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Mangrove Ecosystem Dynamics and Management Challenges in Sei Carang, Tanjungpinang City

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ABSTRACT

The characteristics of different mangrove habitats possess varying water conditions. This study aimed to analyze the ecological characteristics of mangroves and the challenges in mangrove rehabilitation in the Sei Carang waters of Tanjungpinang City. The research was conducted on December 4, 2024, at an observation site located within the mangrove ecosystem in the estuarine waters of Sei Carang, Tanjungpinang City. The tools and materials used in this study included a GPS, compass, thermometer, pH meter, handheld refractometer, DO meter, and writing instruments. The research findings indicate that the ecological characteristics of the mangrove ecosystem in the Sei Carang estuarine waters are favorable for the existing mangrove vegetation, as evidenced by the alignment of the measured parameters with optimal conditions. Furthermore, the challenges faced in mangrove restoration in Sei Carang, Tanjungpinang City, include insufficient monitoring, unclear institutional responsibilities for mangrove management, and natural factors.

INTRODUCTION

Mangrove plants are unique because they exhibit characteristics of both terrestrial and marine vegetation **(Zalessa *et al.*, 2025)**. Generally, mangroves have a distinctive root system called pneumatophores, which are specialized aerial roots. This root system is an adaptation to oxygen-deficient or even anaerobic soil conditions. The mangrove ecosystem is a type of aquatic ecosystem that thrives on muddy substrates influenced by tidal seawater and freshwater flowing from river estuaries. According to Wailisa *et al.* in the study of **Sreeparvathi *et al.* (2024)**, mangrove ecosystems are critical for coastal areas due to their role in protecting these regions by attenuating high waves, tsunamis, strong winds, and saltwater intrusion. Additionally, mangrove ecosystems serve as spawning grounds, nursery grounds, and feeding grounds for aquatic organisms **(Liles *et al.*, 2021; Nhon *et al.*, 2024; Song *et al.*, 2024)**

The roles and functions of mangrove ecosystems may diminish or even disappear when the ecosystem is damaged **(Safitri *et al.*, 2020; Kasim, 2021; Elumalai *et al.*, 2024; Ibrahim *et al.*, 2024; Vora *et al.*, 2024)**. According to the Indonesian Ministry of Environment Decree No. 201 of 2004, one of the standard criteria for assessing mangrove damage is mangrove density or coverage. Damaged or degraded mangrove ecosystems can negatively impact water quality **(Breckwoldt *et al.*, 2016; Kim et *al.*, 2018; Kasim, 2021; Mishra *et al.*, 2023; Song *et al.*, 2024)**. A decline in water quality will, in turn, affect all components within the mangrove ecosystem. Akamaking *et al.* in the study of **Neres *et al.* (2024)** also noted that coastal water conditions significantly influence the productivity and functionality of coastal ecosystems. Poedjirahajoe *et al.* in **Qin *et al.* (2014)** emphasized that habitat quality is a crucial factor supporting the growth, development, rehabilitation success, and management of mangrove ecosystems. Poedjirahajoe *et al*. in **Qin *et al.* (2014)** stated that habitat quality influences mangrove growth, as indicated by their density. Changes in habitat water quality factors, such as pH, temperature, dissolved oxygen (DO), and salinity, can impact mangrove vegetation. Mangrove species capable of adapting to altered habitat conditions may dominate the mangrove area, potentially displacing less adaptable species ***(Giffin* et al., 2021; *Guo et al.*, 2024; Triyanti *et al.*, 2024).**

Over the past two decades, mangrove ecosystems have experienced a drastic decline in quality. Currently, remaining mangroves are often found as small communities around river estuaries, typically 10–100 meters thick, dominated by *Avicennia marina*, *Rhizophora mucronata*, and *Sonneratia caseolaris*, each with unique benefits. For example, *Avicennia* trees are known for their ability to accumulate heavy metal pollutants in their leaves, roots, and stems, thus serving as natural filters to reduce marine pollution. They also provide economic benefits, such as timber, and act as protective buffers for terrestrial and marine ecosystems **(Mahmudi *et al.*, 2021; Rendón *et al.*, 2022; Veloso-Junior *et al.*, 2023; Carvajal-Oses *et al.*, 2024)**. Mangrove vegetation consists of trees and shrubs belonging to eight families and 12 genera of flowering plants, including *Avicennia*, *Sonneratia*, *Rhizophora*, *Bruguiera*, *Ceriops*, *Xylocarpus*, *Lumnitzera*, *Laguncularia*, *Aegiceras*, *Aegialitis*, *Scyphiphora*, and *Conocarpus* **(Brown *et al.*, 2023; Carpenter *et al.*, 2024; Corona-Salto *et al.*, 2024)**. Mangrove ecosystems, typically dominated by *Rhizophora*, *Avicennia*, *Sonneratia*, and *Bruguiera*, have unique adaptations that enable them to thrive in acidic, anoxic, waterlogged, saline, unstable, and tidally influenced muddy substrates **(Susiana, 2015)**.

