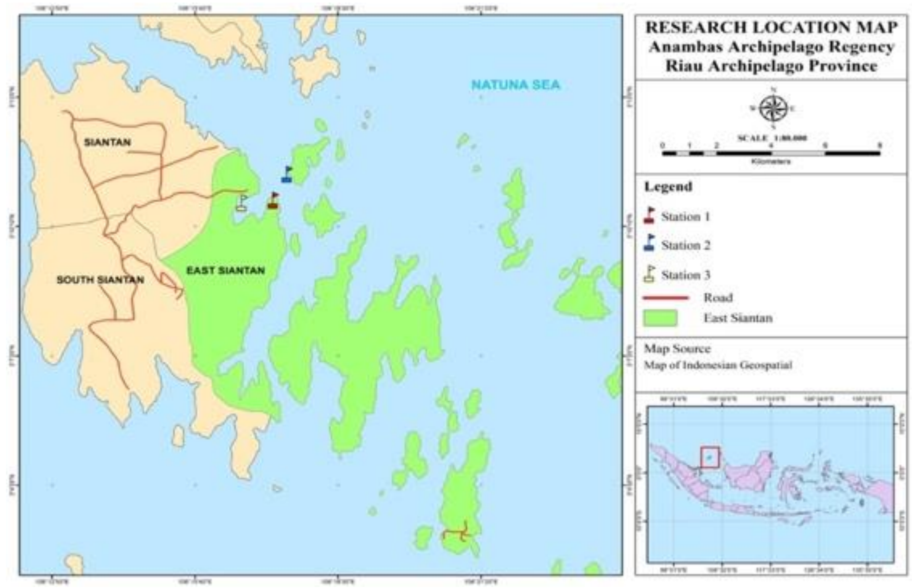


Fig. 1. Map of research location

Table 1. Characteristics of data collection site

Station	Location	Coordinates	Characteristics
I	Tanjung Kumbik, TemburunVillage	3° 10' 49.57" N 106° 16' 38.60" E	Area close to tourist areas and far from populated areas
II	Desa Batu, Belah Village	3° 10' 45.18" N 106° 17' 14.91" E	Area close to populated areas
III	Temburun, Temburun Village	3° 11' 18.97” N 106° 17' 29.94" E	Area close to tourist areas and populated areas

Tools and materials

Station sampling was recorded using a handheld GPS device (Garmin GPSMAP 64s), which offers high accuracy for field-based location mapping. Roll meters and raffia ropes were used for marking transects, while stakes and fabric rulers were employed to delineate quadrants. For documentation, a digital camera and a DJI Mavic Pro drone were utilized—both proven effective for canopy cover surveys and spatial monitoring of mangrove vegetation **(Aye *et al*., 2022)**. Environmental parameter measurements were conducted using a Water Quality Checker (WQC), a soil tester, and a refractometer, as applied in coastal studies by **(Hariyanto *et al*., 2019)**. These tools have demonstrated high precision in field studies conducted in tropical ecosystems. The biological materials observed included mangrove vegetation, water samples, sediment substrates, and associated biota within the ecosystem, following the multi-parameter approach outlined by **Hochkirch *et al*. (2021)**.

Data collection

The study utilized primary data, including mangrove structure, biota, and environmental parameters (temperature, pH, salinity, and substrate), which were collected in the field three times daily throughout the week. This followed a temporal-spatial protocol based on previous ecological studies, as well as the measurement approaches applied in studies by **(Li *et al*., 2021; Norte *et al*., 2024)**. Secondary data comprised tidal records from the iPASOET BIG station (September 2023), analyzed using the Admiralty method **(Zu Ermgassen *et al*., 2020)**. Additional sources included base maps, drone imagery, previous research, and coastline profiles to support site validation and ecosystem assessment in East Siantan, Anambas Archipelago. This approach followed the methodology described by **Winarso *et al*. (2023)**.

Mangrove vegetation

Mangrove vegetation observations were conducted using the quadrant transect method, installed perpendicular to the coastline and extending inland. Each transect included a 10×10m plot for trees, a 5×5m plot for stumps, and a 2×2m plot for seedlings. This multi-level quadrant method aligns with standards for observing vegetation communities in mangrove ecosystems, as outlined by **Mulya *et al*. (2021)** and **Tran *et al*. (2022)**. Transects were spaced 50 meters apart, and within each plot, data were recorded on species type, number of individuals, and diameter at breast height (DBH). This method has been shown to accurately describe species dominance and the vertical structure of mangrove forests **(Ilham *et al*., 2018; Norte *et al*., 2024)**. For species that could not be immediately identified, plant parts were collected and matched with field taxonomy guides, as commonly practiced in previous research study **(Syah *et al*., 2024)**.

