Journal of Natural Resources and Environmental Management
http://dx.doi.org/10.29244/jpsl.14.4.770

RESEARCH ARTICLE

Mangrove Forest Restoration in the Western Part of Rambut Island Wildlife Reserve, Seribu Islands

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Article History
Received 28 February 2024
Revised 19 April 2024
Accepted 30 April 2024

Keywords
mangrove forest, planting technique, Rambut Island, restoration

ABSTRACT

The restoration of mangrove forests is a crucial endeavor to restore damaged areas. The area that needs restoration is the mangrove forest located in Rambut Island Wildlife Reserve. This particular mangrove forest spans approximately 14.31 hectares, with a research site covering 2.14 hectares in the western part of Rambut Island. The objectives were to accurately map the mangrove forests's location and size that require restoration, identify mangrove species, and determine suitable restoration techniques. Sentinel-2A imagery data and field surveys conducted from July to August 2022 mapped the forest area and collected primary data on vegetation, soil, inundation, and water salinity. Based on the findings, it has been determined that approximately 0.37 hectares of the area require restoration measures. The recommended mangrove species for restoration consist of *Avicennia* sp., *Bruguiera* sp., *Rhizophora* sp., *Ceriops* sp., *Heritiera* sp., *Sonneratia* sp., and *Xylocarpus* sp. The planting technique that can be applied to all restoration plots, except for plot number 7, is the *cemplongan* technique, while the *Bronjong* technique is recommended for plot number 7.

Introduction

Mangrove forests are important in maintaining the balance between marine and terrestrial ecosystems. According to Alwidakdo et al. [1], the location of mangrove forests is highly specific and has a unique ecological role. This formation forest grows in tidal areas (especially protected coastal areas, lagoons, and river mouths) with dense communities that can tolerate high salt content. Based on a national mangrove map [2], the area of mangrove forests in Indonesia is estimated to be 3.36 million ha. Majid et al. [3] stated that the area of mangrove forests in Indonesia is approximately 25% of the mangrove forest area worldwide, with a variety of species along Indonesia's coastline in coastal areas [4].

Mangrove forests have a variety of functions. Besides being able to absorb carbon, mangrove forests have a special function, such as forest formations that can withstand seawater currents that erode the coastal plains, as protectors of coastal areas and small islands, fauna habitats, especially endemic birds, and sedimentation buffers [5]. Mangrove forests have suffered significant damage because, according to Winarno [6], the decline around mangrove forests has occurred because of building activities, conversion of mangrove forests, and reduced mangrove forest quality. Damage to mangrove forests has an impact on reducing the diversity of flora and fauna, reducing the area and density of mangroves, increasing seawater abrasion, and intrusion of seawater further inland [7]. Restoration efforts need to be made to protect damaged mangrove forests.

The Rambut Island Wildlife Reserve is a damaged mangrove forest area that needs to be restored. Rambut Island was designated a Wildlife Reserve area [8], dated May 7th, 1999, covering an area of ± 90 ha. According to Winarno [6], the island is a habitat for various animals, especially water birds, and a haven for migratory birds. Therefore, Rambut Island requires restoration activity. Restoration activities will be optimal if there is good planning for the developer to develop the restoration area. This study aimed to facilitate mangrove

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forest restoration in the western part of Rambut Island by providing comprehensive mapping, species identification, and planting recommendations. By understanding this unique ecosystem's ecological dynamics and restoration needs, we can inform targeted conservation actions and promote sustainable management.

Materials and Methods

Study Area

Field research was carried out over the course of two months, from July to August 2022. The study focused on the western part of the Rambut Island Wildlife Reserve, which is located in Seribu Islands, DKI Jakarta. This area was chosen due to its unique ecological characteristics, making it an ideal site for the research. The specific locations within the reserve where the research was conducted are visually represented in Figure 1. Data processing was conducted between September 2022 and January 2023. Primary and secondary data were collected. The primary data included water salinity, area coordinates, soil texture, inundation class, inundation frequency, and vegetation analysis data. The secondary data collected included the daily tidal data.

