



| Research Article

Assessment of Mangrove Degradation Using Vegetation Structure and Environmental Parameters in Gosong Telaga Barat Village, Aceh Singkil Regency, Indonesia

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Abstract: Mangrove ecosystems play a crucial role in maintaining coastal stability and supporting local livelihoods. However, increasing anthropogenic pressures have led to significant degradation in many coastal areas. Previous studies have predominantly focused on large-scale mapping and land cover changes, while local-scale ecological assessments integrating vegetation structure and environmental parameters remain limited. This study aims to analyze mangrove degradation by combining vegetation structure analysis and environmental measurements at a local scale. Field data were collected in October 2023 using a line transect–quadrat method (10 m × 10 m plots). Vegetation parameters included species composition, density, frequency, dominance, and Importance Value Index (IVI), while environmental variables included salinity, temperature, pH, and substrate moisture. Statistical analyses (independent t-test and Pearson correlation) were applied to examine differences and relationships among variables. The results show a low survival rate of 33.20%, significantly below the optimal rehabilitation threshold (60–80%). Environmental factors, particularly salinity and substrate conditions, showed significant correlations with survival and growth parameters ($p < 0.05$). IVI analysis indicates dominance of specific species with limited regeneration capacity. These findings suggest that mangrove degradation in the study area is driven by both ecological constraints and inappropriate rehabilitation practices. This study contributes to the development of an ecologically based restoration approach by integrating vegetation and environmental indicators at the local scale.

Keywords: Mangrove Degradation; Vegetation Structure; Coastal Ecosystem; Ecological Restoration; Environmental Parameters

1. INTRODUCTION

Indonesia is recognized as the country with the largest mangrove ecosystem area in the world. According to data from the Ministry of Environment and Forestry (KLHK) in 2024, the total mangrove area in Indonesia reaches approximately 3.44 million hectares, distributed across various coastal regions of the archipelago. This area represents a significant proportion of global mangrove coverage and places Indonesia in a strategic position in maintaining the sustainability of global coastal ecosystems (Heriamsal & Amin, 2024). Mangrove ecosystems play a crucial ecological role, including acting as a natural barrier that protects coastlines from abrasion, stabilizing sediments, providing habitat for various marine organisms, and serving as one of the most effective natural carbon sinks within the blue carbon system (Alongi et al., 2020). In addition, mangroves also provide

important socio-economic benefits for coastal communities by supporting fisheries productivity, conserving biodiversity, and increasing coastal resilience to the impacts of climate change (Suriadi et al., 2024).

Despite their significant ecological and socio-economic importance, mangrove ecosystems are currently facing various pressures due to human activities and environmental changes. Over the past three decades, Indonesia is estimated to have lost approximately 800,000 hectares of mangrove forests due to land conversion, resource exploitation, and coastal development (Ilman, 2016; Sasmito et al., 2023). Mangrove degradation can lead to serious ecological impacts, including biodiversity loss, increased coastal vulnerability to erosion, reduced carbon sequestration capacity, and disruption of ecological functions in coastal ecosystems (Da Costa et al., 2023). Ultimately, these impacts can affect the livelihoods of coastal communities that heavily depend on the sustainability of mangrove resources.

Aceh Singkil Regency is one of the coastal regions located in the western part of Sumatra Island that possesses a relatively extensive mangrove ecosystem and plays an important role in maintaining coastal environmental stability (Manik et al., 2023). However, several mangrove areas in this region have begun to face considerable pressure from human activities. One of the areas facing this issue is Gosong Telaga Barat Village. Various activities, such as mangrove wood harvesting, land conversion, and unsustainable use of coastal resources, have become major drivers of mangrove ecosystem degradation in this region (Efriyeldi et al., 2018). In addition, low ecological awareness and limited information regarding the importance of mangrove functions have also accelerated the degradation process. In some cases, local communities use mangrove wood for household needs, such as fencing or simple construction, without accompanying replanting efforts (Cahyani et al., 2024).

