



Post-Tsunami Vegetation Structure and Diversity of Coastal Forests on Sebesi Island, Lampung, Indonesia

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ABSTRACT

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Sebesi Island is 19.1 km from the Anak Krakatau Volcano, which caused a tsunami in 2018, and is situated in Lampung Bay of the Sunda Strait. Coastal forests are essential for protecting the island from the impacts of erosion and tsunamis. This study analyzed the structure and diversity of coastal forest vegetation on Sebesi Island following the 2018 tsunami, using density analysis, the Important Value Index (IVI), dominance levels, and assessments of vertical and horizontal stand structures. Twelve plant species were recorded. *Hibiscus tiliaceus* predominated in the tree phase (33.33%), *Rhizophora* sp. achieved 100% density and an IVI of 300 in the pole phase, and *Cyperus rotundus* exhibited the highest seedling density (66.67%). Three vertical strata of vegetation were found, with stratum C (4–20 m high) exhibiting the greatest species variety. These results demonstrate the dominance of native species, particularly mangroves, and their structural complexity in the regeneration process. The study promotes the use of native vegetation in coastal ecosystem management and provides crucial baseline data for post-tsunami restoration. Future conservation and catastrophe mitigation measures should focus on mangroves in particular because of their high ecological resilience and role as natural buffers.

1. INTRODUCTION

One of the provinces in southern Sumatra that faces the Sunda Strait immediately is Lampung Province. The transportation route between Java Island and Sumatra Island is connected via the Sunda Strait [1]. In addition to serving as a route for shipping between the islands of Java and Sumatra, the Sunda Strait is home to numerous small islands with significant ecological, economic, and tourism potential [2]. Lampung Bay is the common name for the Sunda Strait region, which is geographically a part of Lampung Province, the Bay Region, and spans the administrative regions of South Lampung Regency and Bandar Lampung City. There are a lot of fascinating islands in the Bay Area, and each one is different. The majority of the 32 tiny islands in the Lampung area are ecotourism destinations and have a high level of biodiversity [3]. Sebesi Island is among the islands with a high level of ecotourism appeal.

Among the islands with permanent residents is Sebesi Island [4, 5]. The island has become a popular tourist destination in Lampung Province, renowned for its exceptional natural beauty, including stunning beaches and hills reaching 844 meters above sea level, which are often used as recreational sites (Figure 1). Geographically, Sebesi Island is unique as it is the nearest island—located just 19.1 km—from the still-active Anak Krakatau Volcano.

Anak Krakatau Volcano, part of the original Krakatau Volcano that famously erupted in 1883, re-emerged as a new volcanic island known as Anak Krakatau. In 2018, the Sunda Strait saw an eruption that caused a tsunami [6-9]. One of the regions most badly hit by the 2018 tsunami was Sebesi Island, underscoring the island's ecological vulnerability and the necessity of improved coastal resilience. Coastal forest protection is one strategy to shield the island region from tsunamis. Among the many advantages of coastal woods are their ability to deter tsunami waves, prevent abrasion, and safeguard wildlife and plants [10]. In addition, coastal woods have a significant role in social, cultural, and economic facets of life, particularly for the local populations that surround the coast.

To support conservation efforts and sustainable management of coastal plant flora, it is critical to understand the diversity of plant species found in coastal locations [11]. The health of an ecosystem can be affected by the species' degree of diversity, whether it is high or low in coastal areas [12]. According to the findings of local interviews, the majority of the plant species found in Sebesi Island's coastal woods are naturally occurring, however, some are community-planted. Coastal forest management can be optimised to preserve the ecosystem with the aid of species diversity [13]. Numerous studies have been conducted on the variety of plant species and vegetative structure seen in coastal forests [14-17].

However, Sebesi Island has not had a thorough post-tsunami vegetation survey, and the South Lampung Regency Government's 2002 data solely addressed mangrove ecology [18]. This study evaluates the vegetation structure and variety following the 2018 tragedy to solve the specific ecological issue of post-tsunami coastal forest degradation on Sebesi Island.