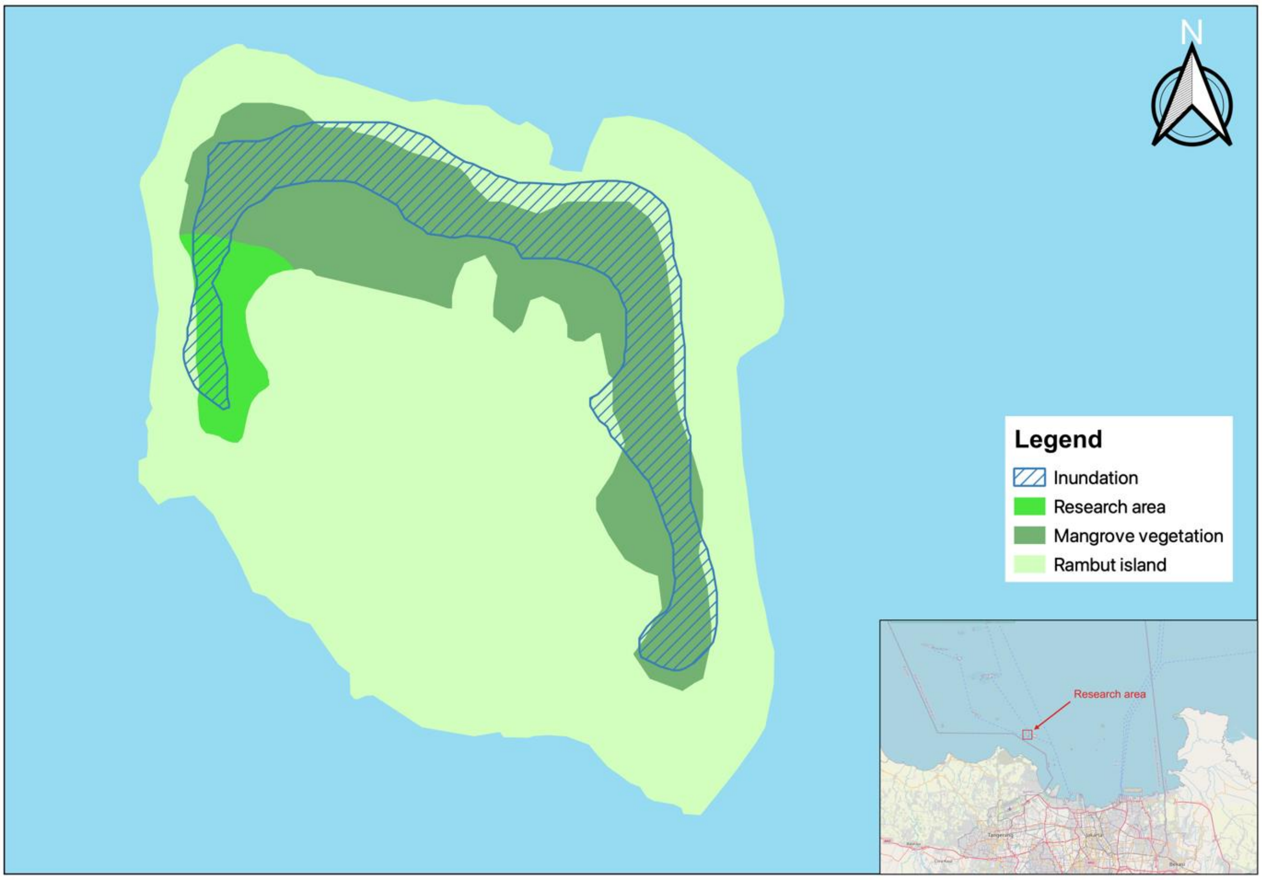

Figure 1. Mangrove forest in Rambut Island Wildlife Reserve, Seribu Islands.

