Structure and Composition of Mangrove Vegetation on Kelasa Island: Dominance of *Rhizophora apiculata* and Its Implications for Coastal Ecosystem Sustainability

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Abstract. Mangroves provide essential ecosystem services such as capturing carbon, habitat provision, and shoreline protection, making them essential for coastal sustainability.Understanding their structure and composition is essential for fostering conservation efforts and ensuring long-term resilience. This study investigates the mangrove vegetation on Kelasa Island, revealing key ecological trends relevant for future management. Using transect line and plot sampling across nine 0.09 ha plots, 117 mangrove individuals were identified, predominantly *Rhizophora apiculata* and *Rhizophora mucronata*. Density varied by growth stage, with mature trees averaging 87 individuals/ha, saplings 17 individuals/ha, and seedlings 13 individuals/ha. Despite lower species diversity compared to nearby islands in the Bangka Belitung Province, Kelasa Island exhibits higher seedling density. The mangrove community is largely dominated by *R. apiculata*, indicating a trend towards monospecific dominance with robust regeneration. The forest spans approximately 2.57 ha on the island's eastern coastline, characterized by sandy coral fronts and muddy-rocky substrates. Though relatively young and sparsely distributed, the mangrove stands show ecological stability, demonstrated by high dominance indices and uniformity across growth stages. These findings underscore the critical role of *R. apiculata* in maintaining ecological balance within the Kelasa Island mangrove ecosystem under moderate environmental pressures. The study highlights the importance of conserving these mangrove communities for their resilience, coastal protection, and biodiversity contributions.
Key words: *Mangrove, Rhizopora apiculate, Dominance*

1 Introduction

Mangrove habitats offer a multitude of ecosystem services, making them essential parts of coastal environments such as shoreline stabilization, habitat provision for various species, and significant carbon sequestration capabilities [3]. These services are critical for sustaining biodiversity and promoting long-term ecological balance in coastal areas [13]. Additionally, mangroves act as natural barriers that shield coastlines from erosion and severe weather and contribute to the livelihood of coastal communities [14]. However, increasing anthropogenic pressures, including coastal development, pollution, and unsustainable resource extraction, have led to the degradation of many mangrove habitats worldwide [9].

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Indonesia, as home to one of the greatest amount of mangrove forests globally, plays a pivotal role in global mangrove conservation efforts [10]. The Bangka Belitung Islands, part of this national mangrove landscape, face growing environmental challenges. While studies on mangrove structure and diversity have been conducted in several parts of Indonesia [22], research on specific islands such as Kelasa remains limited. Understanding the structure, composition, and ecological dominance of mangrove species like *Rhizophora apiculata* on these islands is crucial for informed conservation and management strategies, especially in regions experiencing environmental pressures.

This paper aims to fill this research gap by investigating the composition and organization of Kelasa Island's mangrove vegetation, emphasizing *Rhizophora apiculata's* dominance. The study's findings provide insights into the implications of this dominance for the sustainability of the coastal ecosystem, emphasizing the importance of targeted conservation efforts to maintain the ecological balance and resilience of these critical habitats.

2 Methods

The mangrove data identified in the field showed that, including species, number of individuals, and tree diameter, further analysis is performed to determine species density, species frequency, area of coverage, and the importance and diversity of species.

2.1.1 Density (Di)

Based on [7] stated that, species density refers to total individuals in 1 species (i) within specificgiven area:

$$Di = \frac{ni}{A} \quad \text{......(1)}$$

where Di $_I$ (density of species i);
n_i referes to total number of individuals of species i (Specific);
The sampling area's whole area, or the sample plot's total area, is denoted by A.