Figure 1. Sebesi Island beach

The provision of baseline biological data to direct restoration, improve coastal resilience, and lead conservation efforts for endangered island ecosystems is what gives it



Figure 2. Research location

2.2 Plot sizes and vegetation classification

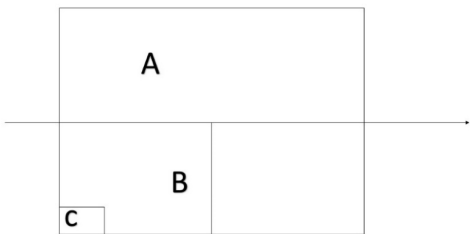


Figure 3. Research sample plot design

scientific significance. This research is anticipated to support ecological conservation and sustainable recovery efforts, especially in comparable coastal and small-island habitats, given Sebesi Island's vulnerability to frequent natural disasters.

2. MATERIALS AND METHODS

This study was carried out on Sebesi Island in Lampung Province in August and September of 2023 (Figure 2). Primary data, data derived from field measurements, was employed in this study.

2.1 Study area and sampling design

Data on the structure and diversity of coastal forest vegetation were gathered through vegetation analysis. On Sebesi Island, sampling was done along the coastline where the 2018 tsunami struck. Starting from the area nearest to the sea and moving inland, sampling plots were arranged in a systematic manner along the shoreline. Plots spanning regions with different vegetation densities and tsunami impact exposure were placed 50 meters apart. Sampling places were chosen based on three criteria: (1) closeness to the shoreline, (2) representation of both mangrove and non-mangrove vegetation types, and (3) areas with obvious indications of disturbance or regeneration.

Different growth stages were categorised using three plot sizes:

- a. 20 m × 20 m for the mature tree category
- b. 10 m × 10 m for the sapling category
- c. 2 m × 2 m for the seedling category were created in order to collect data (Figure 3) [19].

2.3 Data collection procedures

Plant height, diameter at breast height (DBH), species identification, number of individuals, and canopy cover were

among the vegetation metrics that were measured. A clinometer for height estimation (for tall trees), a measuring tape for plot boundaries, a diameter tape for DBH, and a GPS unit for plot coordinate marking were among the measurement instruments.

Using field guides and references pertinent to tropical coastal vegetation, species identification was carried out.

The study area's coastal vegetation is dominated by mangrove species, hence, Cintron and Novelli's technique [20] was used to classify the different plant groups. This comprises:

- Seedlings and saplings: 4–10 cm in diameter
- Trees that are mature: diameter \geq 10 cm

2.4 Analysis of data

Species Composition and Importance Value Index (IVI)

$$\text{Density (D)} = \frac{\text{Total number of individuals}}{\text{Size of plots}}$$

$$\text{Relative Density (RD)} = \frac{\text{Number of individuals of the species}}{\text{Number of individuals of all species}} \times 100$$

$$\text{Frequency (F)} = \frac{\text{Number of quadrats in which species occurred}}{\text{Total size of plots}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Number of occurrence of the species}}{\text{Number of occurrence of all species}} \times 100$$

$$\text{Relative Dominance (RDm)} = \frac{\text{Total basal area of the species}}{\text{Total basal area of all species}} \times 100$$

$$\text{Dominance (Dm)} = \frac{\text{Total basal area of the species}}{\text{Total size of plots}}$$

IVI of tree and pole growth level = RD + RF + RDm

IVI of sapling and seedling growth level = RD + RF

To determine the level of control of a species in the sample plot, it is calculated using the following formula:

$$\text{Interval Class (I)} = \frac{\text{the highest IVI Value} - \text{the IVI value at its lowest}}{3}$$

Dominance classification

- High Category (Dominant), if IVI > (lowest IVI 2I)
- Medium, if IVI = (lowest IVI + I) – (lowest IVI + 2I)
- Low (Not dominant), if IVI < (lowest IVI + I)

Vegetation Structure Analysis

Determine Vertical and Horizontal stands in plant vegetation. To determine the horizontal structure by determining canopy stratification, using the following criteria:

- Stratum A: height > 30 m
- Stratum B: 20 – 30 m
- Stratum C: 4 – 20 m
- Stratum D: 1 – 4 m
- Stratum E: < 1 m

3. RESULTS AND DISCUSSION

One of the most crucial elements in a forest ecosystem's survival is natural regeneration. This is also true of Sebesi Island's coastal forest ecology, which contains a variety of plant species and compositions. Natural regeneration promotes the continuation of ecosystem services, including habitat provision, coastline protection, and biodiversity maintenance, in addition to demonstrating an ecosystem's ability to rebound from shocks like tsunamis. According to the findings of studies conducted on Sebesi Island, natural regeneration is calculated using a plant species' density value at each stage of growth, as shown in Table 1.

