Spatial distribution of mangrove vegetation species, salinity, and mud thickness in mangrove forest in Pangarengan, Cirebon, Indonesia

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Abstract. *Purwanto RH, Mulyana B, Satria RA, Yasin EHE, Putra ISR, Putra AD. 2022. Spatial distribution of mangrove vegetation species, salinity, and mud thickness in mangrove forest in Pangarengan, Cirebon, Indonesia. Biodiversitas 23: 1383-1391.* The mangrove rehabilitation programs in the northern coastline of West Java showed varying levels of success due to the lack of information on habitat suitability and species distribution. This research aimed to investigate the spatial distribution of mangrove vegetation species, salinity, and mud thickness in Pangarengan mangrove forest, Cirebon, Indonesia. Data on mangrove vegetation, salinity, and mud thickness were collected from 78 randomly distributed sample plots. Species composition was analyzed using important value index, and spatial distribution was examined using QGIS. Results revealed that *Rhizophora mucronata* was the most dominant and widely distributed species in all areas of Pangarengan mangrove forest with the important value index (IVI) for seedlings, saplings, poles, and trees were 178.69%, 219.71%, 242.21%, and 167.56%, respectively. *Avicennia marina* showed significant IVI in saplings (59.41%) and trees (105.21%). Other species had an IVI of less than 20% for each growth stage. Salinity ranged from 0-28 ppt and gradually decreased from the shoreline to settlement areas. Mud thickness ranged from 55 to 175 cm but with no regular pattern observed. In conclusion, the Pangarengan mangrove forest was dominated by *R. mucronata*. Our findings suggest that to enhance the likelihood of success in mangrove rehabilitation programs, *R. mucronata* might be a good choice, but to increase the species diversity other species might need to be planted by applying specific treatments, such as a vertical aquaponic system.

Keywords: Geographic Information System, habitat, important value index, species composition, structure of vegetation

INTRODUCTION

Mangrove areas in Indonesia are one of the largest in the world. According to Giri et al. (2011), the total mangrove areas in the world are 137,760 km^2 of which 31,129.89 km^2 (22.6% of global total) are located in Indonesia. Mangrove in Indonesia contains a high diversity of flora and fauna (Purwanto et al. 2021; Yudha et al. 2021), storing the carbon around 1,083±378 Mg C/ha (Murdiyarso et al. 2015), and protecting from tsunami effects (Onrizal and Mansor 2016).

Land-use change of mangrove areas has caused a significant mangrove loss in Indonesia. The main drivers of mangrove loss in Indonesia are timber exploitation and the development of aquaculture (Ilman et al. 2016). In the last three decades, deforestation of mangroves has released annual emissions of around 0.07-0.21 PgCO$_2$-eq (Murdiyarso et al. 2015). According to Arifanti (2020), the increase of CO$_2$, temperature and sea level strongly affect the existence of the remaining mangrove area in Indonesia.

There have been various efforts of mangrove rehabilitation, including those conducted along the northern coastline of West Java. These efforts received great attention from stakeholders and attracted many studies, such as Maulani et al. (2021) in Muara Gembong, Bekasi District; Nusantara et al. (2015) in Karawang District; Siringoringo et al. (2018) in Pamanukan, Subang District; Surayya et al. (2020) in Indramayu District; and Rakhmadi et al. (2019) in Cirebon District. While such rehabilitation initiatives deserve appreciation, there are still several problems that remain on the ground. The studies on those rehabilitation programs resulted in similar conclusion, i.e., the need for serious rehabilitation interventions to recover the ecological functions of the degraded ecosystems.

A similar situation also occurs in the remaining mangrove areas in Cirebon District. There was 1,780 ha of total mangrove areas in Cirebon District in 2018 (Dinas Kehutanan Provinsi Jawa Barat, 2019). The Government of Cirebon reported that the potential area for mangrove rehabilitation is around 2,193.70 ha, of which approximately 892.30 ha has been rehabilitated by the government, NGO, private sectors, and community (Pemerintah Kabupaten Cirebon 2014). In Cirebon, mangrove forest exist in the subdistricts of Losari, Pangenan, and Gebang (Pemerintah Kabupaten Cirebon 2014). Despite the small extent of the remaining mangroves with only 21.5 ha, the Pangarengan mangrove forest in Pangenan Subdistrict is home to 24 species of flora and 12 species of fauna and has a carbon stock of 11.719-590.310 MgC/ha (Purwanto et al. 2021). Considering the importance of the mangrove ecosystem in

biodiversity conservation and carbon storage, Raharjo et al. (2016) recommended expanding the existing mangrove forest in Cirebon District by conducting mangrove rehabilitation programs.