Associated biota

The associated biota observed included benthic fauna, crustaceans, and other epifaunal organisms. Observations were made using direct visual census within 2×2m plots at each station, focusing on biota found around mangrove roots or adhered to the substrate. Visual census methods have proven effective in assessing mangrove fauna diversity in tropical regions **(Zu Ermgassen *et al*., 2020; Aye *et al*., 2022)**. Initial identification was based on external morphology, supported by field guides and scientific literature. For unidentified species, photographs and samples were taken following the procedures recommended by **Norte *et al*. (2024)** and **Sulistiyowati *et al*. (2025)**. Each species matched its morphological characteristics using available references, while unknown specimens were documented for further identification.

Environmental parameters

Environmental parameters measured included temperature, salinity, water pH, soil pH, tidal range, and substrate composition. The detailed measurement schedule is presented in Table (2). Temperature, salinity, and pH were measured *in situ* three times a week (morning, afternoon, and evening) using a Water Quality Checker (WQC) and a soil tester, following methods used in previous coastal studies **(Hariyanto *et al*., 2019; Aye *et al*., 2022)**. Tidal data were sourced from 30 days of real-time observations at Tarempa Station by iPASOET BIG in September 2023, with 60-minute intervals, and analyzed using the Admiralty method as described by **Zu Ermgassen *et al*. (2020)** and **Li *et al*. (2021)**.

Substrate samples were collected by digging to a depth of 10– 15cm using a small shovel, gathering approximately 1000 grams per sample. These were stored in labeled ziplock plastic bags for visual analysis. Substrate types were classified as sandy mud (LP), muddy sand (PL), and hard/rocky sand (PK), following the categories established by **Dharmawan *et al*. (2020)**. This classification method has been validated as a practical approach for habitat-based mangrove structure studies **(Tran *et al*., 2022)**.

Table 2. Measurement of mangrove environmental parameters in East Siantan District

No.	Environmental Parameter	Unit	Sampling Time			Repeat sampling
			Morning	Afternoon	Evening	
1.	Temperature	˚C	√	√	√	3 times a week
2.	Salinity	‰	√	√	√	3 times a week
3.	Water pH	-	√	√	√	3 times a week
4.	Soil pH	-	√	√	√	3 times a week
5.	Tide	-	-	-	-	Every hour for 30 days
6.	Substrate	-	-	-	-	1 time per station

Mangrove community structure

a. Species density

Species density was used to calculate the number of individuals of a species in a given unit area. This parameter provides an overview of how densely a species grows in a mangrove community. The calculation formula is Di = Ni/A, where: "Di" is the density of species-i (individuals per hectare), "Ni" is the number of individuals of species i, and "A" is the total area of the sample plot (m^2). This concept was first developed in quantitative ecology by **Phillips *et al.* (1969)** and has been widely applied in tropical vegetation studies, as described by **Krebs (1999)**, and further explored in the study of **Agustini *et al*. (2016)**.

b. Relative density

Relative density (RDi) indicates the proportion of individuals of a species to all individuals of all species in a community, calculated using the formula: RDi = (Ni/∑n) x 100%. Where, RDi is relative density; ni is the total number of individuals of species i, and ∑n is the total number of individuals of all species. Relative density is significant in assessing the quantitative contribution of each species. This approach is the basis for community structure analysis used in tropical coastal vegetation **(Krebs, 1999; Brouwer *et al*., 2009)**.

c. Frequency of species

The frequency of a species (Fi) is the probability or chance of finding that species in several sample plots, calculated using the formula: Fi = Pi/∑p. Where Pi is the number of plots in which species-i is found, and ∑P is the total number of plots observed. The concept of frequency is used to indicate the spatial distribution of species in a community and was adopted from the methodology of **Mueller-Dombois and Ellenberg (1974)**.

d. Relative frequency

Relative frequency (RFi) indicates the relative contribution of a species based on its occurrence frequency, calculated using: RFi = (Fi/∑f) x 100%. Where, Rfi is the relative frequency of species, Fi is the frequency of species-i, and ∑F is the total number of plots. This formula is commonly used in combination with density and dominance to determine the importance value index **(Curtis & Mcintosh, 1951; Krebs, 1999)**.

e. Canopy cover

Canopy cover (Ci) describes the proportion of land area covered by the canopy projection of a species. It is calculated using the formula: Ci = (∑BA/A), where Ci represents canopy cover. Meanwhile, the analysis of ∑BA = $\pi d^2/4$, where d is the diameter at breast height, and A is the Total area of the sampling plot (m^2). This method aligns with the ecological measurement standards of **Ludwig *et al*. (2007)** and **Brouwer *et al.* (2009)**.