Table 1. Sebesi Island's stand density at each growth stage

No.	Local Name	Scientific Name	Density Per Phase (%)			Category
			Seedling	Pole	Tree	
1	Mangrove	<i>Rhizophora</i> sp.	23.81	100	20.83	Tree
2	Sea Hibiscus	<i>Thespesia populnea</i>	0	0	25	Tree
3	Casuarina	<i>Casuarina</i> sp.	0	0	16.67	Tree
4	Pine	<i>Pinus merkusii</i>	0	0	4.17	Tree
5	Waru	<i>Hibiscus tiliaceus</i>	0	0	33.33	Tree
6	Tropical Almond	<i>Terminalia catappa</i>	0	0	12.50	Tree
7	Indian Beech	<i>Pongamia pinnata</i>	0	0	4.17	Tree
8	White Mangrove	<i>Avicennia marina</i>	0	0	4.17	Tree
9	Purple nutsedge	<i>Cyperus rotundus</i>	33.33	0	0	Undergrowth
10	Yellow Nutsedge	<i>Cyperus esculentus</i>	16.67	0	0	Undergrowth
11	Kera Bengu	<i>Mucuna pruriens</i>	16.67	0	0	Vines
12	Merbau Pantai	<i>Intsia bijuga</i>	16.67	0	0	Tree

According to Table 1, the purple nutsedge species (*Cyperus rotundus*) had the highest density results on Sebesi Island during the seedling phase. This is because the plant grows quickly and can also survive on disturbed soil [21]. Mangrove species exhibit the second-highest density value. Although they are frequently found on Sebesi Island, mangrove plants are only present in specific locations; not all of the island's beaches are covered in them. Since the community plants a number of different plant species, the hibiscus species had the highest density value in the adult phase (Figure 4). Aside from

that, this species is found natively around the Asian shore. There are plants of this kind that can withstand severe salinity [22-24]. The most prevalent plant category in Sebesi is the tree category, or Waru plants. Sebesi Island is home to twelve different kinds of flora. Other varieties, like coconut plants, are found on Sebesi Island, according to field observations; however, the area is not close to the shore or the ocean. Nine plant species fall within the tree category out of the twelve planting kinds. This is consistent with studies by Klinka et al. [25] and Saha et al. [26] that show tree species are resistant to

drought in addition to high water salinity.

High-density mangrove species, notably *Rhizophora* sp., are present during all growth stages, which is indicative of their vital ecological role in disaster recovery, especially in the wake of the 2018 tsunami. It has been demonstrated that mangroves serve as bio-shields that absorb wave energy, stop coastal erosion, and promote sediment deposition. Their dominance in Sebesi suggests that the restoration of natural coastal defence is on the rise. On Sebesi Island, mangrove plants have the highest density across all phases. Propagules floating in the sea are a useful method of regenerating new plants, and mangrove plants are more tolerant of maritime conditions [27, 28]. Compared to other plant species, mangrove plants produce new generations more quickly for this reason.

The growth of natural vegetation in a region is supported by the interactions between ecosystem components, which have a significant impact on the structure and composition of vegetation in that area [29]. The dynamics of a complex ecosystem are reflected in this relationship, with the environment, soil, and climate all playing a role in determining whether vegetation exists. One metric used to assess a species' degree of control or dominance in a given ecosystem is the IVI. IVI determines each species' proportional contribution at

different stages of growth. IVI is a crucial metric for assessing species dominance in a measurement plot as a result. Table 2 shows the vegetation mix and degree of control of each species discovered in Sebesi Island's measurement plots.



Figure 4. Waru on the coast of Sebesi Island

Table 2. Composition and level of species control on Sebesi Island

No.	Local Name	Nama Ilmiah	IVI Per Phase			Mastery Level
			Seedling	Pole	Tree	
1	Mangrove	<i>Rhizophora</i> sp.	40.48	300	47.58	High
2	Sea Hibiscus	<i>Thespesia populnea</i>	-	-	72.19	Low
3	Casuarina	<i>Casuarina</i> sp.	-	-	45.75	Low
4	Pine	<i>Pinus merkusii</i>	-	-	17.97	Low
5	Waru	<i>Hibiscus tiliaceus</i>	-	-	93.91	Low
6	Tropical Almond	<i>Terminalia catappa</i>	-	-	32.98	Low
7	Indian Beech	<i>Pongamia pinnata</i>	-	-	18.68	Low
8	White Mangrove	<i>Avicennia marina</i>	-	-	18.58	Low
9	Purple nutsedge	<i>Cyperus rotundus</i>	66.67	-	-	Low
10	Yellow Nutsedge	<i>Cyperus esculentus</i>	26.19	-	-	Low
11	Kera Bengu	<i>Mucuna pruriens</i>	26.19	-	-	Low
12	Merbau Pantai	<i>Intsia bijuga</i>	40.48	-	-	Low