2.1.2 Specific Relative Density (RDi)

As defined by [7], The ratio of the number of stands of species I (ni) to the total number of stands of all species (∑ n) is known as the species relative density:

$$RD_I = (n_i / n) x\ 100 \quad \text{......(2)}$$

where :
RDi : relative density in percentage (%)
ni : number of Species i in total
n : density of all species

2.1.3 Frequency Type (Fi $_i$)

As stated by [7], Frequency Type is the likelihood of finding species I in the sample plots in relation to the total number of plots examined.

$$Fi = \frac{pi}{\sum p} \quad \text{......(3)}$$

Fi: type's frequency i
Pi: how many sample plots contain the i-th kind;

p: how many sample plots were made in total.

2.1.4 Relative Frequency Type (RF $_i$)

According to [7], The ratio of the frequency of species I (Fi) to the total number of frequencies is the relative frequency of species:

$$RFi = \left(\frac{Fi}{\sum F}\right) x100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Relative frequency of type (RFi) Fi is the type's frequency, and F is the type's number of frequencies.

2.1.5 Closure type (C$_i$)

Species closure (Ci) refers to the area occupied by mangrove species i in a unit area [7]

$$ci = \frac{\sum BA}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Ci: Dominance or closure of a species (dbh = trunk diameter at chest height, = 3.1416)
BA: dbh 2 /4
A: the entire sampling area

density category is determined based on the interpretation of satellite imagery and field surveys. The classification of mangroves is as follows:

Table 1. Classification of mangrove density KEP MEN LH 201/2004

Mangrove Density Classification	Density (field survey) (Trees/Hectare)
High	>=1500
Moderate	>=1000 - <1500
Low	<1000

2.1.6 Relative Closure Type (RC $_i$)

[7] defines relative closure type or species dominance (Ci represents the comparison between the total number of individuals of species I (Ci) and the total dominance of all individuals (∑C), or the area occupied by species I to the total area of coverage of all species:

$$RCi = \left(\frac{Ci}{\sum C}\right) x100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

RCi: relative closure type
∑Ci: the overall degree of individual dominance

2.1.7 Important Value Index (IVI)

A species' total value to a community is estimated using the Important Value Index (IVI). The range of the index is 0 to 300 (or 300%). The IVI sheds light on a mangrove species' function or impact on the community [7]. The values of Relative Dominance (RCi), Relative Density (RDi), and Relative Frequency (RFi) add up to the IVI. The formula for calculating the IVI is [8]:

IVI = RDi + RFi + RCi ……………………………………………………………(9)

2.1.8 Diversity (H')

The Shannon-Wiener diversity index aims to measure the level of diversity within a community [20]. The formula used is as follows:

$H' = \Sigma (n_i/N) \ln(n_i/N)$……………………………………………………………(10)

H': Shannon-Wiener diversity index
n_i: Number of individuals of the i-th species
N: Total number of individuals in the sampled plot

2.1.9 Dominance Index (D)

Dominance Index is used to determine which species dominate a particular area. The dominance values range from 0 to 1, calculated using the formula:

$D = \Sigma (n_i/N)^2$……………………………………………………………………(11)

D: Simpson's Dominance Index
n_i: Number of individuals of the i-th species
N: Total number of individuals

2.1.10 Evenness (E)

The Evenness Index measures the balance or uniformity of species within a population (Odum, 1993). The formula is given as:

$E = H' / \ln(S)$……………………………………………………………………(12)

E: Evenness Index
H': Shannon-Wiener diversity index
S: Total number of species

3 Rsults and Discussion

3.1 Kelasa Island's Mangrove Vegetation Structure and Composition

The line transect and plot approach was used to observe the mangrove vegetation. Data was gathered from nine sampling plots, each measuring 10 m by 10 m (0.09 hectare), for the tree and sapling categories. In the meantime, the seedling category within the same plot area employed a lower transect size of 1 m x 1 m. A total of 117 true mangrove species from the family Rhizophoraceae were recorded, including *Rhizophora apiculata* Blume and *Rhizophora mucronata* Lam. The number of individual mangroves at different growth stages varied, with approximately 87/0.09 ind/ha for the tree category, 17/0.09 ind/ha in sapling, and 13/0.0009 ind/ha for the seedling. The tree numbers on Kelasa Island is relatively lower compared to studies on other small islands in the Bangka Belitung Archipelago Province, such as Mendanau Island and Batu Dinding Island, and Kelapan Island in South Bangka Regency [1,2].

