



| Research Article

Analysis of the Mangrove Forest Degradation Level in Pasar Rawa Village, Gebang Subdistrict

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Abstract: Mangrove ecosystems play a vital role in providing coastal protection, carbon sequestration, and ecological resilience. However, increasing degradation due to anthropogenic pressures threatens their sustainability. This study examines the variation in mangrove vegetation structure in Pasar Rawa Village, North Sumatra, by evaluating ecological conditions across three transects with varying levels of degradation. Using the nested sampling method, data were collected on species composition, density, and regeneration across seedling, sapling, and tree strata. Results show a clear degradation gradient: Transect 1 (light damage) is dominated by *Rhizophora sp.* with a stable community; Transect 2 (moderate damage) shows greater species diversity and transitional succession; Transect 3 (severe damage) has low density and species dominance. While natural regeneration is still present in all transects, its success depends on controlling anthropogenic activities and supporting ecological recovery. Therefore, adaptive conservation strategies that include community participation, regulation enforcement, and species-specific replanting are crucial. These findings offer a spatially explicit model for mangrove rehabilitation based on degradation levels, contributing to both scientific knowledge and local policy development.

Keywords: Mangrove Degradation; Vegetation Structure; Ecological Gradient; Natural Regeneration.

1. INTRODUCTION

Indonesia is one of the largest archipelagic countries in Southeast Asia, with vast coastal natural resources and diverse ecosystems scattered across Java, Sumatra, Kalimantan, Sulawesi, Papua, and the Maluku Islands (Safnowandi, 2021). The coastal areas of Indonesia have unique characteristics as they consist of physical, biological, and social systems that interact with one another (Hafsaridewi et al., 2019). This region is also highly vulnerable to environmental and anthropogenic pressures. Various activities, such as settlement, fisheries, agriculture, and tourism, often exert pressure on the sustainability of coastal resources (Haryanto et al., 2020).

One of the most essential and distinctive coastal ecosystems is the mangrove ecosystem. Mangroves are vital ecosystems that provide social, economic, and environmental services (Permana et al., 2024). This ecosystem thrives in tidal zones with muddy substrates and brackish waters, typically found along coastlines and river estuaries (Kusmana & Rifana, 2023). Mangroves provide coastal protection, support biodiversity, and play a crucial role in the global carbon cycle, absorbing carbon dioxide and buffering against climate change.

They also provide direct and indirect economic benefits to local communities, serving as natural habitats for various species of fish, crabs, and shellfish, and as protective zones for seagrass beds and coral reefs (Rusnani et al., 2021).

Although Indonesia has the largest mangrove forest cover in the world, the degradation of this ecosystem continues to increase year by year. Several factors have been identified as the leading causes of mangrove degradation, such as pollution, uncontrolled land conversion, and illegal logging activities (D. P. Sari et al., 2022). The considerable degradation can reduce the functions and benefits of mangrove ecosystems, which not only decreases biodiversity and ecosystem services but also increases the vulnerability of coastal areas to natural disasters such as tidal floods, coastal erosion, and tsunamis (Harefa et al., 2022).

One of the coastal areas showing significant signs of mangrove forest degradation in North Sumatra Province is Pasar Rawa Village, Gebang District, Langkat Regency. This area used to have a high ecological function with natural mangrove ecosystems, providing coastal protection, habitat provision, and supporting the local economy (R. Sari et al., 2023). However, in recent decades, this area has experienced large-scale exploitation by the local community for charcoal production through illegal and unsustainable mangrove logging (Daulay et al., 2023).

The use of mangrove wood for charcoal, though common in Indonesia's coastal regions, has been proven to be one of the leading causes of mangrove forest damage. According to (Utomo et al., 2018), intensive mangrove logging disrupts nutrient cycles and causes the loss of the upper soil layer, which is crucial for natural regeneration. This can result in permanent disturbances to the succession process, drastically altering the dynamics of the coastal ecosystem.

