JPPIPA 10(12) (2024)

Jurnal Penelitian Pendidikan IPA
Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Analysis of Vegetation Structure and Sustainable Management of Mangrove Forests

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Received: September 9, 2024
Revised: October 19, 2024
Accepted: December 25, 2024
Published: December 31, 2024

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DOI: 10.29303/jppipa.v10i12.9683

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Abstract: The objective of this study is to examine the structure of mangrove vegetation on Dompak Island and develop sustainable management strategies. The research employs a descriptive approach with purposive sampling as the sampling technique. Research instruments include a hygrometer, raffia rope, location map, hand refractometer, roll meter, hand counter, and identification book. Additional materials used are tissue, an oven, GPS, 70% alcohol, rope, plastic bags, analytical scales, a camera, distilled water, aluminum foil, a multi-tester, mangrove data, and a refractometer. The study identified six mangrove species on Dompak Island: *Avicennia marina*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Rhizophora stylosa*, *Sonneratia alba*, and *Ceriops tagal*. Among these, *Rhizophora apiculata* was the most abundant, with 68 individuals at the tree level, 18 at the sapling level, and 19 at the seedling level. Based on SWOT analysis, the recommended strategy for managing Dompak Island's mangroves is conservation-focused. This includes protecting the ecosystem, prohibiting destructive activities such as deforestation, and implementing regulations for local communities to ensure the sustainability of mangrove forests. In conclusion, the mangrove vegetation structure on Dompak Island, Tanjungpinang City, remains diverse and well-preserved.

Keywords: Mangrove; Sustainable; Vegetation

Introduction

Indonesia is one of the largest archipelagic countries in Southeast Asia and has a very large number of coastal areas with a coastline of 95,181 km. This value makes Indonesia the fourth longest coastline in the World. The large potential of coastal natural resources owned by Indonesia with a diversity of ecosystems in it, one of them is the mangrove ecosystem (Junianto et al., 2023). Mangrove ecosystems are intertidal ecosystems where there is a strong interaction between marine, brackish, riverine and terrestrial waters. This interaction makes the mangrove ecosystem diverse in flora and fauna. Mangroves live in tropical and subtropical regions, especially in latitudes between 25°N and 25°S (Sari et al., 2023; Njana, 2020; Daniel et al., 2024; Hanggara et al., 2021; Xu et el., 2024). Mangrove ecosystems provide enormous benefits to the environment in coastal areas, namely controlling coastal abrasion, preventing marine intrusion, improving water quality, increasing productivity of coastal waters, and as a habitat for the enlargement and protection of economically valuable biota in coastal waters and can improve the welfare of coastal communities (Hadiprayitno et al., 2023; Lismarita et al., 2022; Li et al., 2024; Casal et al., 2024). Mangroves are a community of plants that grow in tropical and subtropical regions around the world (Riska et al., 2023). In coastal places, the transition between land and water has created diverse ecosystems that are highly productive and can provide enormous economic value to humans (Nurhasanah et al., 2023).

Mangrove ecosystems have many physical, chemical, ecological and economic benefits, and play an important role in protecting land from sea wave

How to Cite:
Jelibseda, kamal, E., Razak, A., & Diliarosta, S. (2025). Analysis of Vegetation Structure and Sustainable Management of Mangrove Forests. *Jurnal Penelitian Pendidikan IPA*, *10*(12), 11239–11248. https://doi.org/10.29303/jppipa.v10i12.9683

abrasion (Alwi et al., 2019; Hilmi et al., 2019; Sadi et al., 2024). Sea tides affect the ecology of mangroves, forest areas that inhabit the coastline. The mangrove environment is a special type of natural ecosystem with significant ecological and financial value. In addition to providing habitat (residence), mangrove ecosystems function as places to find food and breed for aquatic biota and protect the coastline from wind, currents and ocean waves (Laraswati et al., 2020). In addition to providing environmental benefits to coastal areas, mangrove ecosystems are also home to various marine biota, including fish, shrimp, crabs, plankton and benthos. Another important economic resource is mangrove forests. According to research findings, mangroves help reduce climate change and store carbon (Maulidia et al., 2022; Sadono et al., 2020). Mangrove habitat is one of the many ecosystems found in Indonesia. Mangrove forests have various functions, such as providing food for various animals, protecting the coastline, spawning grounds, sediment traps, stopovers for migratory birds, and habitats for biota (Cannicci et al., 2021; Fudloly et al., 2020). The mangrove ecosystem has a distinctive vegetation structure, compiling several characteristics sequentially such as trees, saplings, poles, and seedlings, thus forming a series of certain zones (Al Idrus et al., 2023).