Method of Collecting Data

Area mapping was carried out using Sentinel-2A imagery data and the coordinates of the areas that delimited the beginning to the end of the research area boundaries. Vegetation data were obtained using the grid method, which divided all research locations. Vegetation analysis was performed by identifying the type and number of individuals from the growth stages of seedlings, saplings, and trees. According to Wyatt [9], the criteria for each mangrove growth rate can be separated into three types. Seedling criteria is rejuvenation starts from sprouts to less than 1.5 m height, sapling is rejuvenation with height greater than equal to 1.5 m to a stem diameter of less than 10 cm, and tree is woody plant with a stem diameter greater than equal to 10 cm or more. The plot shape was square with a size of 20 × 20 m at the tree level, 5 × 5 m sub-plots at the sapling level, and 2 × 2 m at the seedling level.

Soil samples were obtained by compositing soil from ten random locations in the western part of Rambut Island (Figure 2). Samples were taken at a depth of 20 cm to analyze the soil texture at the Indonesian Center for Biodiversity and Biotechnology (ICBB) Laboratory. Water salinity data obtained from the inundated plots. Water salinity was measured using a refractometer. The inundation height data were obtained using a ruler. Data on the frequency of inundation were obtained through interviews with the Rambut Island developer and direct field observations. The soil-collection points are presented in Figure 2.

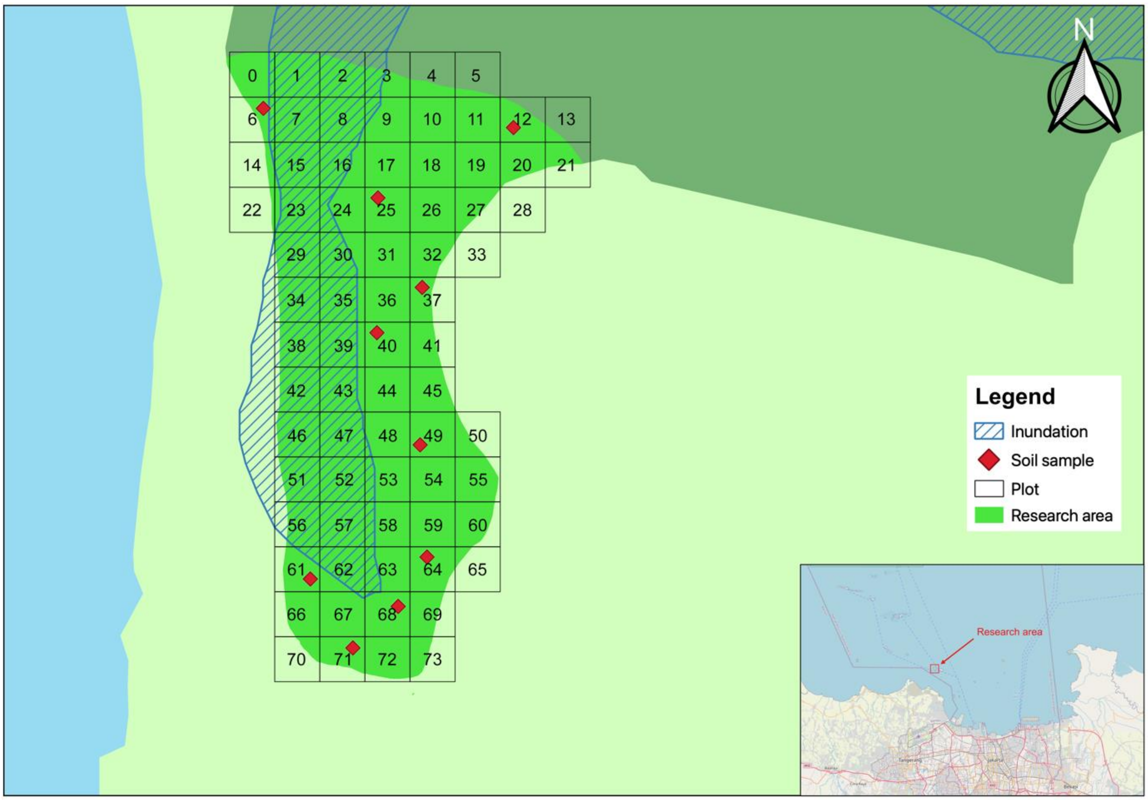

Figure 2. Soil sample points in the research area.