In addition to exploitation, the area is also vulnerable to land conversion for settlement and traditional shrimp ponds, which has become a common trend in the coastal regions of North Sumatra (Alamsyah et al., 2022). According to the Ministry of Environment and Forestry, North Sumatra is one of the provinces experiencing a significant decline in mangrove forest cover, especially along the eastern coast, due to human activities and a lack of participatory natural resource management.

In response to these conditions, the local government can implement various policies to maintain the development of this ecosystem (Harefa et al., 2023). One of the policies involves interventions by the Forest Management Unit (KPH) and the Village Forest Management Institution (LPHD) through replanting and mangrove forest rehabilitation programs (Dharma, 2024). Through these policy efforts, it is expected that the mangrove degradation in Pasar Rawa Village can be gradually restored, beginning with the recovery of mangrove quantity and continuing with the minimization of human-induced damage through consistent monitoring. Although this initiative is commendable, Hauliah (2021) the success of rehabilitation does not solely rely on planting actions but also on continuous evaluation of the biophysical conditions, natural regeneration, and community involvement in long-term maintenance.

However, significant gaps remain in the existing literature on mangrove degradation and rehabilitation. Most prior studies have predominantly focused on administrative and socio-economic aspects, while biophysical assessments, particularly those examining vegetation structure across degradation gradients, are still very limited, especially at micro scales such as village-level ecosystems. Moreover, studies that integrate quantitative analysis of vegetation community structure (*from seedling to mature tree strata*) with spatially explicit anthropogenic pressures are scarce. The application of degradation-based zonation approaches for formulating site-specific restoration strategies has also been underutilized in Indonesia, despite its proven effectiveness in several international studies (Gerona-Daga & Salmo, 2022).

Therefore, this study aims to address the aforementioned research gap by developing an evaluative approach to assess the structure of mangrove vegetation communities based on ecological degradation levels, such as biodiversity variation, in Pasar Rawa Village. The methodology employs a combination of line transect and nested plot techniques to identify and analyze vegetation structure across different growth strata (Putri et al., 2021). The analytical results will be used to construct a degradation zonation model, which will serve as the basis for designing adaptive and site-specific rehabilitation strategies. Accordingly, this study not only generates quantitative data on species composition and density but also provides essential ecological insights such as biodiversity metrics related to the potential for natural regeneration and the recovery capacity of degraded mangrove zones. Through this approach, the study is expected to offer both scientific and practical

contributions to mangrove conservation efforts at local and national levels, while also enriching the scientific literature on mangrove ecosystem dynamics in the context of degradation and recovery.

2. RESEARCH METHODS

This research was conducted in Dusun X Paluh Baru, Pasar Rawa Village, Gebang Subdistrict, Langkat Regency, North Sumatra. Geographically, Pasar Rawa Village is located at the coordinates 4°01'12.0"N 98°23'24.0" E, and the study was carried out in April 2024. This location was selected due to its diverse ecosystem characteristics, encompassing mangrove vegetation zones with varying levels of degradation. Observations were conducted during regular tidal periods to minimize disturbances from extreme hydrological dynamics that could affect the validity of the field data.