Mangrove forests also serve economic, ecological, and social functions. The economic functions include providing household needs, supplying industrial requirements, and producing seedlings (Budiarti et al., 2023). Mangrove forest as a tropical coastal vegetation community is dominated by various types of mangrove trees that can grow and develop in muddy coastal tidal areas (Rifdan et al., 2023). Mangrove ecosystems in Indonesia are very important in the global carbon cycle because they have an area of 22.6% of the world's mangroves or the first highest in the world (Rumanta et al., 2023).

Mangrove environments serve as habitats for fish, shrimp, and shellfish, among other aquatic species, and can be used for breeding, laying eggs, and gathering food. Mangrove trees create debris and hold back silt from the land, providing primary and temporary homes for a variety of marine life. In addition to their economic uses as firewood, building materials, charcoal, and dyes, mangrove forests also serve as physical barriers against waves, absorbers of heavy metals, and potential sources of carbon dioxide sequestration, all of which reduce the impacts of global warming (Faristy & Putri, 2024; Rahman et al., 2024).

Two categories of mangroves can be distinguished: major mangroves, which form pure stands and dominate mangrove communities and associations, and minor mangroves, which rarely or never form pure stands and do not dominate communities and structures (Purnawan et al., 2019). The total area of Indonesia's mangrove area is 3,364,076 Ha, based on the National Mangrove Map which was officially published by the Ministry of Environment and Forestry in 2021. Based on initial observations and observations, one of the areas in Indonesia that has mangrove forests is on Dompak Island, Tanjungpinang City, Riau Islands. There are 53 species from 32 families, including 28 mangrove plants. One of these species, *Scyphiphora hydrophyllacea*, is endangered. The loss of tropical rainforests and other life forms can be threatened by the decline in mangrove habitat. Mangrove habitats experience various problems, such as over-exploitation by local communities, land conversion into fish and shrimp ponds, and land conversion into agricultural land and settlements (Eddy et al., 2018; Purnawan et al., 2019).

The mangrove ecosystem in the Riau Islands is found in several areas or zones with varying forms of ownership. Mangrove forests, especially those in protected forest areas and marine conservation areas, are fully managed by the government through relevant agencies and are located within state forest areas. In addition, there are also mangrove areas located within concessions controlled by private parties. And the third is mangrove forests outside the status of the area, most of which are along the coast. Coastal areas that are not privately owned remain the property rights of the State and are used according to the interests of the community. The process of changing the status of state land to non-state ownership can be carried out through the release or release of rights regulated in accordance with the Agrarian Law.

Given the importance of the benefits and roles of mangroves, it is recommended to apply the principle of studying, utilizing, and maintaining them optimally by knowing and observing the structure of mangrove vegetation. The findings of this study can be the basis for formulating the provisions needed in managing and controlling human activities. Dompak Island is located in the southern part of Tanjungpinang City, has a diverse and productive mangrove ecosystem along its coast. This mangrove ecosystem is a unique environment and rich in natural resources. Mangroves function as protectors and sources of nutrition for various organisms that live in it. Dompak Island has an area of about 4,280 hectares and has great potential in terms of mangrove resources. About 27.6% of the total mangrove ecosystem in Tanjungpinang is found on Dompak Island. Research needs to be conducted to evaluate the condition of the mangrove ecosystem related to the things mentioned earlier.