Data Analysis

Restoration Map Area

Map analysis involved the use of supervised classification techniques to identify and delineate mangrove areas. After generating the initial map, it was manually digitized to accurately target the specific research area of interest. This process allowed for a focused examination of potential mangrove zones. To enhance precision, the plots within the research area were automatically measured using grid tools available in ArcGIS 10.8.

Vegetation Analysis

The collected vegetation data were processed into species density. Species density was calculated according to the formula by Mueller-Dombois and Ellenbergh [10], which divides the number of individual species by the size of the sample plot area. Sites that require restoration measures are on land with a low density of tree species and lack of regeneration of seedlings, as well as areas without vegetation. According to DGFMI [11], an area is considered to meet the availability of sufficient regeneration and trees if there are 2500 individuals per hectare for seedlings, 400 individuals per hectare for saplings, and 25 individuals per hectare for trees. Density level categories below or below this stipulation need to be restored.

Species Site-Matching

The analysis of matching mangrove species is based on several factors. These include the suitability of mangrove species according to inundation class and salinity which is compatible with environmental conditions. Additionally, the preferences of mangrove species for specific soil types are considered. The detailed results of this analysis are presented in Tables 1, 2, and 3.

Table 1. Distribution of mangrove tree species based on inundation class.

Tidal type/inundation class	Inundation class (salinity and tidal frequency)	Dominant tree species
All high tides	A. Brackish to salty, salinity 10–30 ppt, always inundated A1. 1–2 times/day, minimum 20 days/month	*Avicennia* sp. *Sonneratia* sp.
Medium-high tides	A2. 10–19 days/month	*Rhizophora* sp., *Bruguiera* sp.
Normal high tides	A3. 9 days/month	*Xylocarpus* sp., *Heritiera* sp.
Springs tides only	A4. A few days/month	*Lumnitzera* sp., Scyphyphora *sp.*
Storm high tides only	B. Freshwater to brackish water B1. Rarely hit by tidal	Halophyta, *Nypa fruticans*, Oncosperma, Cerbera

Table 2. The suitability of various mangrove species for environmental factors was assessed.

Species	Salinity (ppt)	Sand tolerance	Mud tolerance	Inundation frequency
Rhizophora mucronata	10–30	MD	ST	20 days/month
R. stylosa	10–30	ST	ST	20 days/month
R. apiculata	10–13	MD	ST	20 days/month
Bruguiera parviflora	10–13	MD	ST	10–19 days/month
B. sexangula	10–13	MD	ST	10–19 days/month
B. gymnorrhiza	10–13	SV	MD	10–19 days/month
Sonneratia alba	10–13	ST	ST	20 days/month
S. caseolaris	10–13	MD	MD	20 days/month
Xylocarpus granatum	10–13	MD	MD	9 days/month
Heritiera littoralis	10–13	MD	MD	9 days/month
Lumnitzera racemosa	10–13	ST	MD	A few days/year
Ceriops manghas	0–10	MD	MD	Seasonally inundated
Nypa fruticans	0–10	SV	ST	Seasonally inundated
Avicennia sp.	10–30	ST	ST	20 days/month

* Note: Suitable (ST), Moderate (MD), Inappropriate (SV), Unsuitable (VS).

Table 3 Soil preferences for mangrove tree species.