Efforts to understand the extent of mangrove ecosystem degradation cannot rely solely on the analysis of changes in land cover area; they also require assessments of the structure and condition of mangrove vegetation. Vegetation structure, which includes species composition, density, frequency, dominance, and diversity, is an important ecological indicator for assessing the health and stability of mangrove ecosystems (Bunting et al., 2022). Vegetation analysis can provide a more detailed understanding of the extent of ecosystem damage, regeneration capacity, and the sustainability potential of mangrove ecosystems in a particular area. Therefore, a vegetation-based analytical approach is essential for a more comprehensive evaluation of mangrove ecosystem conditions.

Previous studies on mangrove ecosystems have generally focused on mapping mangrove distribution, changes in mangrove forest extent, and analyses of ecological and economic benefits at broader regional scales (Ebeler et al., 2025). However, studies that specifically analyze the extent of mangrove degradation based on vegetation structure at the local scale, particularly at the village level, remain relatively limited, especially in the coastal areas of Aceh Singkil Regency. This limitation indicates a research gap in understanding the actual ecological conditions of mangrove ecosystems at the local scale, which is often the primary location where degradation processes occur.

Local-scale studies are therefore crucial, as they can provide more detailed, context-specific ecological information to support more effective mangrove management and rehabilitation planning. Without specific information on vegetation structure and mangrove species composition, mangrove rehabilitation programs often fail to address the actual ecological problems occurring in the field (Marquez & Olavides, 2024). Consequently, research that examines mangrove vegetation conditions in greater depth is required to determine the level of mangrove ecosystem degradation in a coastal region.

However, studies integrating vegetation structure and environmental parameters at the local scale remain limited. This gap is important because degradation processes often occur at site-specific levels, directly influencing rehabilitation success. Therefore, this study offers a novel contribution by integrating vegetation structure analysis (IVI) with environmental parameters to identify the main drivers of mangrove degradation and rehabilitation failure at the local scale.

Based on this research gap, this study aims to analyze the extent of mangrove degradation in Gosong Telaga Barat Village, Aceh Singkil Regency, using mangrove vegetation conditions as a basis. The novelty of this research lies in using a mangrove vegetation structure analysis approach as an ecological indicator to assess mangrove ecosystem degradation at the local scale. The findings of this study are expected to contribute to the scientific understanding of mangrove ecosystem conditions and to serve as a basis for developing more sustainable mangrove management and conservation strategies in coastal areas.

2. RESEARCH METHODS

Study Area

This research was conducted in October 2023 in Gosong Telaga Barat Village, Aceh Singkil Regency, Aceh Province, Indonesia. This area is one of the coastal regions with relatively extensive mangrove ecosystems and plays an important role in maintaining coastal environmental stability while supporting local community economic activities, particularly in the fisheries sector. In recent years, mangrove areas in this region have experienced increasing pressure from coastal resource-use activities, such as mangrove logging and land conversion, which may lead to ecosystem degradation. Therefore, this study area was selected to monitor the condition of mangrove vegetation as an ecological indicator of mangrove ecosystem degradation in the coastal area of Gosong Telaga Barat Village.

Vegetation Monitoring Design

This study employed a quantitative descriptive approach using a mangrove vegetation monitoring method to evaluate the structure of the mangrove community at the study site. Vegetation data were collected using the line transect–quadrat method, which is commonly applied in mangrove ecological studies. Transects were established perpendicular to the shoreline and extended inland to represent the natural zonation of mangrove vegetation. The Importance Value Index (IVI) was calculated as the sum of relative density, relative frequency, and relative dominance for each species.