f. Relative cover

Relative cover (RCi) is the percentage contribution of the cover area of a species compared to the total cover of all species, calculated as: RCi = (Ci/∑C) x 100%. Where, RCi is relative cover, Ci is the cover of species-i, and C is the total cover for all species. This analysis is often combined in vegetation structure studies to assess species dominance **(Mueller-Dombois & Ellenberg, 1974)**.

g. Importance value index

The importnace value index (INP) is used to indicate the relative dominance of a species in a vegetation community by summing the RDi, RFi, and RCi values: a) For the tree category, the formula is: INP = RDi + RFi + RCi, while b) For the seedling and sapling categories, the formula is: INP = RDi + RFi. Where, INP is the Importance Value Index, RDi is Relative Density, RFi is Relative Frequency, and RCi is Relative Cover. This concept originates from the classic vegetation study by **Curtis and Mcintosh (1951)** and has been widely applied in mangrove ecology studies **(Agustini *et al*., 2016)**.

Mangrove biological indices

a. Diversity index (H')

This index quantifies biodiversity by considering both the number of species and their distribution. Using a mathematical formula: H' = (-∑C(ni/n) x Ln (ni/n)), it calculates how diverse a community is. Developed in 1949, it remains a key tool in ecological studies, especially for tropical forests **(Udwig *et al*., 2007; Supriadi *et al*., 2018)**.

b. Evenness index (E)

The evenness index (E) measures the extent to which individuals are evenly distributed among species. It is calculated as: E = (H'/H'max), whereas the analysis is H'max = Ln s. Where, E is the evenness index; H' is the diversity index; H'max is the maximum diversity index; "s" is the number of species. This index provides an overview of the balance of individual distribution in a community **(Ludwig & Reynolds, 1988)**.

c. Dominance index (D)

This index quantifies biodiversity by considering both the number of species and their individual distribution. Using a mathematical formula, it calculates the diversity of a community developed in 1949, as cited in **Okpiliya (2012)**. It remains a key tool in ecological studies, especially for tropical forests **(Ludwig & Reynolds, 1988; Supriadi *et al*., 2018)**.

RESULTS AND DISCUSSION

Mangrove species identification

Nine mangrove species from four families were identified in East Siantan Subdistrict. These include:

- **Family Rhizophoraceae**: *Rhizophora stylosa*, *Rhizophora mucronata*, *Rhizophora apiculata*, *Bruguiera gymnorrhiza*, *Bruguiera cylindrica*, and *Ceriops tagal*
- **Family Sonneratiaceae**: *Sonneratia alba*
- **Family Myrsinaceae**: *Aegiceras floridum*
- **Family Meliaceae**: *Xylocarpus granatum*

The most frequently encountered tree species was *Rhizophora apiculata*, while *Rhizophora stylosa* dominated the stump and seedling categories. The least commonly observed species were *Aegiceras floridum* (tree and stump categories) and *Sonneratia alba* (seedling category).

Astronomically, the Anambas Archipelago lies between 2°10'0.02"–3°40'0.19" N and 105°15'0.03"–106°45'0.24" E **(Apriliani *et al*., 2023)**. East Siantan Subdistrict forms part of the Anambas Archipelago and Surrounding Sea Conservation Area, which has contributed to the relatively well-preserved condition of its mangrove forests. These are natural mangroves growing in intertidal zones with substrates ranging from muddy sand to sandy mud—an ideal habitat according to the ASEAN mangrove management strategy **(ASEAN, 2024)**, which notes that mangrove root systems thrive in mud or sandy mud substrates.

However, indications of exploitation have been observed, including forest clearing for residential expansion and the use of mangroves as firewood. The dominance of *Rhizophora apiculata* and *Rhizophora stylosa* reflects favorable environmental conditions and substrate types at the study sites. *Rhizophora apiculata* prefers muddy areas regularly flooded by tides **(Onrizal *et al*., 1970)**, while *Rhizophora stylosa* thrives in sandier substrates and areas with coral fragments along coastlines **(Jalaludin *et al*., 2020)**. In contrast, *Aegiceras floridum* and *Sonneratia alba* are less common due to limited adaptive capacity. Variations in adaptive ability contribute to differences in forest composition and species distribution **(Mughofar *et al*., 2018)**.