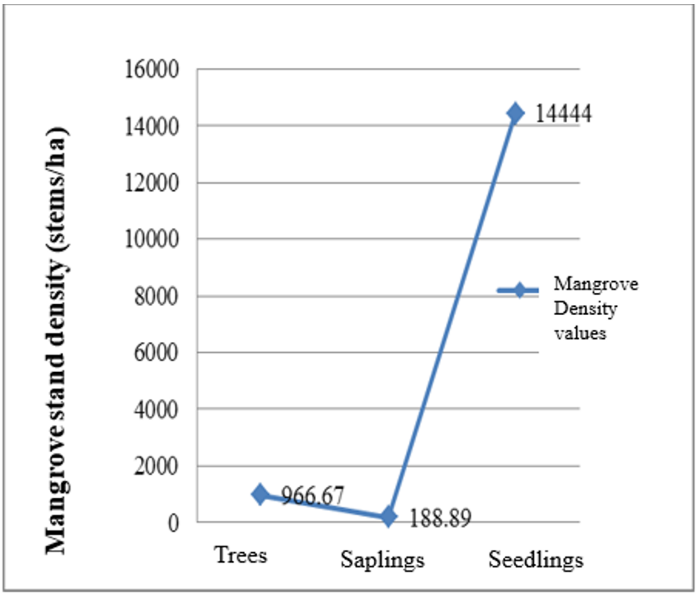

Fig 1. Mangrove Stand Density at Various Growth Stages

Based on the data analysis, the seedling growth stage has a higher mangrove stand density compared to other growth stages. Figure 1 portrays the total mangrove stand density at various growth stages. The seedling category has a density of 14,444 stems/ha, while the sapling growth stage has a density of 188.89 stems/ha, and the tree growth stage has a density of 966.67 stems/ha (Figure 1). The lowest stand density is found in the sapling category, indicating that the mangrove species present in the vegetation community on Kelasa Island are likely those that have successfully survived as seedlings under the canopy of low-cover mangrove trees. These species, primarily Rhizophora apiculata, have successfully competed for nutrients and space with other species. Their presence may result from propagules falling from surrounding parent trees.

The highest mangrove stand density is in the seedling category, with 14,444 stems/ha, suggesting that the mangrove vegetation community shows good regeneration [7]. The decrease in sapling individuals can be linked to the death of some individuals as they mature into the following stage of development, which can forecast the forest's future makeup [23].

From the analysis of individual density across different growth stages, the resulting curve resembles a right-leaning J shape (Figure 1). This condition indicates that species density and the number of species in the Kelasa Island Forest are in a normal/equilibrium state. [21] stated that a normal mangrove forest typically has an inverted J-shaped curve, ensuring the continuity of stands in the future. The mangrove forest on Kelasa Island can be considered to have good regeneration, marked by the high density of individuals in the juvenile stage.

Table 1. Accumulated Results of Mangrove Vegetation Analysis from All Observation Stations on Kelasa Island at Various Growth Stages

GS	Species Name	Di (tree/ha)	RDi (%)	F	RFi (%)	BA (m^2)	Ci	RCi (%)	IVI
Tree	*R. apiculata* Blume.	777.8	80.5	0.89	72.7	4792.5	0.65	67.7	220.9
	R. mucronata Lam.	188.9	19.5	0.33	27.3	2284.1	0.04	32.3	79.1
	Total	966.7	100	1.2	100	7076.6	0.69	100	300
Sapling	*R. apiculata* Blume.	166.67	88.2	0.56	71.4	194.73	0.78	86.9	246.6
	R. mucronata Lam.	22.22	11.8	0.22	28.6	29.36	0.01	13.1	53.4
	Total	188.9	100	0.8	100	224.1	0.79	100	300
Seedling	*R. apiculata* Blume.	14444.4	100	0.56	100	-	1	-	200
	Total	14444.4	100	0.56	100	-	1	-	200