The research conducted includes analysis of begetasi structure and sustainable mangrove management on Dompak Island, Tanjungpinang City, Riau Islands. This research is expected to be initial data for further research on mangrove ecosystems and become a source of information for local governments in formulating holistic policies in coastal areas. The goal is to protect and preserve mangrove ecosystems by ensuring that their use is accompanied by sustainable protection and preservation efforts. This research is significant because it integrates ecological analysis with sustainable management. The combination of analyzing mangrove vegetation structure and developing sustainable management strategies offers a holistic approach. This approach may be considered novel if previous studies focused solely on one aspect, such as vegetation analysis, without addressing management strategies. Another reason this research is considered important is its emphasis on the application of conservation and adaptive management. A conservation-based approach that prioritizes mitigating environmental impacts, prohibiting destructive activities, and establishing specific policies for mangroves demonstrates a focus on adaptive management, which may not yet have been fully developed in previous studies.

Method

This study uses a descriptive approach. Based on the conditions that exist during the study, descriptive techniques are used to describe the phenomena studied. A purposive (sampling) approach is used to take samples of the mangrove ecological community (Harefa et al., 2020). According to Akbar et al. (2018) and Asman et al. (2020), purposive sampling is a sampling strategy that uses certain considerations based on criteria intended to determine the number of samples to be collected and studied. The equipment used in this study includes a hygrometer, raffia rope, location map, Hand Refractometer, meter roll, hand counter, and identification book. In addition, materials such as tissue, oven, GPS, meter roll, 70% alcohol, rope, plastic bags, analytical scales, cameras, distilled water, aluminum foil, multi tester, mangrove data, and refractometer were also used.

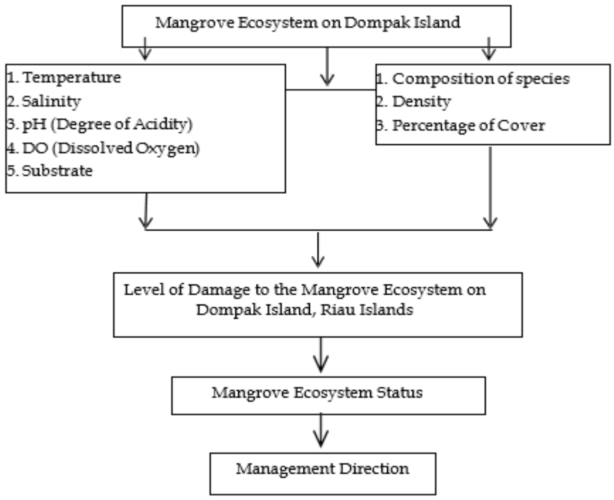

Figure 1. Research flow

This data collection technique uses is with Primary data collected by conducting a transect method that is carried out parallel to the coastline along 100 m and a width of 10 m and also adjusted to field conditions. Each line is made a plot measuring 10 x 10 meters for trees, 5 x 5 meters for saplings and 1 x 1 m for seedlings in each transect and recorded the vegetation of all types and the number of mangrove plants found in the plot area. Samples were taken at three different locations (dense, medium, less), with three replications for each location as in the map below. Sampling was carried out on the transect plot using a zig-zag system. Using literature or the assistance of mangrove identification specialists, samples from each type of mangrove forest were identified in the laboratory after being stored in a 5–10% formalin solution.

Figure 2. Research location map

The identification of mangrove vegetation is essential in understanding the structure and composition of mangrove ecosystems. As outlined by Djamaluddin (2018) and Dharmawan & Pramudji (2014) the identification key book serves as a valuable guide for recognizing different mangrove species. Additionally, the analysis of mangrove vegetation structure involves using specific formulas to assess various ecological parameters such as density, frequency, and dominance, which are crucial for evaluating the health and biodiversity of mangrove habitats. These combined approaches help in better understanding and conserving mangrove ecosystems. The following formula is used to determine the number of plants stands-i in a unit area of mangrove:

$$\mathrm{Di} = \frac{\mathrm{ni}}{\mathrm{A}} \tag{1}$$

Relative Density: is a comparison between the number of vegetation stands I and the total number of all vegetation stands with the following formula:

$$\mathrm{RDi} = \frac{\mathrm{ni}}{\sum \mathrm{n}} \times 100 \tag{2}$$

Frequency: It is the probability of finding vegetation i in a given plot:

$$\mathrm{Fi} = \frac{\mathrm{pi}}{\sum \mathrm{p}} \tag{3}$$

Relative Frequency: is the comparison between the frequency of vegetation i and the total frequency for all vegetation with the following formula:

$$\mathrm{RFi} = \frac{\mathrm{Fi}}{\sum \mathrm{F}} \times 100 \tag{4}$$

Dominance (closing): is the area of vegetation cover I in a unit area with the following formula:

$$\mathrm{Ci} = \sum \mathrm{BAi} \,/\, \mathrm{A} \tag{5}$$

Relative Dominance: is a comparison between the area of vegetation cover I and the total area of cover for all vegetation with the following formula:

$$\mathrm{RCi} = \frac{\mathrm{Ci}}{\sum \mathrm{C}} \times 100 \tag{6}$$

Important Value Index: is a description of the influence of mangrove vegetation in the mangrove community. The importance value of vegetation ranges from 0 to 300 with the following formula:

$$\mathrm{IVi} = \mathrm{RDi} + \mathrm{RFi} + \mathrm{RCi} \tag{7}$$

In the final stage, the data was analyzed using mangrove management analysis using SWOT analysis.

Result and Discussion

Mangrove ecosystems are located at the interface between land and sea. They can be affected severely by global climate change associated with SLR, and other environmental or ecological changes (Ali & Rahman, 2025). In coastal and marine waters, mangrove ecosystems play an important ecological function. To maintain air quality around the mangrove environment, mangroves can also bind carbon. In addition, mangrove ecosystems can absorb waste pollutants and stop sedimentation, which are two examples of environmental elements that can have a negative impact on the mangrove ecosystem. As a result, various vegetative creatures, including roots, stems, branches, and leaves, choose the mangrove environment as a habitat (Saru, 2020). According to biology, mangrove habitats provide a breeding ground for biota such as crabs, which are found in fresh, brackish, and salt water and inhabit this environment (Poedjirahajoe & Matatula, 2019; Sipayung & Poedjirahajoe, 2021).

In the mangrove environment, organisms, or biota, depend on waste for food and nutrition. Organic waste, which includes leaves, twigs, and other mangrove plants that fall to the substrate and then dry and change color, is another term for waste. Waste is one of the factors that affects the abundance of the mangrove ecosystem in terms of productivity, because waste decomposes when it falls to the substrate and provides nutrients that can be used by biota as food. Organic materials contained in decomposed waste support the biota of the mangrove environment (Muslimin et al., 2021). Its special quality, the mangrove ecosystem is also known as a tropical forest is an important ecosystem on the coast and coastal waters. In addition to being a very resilient coastal forest, the mangrove ecosystem helps maintain the balance of the aquatic biological cycle. Therefore, the mangrove environment functions as a habitat for aquatic life, including fish, as well as a place to find food, lay eggs, and take shelter. Ultimately, the mangrove ecosystem benefits the local economy (Rajab, 2020).

Mangrove Vegetation

This research was conducted from July to September 2024 in the Dompak Island area, Tanjungpinang City, Riau Islands. Based on data collection and analysis activities, the following research results were obtained as shown in Table 1.

Due to its presence in all observation stations, *Rhizhopora apiculate* is estimated to have the highest species distribution. Because Rhizophora species are highly adaptive to variations in environmental conditions including salinity, substrate, pH, and temperature, they are also abundant in the Pancur River mangrove habitat in West Bangka Regency, which allows for the expansion of mangrove life (Rosalina & Sofarini, 2021).