Mangrove species density

Mangrove species density refers to the number of individuals per species within a defined area **(Masruroh & Insafitri, 2020)**. According to Ministerial Decree No. 51 of 2004, mangrove density is classified as:

- Dense: ≥ 1,500 individuals/ha
- Moderate: 1,000–1,500 individuals/ha
- Sparse: < 1,000 individuals/ha

All three stations were classified as dense, with Station 3 recording the highest density (2,890 ind/ha), and Station 2 the lowest (2,482 ind/ha).

Tree level

- *Rhizophora mucronata*: 1,407 ind/ha (Station 1)
- *Rhizophora stylosa*: 1,152 ind/ha (Station 2)
- *Rhizophora apiculata*: 1,559 ind/ha (Station 3)

Sapling level

- *Rhizophora mucronata*: 659 ind/ha (Station 1)
- *Rhizophora stylosa*: 786 ind/ha (Station 2)
- *Rhizophora apiculata*: 527 ind/ha (Station 3)

Seedling level

- *Rhizophora stylosa*: 4,286 ind/ha (Station 1); 6,029 ind/ha (Station 2)
- *Rhizophora apiculata*: 4,329 ind/ha (Station 3)

Lowest densities were observed in *Ceriops tagal* (tree and sapling levels, Station 1), *Aegiceras floridum* (Stations 2 and 3), and at the seedling level: *Rhizophora apiculata* (Station 1), *Sonneratia alba* (Station 2), and *Rhizophora stylosa* (Station 3).

The dominance of *Rhizophora* spp.—*R. mucronata*, *R. stylosa*, and *R. apiculata*—across all stations indicates their adaptability to muddy and sandy substrates. **(Jalaludin *et al*., 2020)** notes that:

- *R. mucronata* thrives in muddy, soft soil
- *R. stylosa* prefers sandy or coral-fragmented coastlines

- *R. apiculata* grows best in transitional zones

High densities of seedlings and saplings suggest strong regeneration, an indicator of a healthy mangrove ecosystem. In contrast, low densities of *Ceriops tagal* and *Aegiceras floridum* reflect environmental limitations and anthropogenic impacts such as land conversion, logging, and pollution **(Wiarta *et al*., 2025)**. Key environmental factors influencing mangrove density include soil type, salinity, and temperature **(Kusmana, 2011)**.

Species frequency of mangroves

Species frequency refers to the occurrence rate of a species across sample plots **(Manan *et al*., 2025)**. The results are as follows:

Tree level

- Highest: *Rhizophora apiculata* – 0.98
- Lowest: *Aegiceras floridum*, *Bruguiera gymnorrhiza* – 0.10

Sapling level

- Highest: *Rhizophora apiculata* – 0.61
- Lowest: *Aegiceras floridum* – 0.02

Seedling level

- Highest: *Rhizophora stylosa* – 0.59 (Station 2)
- Lowest: *Rhizophora stylosa* – 0.02 (Station 3)

The high frequency of *R. apiculata* and *R. stylosa* across all stations shows these species are broadly distributed, while low frequencies of *Aegiceras floridum* and *B. gymnorrhiza* indicate limited distribution. As **Mangindaan *et al*. (2012)** suggestd, species frequency correlates directly with the number of plots in which the species is found. This pattern reflects the species' ability to establish across different microhabitats, as supported by **Tidore *et al*. (2021)**.

Mangrove species cover

Species cover refers to the percentage of ground area occupied by a species **(Lestaru *et al*., 2018)**. Coverage results per station are:

- **Station 1**: *Rhizophora mucronata* (55%) – highest; *Ceriops tagal* (4%) – lowest
- **Station 2**: *Rhizophora stylosa* (32%) – highest; *Aegiceras floridum* (4%) – lowest
- **Station 3**: *Rhizophora apiculata* (46%) – highest; *Aegiceras floridum* and *Bruguiera gymnorrhiza* (1%) – lowest

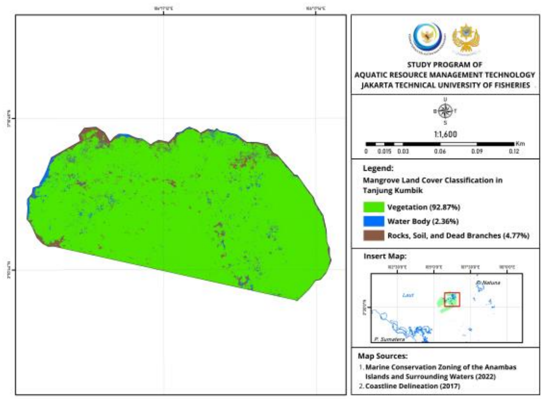
Coverage differences are influenced by species adaptability, tree diameter, and stand density. Larger tree diameters lead to higher coverage values **(Akbar *et al*., 2015)**, while smaller diameters reduce species cover **(Pohos *et al*., 2021)**. Thus, *Rhizophora* species have higher coverage due to their larger trunk sizes and population abundance.