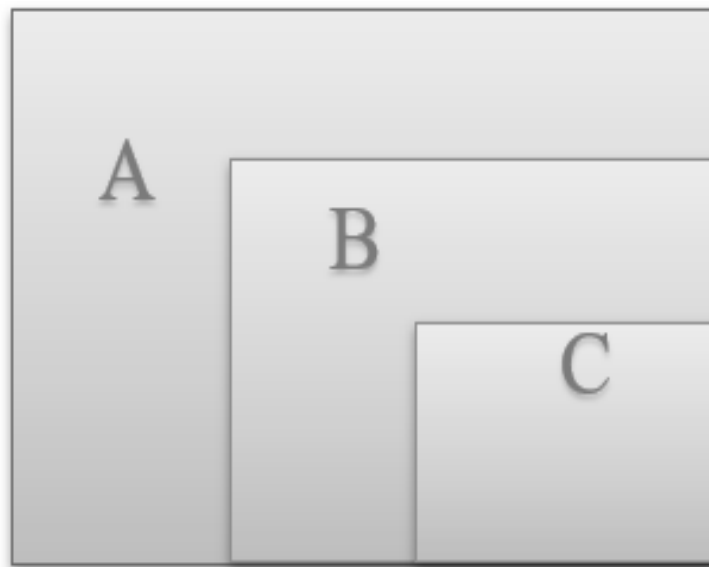


Figure 1. Observation plot (Source: Fitria, 2022)

Along each transect, 10 m × 10 m observation plots were established to monitor mangrove trees. Within each plot, all mangrove individuals were recorded by identifying species, counting individuals, measuring stem diameter at breast height (DBH), and recording tree height. Species identification was conducted based on morphological characteristics using relevant mangrove identification guides. In addition, the coordinates of each plot were recorded using a Global Positioning System (GPS) device to ensure accurate observation locations and to support spatial documentation of the study.

Environmental Parameters and Data Analysis

Environmental, physical, and chemical parameters were also measured at each observation plot to support the interpretation of mangrove vegetation conditions. The parameters observed included water temperature, salinity, water pH, and substrate moisture, which were measured directly in the field using portable measuring instruments. The vegetation data obtained were then analyzed to describe the structure of the mangrove community as an indicator of ecosystem condition and the level of mangrove degradation at the

study site. Vegetation analysis was conducted by calculating species density, frequency, and dominance for each identified mangrove species. These parameters were subsequently used to calculate the Importance Value Index (IVI) to assess the dominance and ecological role of each species within the mangrove community. Environmental parameter data were analyzed descriptively using the ranges of values obtained from field measurements. The results were then interpreted alongside the vegetation analysis to provide a comprehensive overview of the condition of the mangrove ecosystem and the extent of degradation in Gosong Telaga Barat Village, Aceh Singkil Regency. Statistical analysis was conducted using an independent t-test to compare differences between locations and Pearson correlation to examine relationships between environmental variables and vegetation parameters.

3. RESULTS AND DISCUSSION

a. Mangrove Survival Rate

The monitoring results indicate that the mangrove survival rate at the study sites is relatively low. The survival rate was calculated by comparing the number of living plants with the total number of planted mangroves at each study site, while the mortality rate was calculated as the percentage of damaged or dead plants relative to the total number of planted mangroves. The detailed results are presented in the following Table 1.

Table 1. Results of Mangrove Survival Monitoring

Location	Total Planted	Alive	Damage/Dead	Survival Rate (%)	Mortality Rate (%)
Location 1	24.777	9.502	15.275	38,36	61,64
Location 2	27.802	7.957	16.765	28,63	71,37
Total	52.579	17.459	32.040	33,20	66,80

(Source: Data Processing, 2023)

Based on Table 1, the mangrove survival rate at Location 1 was 38.36%, while Location 2 showed a lower rate of 28.63%. Overall, the survival rate of mangroves in the study area reached only 33.20%, while the mortality rate reached 66.80%. These values indicate that most planted mangrove seedlings did not survive during the monitoring period. The low survival rate suggests that the regeneration process of mangrove vegetation in the coastal area of Gosong Telaga Barat Village is facing considerable ecological pressure. This condition may reflect limitations in habitat suitability, environmental disturbances, or other external factors affecting the success of mangrove growth during the early stages of rehabilitation.

Compared with previous studies such as (Wodehouse & Rayment, 2019), the optimal success rate of mangrove rehabilitation generally ranges between 60–80% during the early growth phase, particularly when planting activities consider habitat suitability, hydrological dynamics, and substrate characteristics that support mangrove growth. Therefore, the survival rate observed in this study is considerably lower than the commonly reported success rates in coastal ecological literature. This difference suggests that ecological conditions at the study sites may not fully support optimal mangrove rehabilitation processes.