Notes: GS: Growth Stage, BA: Basal Area, D: Density, RDi: Relative Density, F: Frequency, RFi: Relative Frequency, Ci: Dominance, RCi: Relative Dominance, IVI: Importance Value Index (IVI)

The density of mangrove stands that make up the vegetation is related to the number of species present at all growth stages, including seedlings, saplings, and trees. Rhizophora apiculate, when it comes to species with stand densities in trees, R. Apiculata blume has the highest stand density with saplings, and seedlings of 777.8 stems/ha (220.9), 166.67 stems/ha (246.6), and 14,444.4 stems/ha (200), respectively. The Importance Value Index (IVI) also shows that R. apiculata has the highest value compared to Rhizophora mucronata Lam., which is present at all observation points on Kelasa Island. According to Table 1, there is consistency in the dominance of species across all growth stages—trees, saplings, and seedlings—indicating that the mangrove vegetation structure on Kelasa Island is dominated by a single species, R. apiculata, with a tendency toward monospecies dominance.

This species dominance is supported by the vegetation analysis, which shows a high dominance index value approaching 1 (Table 1). When a species dominates an area, the species composition within the mangrove vegetation community tends to be uniform and less varied. There is a tendency for species diversity to decrease as individual density increases across different growth stages, and vice versa. The relative frequency of all tree species was recorded at >70% (Table 1), which is lower than the mangrove forest composition on Batanta Island, Raja Ampat, Papua (<20%) [18]. This very high frequency reflects the high homogeneity. Most tree species grow in almost every observation plot, indicating low variation among sample plots. This also means that the species composition across different plots is low and tends to be uniform. Overall, it can be concluded that the vegetation on Kelasa Island consists of a homogeneous community.

3.2. Overview of Mangrove Vegetation Community Conditions at 3 (Three) Observation Points on Kelasa Island

Kelasa Island is a small island located within the administrative area of Central Bangka Regency. The island is characterized by hilly terrain and rocky outcrops. A small mangrove ecosystem grows on the eastern side of the island, covering an area of approximately 2.57 hectares. The substrate condition consists of sandy coral in the front and muddy with coral rocks at the back. The mangrove growth is homogeneous, dominated by *Rhizophora* species. The island is uninhabited but is used as a temporary resting place by fishermen. The location of mangrove data collection on Kelasa Island is presented in Figure 2 below:

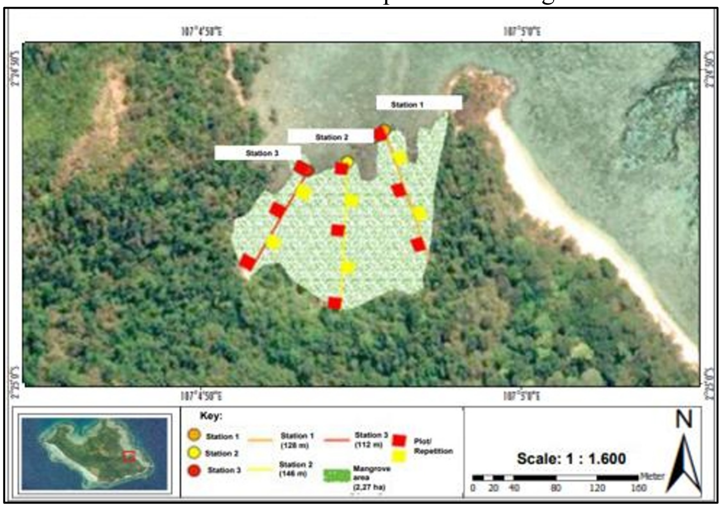

Fig 2. Observation points for mangrove vegetation data collection

Figure 2 shows the observation points taken in Kelasa Island during the research. In the mangrove vegetation community data plots on Kelasa Island, only two mangrove species were found, *Rhizophora apiculata* and *Rhizophora mucronata*, with *Rhizophora apiculata* being the dominant species. Mangroves were only found on the east side of the shore, where substrate was sandy mud. This substrate condition leads to less fertile mangroves compared to those typically found in estuarine or riverine areas.