Mangrove plants adapt to low oxygen levels in aquatic environments through distinctive root systems, such as stilt roots, buttress roots, and knee roots. Stilt roots spread extensively on the substrate surface and feature pneumatophores—pencil-shaped roots that grow vertically above the substrate to absorb oxygen from the air, as seen in

Avicennia spp., *Xylocarpus*, and *Sonneratia* spp. Unlike stilt roots, buttress roots emerge from tree trunks and penetrate the substrate surface, lacking pneumatophores but containing lenticels—tiny pores facilitating air exchange and oxygen absorption, as found in *Rhizophora* spp. Mangrove forests are habitats for diverse wildlife, including fruit bats, monkeys, proboscis monkeys, monitor lizards, crocodiles, snakes, frogs, herons, sea eagles, and more **(Numbere & Aigberua, 2022; Rahmat *et al.*, 2025)**. Mangrove forest destruction has various impacts, such as increased saltwater intrusion into inland areas. Converting mangrove forests into aquaculture zones can lead to prolonged waterlogging, creating breeding grounds for mosquitoes and consequently increasing malaria cases among nearby communities. Mangrove forests provide several ecological functions, including producing large quantities of detritus from fallen leaves, twigs, flowers, and fruits. Some of this detritus serves as food for detritus-feeding macrobenthos, while the rest is decomposed by bacteria into nutrients that enhance water fertility.

Tanjungpinang City, located in the Riau Islands, has a mangrove ecosystem covering approximately 1,300 hectares, of which 100 hectares have been damaged due to logging and land reclamation for settlements and industries. The converted mangrove areas have caused flooding in several parts of Tanjungpinang City. The local government has initiated conservation efforts to preserve the remaining mangrove forests to maintain their existence and ecological benefits. The mangrove ecosystem in Tanjungpinang is a designated natural conservation area, particularly in Sei Carang. The estuarine waters of Sei Carang are influenced by tidal seawater. The mangrove ecosystem acts as a buffer, protecting against flooding and shielding the coast from waves and currents **(Ci *et al.*, 2023; Hagger *et al.*, 2024; Vora *et al.*, 2024; Yulma *et al.*, 2025)**. Mangrove ecosystem degradation in Sei Carang began with bauxite mining activities in 2018. The area now features natural mangrove vegetation, post-mining zones, and degraded mangrove vegetation due to logging activities. This study aimed to analyze the ecological characteristics of mangroves and the challenges in mangrove rehabilitation in the Sei Carang waters of Tanjungpinang City.

MATERIALS AND METHODS

This research was conducted on December 4, 2024, within the mangrove ecosystem located in the estuarine waters of Sei Carang, Tanjungpinang City, Riau Islands Province, Indonesia (Fig. 1). The site is characterized by a dynamic coastal interface influenced by tidal fluctuations, riverine input, and urban development. The mangrove area represents a transitional zone subjected to both natural and anthropogenic pressures, making it a suitable case study for examining mangrove ecosystem dynamics and management challenges.

To ensure comprehensive data collection, the following tools and instruments were utilized:

a. Global Positioning System (GPS): to record the exact coordinates of each sampling point, enabling spatial mapping of ecological patterns;
b. Compass: to determine transect orientation in relation to tidal and river flow directions;
c. Digital thermometer: for measuring both ambient and surface water temperature;
d. Portable pH meter: to assess water acidity, which influences mangrove growth and nutrient cycling;
e. Handheld refractometer: for measuring salinity, a key abiotic factor affecting species zonation in mangrove ecosystems;
f. Dissolved Oxygen (DO) meter: to evaluate oxygen levels in the water, essential for aquatic life and microbial processes;
g. Field notebook, data sheets, and writing instruments: for manual recording of observational and numerical data during fieldwork.

To analyze the mangrove community structure, a stratified random sampling approach was applied using line transect and quadrat methods:

a. Three line transects were established perpendicular to the shoreline, extending from the water edge to the landward zone, with each transect spaced approximately 50 meters apart to capture spatial variability.
b. Along each transect, quadrats measuring 10 m × 10m were placed at 25-meter intervals. Within each quadrat, all mangrove trees were identified to species level using standard taxonomic keys.