With an IVI of 300 at the pole phase and 47.58 at the mature phase, *Rhizophora* sp. (mangrove) exhibits a high degree of expertise (Table 2). This demonstrates that Sebesi Island's coastal region is dominated by mangroves. According to a number of studies, mangrove trees offer significant ecological advantages, including preventing beach erosion and serving as habitat for marine biota [30, 31]. According to study findings, the majority of tree-level species, including sea hibiscus, casuarina, and waru plants, still possess a low degree of competence. Despite this, the IVI for this plant is rather high—72.19 for Sea Waru, 45.75 for Pine plants, and 93.91 for Waru plants. This is because Sebesi Island's coastline still has a very small number of individual plants. During the seedling stage, purple nutsedge and Kera Bengu plants predominate. In the meantime, IVI is in phase seedlings, specifically Kera Bengu (26.19), yellow nutsedge (26.19), and purple nutsedge (66.67). Due to its rapid growth and ability to adapt to sandy soil and open terrain, dominance in the seedling phase has great regeneration capacity [32-34]. The only time beach Merbau plants are seen on the beach is during the seedling stage. This is because adult Merbau plants on Sebesi Island grow naturally, but their growing place is still distant from the beach.

According to these results, mangrove species' dominance in

both regeneration and mature stages validates their long-term importance in ecological stability, even though pioneer species and undergrowth vegetation like nutsedge considerably contribute to regeneration in the early post-disturbance phases. Similar patterns of mangrove reestablishment being essential for natural defence and biodiversity continuity are seen on Sebesi Island when compared to comparable post-tsunami vegetation studies in Aceh and Sri Lanka [35, 36]. Nonetheless, Sebesi's unique blend of tropical hardwoods and undergrowth plants provides information on successional stages unique to the area.

In attempts to conserve and maintain coastal vegetation, INP and the degree of species control are crucial. Mangrove plants are the dominant species of Sebesi Island. Dominance is still low for other types, though. However, some species are not very dominant. By comparing the number of distinct species present in the measurement plot with the tree diameter classes, the horizontal stand structure was examined. The purpose of this investigation is to comprehend Sebesi Island's tree size distribution and vegetation regeneration trends. Figure 5 displays the findings of the study on horizontal stand structure.

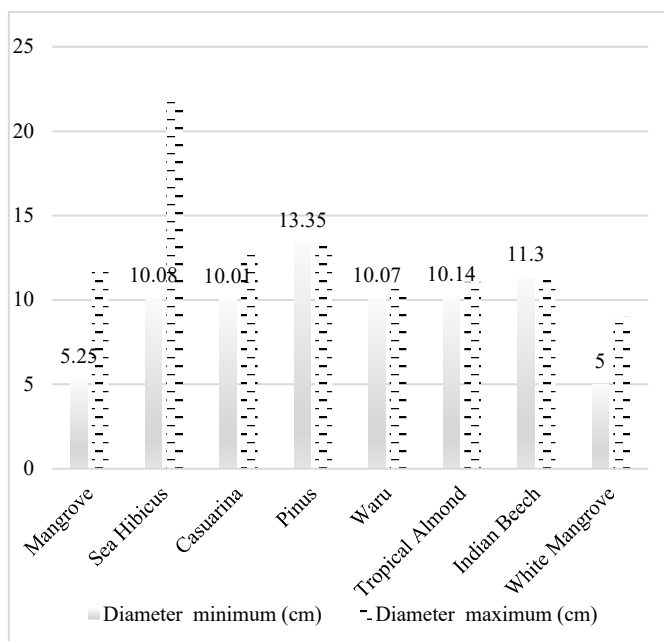


Figure 5. Sebesi Island's horizontal stand structure for tree classifications



Figure 6. Sebesi Island mangrove (*Rhizophora* sp.) plants

Only plants that fit into the mature and pole/stake categories have their diameters calculated, as illustrated in Figure 5, while Figure 6 shows the diversity of mangrove flora on Sebesi Island. The extent of mangrove vegetation has increased significantly due to the species' adaptability to the island's coastal conditions. In contrast, pine species are relatively scarce on Sebesi Island, as they are planted by local residents and do not occur naturally.