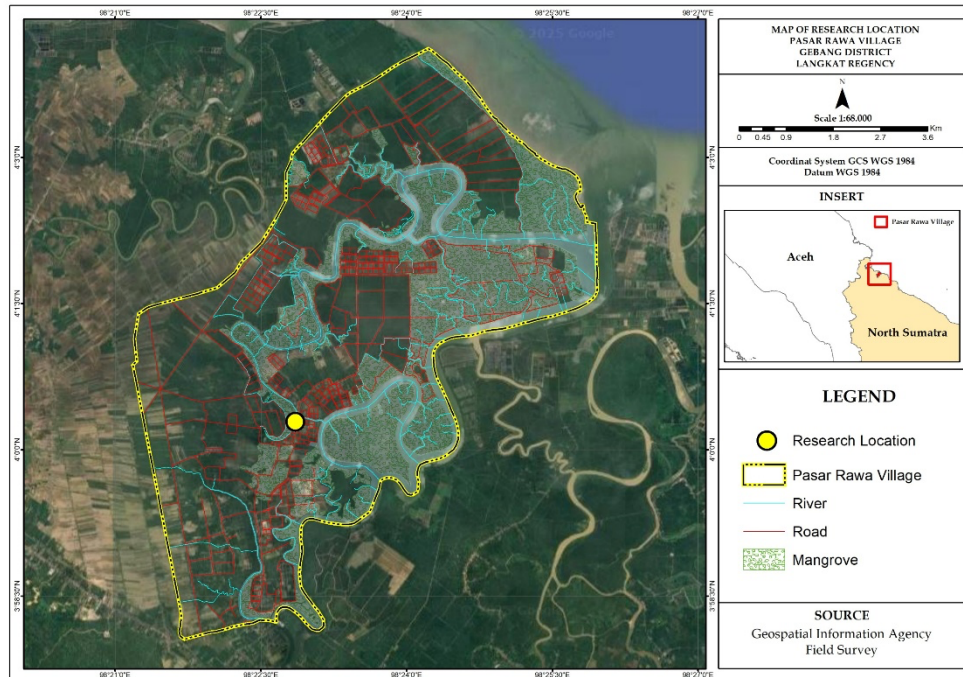


Figure 1. Research Location Map (Source: Data Processing, 2025)

Vegetation data collection was carried out using the Nested Sampling method, which is a combination of the transect method and fixed-size plot sampling, as adopted from the standard mangrove ecological research method (Putri et al., 2021). This technique enables a hierarchical analysis of vegetation composition and structure, categorizing vegetation into three growth classes: seedlings, saplings, and trees. A total of three transect lines were established perpendicular to the river, extending toward the land. Each transect represents different vegetation conditions, with two transects representing degraded areas and one serving as a control with relatively good conditions. The length of each transect varied:

- Transect 1 was 90 meters long, comprising nine plots,
- Transect 2 was 80 meters long, comprising eight plots
- Transect 3 was 70 meters long, comprising seven plots.

Along each transect, observation plots of different sizes were established based on growth categories: 10 m × 10 m for trees (diameter >10 cm), 5 m × 5 m for saplings (height 1–5 m and DBH <10 cm), and 2 m × 2 m for seedlings (height <1 m). Plot placement was carried out systematically and randomly to represent variation in vegetation conditions within each transect optimally. In this data collection, the Tracklia application was used to determine the coordinate points of the plot to be studied. The primary parameter measured in each plot was vegetation density, which was calculated using the following formula:

$$\text{Density (ind/m}^2\text{)} = \frac{\text{number of individuals/species}}{\text{total area of observation plot}}$$

This calculation was used to determine species distribution and population density in each mangrove ecosystem zone. Subsequently, the collected data were analyzed using quantitative descriptive analysis to compare vegetation structure and density among transects and to identify species dominance. This analysis was also used to assess the level of degradation and the success of rehabilitation based on the distribution of natural regeneration and the influence of ecological disturbances in each transect.

3. RESULTS AND DISCUSSION

Mangrove Vegetation Structure Based on Ecosystem Damage Gradation

Observations on the vegetation structure of mangrove forests in Pasar Rawa Village were conducted using a combination approach that combines the line transect method for tree-level analysis, and the nested plot method for seedling and sapling strata. This observational design is shown in **Figure 2**.

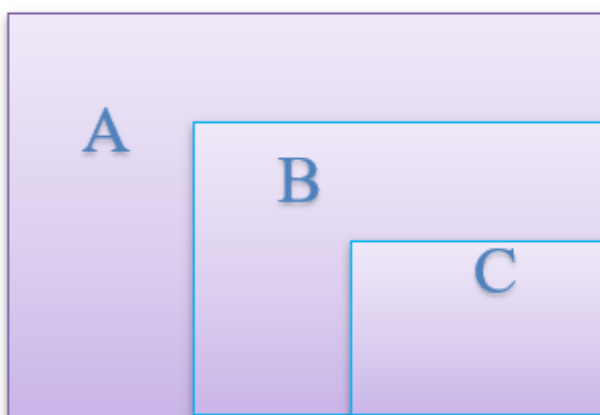


Figure 2. Observation Plot (Source: Putri et al., 2021)

Each observation unit was classified into growth categories with different plot sizes, namely 2 m × 2 m for seedlings, 5 m × 5 m for saplings, and 10 m × 10 m for trees. The plots were systematically placed along three main transects, selected based on the level of vegetation degradation: transect 1 (low degradation), transect 2 (moderate degradation), and transect 3 (severe degradation). The establishment of these transects aimed to represent the spatial gradient of ecosystem degradation.