Nowadays, private companies have an emerging interest in mangrove rehabilitation. For instance, PT. Cirebon Electric Power planted around 70,000 mangrove seedlings to rehabilitate the coastline in Cirebon in 2011-2014, with a survival rate ranging from 30% to 80% (PT Cirebon Electric Power 2017). However, Nusantara et al. (2015) reported a low survival rate (14.3%) in a mangrove rehabilitation program by oil and energy company in Karawang District due to disposal of dredged material and lack of information on habitat suitability for mangrove species. Despite the varying success, the mangrove rehabilitation programs in the northern coastline of West Java by private sectors should be appreciated as their good commitment to protecting and conserving the environment, especially the mangrove ecosystem. The low success rate implies the need for improved knowledge on species and habitat when conducting mangrove rehabilitation programs.

Understanding the spatial distribution of species, salinity, and mud thickness are important in mangrove rehabilitation programs. In species selection, the physicochemical characteristics of mangrove habitat, such as salinity and mud thickness, must be considered. Other factors of concern include soil texture, species suitability, and level of stakeholders' awareness (Nusantara et al. 2015). Thus, this research aimed to investigate the spatial distribution of mangrove species, salinity, and mud thickness in the Pangarengan mangrove forest. The findings of this study can serve as a reference when planning and implementing mangrove rehabilitation programs in these areas.

MATERIALS AND METHODS

Research area

This research was conducted in the Pangarengan mangrove forest in the northern coastline of Java Island, Cirebon District, West Java Province, Indonesia. This area has an extent of 21.5 ha and is affected by freshwater from the Cipaluh River and the tide of the Java Sea (Purwanto et al. 2021). Seventy-eight randomly distributed sampling plots (Figure 1) were established using the method from the study of Nehru and Balasubramanian (2018) in small mangrove areas scattered in Nicobar Island, India.

Figure 1. Map of the study area and sampling locations in Pangarengan mangrove forest, Cirebon District, West Java Province, Indonesia (Purwanto et al. 2021)

Data collection

Primary data on species composition, salinity, and mud thickness were collected in June 2021. Fieldwork was conducted during the dry season with low precipitation and stable temperature. On average, the precipitation in Cirebon area between May and November in 2018-2019 was less than 10 mm/day (Badan Pusat Statistik Kabupaten Cirebon 2019, Dinas Komunikasi Informatika dan Statistik Kota Cirebon 2020). The temperature throughout the year was relatively stable from 26ºC to 29ºC (Dinas Komunikasi Informatika dan Statistik Kota Cirebon 2021).

Mangrove forest inventory was performed using a nested sampling plot. The subplot sampling sizes were 2 x 2 m (seedlings), 5 x 5 m (saplings), 10 x 10 (poles), and 20 x 20 m (trees) (Yuliana et al. 2019, Purwanto et al. 2021). The criteria of seedlings were plants with dbh of less than 2 cm and height ≤ 1.5 m, saplings were dbh of 2-<10 cm, poles with dbh 10-<20 cm, and trees were plants with dbh more than 20 cm. Name of species, number of species, and diameter at breast height (dbh) were recorded for each plot. Dbh was measured using caliper for mangrove plants with dbh < 15 cm and measuring tape for dbh ≥ 15 cm.

Physicochemical parameters, namely, mud thickness and salinity, were also measured at each plot by using a stick and a salinity refractometer (Matatula et al. 2019). The stick was pressed into the mud until it reached the hardest soil. After removing the stick, the length of the dipped part was measured. Salinity was recorded in the high tide for each sampling plot. The water was sampled using a pipette and then dropped into the sensor area. The position of each plot was also recorded using GPS for spatial distribution analysis.