Species	Preference
Avicennia alba	deep mud, riverbanks, dry areas, high salinity
A. officinalis	deep mud, riverbanks, dry areas, low salinity
A. marina	deep mud, riverbanks, dry areas
A. lanata	deep mud, riverbanks, dry areas, high salinity
Aegiceras corniculatum	deep mud, riverbanks with high salinity
A. floridium	sandy soil, rocky and coral beaches, riverbanks with high salinity
Bruguiera gymnorrhiza	bubbly or sandy silt, sand, low salinity, peat, corrugated on drier soils, midzone to inland
B. parviflora	Loam, loamy or sandy silt, high salinity, riverbanks, inland zone
B. sexangula	grows anywhere with good drainage, low salinity estuary rivers or freshwater
B. cylindrica	silt (clay to dusty loam), sandy to loamy soil, towards the mainland
Rhizophora mucronata	Mud with wide salinity range, riverbank, peat, seaward to mid-zone
R. stylosa	sandy, rocky, or coral mud towards the sea
R. apiculata	deep silt with wide salinity, sandy soil, estuary area, riverbank, seaward to middle zone
Ceriops tagal	peat, silt, and dry areas, high salinity, inland zones
C. decandra	deep mud, riverbanks, dry areas, high salinity
Kandelia candel	deep mud, riverbanks, dry areas, low salinity
Sonneratia caseolaris	deep mud, riverbanks, dry areas
S. alba	deep mud, riverbanks, dry areas, high salinity
Nypa fruticans	deep mud, riverbanks with high salinity
Heritiera littoralis	sandy soil, rocky and coral beaches, riverbanks with high salinity
Lumnitzera racemosa	bubbly or sandy silt, sand, low salinity, peat, corrugated on drier soils, midzone to inland
L. littorea	Loam, loamy or sandy silt, high salinity, riverbanks, inland zone
Xylocarpus granatum	silt (clay to dusty loam), sandy to loamy soil, towards the mainland
X. moluccensis	grows anywhere with good drainage, low salinity estuary rivers or freshwater
Excoecaria agallocha	Mud with wide salinity range, riverbank, peat, seaward to mid-zone

Selection of Planting Techniques

The selection of planting technique affects the ability of mangroves to grow and adapt. Proper planting techniques can protect mangroves from waves and inundation. Furthermore, planting technique is selected based on the environment condition. As a reference, six planting techniques are listed in Table 4.

Table 4. Planting techniques for mangrove forests.

Planting technique	Environment condition	Technical implementation
Guludan	Applied to land with inundation of more than 1 m	A bamboo mound is made at least 8 cm in diameter with a band width of 4.5 m and a length of 6 m, then filled with soil 50 cm thick, with 40 cm of which is submerged in water so that planting can be carried out.
Tiang Pancang	Applied to deep silt land with big wave	seedlings are planted and tied to stakes measuring 1 m with a diameter of 7.5 cm; then stuck into the mud as deep as 0.5 m.
Ruas Bambu	Applied to deep silt land	bamboo with a diameter of 20–25 cm and a height of 1 m is stuck in the mud as deep as 0.5 m; then the bamboo is hollowed out and filled with mud as a medium for planting mangroves [12].
Lubang Berlumpur	Applied to silt land	seeds planted in large holes filled with mud.
Bronjong	Applied to inundated areas around ± 60 cm	woven bamboo filled with soil as a growing medium [12].
Cemplongan	Applied to land without constraints	prepare the land by making a circle around the planting hole for tillage.

Results and Discussion

Distribution Areas

The mangrove forest on Rambut Island Wildlife Reserve has an area of approximately 14.31 ha, with 2.14 a research area extending along the contour of the coastline. The total number of research plots was 74 (Figure 3), which were divided into vegetated and non-vegetated areas.