Based on the average stem diameter, measured at the chest height of an adult (around 1.3 m), the value was relatively low at 15.14 ± 5.72 cm. This is likely why the stands in the mangrove vegetation community on Kelasa Island tend to be somewhat dense and slightly spaced apart, with most trees in the sapling or young tree phase. Overall, the mangrove vegetation condition on Kelasa Island can be classified as natural with a Sparse Mangrove Density (MKJ), and it is not evenly distributed in all four cardinal directions on the island. The unique island morphology is suspected to limit mangrove distribution in this area, as mangroves generally thrive in tidal regions.

Figure 3 shows an overview of the mangrove vegetation community on Kelasa Island's eastern side. As indicated in Table 2, the findings of the study of mangrove data from Kelasa Island's eastern side are based on [16] regarding the Standard Criteria and Guidelines for Determining Mangrove Damage.

Table 2. Mangrove Stand Density for Tree Category on Kelasa Island, Central Bangka

No	Observation Points	Density (Trees/ha)	Density Status	Average % cover	Coverage Status
1	MG01	1000 ± SD=3.00	Good-Moderately Dense	14.85% ± 12.98	Low

2	MG02	1133 ± SD=7.09	Good-Moderately Dense	6.46% ± 1.59	Low
3	MG03	766.67 ± SD=2.52	Damaged – Sparse	11.37% ± 5.46	Low

MG01 : Mangrove Kelasa Observation Point
MG02 : Mangrove Kelasa Observation Point 2
MG03 : Mangrove Kelasa Observation Point 3

The total mangrove stand density for the tree category on Kelasa Island is 1000 trees/ha at Station 1 (MG01), indicating a condition of "Good - Moderately Dense," and 1133 trees/ha at Station 2 (MG02), also categorized as "Good - Moderately Dense." Meanwhile, at Station 3 (MG03), the density is 766.67 trees/ha, classified as "Damaged - Sparse," in accordance with Decree No. 201 of 2004 of the Ministry of Environment on Mangrove Damage Criteria and Guidelines. This suggests that the eastern part of Kelasa Island is the only suitable habitat for the growth of the mangrove vegetation community, benefiting from low coastal elevation and shallow seabed that is still affected by tidal movements. Generally, the mangrove vegetation community in the eastern part of Kelasa Island is in good/stable condition, relatively natural, and without significant ecological pressure that directly impacts the survival of mangroves in the area.

Based on the data collected from Kelasa Island, the dominant mangrove species found is from the genus *Rhizophora*. At Station 1 (MG01), *Rhizophora apiculata* recorded the highest Importance Value Index (IVI) for trees at 182.3, similarly at Station 2 (MG02) with an IVI of 300 (monospecies), and at Station 3 (MG03) with an IVI of 185.38. This indicates that this mangrove species plays a critical role in maintaining the stability and existence of the mangrove ecosystem. Observations suggest that the structure of the mangrove vegetation community on Kelasa Island is homogeneous and tends to be monospecific. The degradation or loss of this species could impact the survival of other mangrove species found at the three observation stations on the island. *Rhizophora apiculata* plays a crucial role in maintaining the sustainability of the mangrove ecosystem in the coastal areas of eastern Kelasa Island. This species generally thrives in waterlogged conditions during normal tides and prefers sandy-muddy substrates. It can dominate vegetation in a location up to 90% and often grows well at the forefront of mangrove zones, usually alongside other species [19].

