

Diversity, density, and ecological significance of mangrove species in Bali Barat National Park

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Abstract. This study assessed the condition of mangrove ecosystems in the Bali Barat National Park, focusing on Menjangan Island and Terima Bay, which are important for coastal protection and biodiversity conservation. Vegetation data were collected using the Line Transect Plot method, covering the trees, saplings, and seedlings. A total of 14 mangrove species were recorded, with 9 species in Terima Bay and 5 species on Menjangan Island. Analysis using the Important Value Index (IVI) revealed that *Excoecaria agallocha* was the most dominant species in Terima Bay, whereas *Xylocarpus granatum* dominated Menjangan Island, reflecting high adaptability to local conditions. Most individuals were found in the sapling category, suggesting good natural regeneration, whereas the highest density occurred at the seedling stage. Differences in the associated biota between sites indicated habitat heterogeneity. Overall, mangrove ecosystems in the Bali Barat National Park remain relatively healthy, providing essential ecosystem services and supporting diverse species. These findings highlight the importance of continued conservation, monitoring, and management interventions to maintain mangrove structure, regeneration, and biodiversity, thus reinforcing their role in climate resilience and nature protection.

Keywords: Ecosystem condition, importance value index, mangrove community structure, sapling recruitment

1 Introduction

Mangrove ecosystems are widely recognized as among the most productive coastal ecosystems globally, exhibiting exceptionally high rates of primary productivity and carbon accumulation compared with other tropical forest systems [1]. Mangrove vegetation functions as a natural buffer against abrasion, seawater intrusion, and extreme waves while also providing critical habitats for various benthic species, fish, crustaceans, and waterbirds

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[2]. Mangroves play a vital role in storing large amounts of blue carbon, making them crucial for climate change mitigation [3]. These ecosystems also support coastal livelihoods through fisheries, ecotourism, and non-timber forest products, positioning them as key components in the management strategies of marine protected areas (MPAs) [4].

The Bali Barat National Park (BBNP), an MPA that hosts important mangrove ecosystems, is located in the western part of Bali Island, Indonesia. The BBNP encompasses diverse coastal ecosystems, including lowland rainforests, seagrass beds, coral reefs, and mangroves, which play vital roles in maintaining coastal ecosystem stability. The mangrove vegetation in BBNP provides ecosystem services, serves as a habitat buffer, and supports the survival of protected species such as the Bali starling (*Leucopsar rothschildi*) [5]. Furthermore, the presence of mangroves in this area has strategic value for enhancing climate resilience and promoting conservation-based ecotourism development.

Nevertheless, mangrove ecosystems worldwide are facing significant pressure. The rate of mangrove loss is driven by land conversion, coastal development, pollution, and climate change [6]. Recent global assessments based on high-resolution satellite data have demonstrated that human-driven land-use change was the dominant driver of mangrove loss worldwide between 2000 and 2016, with a majority of losses associated with conversion to agriculture and aquaculture, underscoring the need for urgent, context-specific conservation strategies [7]. Indonesia has experienced extensive mangrove loss over the past decades, primarily driven by aquaculture expansion, logging, and land-use changes, highlighting the need for site-specific ecological assessments to support improved mangrove management strategies [8]. At the local scale, including in BBNP, threats include illegal logging, coastal waste accumulation, and tourism pressures that have not yet been fully managed under sustainability principles [9]. Such degradation may reduce the capacity of mangrove ecosystems to provide environmental services, including their role as carbon sinks and as a foundation for fishery productivity [10].

Given these conditions, scientific assessments of community structure, ecological conditions, and potential pressures on mangroves in BBNP are highly important, as structural vegetation attributes such as stand density, basal area, and biomass are increasingly being used as indicators of mangrove ecosystem integrity and degradation status [11]. This study aimed to analyze the composition and structure of mangrove vegetation in Bali Barat National Park and to derive management recommendations based on ecological indicators obtained from vegetation and associated biota data. These findings are expected to strengthen the scientific foundation for mangrove conservation management in BBNP, while also supporting sustainable coastal conservation and restoration efforts in Indonesia [12].