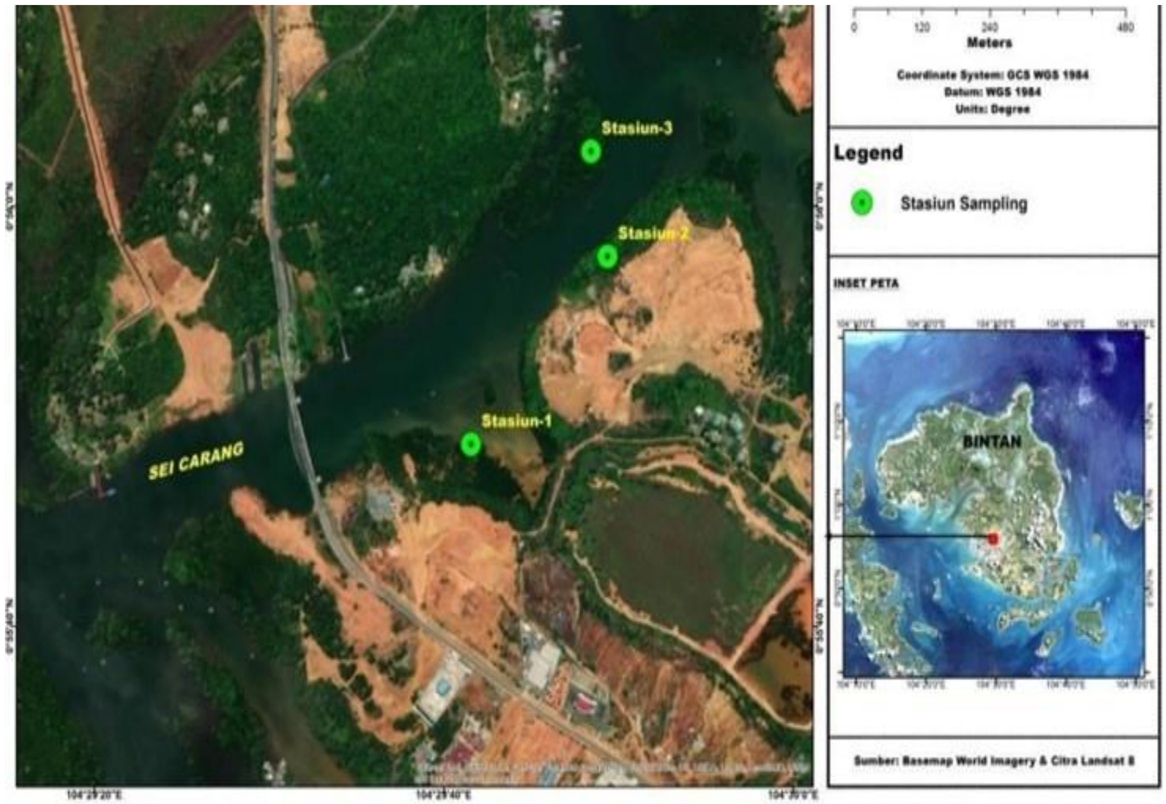

Fig. 1. The location of research

RESULTS

Overview of mangroves in Sei Carang

The estuarine waters of Sei Carang are surrounded by mangrove vegetation, primarily along the outer boundaries where the mangroves meet the estuarine waters. *Sonneratia* sp. and *Avicennia* sp. dominate the open areas, while *Bruguiera* sp., *Rhizophora* sp., and *Xylocarphus* sp. are found in the central zones. The mangroves in the Sei Carang estuary have experienced significant degradation due to bauxite mining activities and the exploitation of mangroves for land conversion. Transforming mangrove ecosystems into aquaculture areas has increased waterlogging periods, providing breeding grounds for mosquito populations and increasing malaria risks, which negatively affect nearby communities.

Ecological characteristics of mangroves in Sei Carang

The ecological characteristics of mangroves in Sei Carang, Indonesia, reflect the unique interplay of environmental, biological, and hydrological factors typical of mangrove ecosystems. This research addressed the ecological characteristics of mangroves in Sei Carang using physical and chemical environmental analysis.

Salinity

Salinity was measured using a refractometer, with values expressed in parts per thousand (ppt). Salinity is a critical factor influencing the growth, survival, and spatial zonation of mangroves. Measurements revealed salinity levels of 25 o/oo at station 1, 20.1 o/oo at station 2, and 18.1 o/oo at station 3. These values fall within the optimal salinity range for mangrove growth. This indicates that the Sei Carang waters receive a substantial supply of freshwater, reducing salinity to a level below 30 o/oo.

pH

The pH was measured using a pH meter. Results showed values of 6.56 at station 1, 6.69 at station 2, and 6.80 at station 3. These findings indicate that the Sei Carang estuary waters are generally neutral and suitable for mangrove vegetation and aquatic organisms.