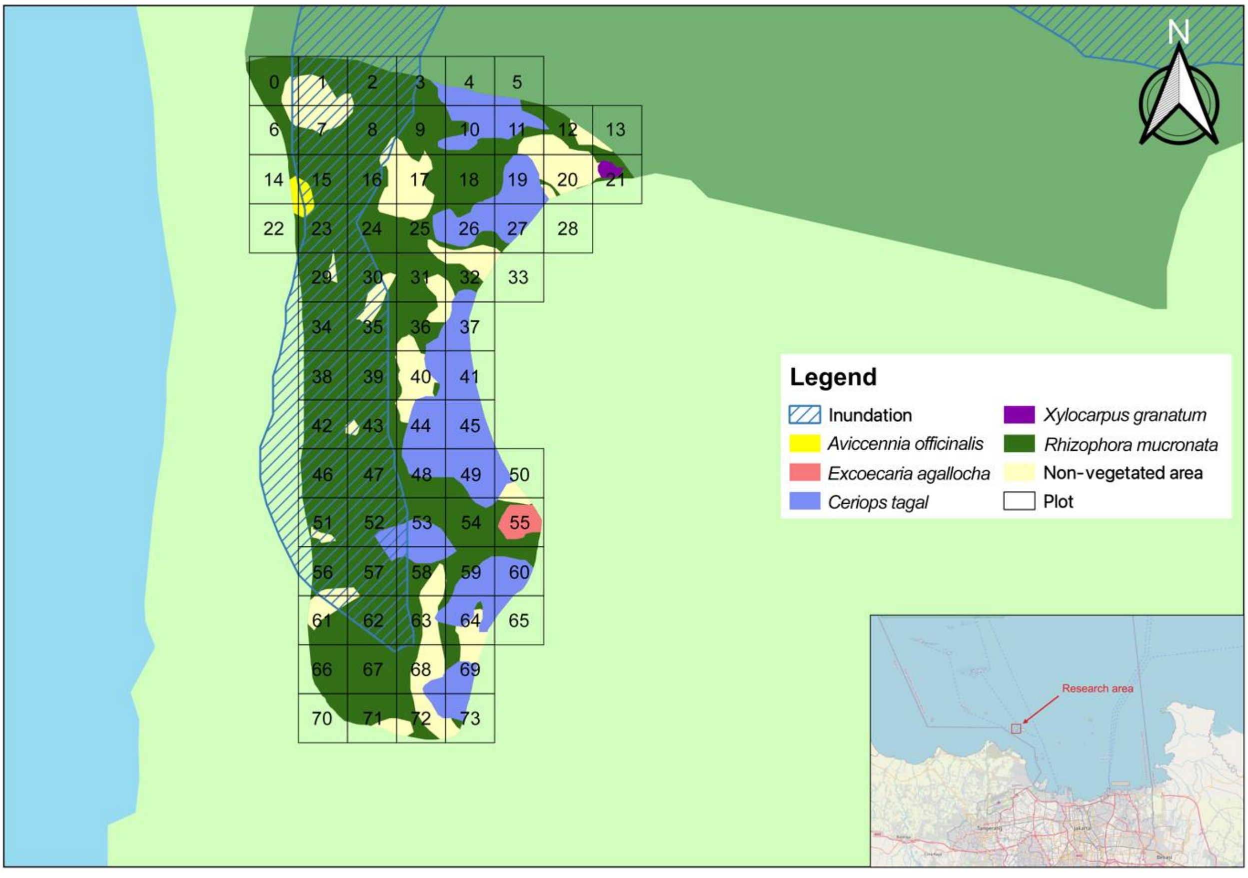

Figure 3. Map of dominant species in the study area.

The vegetated areas were dominated by *Rhizophora mucronata, Ceriops tagal, Excoecaria agallocha, Avicennia officinalis*, and *Xylocarpus granatum*. Meanwhile, the non-vegetated areas were bare-soil lands. Vegetated areas requiring restoration included Plots 28, 50, and 64. These plots were still classified as requiring restoration because the stages of seedlings, saplings, or trees did not meet the sufficient density category. The non-vegetated areas requiring restoration action included plots 5, 7, 13, 20, 33, 64, 65, and 73. The area requiring restoration action in the research area was approximately 0.37 ha.