2. Methods

2.1. Time and place

The study was conducted during the East Monsoon Season, from August 7 to 11, 2023, on Menjangan Island and Terima Bay, Bali Barat National Park, and Buleleng Regency. Mangrove data were collected between 09:00 and 16:00 Central Indonesia Time (WITA). Sampling was conducted at eight stations representing the mangrove area, including four stations in Terima Bay and four stations on Menjangan Island. The data collection maps are shown in **Fig. 1** and **Fig. 2**.

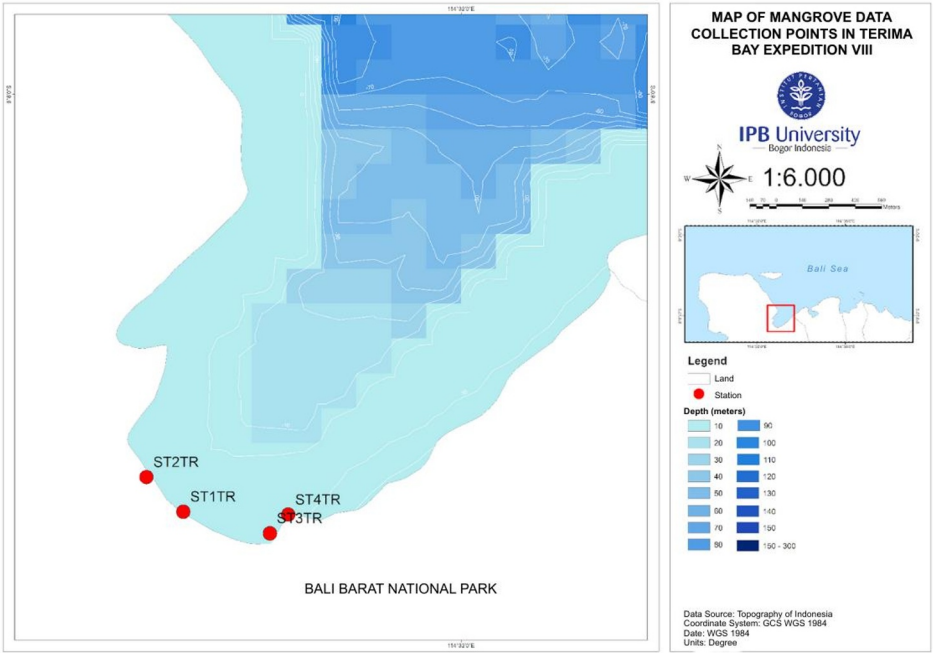


Fig. 1. Study site for mangrove data collection in Terima Bay.

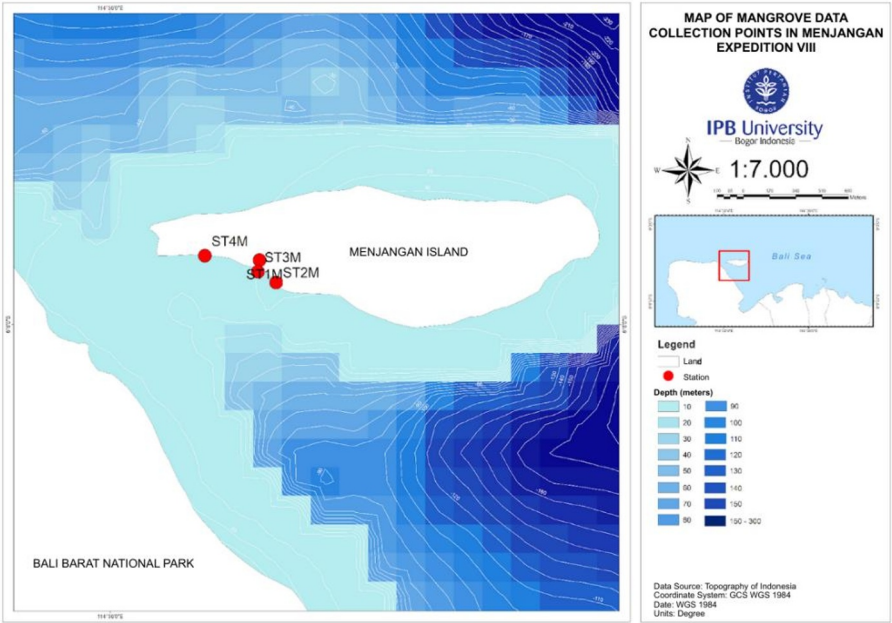


Fig. 2. Study site for mangrove data collection in Menjangan Island.