The percentage of mangrove cover at Station 1 (MG01) is classified as "poor" with a mangrove cover value of 14.85% ± SD = 12.98%, Station 2 (MG02) has a cover value of 6.46% ± SD = 1.59%, also classified as "poor," and Station 3 (MG03) has a cover value of 11.37% ± SD = 5.46%. According to the Ministry of Environment Decree No. 201 of 2004 on Mangrove Damage Criteria and Guidelines, the overall mangrove cover is relatively low on Kelasa Island. This indicates that the mangrove vegetation community is relatively uniform and consists of young trees, with heights ranging from 4 to 8 meters, and has very good regeneration. However, not all sides of Kelasa Island are home to mangrove trees.

If there is a difference in the classification of mangrove condition status based on density or percentage cover, the percentage of canopy cover should be used as the reference, which can be determined through basal area measurements (diameter at breast height) or hemispherical photography. The hemispherical photography method is a new approach used by mangrove surveyors by taking vertical photos of the mangrove canopy towards the sky. This allows for the calculation of the actual mangrove cover by comparing sky pixels with vegetation pixels. The canopy of the mangrove community at Stations 1, 2, and 3 (Figure 4)

Fig 4. Mangrove coverage at observation points on Kelasa Island, Central Bangka

Figure 4 depicts the canopy structure of the mangrove community at different stations. Based on Figure 4.a, mangrove vegetation is only distributed in the eastern region of Kelasa Island, covering an area of 2.57 hectares, indicated by the light green color. The mangrove zoning found tends to be homogeneous, with the species identified belonging to only one genus from the Rhizophoraceae family, namely *Rhizophora* sp. This aligns with the field observations, where the types of mangroves found were not numerous and relatively homogeneous. The composition of Kelasa Island's mangrove vegetation community is determined using data analysis. It tends to be monospecific, although it consists of two species: *R.apiculata* and *R. mucronata*. In the front area bordering the sea, *Rhizophora apiculata* was found forming a zonation, followed by *Rhizophora mucronata*, which grows towards the back formation bordering terrestrial vegetation or coastal fringe vegetation. According to Figure 4.b, the topography of the area inhabited by mangroves is located at the 0 m contour line in the low tide region. This is consistent with research by [1, 4], which indicates that mangroves generally grow in intertidal areas with gentle topography in tropical regions.

3.3 An Ecological Index of Kelasa Island's Mangrove Vegetation Community

Determination of balance and stability of mangrove forest on Kelasa Island was carried out by calculating ecological indices, which include diversity index, evenness index, and species dominance index, categorized differently. The values of the ecological indices can generally assist researchers in describing the mangrove forest area on Kelasa Island, including whether it has stable, vulnerable, or stressed balance categories.

Table 3. Values of Diversity, Evenness, and Dominance Indices on Kelasa Island

No	Growth level	H'	C	E
1	Tree	0.494	0.686	0.712
2	Sapling	0.362	0.790	0.522
3	Seedling	1.466	1	0

The variety of plant species at the study site is shown by the species diversity index. The community is more stable and features a wider variety of species when the H' value is larger.

Trees, saplings, and seedlings have diversity index values ranging from 0.362 to 1.466, according to Table 3. According [6], the diversity index values indicate that the structure of vegetation or community at various growth stages is in a relatively stable condition and does not experience significant ecological pressure (H' < 1).

The evenness index for mangroves on Kelasa Island ranges from 0.00 to 0.712. The evenness values obtained indicate a very uniform distribution of species (E close to 1) with a very good category [24]. The obtained values (>0.6) show a high level of evenness with no dominance. This result suggests that each species has a relatively different number of individuals, with some species being more dominant. The distribution of plant species in the mangrove forest on Kelasa Island can be said to be uneven, indicating an imbalance in the distribution of certain species across all growth stages. A low species evenness value occurs when a community has a dominant species.