Based on the mangrove vegetation inventory conducted along the three observation transects, significant differences in structure and species composition were found between the locations. These differences reflect the ecological conditions of each zone as well as the level of environmental pressure experienced. Transect 1, categorized as an area with low degradation, exhibited a relatively stable community structure. The vegetation community in this transect was dominated by two main species, *Rhizophora* sp. and *Bruguiera* sp., with *Rhizophora* sp. occupying the dominant position in terms of both frequency of occurrence and ecological importance value.

The consistent presence of *Rhizophora* sp. along the transect indicates its high adaptive capacity to muddy substrates, anaerobic conditions, and moderate salinity, which are characteristic of tropical mangrove environments. Its strong prop roots and regenerative ability through propagules are the main factors contributing to this species' success in dominating the community. In contrast, transect 2 presented a more complex and diverse vegetation structure, comprising four main species: *Ceriops* sp., *Bruguiera* sp., *Avicennia* sp., and *Sonneratia* sp. This higher species diversity suggests that the transect is in a transitional stage of vegetation succession, where the recovery process is ongoing but has not yet reached a stable state.

The presence of *Avicennia* sp. and *Sonneratia* sp., which are generally more tolerant of fluctuating oxygen levels and high salinity, indicates an adaptive dynamic in response to environmental pressures. This species composition suggests that, although degradation has occurred, the ecosystem remains capable of supporting a

variety of mangrove species, thereby reinforcing the classification of transect two as a moderate degradation zone. Furthermore, transect 3 represents the most severely degraded ecosystem condition. The vegetation identified consisted of only two species, namely *Bruguiera* sp. and *Rhizophora* sp., with very low density and uneven distribution.

Vegetation Density and Natural Regeneration Potential of Mangroves

The low number of species and low density of vegetation indicate that the natural regeneration process is hampered, which is most likely caused by the loss of protective structures of mature vegetation, damage to the substrate due to erosion, and excessive anthropogenic pressures such as logging and land conversion. This condition creates an open zone that is very vulnerable to direct seawater infiltration and does not support the growth of seedlings or saplings.

Table 1. Mangrove Vegetation Density Values Based on Observation Routes

Location	Density (btg/Ha)			Standard
	Tree	Stake	Seedling	
Line 1	5500	31100	25000	Light Damage = 1500
Line 2	900	5400	12000	Moderate Damage = 1500–2000
Line 3	100	8500	12000	Heavy Damage = >2000

(Source: Kementerian Lingkungan Hidup, 2004)

Although the tree density in lanes 2 and 3 is relatively low, the regeneration value in the seedling and sapling strata remains relatively high. Lane 1, for example, recorded a sapling density of 31,100 stems per hectare and seedlings of 25,000 stems per hectare. Meanwhile, lanes 2 and 3 each recorded a seedling value of 12,000 stems per hectare, indicating that the potential for natural regeneration has not been entirely lost. This condition suggests that if environmental factors, such as light intensity, soil fertility, and groundwater availability, are appropriately managed, then long-term regeneration success is still



Figure 3. Mangrove Damage (Source: Field Survey, 2024)

Nevertheless, high densities of seedlings and saplings do not automatically guarantee the success of the successional process. External factors such as anthropogenic pressures and faunal disturbances can hinder the transition of vegetation toward the tree stratum. Field identification revealed that human disturbances, such as illegal logging for fuel and intensive fishing activities, have directly damaged the seedling zones. Additionally, biotic pressures from fauna such as *Littoraria* sp. (leaf-eating snails), crabs that cut young stems, as well as disturbances from monkeys and birds that prey on plant shoots, also serve as significant limiting factors for regeneration.