In addition to environmental factors, the success of mangrove rehabilitation is also strongly influenced by planting techniques and the selection of species that match the natural zoning of mangrove ecosystems. A study (Asbridge et al., 2024) shows that planting activities that do not account for substrate characteristics, tidal patterns, and hydrodynamic conditions can lead to high mortality rates during early growth stages. Mismatches between planted mangrove species and their suitable habitat conditions are also frequently reported as a major cause of mangrove rehabilitation failure in many coastal regions (Muhammad et al., 2025).

Therefore, the low survival rate found in this study not only reflects local environmental constraints but may also indicate early signs of mangrove ecosystem degradation in the coastal area of Gosong Telaga Barat Village. These findings suggest that mangrove rehabilitation efforts in this area require a more ecologically based management approach, taking into account habitat suitability, the restoration of natural hydrological conditions, and the selection of mangrove species that align with coastal environmental zoning. Such an approach is expected to improve rehabilitation success while supporting the sustainable recovery of mangrove ecosystem functions. The independent t-test results indicate a significant difference in survival rates between Location 1 and Location 2 ($p < 0.05$), suggesting that local environmental conditions strongly influence mangrove survival.

b. Spatial Variation in Mangrove Vegetation Damage

Plot-scale analysis shows that mangrove vegetation damage was not evenly distributed across the study sites. Detailed monitoring results for mangrove vegetation at each plot are presented in the following table.

Table 2. Mangrove Vegetation Monitoring Results at Each Plot in the Study Locations

Plot	Location 1			Location 2		
	Planted	Alive	Damage/Dead	Planted	Alive	Damage/Dead
1	2.567	2.483	84	2.395	1.924	471
2	2.709	2.652	57	2.783	243	2.540
3	3.139	3.075	64	2.117	253	1.864
4	3.005	278	2.727	2.336	116	2.220
5	2.534	638	1.896	2.448	1.950	498
6	2.787	86	2.701	2.075	286	1.789
7	2.965	93	2.872	3.045	2.738	307
8	2.660	114	2.546	2.177	295	1.882
9	2.411	83	2.328	1.455	46	1.409
10	–	–	–	3.891	106	3.785
Total	24.777	9.502	15.275	27.802	7.957	16.765

(Source: Field Survey, 2023)

At Location 1, the highest levels of mangrove damage were observed in plots 6-9. In these plots, the number of damaged or dead plants was significantly higher than the number of surviving plants. For example, in plot 6, only 86 plants survived out of 2,787 planted seedlings, indicating an extremely high mortality rate. Similar conditions were also observed in plots 7, 8, and 9, where damaged plants dominated over surviving plants. This suggests that several areas within Location 1 experience considerable environmental pressure that limits mangrove growth during the early rehabilitation stage.

At Location 2, the condition of mangrove damage appears even more severe in some plots. Plot 10 recorded the highest damage level, where only 106 plants survived out of 3,891 planted seedlings, while 3,785 plants were damaged or died. In addition, plots 2, 3, and 4 showed relatively low survival rates. This pattern indicates that ecological conditions in certain areas of Location 2 may be less favorable for the growth of young mangrove plants compared with Location 1.

The spatial variation in mangrove vegetation damage suggests that mangrove degradation in the study area is not uniform but is influenced by local environmental conditions within each observation area. Ecological factors such as substrate characteristics, tidal dynamics, sedimentation rates, and wave intensity can affect mangrove adaptability and growth during the early planting stages (Fillyaw et al., 2021). In addition, unstable hydrological conditions may alter sediment moisture and increase physiological stress in young mangrove plants (Medina-Calderón et al., 2021).