2.2.Mangrove sampling

The line transect plot method was used to collect data for mangrove ecosystems in Bali Barat National Park. Mangrove vegetation samples were categorized into trees, saplings, and seedlings. The tree category included individuals with Diameter Breast Height (DBH) > 4 cm and height > 1 m. The sapling category consisted of individuals with DBH ≤ 4 cm and height ≥ 1 m. The seedling category included individuals with heights below 1 m, for which stem circumference was not measured. The transect plots used for mangrove vegetation sampling are shown in **Fig. 3**. Sampling stations were coded as ST.TR1–ST.TR4 for stations located in Terima Bay (TR) and ST.MJ1–ST.MJ4 for stations located on Menjangan Island (MJ), where ‘ST’ denotes sampling station.

Mangrove species were identified in the field based on their morphological characteristics using standard taxonomic references. Identification was conducted by examining key diagnostic features, including leaf shape and arrangement, bark texture, root structures (e.g., prop roots or pneumatophores), flower and fruit morphology when present, and the overall growth form. Species identification followed authoritative identification guides and taxonomic keys for the Indo-Pacific mangroves [13]. When reproductive structures were not available, identification was confirmed using vegetative characters and habitat associations, as described previously. The scientific names were verified according to the current taxonomic consensus.

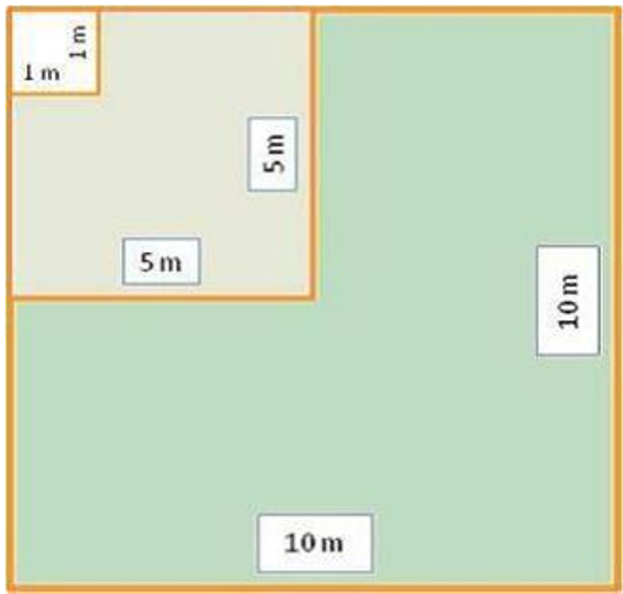


Fig. 3. Transect plot for mangrove vegetation.

Data collection for trees was conducted within 10 × 10 m plots, for saplings within 5 × 5 m plots, and for seedlings within 1 × 1 m plots [13]. The recorded data consisted of the number and species of mangrove stands, tree diameter, and additional supporting information such as associated biota. The data from the datasheets were transferred to Microsoft Excel for further processing. Sampling was carried out at four stations in Terima Bay and four stations on Menjangan Island. The equipment and materials used included a measuring tape, transect lines, compass, writing tools, and Microsoft Excel.

2.3. Species identification

Mangrove species were identified in the field based on their morphological characteristics using standard taxonomic references. Identification was conducted by examining key diagnostic features, including leaf shape and arrangement, bark texture, root structures (e.g., prop roots or pneumatophores), flower and fruit morphology when present, and the overall growth form. Species identification followed authoritative identification guides and taxonomic keys for the Indo-Pacific mangroves [13]. When reproductive structures were not available, identification was confirmed using vegetative characters and habitat associations, as described previously. The scientific names were verified according to the current taxonomic consensus.