Data analysis

Vegetation data were analyzed using the important value index (IVI) for seedlings, saplings, poles, and trees. The IVI approach for the analysis of vegetation structure and composition in mangrove forest has been applied by Utami et al. (2017) and Widyastuti et al. (2018) in Central Java, Yuliana et al. (2019) in South Sumatera, Sadono et al. (2020) in East Nusa Tenggara, Paembonan et al. (2020) in South Sulawesi, Sukuryadi et al. (2021) in West Nusa Tenggara, and Harefa et al. (2022) in North Sumatera. The following equations were employed:

Owing to the lack of data on seedling diameter, IVI was calculated as the sum of relative density and relative frequency.

The spatial distribution approach was initiated from sampling design, ground check and data analysis. First, 78 rectangular sample plots in a random distribution were selected using QGIS followed by a ground check in each plot to collect data on species, salinity, and mud thickness. The spatial distribution of vegetation, salinity, and mud thickness was analyzed using the Voronoi polygon method in QGIS version 3.22.

RESULTS AND DISCUSSION

Species composition and spatial distribution

The Pangarengan mangrove forest was composed of *Rhizophora mucronata, Avicennia marina, Avicennia alba, Sonneratia caseolaris, Sonneratia alba,* and *Nypa fructicans* and exhibited complete growth stages of seedlings, saplings, poles, and trees (Figure 2). The stand structure formed a reverse J shape in which the seedlings density accounted for the highest value, followed by saplings, poles, and trees. This form was related to diameter distribution, crown density, and mortality rate (Westphal et al. 2006). Seedling's abundance was a good sign of sustainable mangrove forest management because it will ensure natural regeneration (Paembonan et al. 2020).

The seedlings and saplings of *R. mucronata* were the most abundant among all species recorded. This trend was also reported at a mangrove forest in Demak District (Damastuti et al. 2022), Rembang District (Wicaksono and Muhdin 2015), and Segara Anakan Lagoon and was attributed to the rehabilitation program and natural colonization (Nordhaus et al. 2019). The high density of seedlings also indicated that natural regeneration could occur in the mangrove forest with saplings, poles, and trees as a possible source of seeds (Paembonan et al. 2020).

Rhizophora mucronata natural colonization was also observed at the successional mangrove forest in Nicobar Island, India (Nehru and Balasubramanian 2018). After the 2004 Indian Ocean tsunami, this area was dominated by *R. mucronata* and *Bruguiera gymnorhiza,* with a cumulative abundance of around 70% (Nehru and Balasubramanian, 2018). Adaptability and survival rate after large-scale disturbance are the key factors in the dominance of *R. mucronata* over other mangrove species.
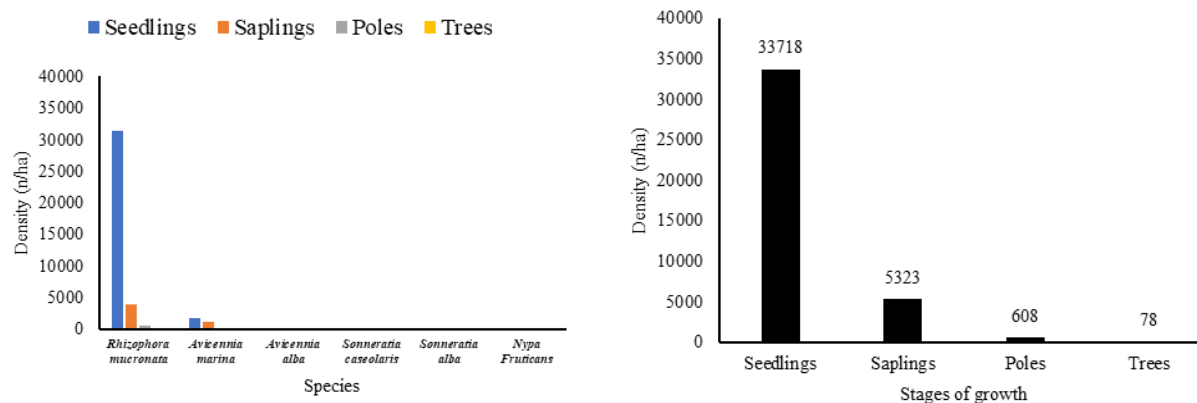
$$Species\ density = \frac{Number\ of\ individu}{Size\ of\ sampling\ plot} \tag{1}$$