Table 1. Distribution of mangrove individuals

Family	Mangrove type	Observation Plot		
		Plot I	Plot II	Plot III
Verbenaceae	*Avicennia marina*	++	++	++
Rhizophoraceae	*Rhizophora apiculate*	+++	+++	+++
Rhizophoraceae	*Rhizophora mucronate*	++	++	++
Rhizophoraceae	*Rhizophora stylosa*	+	+	+
Sonneratiaceae	*Sonneratia alba*	+	+	+
Rhizoporaceae	*Ceriops tagal*	+	+	+

It is believed that this species has a great ability for environmental adaptation and regeneration. One of the reasons why *Rhizophora sp.* has an even distribution in coastal areas is based on the findings of research conducted. The types of mangroves found on Dompak Island, Tanjungpinang City, Riau Islands based on their characteristics according to Noor et al. (2006) are as follows.

Figure 3. *Avicennia marina*/api api putih

This plant is a tree that can grow upright or spreading, with smooth bark, upright respiratory roots, yellow leaf stalks, spots on the leaf surface, white or gray undersides, elongated rounded leaves, and pointed tips. The flowers are trident-shaped, meaning they are clustered together and appear at the end of the cluster. Along the seashore, pioneer plants thrive in muddy environments.

Figure 4. *Rhizophora apiculata*/bakau putih

Overview This tree has a trunk diameter of 50 cm and can grow to a height of 30 m. The average root can grow to a height of five meters. The leaves are dark green, with reddish undersides and light green centers. The shape is elliptical, tapering at the leaf tips. Small clusters. The leaves are yellowish on the flower head and whitish yellow on the crown. The fruit, which is about 3.5 cm long and contains viable seeds, is round, elongated, rough, and bumpy, almost like a small pear. When ripe, the orange-green color will change to dark red at the cotylodon neck. likes deep, fine, and muddy soil. dislikes coarse and sandy substrates. 90% of plants growing from one place can be considered dominant.

Figure 5. *Rhizophora mucronata*/bakau hitam

General description. The tree reaches a height of 27 m with a diameter of 70 cm. has a taproot. The leaves are elliptical in shape, widening to round and elongated. Green in color. Flowers are in clusters with several flowers per cluster attached to each other, the shape of the flower head stalk resembles a fork. Pale yellow in color. The fruit is brownish green with an oval/elongated shape, almost egg-shaped. Most are rough at the base, have a single seed, are more tolerant of sandy substrates. Rarely live far from tidal areas, grow in groups.

Figure 6. *Rhizophora stylosa*/bakau kecil

This tree has several trunks that can reach ten meters in height. It has a taproot that can reach three meters in length. The tips of the green leaves are pointed. The undersides of the rough leaves are speckled. In clusters. This brown fruit has 8–16 flowers per bunch and one viable seed that is 2.5–4 cm long. The flower petals are greenish yellow. The flower head stem is shaped like a fork. Grows on rocky, sandy, and muddy surfaces, especially in estuaries and river embankments.

Figure 7. *Sonneratia alba*/pidada putih

The skin on the trunk is creamy brown with fine cracks on the surface. The leaves are thick like bright green eggs and their positions are opposite each other. The flowers have quite a lot of pollen at the ends of the branches and are white. The fruit is like a flat ball and is grayish green with a diameter of 5-5.75 cm. Plants that grow on muddy substrates. The roots breathe when the sea recedes.

Figure 8. *Ceriops tagal*/soga white/middle white

Shrub or small tree up to 25 meters tall. It has an oval base and smooth, gray, and sometimes brown bark. It often has a small taproot. Its glossy green leaves often have inward-curving edges. The flower stalks are long and thin, ovate at the tips of new branches or in the axils of younger branches, and the flowers are clustered at the ends of clusters. The fruit has a curved calyx tube and is 1.5 to 2 centimeters long. It thrives in estuaries and ponds in dry areas, high salinity environments, and the inner mangrove zone.

Mangrove Composition

The composition of mangrove species found in plots I, II and III from 68 individuals, 37 species of *Rhizopora apiculata* are the most common species found at the tree level. Eight of the eighteen individuals of *Rhizopora apiculata* are the most common species found at the shoot stage. However, at the seedling stage, 13 of the 19 individuals are the most common species of *Rhizopora apiculata* found.