Mangrove land cover

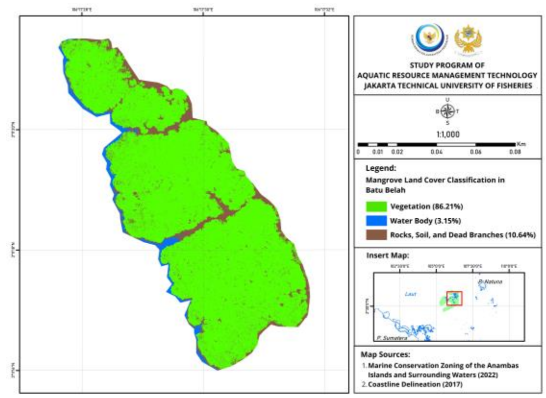
Land cover refers to surface features on Earth such as vegetation, water, rocks, and soil **(Sirait *et al*., 2015)**. Based on image classification:

- **Station 3**: Highest land cover (94.25%)
- **Station 2**: Lowest land cover (86.21%)
- **Tanjung Kumbik**: 92.87% vegetation, 2.36% water bodies, 4.77% open areas (soil, rocks, debris)

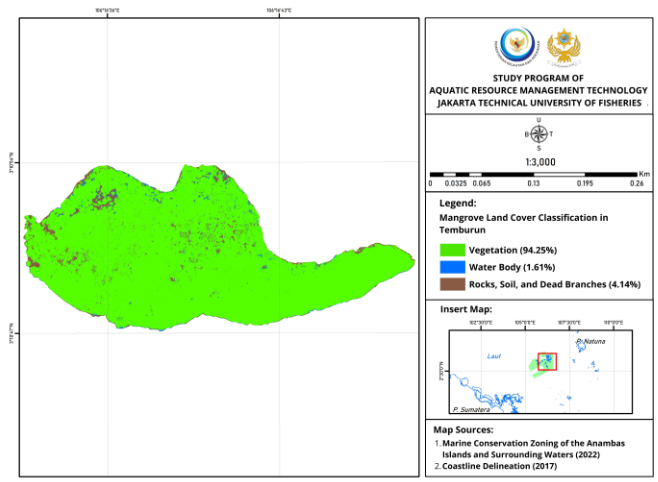
The high vegetation cover in Tanjung Kumbik indicates robust ecological function, serving as carbon sinks, erosion buffers, and habitats **(Donato *et al*., 2011; Alongi, 2014)**. However, open areas suggest localized degradation, possibly from human activities or natural influences like tides **(Friess *et al*., 2016)**. This supports findings that mangrove coverage is highest where human impact is minimal and oceanographic conditions are stable **(Kathiresan & Bingham, 2001)**. As such, continued conservation and monitoring are essential for ecosystem sustainability.



(a) Station 1 at Tanjung Kumbik area



(b) Station 2 at Batu Belah area



(c) Station 3 at Temburuk area

Fig. 2. Mangrove land cover at each research station

Mangrove vegetation cover in Batu Belah reached 95.21%, indicating excellent ecosystem conditions. Only 0.73% of the area is covered by water bodies, while 4.06%

comprises open areas such as rocks, bare soil, or dead branches (Fig. 2b). This high vegetation percentage reflects low anthropogenic pressure and a well-preserved ecosystem. Recent studies have shown that mangrove coverage exceeding 90% is positively correlated with substrate stability, carbon sequestration potential, and low ecosystem vulnerability, due to the high adaptive capacity of mangrove vegetation **(Analuddin *et al*., 2024)**. Therefore, the continued protection and strengthening of local conservation policies are crucial to ensure the mangrove ecosystem continues to provide optimal environmental services.

Similarly, the vegetation cover map for Temburun indicates a mangrove cover of 94.25%, suggesting stable ecosystem conditions. Water bodies account for 1.40%, while 4.14% of the area consists of exposed rocks, soil, and dead organic matter (Fig. 2c). This high vegetation percentage reflects low anthropogenic disturbance and supports critical ecological functions such as coastal protection and carbon sequestration **(Blankespoor *et al*., 2016)**. Studies further emphasize that areas with more than 90% mangrove coverage tend to exhibit higher ecosystem resilience and lower erosion rates **(Sinsin, 2021)**. Thus, sustainable conservation strategies and regular monitoring of land surface cover are vital for the long-term health of the Temburun mangrove ecosystem.