$$Species\ dominance = \frac{Total\ basal\ area\ of\ specie}{Size\ of\ sampling\ plot} \tag{2}$$

$$Species\ frequency = \frac{Number\ of\ plot\ containing\ a\ species}{Total\ of\ sampling\ plot} \tag{3}$$

$$Relative\ density = \frac{Species\ density}{Total\ species\ density} \times 100\% \tag{4}$$

$$Relative\ dominance = \frac{Species\ dominance}{Total\ species\ dominance} \times 100\% \tag{5}$$

$$Relative\ frequency = \frac{Species\ frequency}{Total\ species\ frequency} \times 100\% \tag{6}$$

$$Important\ value\ index = relative\ densiti + relative\ dominance + relative\ frequency \tag{7}$$

Figure 2. Vegetation structure of mangrove species Pangarengan mangrove forest, Cirebon District, West Java, Indonesia
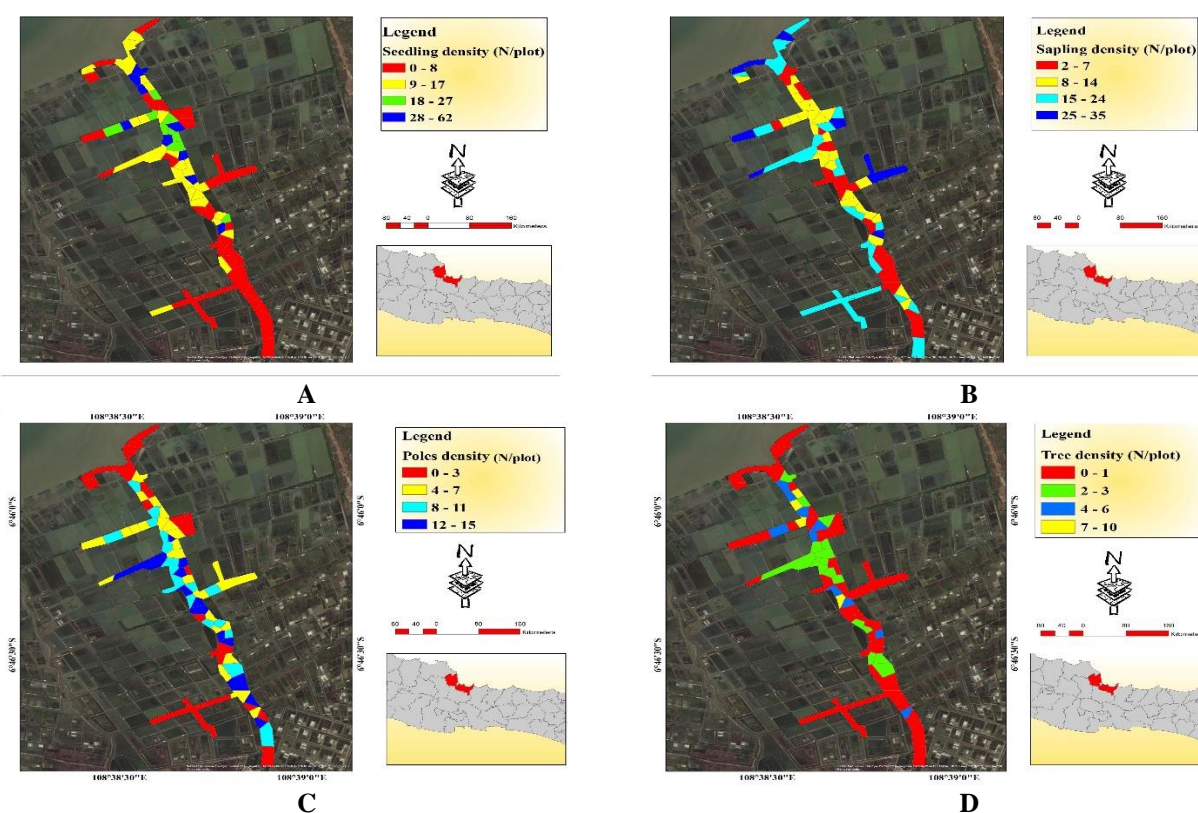