Environmental Parameters

The analysis of vegetation, soil, inundation class, and water salinity based on inundation class preferences (Table 1), environmental factors (Table 2), and soil preferences (Table 3) resulted in mangrove species suitable for planting in the research area. The soil analysis results at the research site were classified into sandy loam texture with a sand percentage of 59.12%, dust of 21.37%, and clay of 19.51%. According to Prinasti et al. [13], the proportion of the sandy loam soil fraction is 40 to 87.5% sand, less than 50% silt, and less than 20% clay. Mangrove forests on Rambut Island comprise mineral mud and peat material with a layer thickness ranging from 70 to 120 cm. Rambut Island exhibits a diurnal tidal pattern. This type occurs once a day. This type of tide causes the relative inundation height to change depending on tidal conditions.

The restoration areas at the research site belong to the class of normal to medium-high tides. The inundation class was determined based on the duration of the inundation in a month. Based on Schmidt and Ferguson's climate classification, Rambut Island is included in climate type C [14], which is rather wet. During the rainy season, the inundation height can reach around 1.0 to 1.3 m for less than 20 days, while during the dry season the inundation only reaches less than 0.6 m for less than 10 days. The research location was limited by sand formed by seawater abrasion of approximately 5 to 10 m along the coastline. However, stagnant water enters when it is high tide; therefore, the stagnant water in several research locations is high tide that enters at high tide, but cannot come out at low tide, which is brackish after mixing with seawater [15].

The inundation class in the normal high-tide area includes plots 5, 13, 20, 28, 33, 50, 64, 65, and 73. The inundation class has a salinity value of 0 because it has no inundation above it; it is in the zone between sea and land, which leans more inland, so there is little influence from seawater [16]. According to Ramdhani et al. [17], the further inland, the lower the salinity level because the land is farther from the tide. The inundation class in the moderate-high tide area only included plot 7, which was relatively frequently inundated. Plot 7 was inundated with water with a salinity of 25 ppt. Yusniawati et al. [18] said that mangrove forests that are directly adjacent to the sea have a high salinity value due to the influence of sea water.

Species Site-Matching

The selection of mangrove species recommended for restoration activities was adjusted based on the original species in the Rambut Island Wildlife Reserve. Based on several references, the original species of mangroves that have been identified include: *Rhizophora mucronata, Rhizophora stylosa, Rhizophora apiculata, Ceriops tagal, Bruguiera gymnorrhiza, Excoecaria agallocha, Xylocarpus granatum, Avicenia officinalis, Phempis acidula*. Recommended species in normal high tides of the inundation class have less ability to adapt to salinity levels. In addition, these species generally live in zones directly adjacent to the land, sea, and drier areas. Supriadi et al. [19] found that *B. gymnorrhiza* grows on a wide variety of substrates with low salinity or on drier soils. This species is the dominant species in dense mangrove forests as a barrier to the final stage of coastal forests as well as the initial stage in the transition to land vegetation types [20].

R. mucronata and *R. apiculata* are often found in muddy or sandy loam soil texture habitats, but *R. mucronata* is more tolerant to harder substrates or sand. Kolinug et al. [21] stated in their research that the Genus Rhizophora was found bordering a zone directly adjacent to the sea from the middle to the rear or directly adjacent to land. *C. tagal* and *C. decandra* grow well on dry and hard peatlands. *C. tagal* and *C. decandra* can live in inland zones and are tolerant of high salinity [12]. *H. littoralis* commonly found on sandy loam soil texture, nearly to the sea, and takes more than 4 years to mature [22]. According to a study by Agustini et al. [23], *X. granatum* grows alongside rivers and brackish water that is not too high in salinity and moderate for sand and silt, with an inundation frequency of less than nine days.