These findings indicate a strong relationship between mangrove land cover and the actual density or thickness of mangrove stands. In general, higher land cover corresponds to denser vegetation, while lower land cover indicates sparser mangrove populations **(Pamungkas *et al*., 2023)**.

Importance value index (INP)

To assess the ecological importance of mangrove species and their role within the East Siantan Subdistrict ecosystem, Importance Value Index (INP) calculations were conducted at the three observation stations. The results of these calculations are presented in Table (3).

Table 3. Mangrove importance index values for Siantan Timur Subdistrict

Station	Species (with Author Citation)	RDi	FRi	RCi	INP	Total
I	*Rhizophora stylosa* Griff., 1836	37.53	36.84	34.59	108.87	300
	Rhizophora mucronata Poiret, 1804	51.71	36.84	54.68	143.23	
	Rhizophora apiculata Blume, 1827	7.74	15.79	7.07	30.60	
	Ceriops tagal (Perr.) C.B. Rob., 1908	3.02	10.53	3.75	17.30	
II	*Sonneratia alba* Sm., 1816	3.79	11.54	7.42	22.75	300
	Aegiceras floridum Roem. & Schul., 1819	1.66	7.69	4.33	13.68	
	Rhizophora stylosa Griff., 1836	46.45	26.92	31.97	105.34	
	Rhizophora mucronata Poiret, 1804	23.93	19.23	19.27	62.43	
	Rhizophora apiculata Blume, 1827	10.19	11.54	6.90	28.63	
	Bruguiera gymnorhiza (L.) Savigny, 1798	13.98	23.08	30.11	67.17	
II	*Sonneratia alba* Sm., 1816	5.88	10.53	11.60	28.01	300
	Aegiceras floridum Roem. & Schul., 1819	0.69	2.63	0.72	4.05	
	Rhizophora stylosa Griff., 1836	4.93	7.24	3.72	15.89	
	Rhizophora mucronata Poiret, 1804	10.03	13.82	9.09	32.94	
	Rhizophora apiculata Blume, 1827	55.28	26.32	46.10	127.70	
	Bruguiera gymnorhiza (L.) Savigny, 1798	1.47	2.63	1.56	5.66	

Station	Species (with Author Citation)	RDi	FRi	RCi	INP	Total
	Bruguiera cylindrica (L.) Blume, 1827	1.56	4.61	2.22	8.39	
	Ceriops tagal (Perr.) C.B. Rob., 1908	8.39	14.47	9.59	32.46	
	Xylocarpus granatum J.Koenig, 1784	11.76	17.76	15.40	44.92	

The importance value index (INP) is calculated by summing the relative density, relative cover, and relative frequency of each mangrove species. Based on the analysis from each observation station in East Siantan Subdistrict, the highest INP values were:

- *Rhizophora mucronata* at Station 1: 143.23
- *Rhizophora stylosa* at Station 2: 105.34
- *Rhizophora apiculata* at Station 3: 127.70

These results clearly indicate that species from the *Rhizophora* genus play a dominant ecological role in the mangrove community across all sites. Mangrove ecosystems contribute significantly to biodiversity and ecosystem function. Their litter and tree structures provide essential shelter, feeding grounds, and breeding areas for a wide range of organisms such as crabs, fish, shrimp, and molluscs **(Halimatusa'diyah *et al*., 2022)**. These functions are crucial to the overall sustainability of the surrounding ecosystem **(Juwita *et al*., 2015)**.

Differences in the INP values among species are largely due to interspecies competition for nutrients and sunlight in each habitat **(Rombe *et al*., 2021)**. According to **Agustini *et al*. (2016)**, dominant species in a plant community will naturally exhibit higher importance values. This dominance is reflected in the relative density, frequency, and coverage of the species at each station.

Biological index

The biological index of mangrove communities consists of three main components: diversity, evenness, and dominance indices. These are used to assess community structure and ecosystem stability.

Diversity index (H')

The diversity index values (H') across the three stations ranged between 1.01 and 1.49. According to criteria established by **Odum (1971)**, if $1 \leq H' \leq 3$, the diversity is considered moderate—indicating a balanced distribution of species and moderate community stability. Thus, all three stations fall into this moderate category, suggesting reasonably stable and well-distributed mangrove communities.

Evenness Index (E)

Evenness index values ranged from **0.68 to 0.78**:

- **Stations 1 and 2**: High evenness, indicating stable ecosystems
- **Station 3**: Moderate evenness, suggesting potential ecological imbalance

A lower evenness index reflects greater differences in species abundance (i.e., potential species dominance), while a higher evenness index reflects a more uniform distribution, with no species overwhelmingly dominating.