Tree Level

The following table shows how many mangrove species were found in each 10 m × 10 m observation plot. The following table shows how many mangrove species were found in each 10 m x 10 m observation plot.

Table 2. Species and number of mangroves at tree level

Species name	Plot 1	Plot 2	Plot 3	Amount
Avicennia marina	9	5	6	20
Rhizophora apiculate	37	19	12	68
Rhizophora mucronate	3	2	2	7
Rhizophora stylosa	1	1	2	4
Sonneratia alba	1	2	1	4
Ceriops tagal	1	1	2	4

Based on the data above, with a total of 68 individuals, the mangrove species *Rhizophora apiculata* is often seen at each observation location. *Avicennia marina* is in second place with 20 individuals. *Avicennia marina*, with 20 individuals and the largest significance value index of 58.87%, is the second most abundant mangrove species at each observation station, according to the data above. *Rhizophora apiculata*, with 68 individuals in total, has the highest importance value index of 103.07%.

Seedling Stage/Sapling

The following table shows how many mangrove individuals were found in a 5 m × 5 m area for each observation transect. The Table 3 is different from *Ceriops tagal* which was not found in all the transects studied, the *Rhizophora apiculata* mangrove plant was often observed at each observation station at the seedling/young tree level, with a total of 18 individuals, followed by *Avicennia marina* up to 8 individuals.

Table 3. Species and number of mangroves at the seedling stage

Species name	Plot 1	Plot 2	Plot 3	Amount
Avicennia marina	3	1	4	8
Rhizophora apiculate	8	5	5	18
Rhizophora mucronate	3	1	2	6
Rhizophora stylosa	2	1	0	3
Sonneratia alba	1	0	0	1

Seedling Level

The following table shows how many mangrove individuals were found in a 1 m × 1 m area on each observation transect.

Table 4. Species and number of mangroves at the seedling stage

Species name	Plot 1	Plot 2	Plot 3	Amount
Avicennia marina	5	4	3	12
Rhizophora apiculate	3	13	3	19
Rhizophora mucronate	2	3	2	7
Rhizophora stylosa	2	1	1	4
Sonneratia alba	0	2	1	3
Ceriops tagal	1	0	0	1

The table above shows that each transect often contains 19 individuals of the mangrove species *Rhizophora apiculata*, followed by 12 individuals of *Avicennia marina*.

Water Quality

Water quality has a significant impact on the diversity and survival of fish species living in mangrove forests. The existence, development, and growth of fish species in the waters of the mangrove forest area are determined by air quality criteria. The following table shows the findings of water quality tests conducted at the research location. Mangroves have special adaptations like, pneumatophores and stilt roots (structures above the ground that resemble inverted roots and are specifically adapted for gaseous exchange in marshy environments) that also have significant contribution in the AGB estimation (Adimoolam et al., 2025).

Table 5. Results of water quality measurements on Dompak Island

Parameter	Tools	Location	Quality standards
Temperature (^{0}C)	Thermometer	28–30	28–30
Salinity ($^0/_{00}$)	Refractometer	26 – 30.5	33–34
Ph	Ph meter	6–7	7–8.5
Substrate	Scope	Muddy	–

The utility value for flora life among mangrove forests is also influenced by the degree of acidity (pH) which is highly correlated with other water characteristics. The waters on Dompak Island are acidic, with a pH range of 6 to 7, based on the results of acidity (pH) measurements at the research location. This shows that the waters of Dompak Island are included in the good category for health. Mangrove growth. The pH of mangrove waters is acidic because of the large amount of organic material found in the waters around the mangrove forest. Under the effect of global climate change, the enhanced wave condition leads to lateral erosion at the mangrove vegetation edge, threatening the survival of mangrove habitat and the safety of coastal defense (Wang et al., 2024).

Management Strategy for Mangrove Forests on Dompak Island

The management plan with the aggressive strategy category is obtained from the evaluation of internal and external elements, which is done by considering every aspect of each factor. Aggressive strategy is by utilizing internal strengths to take advantage of external opportunities as presented in Figure 3 below.