Anthropogenic pressure also contributes to mangrove damage in several research plots. Human activities such as mangrove wood extraction, coastal fishing, and land-use changes may disturb newly planted mangroves, particularly in areas easily accessible to coastal communities. Continuous disturbances may cause ecological stress in mangrove plants and increase the risk of damage. These findings are consistent with (Sunkur et al., 2024), who reported that mangrove degradation generally occurs in a spatially heterogeneous pattern, where damage levels can vary significantly within a single coastal area. Therefore, plot-based monitoring approaches, such as those used in this study, are important for identifying patterns of mangrove vegetation damage in greater detail at the local scale.

c. Mangrove Vegetation Growth Based on Height and Diameter

Mangrove vegetation conditions were also analyzed using growth parameters, including plant height and stem diameter. These parameters were used to assess the development of mangrove plants that survived in the study area. The average height and diameter values for mangrove plants in each observation plot are presented in Table 3.

Table 3. Average Plant Height and Diameter Values

Plot	Average Height (cm)	Average Diameter	Average Height (cm)	Average Diameter
	Location 1	(cm) Location 1	Location 2	(cm) Location 2
1	41,44	3,09	31,86	2,48
2	36,29	2,92	33,42	2,57
3	46,80	3,13	47,11	3,16
4	53,64	3,21	41,64	2,80
5	56,19	3,30	44,12	3,00
6	61,27	3,66	51,40	3,25
7	47,80	3,13	44,90	3,10
8	62,04	3,71	33,20	2,49
9	53,05	3,13	34,10	2,61
10	–	–	41,89	2,88

(Source: Field Survey, 2023)

Based on Table 3, the average height and diameter of mangrove plants differ between the two study locations. At Location 1, the average plant height ranged from 36.29 cm to 62.04 cm, with diameters ranging from 2.92 cm to 3.71 cm. The highest value was found in plot 8, suggesting that environmental conditions there are relatively more favorable for mangrove growth. Meanwhile, at Location 2, the average plant height ranged from 31.86 cm to 51.40 cm, and the average diameter ranged from 2.48 cm to 3.25 cm. In general, growth values at Location 2 tend to be lower than those at Location 1, suggesting that environmental conditions at Location 2 may be less optimal for mangrove development.

The relatively limited growth indicates that most surviving mangroves are still in the early vegetative growth stage. At this stage, mangrove growth is strongly influenced by environmental factors such as nutrient availability, substrate stability, and water salinity. Unstable substrates, excessive salinity, and nutrient limitations may inhibit plant growth and increase the risk of mortality during the early stages of rehabilitation (Ahmed et al., 2022). These findings suggest that mangrove vegetation in Gosong Telaga Barat Village is still in the early stage of ecosystem recovery. This indicates that the success of mangrove rehabilitation programs is determined not only by the number of surviving plants but also by their ability to grow and develop optimally over a longer period (Jamil et al., 2025).

d. Environmental Parameters of the Mangrove Ecosystem

Environmental measurements indicate variations in physical and chemical conditions between the two study locations. The values of the observed environmental parameters are presented in Table 4.

Tabel 4. Physical and Chemical Environmental Conditions at the Study Sites

Physical and Chemical Conditions of the Environment	Location 1	Location 2
Substrate Moisture (%)	4%	5%
Substrate pH	3,6	7,8
Substrate Temperature (°C)	37,8 °C	39,2 °C
Air Temperature (°C)	32,7 °C	33,5 °C
Salinity (‰)	21 ‰	23 ‰

(Source: Field Survey, 2023)

Differences in environmental parameters indicate variations in ecosystem conditions that may influence mangrove growth. At Location 1, the relatively low substrate pH indicates acidic sediment conditions, which may affect nutrient availability and plant nutrient uptake. In contrast, the higher substrate temperature observed at Location 2 may increase physiological stress on young mangrove plants, particularly during early growth stages. Ecologically, environmental parameters such as salinity, temperature, and pH play a crucial role in determining mangrove distribution, growth, and survival rates. High salinity levels can cause osmotic stress in plants and may inhibit mangrove growth by reducing nutrient availability (Barik et al., 2017).