The dominance index for mangroves on Kelasa Island ranges from 0.686 to 1. The values obtained indicate the presence of a dominant species. One species predominates over others in the observed community structure if C is close to 1 [6]. The species dominance index for the mangrove forest on Kelasa Island is classified as high (D > 0.5) across all growth stages. This indicates that dominance (control) of vegetation is concentrated in one species. The highest dominance index value is 1, which means that a stand is dominated by one species, leading to a concentration of dominance in a single species. High dominance of one species within a community can overshadow species from other communities. The impact of the dominance of certain species will significantly influence life in the mangrove forest ecosystem and can provide insights into the widely distributed vegetation species.

3.4 Water Quality

The water quality parameters measured in the mangrove ecosystem of Kelasa Island align with the standards set by the Indonesian Government Regulation No. 22/2021, indicating favorable conditions for both mangrove vegetation and associated aquatic life (Table 4.)

Table 4. Water Quality Parameters in the Mangrove Ecosystem of Kelasa Island

Parameter	Measured Value	Standard Reference*
pH	8.03	6.5–8.5
Salinity (ppt)	30	Natural
Dissolved Oxygen (DO, mg/L)	5.8	Not specified
Ammonia (NH_3-N, mg/L)	0.254	≤0.3
Nitrate (NO_3^-, mg/L)	0.058	≤0.06
Lead (Pb, mg/L)	<0.0002	≤0.008
Copper (Cu, mg/L)	0.006	≤0.008

*Standards based on Water Quality Standard Regulation, Attachment VIII, Government Regulation No. 22/2021

The water quality parameters measured in the mangrove ecosystem of Kelasa Island align with the standards set by the Indonesian Government Regulation No. 22/2021, indicating favorable conditions for both mangrove vegetation and associated aquatic life. The pH level of 8.03 falls within the optimal range of 6.5 to 8.5, supporting the physiological processes of mangrove species such as *Rhizophora apiculata* and sustaining aquatic organisms. Salinity at 30 ppt reflects natural coastal conditions suitable for mangrove ecosystems. Dissolved oxygen (DO) concentration at 5.8 mg/L, although not specified in the regulation, is generally considered adequate to support diverse aquatic life, facilitating aerobic respiration and maintaining ecological balance. Ammonia (NH_3-N) levels at 0.254 mg/L are below the threshold of 0.3 mg/L, indicating a low risk of toxicity to aquatic organisms. Nitrate (NO_3^-) concentration at 0.058 mg/L is near the permissible limit of 0.06 mg/L, suggesting minimal nutrient loading and a reduced risk of eutrophication.

Heavy metal concentrations, with lead (Pb) at <0.0002 mg/L and copper (Cu) at 0.006 mg/L, are well within the permissible limits of 0.008 mg/L for both metals, reflecting minimal anthropogenic pollution and a healthy environment for aquatic life. The presence of bivalve species such as *Donax sp.* and *Tellina sp.* serves as bioindicators of healthy sediment and water conditions. These organisms contribute to sediment stability and nutrient cycling, enhancing the resilience and sustainability of the mangrove ecosystem [17]. Their presence indicates a balanced and functioning ecosystem, which is crucial for the long-term sustainability of coastal environments.Maintaining these favorable water quality conditions is essential for the sustainability of the mangrove ecosystem on Kelasa Island. Continuous monitoring and management are necessary to preserve the ecological integrity and the services provided by this vital coastal habitat.

3.5 *Rhizopora apiculata* Implication on Coastal Ecosystem Sustainability

The dominance of *Rhizophora apiculata* across all growth stages on Kelasa Island plays a pivotal role in shaping the mangrove ecosystem's structure and sustainability. This species exhibits the highest Importance Value Index (IVI), with values of 220.9 for trees, 246.6 for saplings, and 200 for seedlings, reflecting its vital contribution to ecosystem stability. The high IVI of saplings (246.6) indicates their successful transition from seedlings, which demonstrates the capacity for continued growth and regeneration under favorable environmental conditions. Saplings act as an intermediate phase, ensuring continuity between young and mature mangroves, which is critical for sustaining the ecosystem's long-term health [7]. Mature trees, with an IVI of 220.9, provide essential services such as sediment stabilization and canopy cover, which protect young individuals by reducing desiccation and wave action impacts [15].