In structural ecology, the dominance of *Rhizophora sp.* across all transects indicates that this species possesses competitive advantages. Its adaptability to high salinity, anaerobic substrates, and the presence of prop root systems makes it a pioneer species in degraded mangrove ecosystems. This has been confirmed in various global studies on coastal vegetation resilience.

The mangrove vegetation structure in Pasar Rawa Village shows potential for ecosystem restoration, particularly through approaches based on natural regeneration. However, this potential can only be fully realized through integrated conservation efforts, combined with participatory management by the local community. Ecology-based interventions, such as protecting seedling zones and controlling anthropogenic pressures, must be central to long-term rehabilitation strategies.

Gradation of Damage and Variation of Mangrove Vegetation Structure

The differences in mangrove vegetation structure across the three observation transects in Pasar Rawa Village reveal a strong correlation between ecosystem degradation levels and the dynamics of the vegetation community. Transect 1, which experienced minor damage, exhibited dominance by *Rhizophora sp.* and a stable community structure. The predominance of *Rhizophora* reflects stable substrate conditions and relatively minimal disturbances. This aligns with the findings of those who state that *Rhizophora* has a high adaptive capacity to tidal conditions and muddy substrates, making it an indicator species of healthy and optimally functioning mangrove ecosystems (Cerón-Souza et al., 2021). Similarly, (Rahmania et al., 2019) *Rhizophora* was found to show superior resilience, especially in tidal swamp river areas, thereby enhancing the overall ecosystem's resistance. Given this context, it is recommended that *Rhizophora* be prioritized for planting in river swamp habitats due to its higher survival stability compared to other mangrove species such as *Ceriops* or *Bruguiera*.

Conversely, Transect 2, which experienced moderate degradation, exhibited greater species diversity, with four main species present: *Ceriops sp.*, *Bruguiera sp.*, *Avicennia sp.*, and *Sonneratia sp.* This composition illustrates a secondary succession dynamic—a natural recovery process that occurs in ecosystems disturbed by human activities. The observed diversity supports (Moitinho et al., 2022), who noted that mangrove areas undergoing recovery tend to exhibit higher species richness than areas that are either highly stable or severely degraded due to the competition between pioneer and climax species. This condition is also consistent with (Taketani et al., 2018), who suggested that regenerating mangroves show microbial decomposition activity, enriching the substrate with nutrients and enhancing the structural stability of the ecosystem.

In contrast, Transect 3, which suffered severe degradation, demonstrated a simplified vegetation structure with only two identified species and very low density. This loss of structural complexity indicates the presence of intense ecological stressors, such as poor substrate quality, pollution, and human activities like land conversion. Gupta (2021) Reported that heavily disturbed mangrove areas often lose their regenerative capacity due to damaged root systems, limited seed dispersal, and disrupted natural hydrological cycles. Similarly, (Fickert, 2020) concluded that severely degraded mangrove ecosystems tend to retain only a few highly tolerant species and require several years to fully recover.

These three transects clearly illustrate a gradient of ecosystem conditions, ranging from stable to highly degraded. The structural differences underscore that a uniform rehabilitation strategy is ineffective. Transect 1 requires protection to maintain its stability, Transect 2 can benefit from passive restoration and natural growth monitoring, while Transect 3 necessitates active interventions such as replanting and substrate restoration. This approach aligns with the adaptive rehabilitation principles proposed by Young et al. (2022), who emphasized that mangrove restoration strategies should be tailored to the local level of damage and ecological recovery potential. It is essential to note, however, that severely degraded mangrove ecosystems require extended periods to recover; therefore, scientifically informed approaches are crucial, considering both abiotic and biotic factors, and prioritizing the planting of resilient mangrove seedlings.