Recommended species in medium-high tides of the inundation class generally tolerate high salinity. The selected species were generally found in zones directly adjacent to the sea and were more frequently inundated. *A. alba* and *A. officinalis* are generally the species that are often found along rivers that are often affected by tides [24]. The Genus Avicennia fails to grow in 0 to 5% seawater, whereas maximal growth occured in 50 to 75% seawater [25]. In addition, Noprianti et al. [26], Rhizophora grows in a wide range of salinities. *Rhizophora stylosa* has a wide-ranging salinity tolerance of 32 to 36 ppt. *R. stylosa* is unique species of Rhizophora Genus, by reason of the species can grow on harder substrate such as rubble and clam [27]. *S. alba* inhabits the low intertidal zones of downstream estuaries with muddy or sandy substrates and reaches optimal growth in 5 to 50% seawater, which is indicative of tolerance to high salinity [28].

Planting Techniques

Soil texture in the restoration areas is the same, namely sandy loam, and the difference in inundation height causes differences in planting techniques in the restoration areas. The appropriate planting technique that can be applied to this research area is the *cemplongan* technique, which can be applied to all restoration plots, except for plot number 7, which was applied using the *Bronjong* technique. The *cemplongan* technique can be applied to plots 5, 13, 20, 28, 33, 50, 64, 65, and 73. This technique creates a plate around the planting hole for tillage [29]. The ideal spacing for mangrove plants is 1 × 1 m or 1 × 2 m, whereas for plants with wide crowns, the ideal spacing is 5 × 5 m. On riverbanks, embankments, ponds, and areas prone to abrasion, mangroves are planted with a spacing of 0.25 m x 0.25 m or 0.5 × 0.5 m or planted in clusters; therefore, the *cemplongan* technique should be used in restoration areas is a denser spacing. These spacings blocked seawater waves to reduce the impact of abrasion. The *Bronjong* technique is only recommended for plot number 7 because the inundation factor is as high as 51 cm and it is located directly adjacent to sea water; thus, it has the potential to be hit by sea waves. The *Bronjong* planting technique uses bamboo *Bronjong* filled with sediment. *Bronjong* serves to strengthen mangrove plant that are inundated or affected by tides. According to Turisno et al. [30], bamboo *Bronjong* planting media can increase the life potential of mangroves, especially those of the Avicennia Genus.

Conclusions

The mangrove forest located in the Rambut Island Wildlife Reserve requires restoration. The total area of the mangrove forest on Rambut Island is approximately 14.31 hectares, with a specific research area of 2.14 hectares in the western part of the island. Within the research area, it has been determined that 0.37 hectares require restoration measures. To restore mangrove forests, specific species of mangroves are suitable for planting in areas that require restoration. These include *Bruguiera gymnorrhiza, Rhizophora mucronata, R. apiculata, Ceriops tagal, C. decandra, Heritiera littoralis*, and *Xylocarpus granatum*, which should be planted on plots 5, 13, 20, 28, 33, 50, 64, 65, and 73. Additionally, *Avicennia alba, A. officinalis, R. mucronata, R. stylosa, R. apiculata*, and *Sonneratia alba* were planted in plot number 7. Furthermore, this study underscores the significance of considering environmental factors, such as soil texture, inundation frequency, and water salinity in restoration planning. By aligning planting techniques with site-specific conditions, such as utilizing the *cemplongan* technique for most restoration plots and the *Bronjong* technique for areas prone to high inundation, restoration practitioners can maximize the success of their restoration efforts.

Author Contributions

CK: Conceptualization, Writing – Review & Editing, Supervision; **RR**: Conceptualization, Methodology, Data Acquirement & Analysis, Writing – Review & Editing; **AS**: Writing – Review & Editing.

Conflicts of Interest

There are no conflicts to declare.

Acknowledgements

The authors appreciate and thank all reviewers for their support and review. BKSDA DKI Jakarta and PPLH IPB helped carry out this research through technical staff and financial support.

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