Figure 3. Spatial distribution of mangroves in Pangarengan mangrove forest, Cirebon District, West Java Province, Indonesia: A. Seedling, B. Sapling, C. Poles, D. Trees
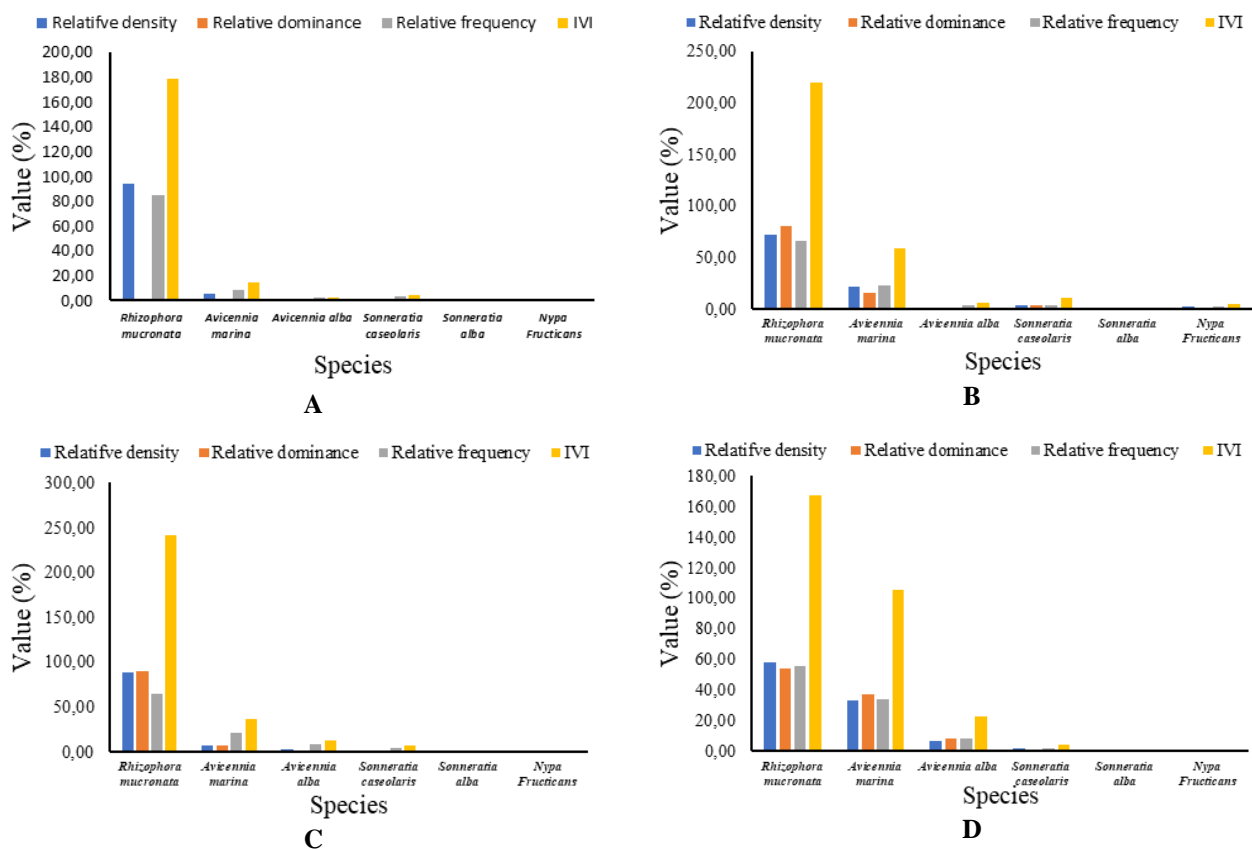
Spatial distribution analysis (Figure 3) showed that the mangrove areas near the settlement needed serious attention as the lowest point of seedlings and trees distribution. Fortunately, saplings and poles stages can still be found in these locations as a source of mangrove seeds. According to mangrove density (diameter > 4 cm) (Hilmi et al. 2021), the growth stage of the poles in the studied area was categorized as rare (391--1,610 n/ha), and trees was categorized as very rare (0--390 n/ha). In consideration of the rare density of seed source for mangrove regeneration, stakeholders in Cirebon District are recommended to take serious action to preserve the Pangarengan mangrove forest.