Associated fauna observed within the mangrove ecosystem were identified in the field based on external morphological characteristics, using standard field guides and taxonomic references. Identification relied on diagnostic features, such as body shape, coloration patterns, shell morphology (for mollusks), appendage structure (for crustaceans), and overall body form and behavior (for fishes). Species identification was primarily conducted at the species level using widely applied regional identification guides for mangrove-associated fauna, supported by relevant taxonomic literature and online reference databases, including the World Register of Marine Species (WoRMS), FishBase, and Conchology. When accurate species-level determination was not possible owing to insufficient diagnostic characters or observational limitations, specimens were identified and recorded at the lowest taxonomic level considered reliable.

2.4. Data analysis

The data analysis of mangroves in this study included the calculation of the Importance Value Index (IVI), derived from the parameters of Relative Density (RD_i), Relative Frequency (RF_i), and Relative Cover (RC_i) for each mangrove species at both the tree and sapling levels. This method provides a quantitative description of the dominance and ecological role of each species within the mangrove community. The IVI calculation followed the approach developed in [13], allowing for a more comprehensive interpretation of the structure and composition of mangrove vegetation at the study sites.

Species Density

$$Di = \frac{ni}{A} \quad (1)$$

Description:

Di = Species Density

ni = Total number of stands

A = Transect area (m²)

Relative Species Density

$$RD_i = \frac{ni}{\sum n} \times 100\% \quad (2)$$

Description:

RD_i = Relative Species Density (%)

ni = Number of stands per species

n = Total stands

Species Frequency

$$Fi = \frac{Pi}{\Sigma P} \quad (3)$$

Description:

Fi = Species frequency

Pi = Observation plot

P = Total observation plot

Relative Species Frequency

$$RFi = \frac{Fi}{\Sigma F} \times 100 \quad (4)$$

Description:

RFi = Relative Species frequency (%)

Fi = Species Frequency

Basal Area

$$BA = \frac{\pi DBH^2}{4} \quad (5)$$

Description:

BA = Basal area (m²)

DBH = Diameter Breast Height (cm)

Species Cover

$$Ci = \frac{\Sigma BA}{A} \quad (6)$$

Description:

Ci = Species cover

BA = Basal Area (m²)

A = Transect area (m²)

Relative Species Cover

$$RCi = \frac{Ci}{\Sigma C} \times 100 \quad (7)$$

Description:

RCi = Relative species cover (%)

Ci = Species cover

Importance Value Index (IVI)

$$IVI = RDi + RFi + RCi \quad (8)$$

Description:

IVI = Important Value Index (%)

RDi = Relative Species Density (%)

RFi = Relative Species Frequency (%)

RCi = Relative Species Cover (%)

3 Results and discussion

3.1 Mangrove species

Mangrove ecosystems, which thrive in intertidal zones and are influenced by tidal dynamics, exhibit high levels of biodiversity and are recognized as among the most productive wetland systems globally. These ecosystems play a pivotal role in maintaining the ecological integrity of coastal and marine environments by providing critical services such as shoreline stabilization, nutrient cycling, and habitat provision.

Nine true mangrove species were identified in the coastal area of Terima Bay: *Lumnitzera racemosa*, *Ceriops decandra*, *Rhizophora mucronata*, *Bruguiera cylindrica*, *Excoecaria agallocha*, *Rhizophora stylosa*, *Rhizophora apiculata*, *Sonneratia alba*, and *Bruguiera gymnorrhiza*. Among these, *Excoecaria agallocha* and *Ceriops decandra* were the most dominant at the mature-tree stage. *Ceriops decandra* was also the most abundant species at the sapling stage, whereas *Rhizophora mucronata* dominated the seedling stage.

In contrast, the mangrove community on Menjangan Island comprises five species: *Xylocarpus granatum*, *Rhizophora apiculata*, *Rhizophora stylosa*, *Sonneratia alba*, and *Pemphis acidula*. The mature mangrove stratum was dominated by *Sonneratia alba*, whereas *Rhizophora stylosa* and *Xylocarpus granatum* were the most prevalent at the sapling and seedling stages, respectively.