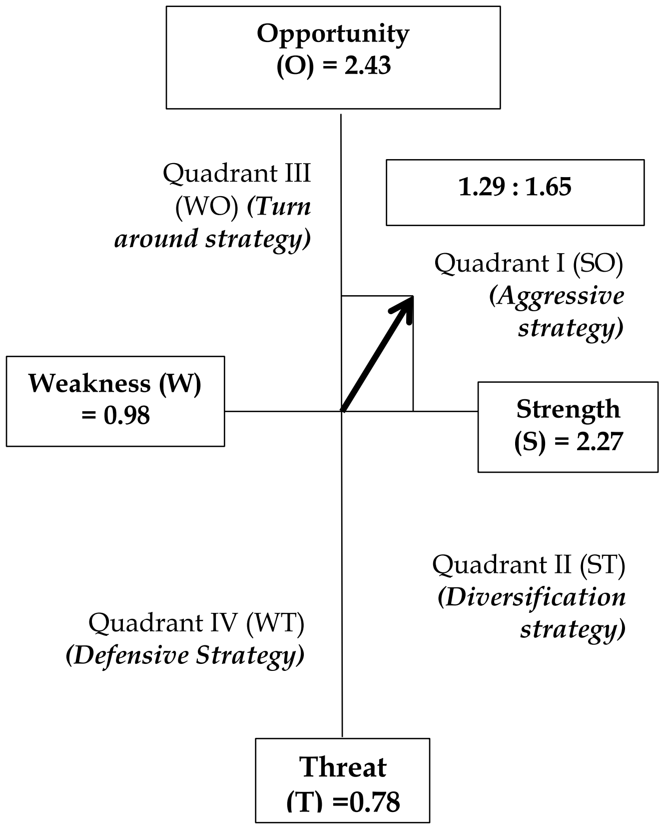

Figure 3. The management strategy

The right approach according to the strategy quadrant is in quadrant I (aggressive strategy), where it is clear that the value of this position is very profitable because of the conditions applied by this strategy, which encourages aggressive growth policies. By calculating the weight value of each component and giving a score to each component as follows, the values in this strategy quadrant are obtained from the internal factor assessment matrix (strength and weakness aspects) and external factors (opportunity and danger aspects).

The value on the X-axis is 1.29, calculated by subtracting the weakness score (0.98) from the strength score (2.27), while the value on the Y-axis is 1.65, derived by subtracting the threat score (0.78) from the opportunity score (2.43).

The water quality management strategy in the Dompak Island area can be seen in the SWOT analysis matrix where the right strategy to implement is in the SO strategy, namely the results of the strategy for sustainability, so it is necessary: Optimizing policy support and biodiversity for ecotourism development, while utilizing nursery centers and community involvement, aims to enhance the regeneration and conservation of mangrove forests in the future.

Conclusion

The following are some conclusions that can be drawn from the research that has been conducted: The mangrove ecosystem on Dompak Island, Tanjungpinang City, Riau Islands, is home to six identified species: *Avicennia marina*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Rhizophora stylosa*, *Sonneratia alba*, and *Ceriops tagal*. Among these, *Rhizophora apiculata* is the most dominant, with 68 individuals at the tree level, 18 at the sapling level, and 19 at the seedling level. This species also has the highest Importance Value Index (IVI), reaching 103.07% at the tree level, 99.26% at the sapling level, and 61.34% at the seedling level. In contrast, *Ceriops tagal* shows the lowest IVI, with values of 32.23% for trees and 14.67% for seedlings, and no individuals were found at the sapling level. Based on a SWOT analysis, the most effective approach to developing the mangrove area is by focusing on conservation to ensure the ecosystem's sustainability. This includes prohibiting destructive activities, such as deforestation, and establishing regulations for the management of mangrove forest areas. Coordination between the provincial and city governments is essential for planning and designating conservation areas for local communities.

Acknowledgments
Thanks to the authors and all those who contributed to the research and writing of this article.

Author Contributions
All authors contributed to writing this article.

Funding
No Funding.

Conflicts of Interest
No conflict interest.

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