When compared to other plants, the Sea Hibiscus has the largest plant diameter. The diameter of adult Waru plants ranges from 10.08 cm at the minimum to 22.05 cm at the highest. Although the sea hibiscus plant is a plant that can adapt to the maritime environment, it can grow unevenly in less fertile soil types, which means that the Sea Hibiscus plant's diameter growth is not proportionate to its height.

Sebesi Island is home to a variety of naturally occurring plant species, including mangrove, sea hibiscus, casuarina, Waru, tropical almond, Indian beech, white mangrove, and Merbau Pantai. This is also consistent with studies by Ratnasooriya et al. [37] and Syafitri et al. [38] that found native species, including Waru, Sea Hibiscus, and tropical almond plants in the vicinity.

By comparing the number of individuals of each species with their stratum class in the measurement plot, the vertical stand structure was examined. Table 3 displays the findings of the vertical stand structure investigation conducted on Sebesi Island.

Table 3. Sebesi Island's vertical stand structure

No.	Stratum	Height (m)	Constituent Species
1	A	30-40	-
2	B	20-30	-
3	C	4-20	Mangrove (<i>Rhizophora</i> sp.), Waru Laut (<i>Thespesia populnea</i>), Casuarina (<i>Casuarina</i> sp.), Pine (<i>Pinus merkusii</i>), Waru (<i>Hibiscus tiliaceus</i>), Tropical Almond (<i>Terminalia catappa</i>), Indian Beech (<i>Pongamia pinnata</i>), white mangrove (<i>Avicennia marina</i>)
4	D	1-4	Mangrove (<i>Rhizophora</i> sp.) and Merbau Pantai (<i>Intsia bijuga</i>)
5	E	0,4-1	Mangrove (<i>Rhizophora</i> sp.) and <i>Intsia bijuga</i>

Table 3 presents the results of the research conducted on Sebesi Island. The highest number of species was recorded in stratum C, with a total of eight species. Strata D and E each contained two species.

This implies that, as is common with regrowing coastal forests, mid-level canopy species currently dominate the structure of coastal forests on Sebesi Island. In order to maintain continuity into higher strata, species that are found in Strata D and E (lower strata), such as seedlings and undergrowth, must be safeguarded because they are essential to the regeneration cycle. Their scarcity suggests that early regeneration is still limited, most likely as a result of post-tsunami disruptions.

In stratum B, there are the most species, which shows that the species on Sebesi Island are dominated by medium and small-sized species. The variety of strata on Sebesi Island indicates that the vertical stand structure is quite complex, with quite varied stratum arrangements. Regions have varying strata, indicating that the ecosystem functions are working optimally in the region [39]. The variety of stand strata produced is sufficient to create shade and maintain ecosystem function. Structural models that make up the stratum and light absorption models are carried out to aggregate the physiological processes of the entire canopy [40].

Strata D and E have fewer species than stratum B, indicating that there is still low species diversity in the lower plants. Regeneration from the lowest layer is essential for long-term forest recovery and resistance against future disturbances like storm surges or tsunamis, making this a significant ecological note. To improve resilience and ecosystem services, more proactive conservation measures are advised, such as protecting juvenile plants and planting enrichment plants.

4. CONCLUSIONS

After the 2018 tsunami, this study found that twelve plant species were flourishing along the coast of Sebesi Island. The *Cyperus rotundus* seedling phase (66.67 ind/ha), *Rhizophora* sp. pole phase, and *Hibiscus tiliaceus* mature tree phase all had

the highest plant densities. *Rhizophora* sp.'s ecological significance in the coastal forest environment was highlighted by its dominance during all growth stages. Stratum C is the most developed of the three layers (C, D, and E) that make up the vertical stand structure. The low number of species found in the lower strata suggests that regeneration is continuing, but not at its best just yet.

These results highlight how crucial coastal vegetation, especially mangroves, is to bolstering ecosystem resilience and promoting ecological recovery after disasters. Planning for catastrophe risk reduction, restoration initiatives, and conservation measures can all benefit from the baseline data provided by the composition and structural complexity described in this paper. The significance of preserving and safeguarding coastal forest ecosystems in post-tsunami landscapes is further supported by the ongoing regeneration of native vegetation, which serves as a natural buffer against coastal dangers.

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