3.2 Associated biota

The mangrove ecosystems of Menjangan Island and Terima Bay, located within the West Bali National Park, are characterized by different substrate types. Menjangan Island is predominantly composed of muddy substrates, whereas Terima Bay features relatively dry sandy substrates. Variations in associated faunal assemblages are closely linked to substrate characteristics and habitat complexity in mangrove ecosystems, as sediment type strongly influences benthic and nektonic community compositions [2].

The associated fauna observed on Menjangan Island include gastropods (*Littoraria scabra* and *Telescopium telescopium*), crustaceans (*Scylla serrata* and *Clibanarius* sp.), pisces (*Periophthalmus barbarous* and *Hyporhamphus balinensis*), echinodermata (*Holothuria atra*, *Diadema setosum*); in contrast, the associated biota recorded in Terima Bay includes crustaceans (*Coenobita* sp. and *Scylla serrata*), pisces (*Periophthalmus barbarous*), echinodermata (*Holothuria atra*), and a variety of fish species inhabiting the mangrove habitat.

3.3 Total individual mangrove stands

The total number of individual mangrove stands refers to the overall number of mangrove trees or plants present within a specific area or mangrove ecosystem. The total number of individual mangrove stands in West Bali National Park (Taman Nasional Bali Barat, TNBB) is illustrated in **Fig. 4**.

Based on the calculations, 122 individuals were recorded in the tree category, 208 individuals in the sapling category, and 56 individuals in the seedling category. These results indicate that more than half of the mangrove population in TNBB consists of saplings, comprising approximately 53.8% of the total population.

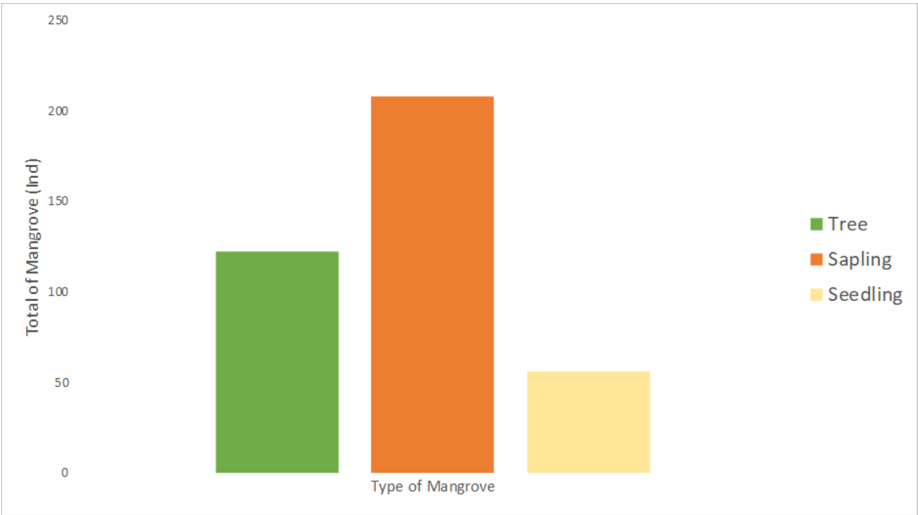


Fig. 4. Diagram of total individual mangrove stands in Bali Barat National Park.

3.4 Mangrove species density

The species densities of mangroves in Bali Barat National Park are presented in **Fig. 5**. This figure illustrates the variation in density across different species and growth stages, providing insights into population structure and distribution patterns within the study area. For clarity, ST.TR refers to sampling stations in Terima Bay, whereas ST.MJ refers to sampling stations on Menjangan Island.