Temperature also plays an important role, as temperatures below 25°C can reduce growth rates and increase plant respiration. Meanwhile, environmental pH influences the growth rates of mangrove-associated microorganisms as well as plant physiological processes, with pH values around 6–7 generally supporting better growth than higher pH levels (Su et al., 2020). Seasonal fluctuations in salinity caused by rainfall and tidal dynamics can also produce periodic growth patterns in some mangrove species, indicating high physiological adaptability to environmental changes (Feng et al., 2020). Therefore, monitoring environmental parameters, as conducted in this study, is important for identifying ecological factors that influence mangrove growth success and for developing more effective mangrove rehabilitation strategies in coastal areas.

e. Indications of Mangrove Degradation and Its Global Ecological Implications

The relatively low mangrove survival rate observed in this study indicates potential degradation of the mangrove ecosystem in Gosong Telaga Barat Village. The recorded survival rate of 33.20% is significantly lower than the commonly reported success rates of mangrove rehabilitation in international studies. This suggests that the regeneration of mangrove vegetation in the study area has not yet occurred optimally due to environmental constraints and external pressures that affect plant growth during the early rehabilitation stages.

Mangrove degradation at the local scale can have broader ecological implications for global coastal systems. Mangrove ecosystems are recognized as among the largest carbon storage systems in coastal environments through blue carbon sequestration, in which mangrove sediments store large amounts of carbon for long periods (Choudhary et al., 2024). The degradation or loss of mangrove vegetation can release stored carbon into the atmosphere, potentially increasing carbon emissions and accelerating global climate change (Adame et al., 2021).

In addition to their role in the carbon cycle, mangroves also provide essential ecological functions as natural coastal protection systems. Mangrove degradation reduces the ability of these ecosystems to dissipate wave energy, prevent coastal erosion, and protect coastal areas from storms and sea-level rise (Temmerman et al., 2023). Several studies have shown that coastal regions experiencing mangrove loss tend to be more vulnerable to climate change impacts and coastal hazards (Foggia et al., 2025).

Therefore, the mangrove degradation identified in this study not only reflects local environmental dynamics but also highlights broader challenges in mangrove ecosystem management and conservation at the global scale. Consequently, mangrove rehabilitation efforts in Gosong Telaga Barat Village should adopt an ecological restoration approach that considers habitat suitability, the restoration of natural hydrological conditions, and the selection of mangrove species appropriate to coastal ecosystem zoning. Furthermore, the involvement of local communities in sustainable coastal resource management is crucial for supporting long-term rehabilitation success.

4. CONCLUSION

Based on the results of this study, the survival rate of mangroves in Gosong Telaga Barat Village was relatively low, at 33.20%, with a mortality rate of 66.80%, indicating that most planted mangrove seedlings did not survive during the monitoring period. This value is considerably lower than the mangrove rehabilitation success rates commonly reported in international studies, suggesting that the ecological conditions at the study site may not fully support optimal mangrove regeneration. The spatial variation in vegetation damage observed across several plots indicates that mangrove degradation in the study area is not uniform but is influenced by local environmental factors, including substrate characteristics, hydrological dynamics, salinity levels, and anthropogenic pressures from coastal community activities.

Furthermore, the relatively low vegetation growth parameters observed across several plots indicate that most surviving mangroves are still in the early stages of vegetative development. This condition suggests that the success of mangrove rehabilitation is not solely determined by the number of seedlings planted, but also by the suitability of environmental conditions that support long-term vegetation growth and development. Therefore, more effective mangrove rehabilitation efforts are needed through an ecological restoration approach that considers habitat suitability, the restoration of natural hydrological conditions, and the selection of mangrove species appropriate to the coastal ecosystem zonation. In addition, strengthening periodic monitoring of mangrove vegetation and promoting local community involvement in coastal ecosystem management are important recommendations to improve the success of rehabilitation programs and support

the sustainability of mangrove ecological functions, including coastal protection and carbon sequestration, in the context of global climate change. This study highlights that the success of mangrove rehabilitation is strongly influenced by environmental suitability rather than by planting intensity alone. Therefore, ecosystem-based restoration approaches that consider hydrological conditions, substrate characteristics, and species suitability are essential for improving rehabilitation outcomes.

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