Meanwhile, the high IVI of seedlings (200) highlights their robust recruitment, ensuring future forest regeneration and ecosystem resilience. These seedlings thrive in sandy-muddy substrates, demonstrating their adaptability and reinforcing the ecological stability of the mangrove community. Together, the presence of these growth stages, each with high IVI values, illustrates a well-functioning mangrove ecosystem capable of withstanding moderate environmental pressures, maintaining structural integrity, and supporting biodiversity [2]. The dominance index (C), reaching a maximum of 1 for seedlings, underscores its competitive advantage in this habitat. While the diversity index (H') is relatively low for trees (0.494) and saplings (0.362), it is higher for seedlings (1.466), indicating robust regeneration potential. Despite the low species diversity, *R. apiculata* contributes to ecosystem resilience through its capacity to stabilize sediments and protect shorelines, especially the root system.

The extensive root system of *R. apiculata* plays a critical role in reducing erosion and trapping sediments on the sandy-muddy substrates of Kelasa Island's eastern coastline. The high seedling density (14,444 stems/ha) highlights strong regeneration, ensuring the long-term sustainability of this mangrove community. The extensive root system of *Rhizophora apiculata* significantly contributes to ecosystem sustainability by reducing erosion and trapping sediments. Research has demonstrated that mangrove roots, particularly those of the *Rhizophora* species, are effective in mitigating tidal forces and stabilizing coastal sediments.

Similar conditions to Kelasa Island`s mangrove have been observed in other mangrove ecosystems, such as Mendanau Island, where *Rhizophora spp.* also dominate and exhibit healthy regeneration cycles [2]. However, the monoculture-like dominance of *R. apiculata* may pose risks by reducing ecosystem resilience to environmental disturbances and species-specific diseases. These species have robust root systems that provide significant ecological benefits, such as stabilizing sediments and reducing coastal erosion. Research indicates that *Rhizophora* species contribute to the formation and maintenance of healthy mangrove forests by enhancing sediment trapping and building soil elevation, which helps protect coastlines from the effects of rising sea levels and storm surges. For instance, a study by [11] shows that *Rhizophora* species have the capacity to accumulate sediments around their root systems, which leads to land formation and the stabilization of coastal zones, promoting ecosystem resilience. Additionally, the dense root networks of *Rhizophora* species support a rich diversity of marine and terrestrial life, enhancing biodiversity and ecosystem function, [8], who found that these species are key to maintaining the ecological balance in coastal mangrove ecosystems.

To enhance ecosystem sustainability, conservation efforts should focus on maintaining the dominance of *R. apiculata* while introducing other mangrove species, such as *Avicennia spp.* or *Sonneratia spp.*, to increase biodiversity. The stable water quality parameters in the area such as salinity (30 ppt) and nitrate levels (0.058 mg/L) create favorable conditions for mangrove growth and carbon sequestration. This ecological stability supports the critical role of *R. apiculata* in coastal protection and climate regulation, emphasizing the need for integrated conservation strategies to ensure the long-term resilience of Kelasa Island's coastal ecosystem.

4 Conclusions

The following conclusions can be made in light of Kelasa Island's mangrove vegetation analysis results:

1. The mangrove forest on Kelasa Island tends to be homogeneous (monospecific, dominated by species of *Rhizopora apiculata.*
2. The average is dominated by tree stand density of 966.67, the mangrove vegetation community from the three observation stations is in Good-Moderate condition (766.67–1133 stems/ha).
3. Water quality around the area classified in a stabilise condition based on the standard of water quality based on Water Quality Standard Regulation, Attachment VIII, Government Regulation No. 22/2021.

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