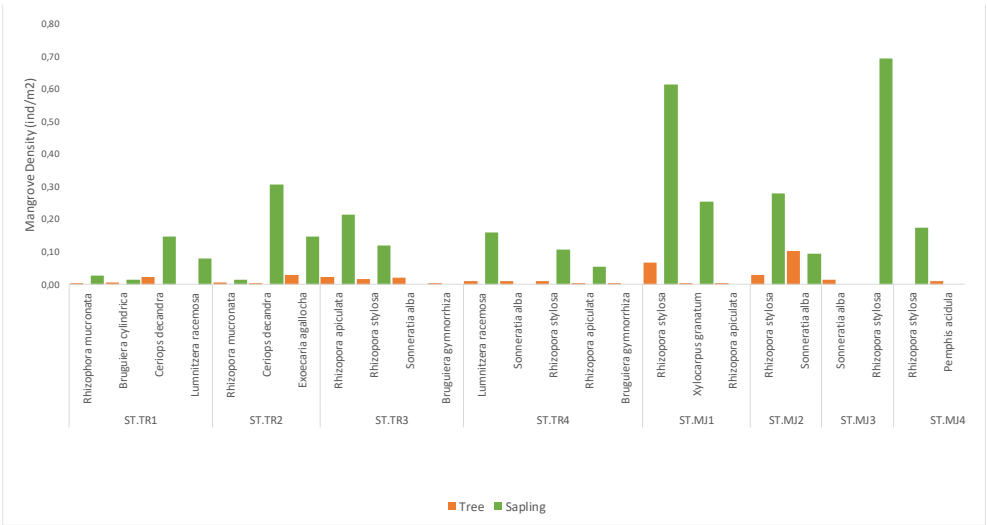


Fig. 5. Diagram of mangrove species density in Bali Barat National Park.

Mangrove density across the four stations in Terima Bay exhibited a clear ontogenetic gradient: mature trees displayed very low *Di* values (< 0.03 ind/m²), indicative of sparse adult stands; saplings showed elevated densities, with *Luminitzera racemosa* reaching approximately 0.15–0.16 ind/m² at ST.TR1 and ST.TR4 and *Ceriops decandra* attaining 0.31 ind/m² at ST.TR2, reflecting successful mid-stage regeneration; and seedlings exhibited the

most pronounced density surge, with *Rhizophora mucronata* at ST.TR2 achieving 3 ind/m² and *Rhizophora stylosa* at ST.TR3 2.67 ind/m², denoting a strong potential for early-stage natural recruitment. Spatial variability in seedling dominance among stations likely corresponds to microhabitat heterogeneity, yet overall early stage regeneration far exceeds mature tree density. Consequently, restoration efforts in Terima Bay should prioritize the enhancement of sapling survival through maturity to restore the structural balance of its mangrove forests.

Mangrove density across the four stations at Menjangan Island revealed sparse mature stands ($Di < 0.11$ ind/m²), with *Xylocarpus granatum* dominating at ST.MJ1 (0.0667 ind/m²), *Sonneratia alba* at ST.MJ2 (0.103 ind/m²) and ST.MJ3 (0.0133 ind/m²), and *Pemphis acidula* at Pulau Menjangan revealed sparse mature stands ($Di < 0.11$ ind/m²); sapling densities were markedly higher, notably *Xylocarpus granatum* dominating at ST.MJ1 (0.0667/m²), *Sonneratia alba* at ST.MJ2 (0.103/m²) and ST.MJ3 (0.0133/m²), and *Pemphis acidula* at ST.MJ4 (0.01 ind/m²); sapling densities were markedly higher, notably *Rhizophora apiculata* at ST.MJ1 (0.6133/m²) and *Rhizophora stylosa* at ST.MJ3 (0.6933/m²), alongside moderate sapling presence of *X. granatum* (0.2533/m² at ST.MJ1), *S. alba* (0.093/m² at ST.MJ2), and *R. stylosa* (0.1733 ind/m² at ST.MJ4); seedling densities peaked only at ST.MJ1 (*X. granatum* 4.3333 ind/m², *R. apiculata* 0.6667 ind/m², *R. stylosa* 0.3333 ind/m²) while early-stage data remain unavailable for other stations. These patterns indicate robust mid-stage regeneration in *Rhizophora* spp. and exceptional seedling recruitment of *Xylocarpus granatum* at ST.MJ1, highlighting microhabitat heterogeneity and the need to prioritize sapling survival and seedling establishment in restoration strategies across Menjangan Island.