Dominance index (C)

The Simpson dominance index values across the stations ranged from 0.30 to 0.42. Based on the Simpson criteria, if 0 < C ≤ 0.5, the dominance level is low. This indicates minimal ecological pressure and stable environmental conditions. According to **Syahrial and Sastriawan (2018)**, low dominance values suggest that mangrove species are competing evenly for resources such as space and sunlight, indicating broad adaptability and an even distribution within the community.

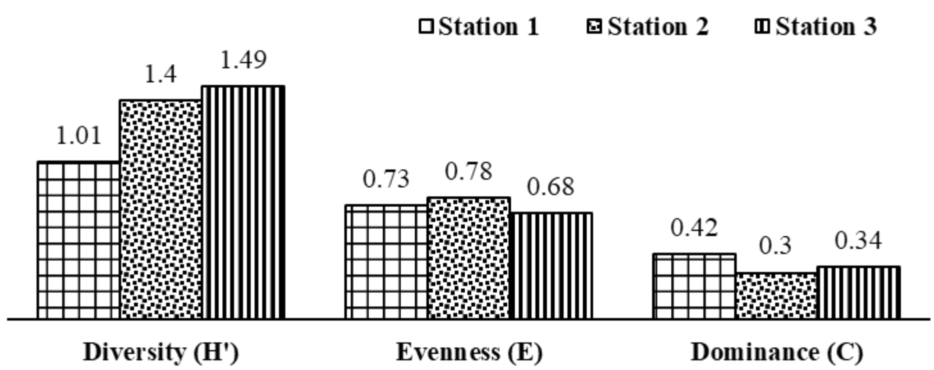


Fig. 3. Mangrove biological index in East Siantan subdistrict

Associated biota

The associated biota found directly in the mangrove ecosystem is extremely diverse, both for settlement and for feeding and temporary stays. Based on field observations at stations 1, 2, and 3, there are 12 species of biota associated with mangroves, including *Cerithidea cingulata, Littoraria scabra, Littoraria angulifera, Littoraria aberrans, Micrelenchus purpureus, Nerita* sp., *Volegalea cochlidium, Isognomon ephippium, Periophthalmus* sp., *Moolgarda seheli, Ilyoplax* sp., and *Argiope aurantia*. The most commonly found biota composition is the phylum Mollusca. This indicates that the biota of the phylum Mollusca is well-suited to the habitat. Nearly 60% of all mollusc species can live in waters with high salinity levels **(Mudjiono, 2009; Reece & Moran, 2015)**.

Aquatic environment

Based on the results of environmental parameter measurements in East Siantan District, several environmental factors that affect mangrove growth are listed in Table (4). The measurement results show that the aquatic conditions in the mangrove ecosystems at the three stations are still classified as good and still comply with the established quality standards (Minister's Decision of the State for Environment No. 51, 2004) with measurement results showing temperatures ranging from 29 to 30°C, salinity ranging from 25 to 33ppt, water pH values ranging from 7.7 to 8.1, and soil pH values ranging from 6.2 to 6.5, with substrates consisting of sandy mud and muddy sand. Additionally, a tidal type analysis was conducted, with the results indicating a single daily tidal type, characterised by a Formzahl value of 3.839. A single daily tidal type is a tidal type that occurs only once, during both high tide and low tide **(Pasomba *et al*., 2019)**.

Table 4. Environmental parameters of mangroves in East Siantan District

No.	Parameter	Station			Water Quality Standards*
		I	II	II	
1.	Air temperature (˚C)	30	29	29	-
2.	Waters temperature (˚C)	29	29	28	28-32
3.	Salinity	33	31	25	s/d 34
4.	Waters pH	8.1	7.9	7.7	7-8.5
5.	Land pH	6.5	6.4	6.2	6-7
6.	Substrate	Muddy sand	Muddy sand	Muddy sand	-

Note: * Minister Decision of the Environment of the Republic of Indonesia No. 51 of 2004

Mangrove management efforts in the Anambas Archipelago Marine Park

The management of mangrove ecosystems in the Anambas Archipelago, particularly in East Siantan District—which forms part of the Anambas Archipelago and Surrounding Sea Marine Tourism Park (Taman Wisata Perairan, *TWP*)—is governed by Ministerial Decree No. 53/KEPMEN-KP/2014 of the Ministry of Marine Affairs and Fisheries of the Republic of Indonesia. This decree serves as the principal reference for planning marine conservation area management and zoning from 2014 to 2034. Within this policy framework, mangrove ecosystems are designated as one of the three priority tropical marine ecosystems for management, alongside coral reefs and seagrass beds. Mangroves are recognized for their critical ecological functions, including coastal protection from erosion, biodiversity support, and fisheries productivity **(MMAF, 2014)**.