The Pangarengan mangrove forest had low flora diversity. Inventory data revealed five true mangrove species, namely, *R. mucronata, A. marina, A. alba, S. caseolaris,* and *S. alba* (Table 1). The dominant species were *R. mucronata* and *A. marina* (Figure 4). Three of the dominant families in this mangrove forest (Rhizophoraceae, Acanthaceae, and Lythraceae) were also reported in Angke Kapuk Mangrove Protected Forest, Jakarta (Rumondang et al. 2021), and mangrove revegetation area in Karangsong, Indramayu District, West Java (Gunawan et al. 2017).

Table 1. Species distribution of mangrove species in Pangarengan mangrove forest, Cirebon District, West Java Province, Indonesia

Family	Species	IUCN Status	Distribution*			
			Seedlings	Saplings	Poles	Trees
Arecaceae	*Nypa fructicans*	Least concern	Rare	Rare	Rare	Rare
Acanthaceae	*Avicennia marina*	Least concern	Rare	Occasional	Occasional	Rare
	Avicennia alba	Least concern	Rare	Rare	Rare	Rare
Rhizophoraceae	*Rhizophora mucronata*	Least concern	Abundant	Common	Common	Occasional
Lythraceae	*Sonneratia caseolaris*	Least concern	Rare	Rare	Rare	Rare
	Sonneratia alba	Least concern	Rare	Rare	Rare	Rare

Notes: *rare (frequency < 20%), occasional (21%-40%), frequent (41%-60%), common (61%-80%), abundant (> 80%) (Sreelekshmi et al. 2020)

Figure 4. Important value index (IVI) of mangrove species in Pangarengan mangrove forest, Cirebon District, West Java Province, Indonesia: A. Seedling, B. Sapling, C. Poles, D. Trees

As shown in Figure 4, *R. mucronata* in the Pangarengan mangrove forest had the highest IVI for seedlings, saplings, poles, and trees. This value can be attributed to the higher density and basal area of *R. mucronata* compared to the other species. The dominance of *R. mucronata* (68.85% in this study) was also observed at a mangrove forest in Indramayu District, West Java (Gunawan et al. 2017) and in Panjang Island, Jepara District, Central Java (Utami et al., 2017). The abundance of *R. mucronata* is due to the rehabilitation program, not natural growth. In less than a decade, the number of *R. mucronata* in Indramayu District increased significantly by around 27 times (from 25,000 individuals in 2008 to 690,835 individuals in 2016) (Gunawan et al. 2017). Nordhaus et al. (2019) and Harefa et al. (2022) also found that *R. mucronata* and *Rhizophora apiculata* are the common species used in the rehabilitation of mangrove and silvofishery areas.