Overall, the conditions of the mangroves in Terima Bay and Menjangan Island show promising regeneration dynamics, although the mature stands are still thin. Similar patterns of reduced basal area, lower density of large trees, and increased abundance of small stems under disturbed conditions have been reported in other mangrove systems, where size-class distributions have been used to infer regeneration dynamics and ecosystem conditions [14]. Vegetation structures characterized by active sapling recruitment and multispecies composition are widely used to infer mangrove ecosystem conditions and structural resilience [15]. Data show that seedling densities far exceed those of mature trees, which is in line with the general pattern of mangrove regeneration in Indonesia, where seedling densities tend to be high (>5 individuals/ha) in natural and post-disturbance habitats, whereas mature stands are relatively sparse [16]. This pattern underscores the importance of community structure determined by density and the success of early phase regeneration in maintaining ecosystem stability, as outlined by [17], in explaining the vital role of mangroves in climate change mitigation and coastal sediment stabilization. Effective mangrove restoration strategies emphasize enhancing seedling and sapling survival through appropriate site selection, hydrological restoration, and species–habitat matching, rather than relying solely on planting density [18]. Therefore, restoration strategies at both locations should prioritize increasing the survival of juveniles and seedlings to adulthood through microhabitat management (sedimentation, water level regulation, and protection of recruitment sites) to restore the structural balance and function of the mangrove ecosystem in a sustainable manner.

3.5 Important value index

The importance value index (IVI) is a composite metric that integrates the relative density, dominance, and frequency of different mangrove species within an ecosystem. The IVI was expressed as a percentage (%) and provided a comprehensive picture of the contribution of each species to the overall ecological balance. A high IVI at a particular site indicates that the mangrove species present are dominant, well-adapted, and ecologically significant for

community structure and stability [19]. For the mangrove ecosystem of Bali Barat National Park, the IVI values are presented in **Fig. 6** and **Fig. 7**.

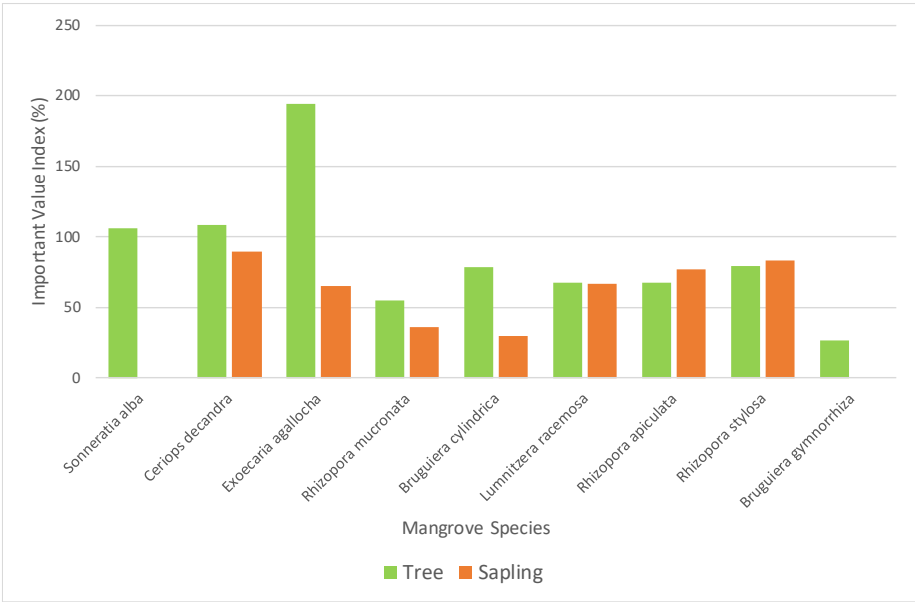


Fig. 6. Diagram of mangrove importance value index in Terima Bay.

Important value index (IVI) in the mangrove vegetation of Terima Bay underscores *Excoecaria agallocha* as the most dominant mature-phase species with the highest IVI (194.21 %), followed by *Ceriops decandra* (108.55 %) and *Sonneratia alba* (106.19 %), reflecting their pivotal roles in canopy formation and coastal sediment stabilization [20]. Conversely, in the sapling phase, *Ceriops decandra* exhibited the strongest recruitment (89.52 %), followed by *Rhizophora stylosa* (83.46 %), and *Rhizophora apiculata* (77.25 %), indicating superior early-stage regeneration.