According to the decree, the resource management strategy in the Anambas TWP is implemented through eight core programmes:

1. Protection of ecosystems and associated biota
2. Rehabilitation of ecosystems and biota
3. Research and development
4. Sustainable use of resources
5. Development of a monitoring system
6. Coordination of monitoring across institutions
7. Strengthening of public awareness
8. Implementation of monitoring and evaluation based on management success indicators **(MMAF, 2014)**

This strategy is aligned with the Ecosystem-Based Management (EBM) approach, which is widely promoted in Indonesia for sustainable marine and coastal resource management **(Yulma *et al*., 2025)**.

Emphasizing mangrove ecosystem rehabilitation and protection is particularly relevant, given that many mangrove areas across Indonesia—including in Anambas—have been degraded due to aquaculture expansion and land conversion. A successful case study of conservation area management is seen in the Pangandaran coastal area, where a combination of ecological restoration, integrated spatial planning, and active community participation has significantly improved mangrove sustainability **(Zallesa *et al*., 2025)**. Following post-tsunami rehabilitation efforts in 2006, community-based ecotourism and environmental education initiatives increased local ecological awareness while enhancing the area's economic value. This approach has helped integrate mangrove protection into spatial planning and encouraged public involvement in ecosystem monitoring and maintenance **(Thirafi *et al*., 2024)**.

Community-based participatory approaches also play a vital role in effective policy implementation. In Tumbak Village, Sulawesi, a locally driven conservation model demonstrates how mangrove protection can be synergized with income generation. Initiatives such as mangrove planting programs, the formation of community monitoring groups (*Kelompok Masyarakat Pengawas*, or POKMASWAS), and the development of conservation-based ecotourism have not only increased mangrove coverage but also improved community income and ecological literacy **(Hulopi *et al*., 2025)**.

Effective mangrove management in the Anambas Archipelago Marine Park exemplifies collaborative governance, combining formal government regulations with adaptive local mechanisms. These include community participation, institutional strengthening, and the integration of traditional knowledge. According to **Hulopi *et al*. (2025)**, synergy between national policies and local actors—facilitated through collaborative forums and local legal instruments—enhances the effectiveness of mangrove habitat protection. Furthermore, the bioactive potential of *Avicennia marina*, as identified by **Mulia *et al*. (2025)**, underscores the strategic ecological and economic value of mangroves in providing natural solutions for aquaculture, particularly fish disease management.

From an institutional perspective, **Ariyanto *et al*. (2020)** emphasized the crucial role of social and customary structures in supporting successful mangrove conservation in Eastern Indonesia. These structures have contributed to reducing land conversion and maintaining vegetative cover. Therefore, a multidimensional approach that integrates scientific knowledge, policy frameworks, and local social capacity forms the essential foundation for sustaining mangrove ecosystems. Such an approach also enhances the long-term socio-economic resilience of coastal communities.

CONCLUSION

Mangrove composition in East Siantan Subdistrict comprises nine species from four families. The most dominant species is *Rhizophora apiculata*, while the least represented is *Aegiceras floridum*. The relatively high mangrove vegetation density across the three observation stations indicates a healthy and functioning ecosystem. The biota associated with the mangrove habitat is dominated by the phylum Mollusca, reflecting a strong ecological relationship between vegetation structure and coastal fauna communities. Water quality at all stations falls within the good category and meets the environmental quality standards outlined in Minister of Environment Decision No. 51 of 2004. The mangrove ecosystem in this region is further supported by a stable single daily tidal type, which sustains ecological cycles and promotes primary productivity.

The management of mangrove areas in this region is regulated by the Minister of Marine Affairs and Fisheries (MMAF) Decision No. 53 of 2014, concerning the Management Plan and Zoning of the Anambas Archipelago and Surrounding Sea Water Tourism Park (*Taman Wisata Perairan*, TWP) for 2014–2034. However, to ensure long-term sustainability, mangrove management must be directed in a more adaptive and collaborative manner. This includes the active involvement of local communities, institutional strengthening, regular monitoring, and effective control of extractive activities. An ecosystem-based approach, coupled with participatory governance, is key to maintaining the ecological, social, and economic functions of mangrove ecosystems sustainably, especially in small island areas such as East Siantan.

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