Dissolved oxygen (DO)

The dissolved oxygen (DO) levels in Sei Carang were recorded at 15.92mg/ L at station 1, 15.6mg/ L at station 2, and 12.22mg/ L at station 3. According to **Salmin (2005)**, waters are considered good and minimally polluted if the DO level exceeds 5mg/ L. However, high sediment agitation caused by currents may lead to turbidity, reducing sunlight penetration and impairing photosynthesis processes in the water column.

Challenges in mangrove restoration

Several challenges were identified in mangrove restoration efforts in Sei Carang: (a) Lack of Monitoring and Supervision: Insufficient monitoring has resulted in uncertainties regarding the long-term success of mangrove restoration efforts; (b) Absence of Clear Regulations: The absence of explicit regulations defining which institutions are responsible for mangrove management has led to fragmentation between the Marine and Coastal Resources Agency (DKPL) and the Environmental Agency (DLH), and (c) Planting Failures: Failures in mangrove planting are attributed to several factors, including natural factors such as abrasion and unfavorable tidal conditions hindering seedling growth and poor seedling quality or the use of incompatible species.

DISCUSSION

Restoring mangrove ecosystems is crucial for protecting coastal areas and enhancing environmental resilience. Mangrove restoration is an increasingly important effort to preserve vital coastal ecosystems. **Tian *et al.* (2024)** and **Yulma *et al.* (2025)** emphasizes the importance of rehabilitating degraded mangrove ecosystems, particularly in areas where natural recovery is unlikely to occur. She advocates for the protection of mangrove buffer zones and the strengthening of the cultural and social values associated with this ecosystem. A collaborative approach between local communities and governments is strongly emphasized to achieve sustainable conservation goals. Next, **Moody *et al.* (2005)** criticized previous restoration approaches that were more focused on timber production and the creation of coastal barriers, often resulting in monoculture plantations. They suggested that restoration plans should include various stages of age and species, as well as considering the dynamic natural processes necessary to create a healthy and sustainable forest.

Inácio Da Costa and Macamo (2023) continued by evaluating the success of mangrove ecosystem restoration in Southeast Asia, highlighting six key steps for successful restoration, particularly hydrological restoration methodologies. The authors emphasized that restoring biogeochemical functions in mangrove forests is crucial for long-term success. **Bretzel *et al.* (2023)** expanded the understanding of vegetation and soil characteristics as indicators of restoration pathways, as well as the impacts of natural disasters, such as tropical storms, on the growth of planted mangroves. This research highlighted the importance of adapting to climate change in mangrove forest management strategies. In the context of community-based conservation, **Kookana *et al.* (2020)** explained that mangrove degradation is often caused by human activities, such as land conversion for agriculture and housing development. In addition, the need for local community involvement in conservation efforts was recommended to achieve sustainable outcomes **(Ma *et al.,* 2018; Monroy-Ortiz *et al.*, 2018; Loperte, 2024; Rahmat *et al.*, 2025)**.

Cao *et al.* (2022) proposed that utilizing mangroves in carbon quota markets could be a solution to support the sustainability of coastal forests and the livelihoods of coastal communities. They emphasized the need for sustainable management systems to prevent greater ecological disasters. On the other hand, **Nuyts *et al.* (2024)** discussed the importance of hydrological classification as a practical tool for mangrove restoration, highlighting that many restoration projects fail due to unsuitable site conditions. They recommended the Ecological Mangrove Restoration (EMR) approach, which focuses on site physical preparation. While, **Robledano *et al.* (2018)**, in their study, provided a global synthesis on the gaps found in coastal habitat restoration research, emphasizing the need to identify knowledge gaps to improve restoration effectiveness. They pointed out that many existing studies do not cover species interactions that can influence restoration success. In this respect, **McGregor and McGregor (2020)** discussed the importance of community involvement in ecosystem restoration projects, as well as the challenges faced in implementing technologies such as machine learning. They illustrated the need for an adaptive framework that considers local needs to improve restoration outcomes. Through this analysis, it is evident that the challenges in mangrove restoration involve interconnected ecological, social, and economic aspects, requiring a holistic and collaborative approach to achieve long-term success **(Sarkar & Bhattacharya, 2003; Winograd, 2016; de Lima & Coutinho, 2024; Dong *et al.*, 2024; Li *et al.*, 2024; Loperte, 2024; Rangel-Buitrago *et al.*, 2024)**.

CONCLUSION

The research findings indicate that the ecological characteristics of the mangrove ecosystem in the Sei Carang estuarine waters are favorable for the existing mangrove vegetation, as evidenced by the conformity of the measured parameters. Additionally, the challenges faced in mangrove restoration in Sei Carang, Tanjungpinang City, include insufficient monitoring, unclear institutional responsibility for mangrove management, and natural factors.

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