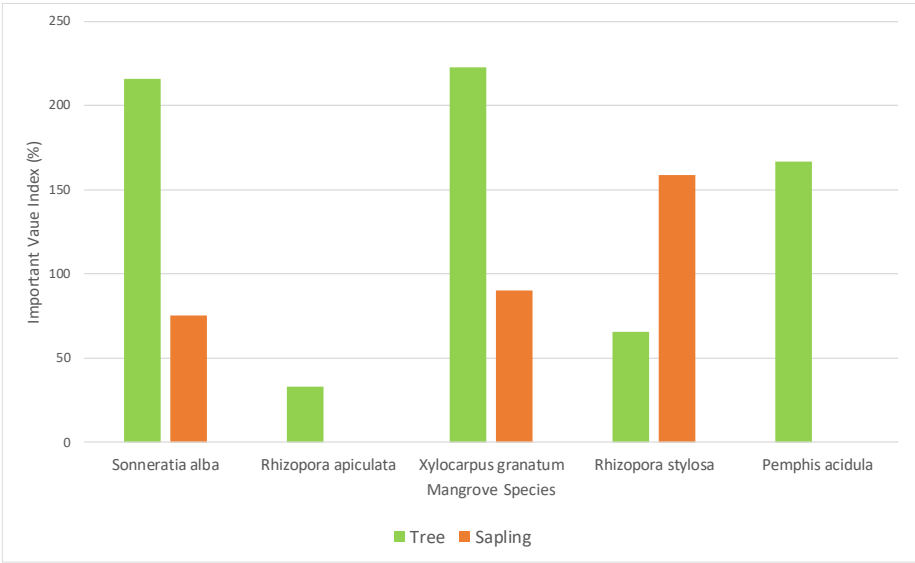


Fig. 7. Diagram of mangrove importance value index in Menjangan Island.

The Importance Value Index (IVI) of mangrove vegetation on Menjangan Island highlighted *Xylocarpus granatum* as the most dominant species at the tree stage, exhibiting the highest IVI value (222.32%), followed by *Sonneratia alba* (215.86%) and *Pemphis acidula* (166.66%). At the sapling stage, *Rhizophora stylosa* showed the strongest regeneration potential, with the highest IVI (158.75%), followed by *Xylocarpus granatum* (90.00%) and *Sonneratia alba* (75.00%).

The shift in species dominance between the mature and sapling phases reflects life-history strategies and microhabitat heterogeneity, in line with mangrove community structure theory, as outlined by [18] regarding life-stage-based restoration techniques. These findings underscore the need for restoration approaches that bolster the sapling survival of key species and maintain adult stands through targeted microhabitat interventions (such as tidal regime adjustments, sediment stabilization, and recruitment site protection) to sustain the structural integrity and functional resilience of these mangrove ecosystems.

4 Conclusion

This study demonstrates that the mangrove ecosystems of West Bali National Park exhibit diverse species compositions and distinct population structure patterns across the two study sites. A total of 14 mangrove species were recorded, with species composition varying according to substrate type and local environmental conditions. Terima Bay was dominated by *Excoecaria agallocha* and *Ceriops decandra*, while Menjangan Island was characterized by *Sonneratia alba* and *Rhizophora stylosa*. Population structure analysis revealed a dominance of sapling-stage individuals, indicating strong natural regeneration potential despite the low density of mature trees. The Importance Value Index further highlighted *Xylocarpus granatum*, *Sonneratia alba*, and *Excoecaria agallocha* were the most ecologically dominant species, whereas *Bruguiera gymnorrhiza* exhibited limited distribution and adaptability. Differences in associated biota between sites reflect ecological heterogeneity related to substrate conditions, and together these findings provide key ecological indicators of mangrove structure and regeneration dynamics that form a scientific basis for site-specific management and restoration strategies in West Bali National Park.

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