Natural Regeneration and Its Challenges in Mangrove Ecosystem Rehabilitation

This study found that although Transects 2 and 3 exhibit low tree density, the high number of seedlings and saplings indicates that natural regeneration processes are still ongoing. This finding suggests that the

mangrove ecosystem retains some capacity for recovery despite being disturbed. A similar observation was made by (Damastuti et al., 2022), who reported that the presence of seedlings and saplings serves as an early indicator of the ecosystem's natural recovery potential. (Dookie et al., 2024) Also highlighted that the extent of seedling and sapling distribution is a critical metric in determining the likelihood of successful mangrove regeneration.

However, this regenerative potential does not automatically guarantee long-term restoration success. Anthropogenic disturbances, such as illegal logging, aquaculture, and intensive fishing, remain major threats to the survival of seedlings and saplings. (Sudhir et al. (2022) In their study of the Indian coastline, researchers noted that despite promising early regeneration, human activity often leads to premature seedling mortality unless accompanied by effective land-use control. This is further supported by (Ellison et al., 2020) those who emphasized the need for active monitoring and control during the seedling and sapling stages to assess development and identify causes of mortality. The surrounding activities within and near the mangrove ecosystem greatly influence regeneration outcomes.

In addition to human disturbances, biotic factors such as interspecific competition and predation by fauna also affect the dynamics of young vegetation. (Spadaro & Butler (2021) found that seedlings of certain species often fail to mature due to herbivorous crab predation and competition from dominant species. This implies that seedling presence alone does not guarantee successful tree establishment unless stable ecological conditions support it. According to (Hsiung et al., 2024), using slightly older seedlings may improve survival rates under anthropogenic pressure, as mature seedlings tend to be more resilient than younger ones. Furthermore, (Elías et al., 2021) suggested that using physical protectors or guards for seedlings enhances their resistance to wave action and natural disturbances.

In Transect 2, where moderate damage was observed, seedlings from several species, such as *Bruguiera* and *Avicennia*, emerged side by side, reflecting diverse early successional dynamics. This aligns with the findings of (Van Hespen et al. (2022) those who noted that mangrove areas undergoing recovery often exhibit high seedling-level diversity before species dominance is eventually established. Meanwhile, in Transect 3, which experienced severe degradation, although seedlings were still present, their types were more limited and their distribution was uneven. These findings suggest that while regeneration processes continue to occur, their success is highly dependent on complex interactions between ecological factors and environmental pressures.

Given the varying degrees of mangrove degradation across the three transects, efforts are needed to regulate and control mangrove growth. One such effort is the implementation of community-based conservation, which integrates local knowledge and active community participation through co-management approaches. This includes replanting efforts, controlling invasive species, protecting mangrove areas from illegal logging, and leveraging both national and international policy frameworks, such as the Ramsar Convention, CITES, and the UNFCCC, to establish protected areas and strengthen law enforcement.

4. CONCLUSION

Observations of mangrove vegetation structure in Pasar Rawa Village reveal a gradient of ecosystem degradation, as reflected by variations in species composition, vegetation density, and the potential for natural regeneration across the three observation transects. Transect 1 (lightly degraded) exhibits a stable community structure dominated by *Rhizophora* sp. and *Bruguiera* sp., characterized by high tree density. Transect 2 (moderately degraded) shows higher species diversity but lower tree density, indicating a transitional phase towards recovery. In contrast, Transect 3 (severely degraded) demonstrates significant degradation, marked by low species dominance and uneven vegetation distribution. Although regeneration through seedling and sapling strata is still observed across all transects, the success of long-term succession depends heavily on the management of anthropogenic pressures and biotic factors. Therefore, conservation strategies that integrate ecological aspects with active community participation are crucial for supporting sustainable mangrove restoration. Local governments and policymakers are encouraged to actively involve communities in sustainable and ecosystem-based rehabilitation programs, in accordance with national regulations such as the Indonesian Minister of Environment and Forestry Regulation No. P.105/MENLHK/SETJEN/KUM.1/12/2018 on Mangrove Rehabilitation and the principles of Community-Based Resource Management (CBRM). Regular

vegetation monitoring and the strengthening of environmental education at both village and regional levels must also be enhanced to ensure that the restoration process proceeds in an optimal and sustainable manner.

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