Nonetheless, different results on dominant species were found in other studies. For instance, *A. marina* had the highest IVI in Angke Kapuk Mangrove Protected Forest, Jakarta (Rumondang et al. 2021), and Segara Anakan Lagoon, Cilacap District, Central Java (Widyastuti et al. 2018). *Rhizophora apiculata* was the dominant species (69%) in the secondary mangrove forest in Bintuni, Papua (Yudha et al. 2021), *S. alba* had the highest IVI in Tanah Merah mangrove forest, East Nusa Tenggara (Sadono et al. 2020). Thus, research on species composition in a particular mangrove forest in Indonesia is still important due to high variability in each location (habitat suitability, weather, and vegetation structure).
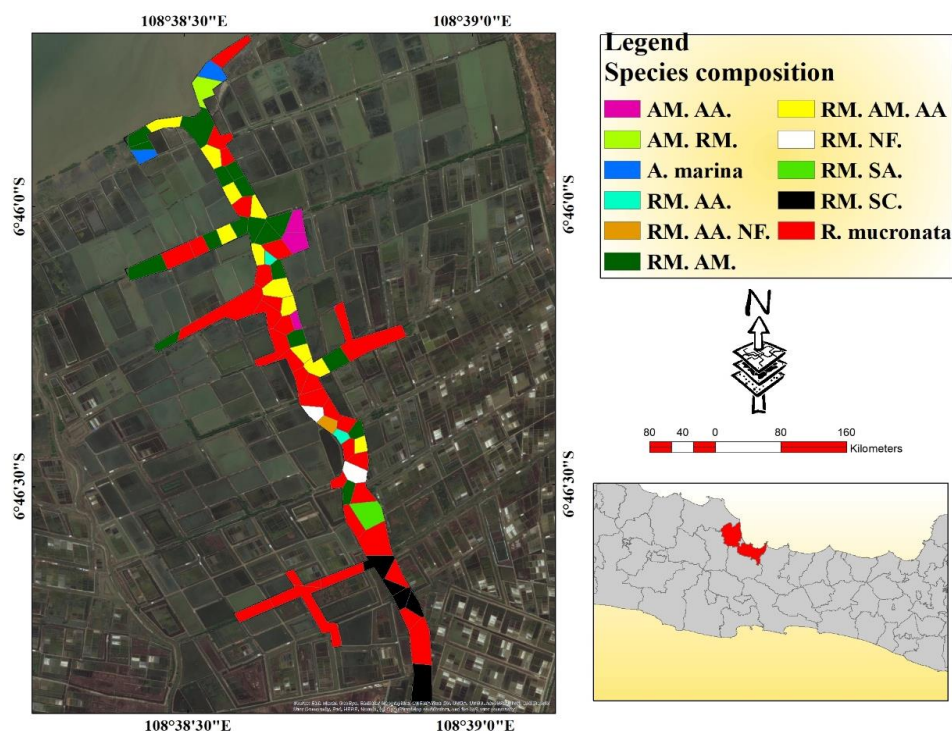
Figure 5. Spatial distribution of species composition in Pangarengan mangrove forest, Cirebon. AM.AA (*A. marina* and *A. alba*), AM.RM (*A. marina* and *R. mucronata*), RM.AA (*R. mucronata* and *A. alba*), RM.AM (*R. mucronata* and *A. marina*), RM.NF (*R. mucronata* and *N. fructicans*), RM.SA (*R. mucronata* and *S. alba*), RM.SC (*R. mucronata* and *S. caseolaris*), RM.AA.NF (*R. mucronata*, *A. alba*, and *N. fructicans*), and RM.AM.AA (*R. mucronata*, *A. marina*, and *A. alba*)

Spatial distribution of salinity and mud thickness

During the high tidal period, the salinity in the Pangarengan mangrove forest ranged from 0 ppt to 28 ppt. Low salinity areas were found near the settlement, and high salinity areas were close to the sea (Figure 6). Brackish water, a transitional area between marine water and freshwater, occurred in the middle area. Seawater flow was stronger than freshwater flow in the high tidal period and vice versa.

Rhizophora mucronata can grow in a wide range of salinity. The Rhizophoraceae family is generally highly resilient in fresh and saline water (Win et al. 2019). For instance, the seedlings of *R. mucronata, R. apiculata,* and *Rhizophora stylosa* have shown high survival and adaptation in an experimental aquaponic site in North Jakarta (Hilmi et al. 2022). As displayed in Figure 5, *R. mucronata* was distributed from the area nearest to the settlement up to the mangrove areas close to the sea. In addition, *R. mucronata* has either grown together with other species or created its own colony.

Sonneratia caseolaris and *S. alba* were found in the Pangarengan mangrove forest area with a salinity of 0-10 ppt. *Sonneratia* spp. show decreased abundance with the increase in salinity and only grew in habitats with salinity below 22 ppt (Nordhaus et al. 2019). A similar phenomenon was reported in the mangrove area in Hainan, China, in which *S. caseolaris* and *Sonneratia apetala* were found in the upstream areas of the river estuaries with the lowest salinity (Xiong et al. 2021). Win et al. (2019) also reported that *S. caseolaris* in Myanmar grow in low salinity. However, *S. alba* was reported to thrive in a high salinity area in the Philippines (Raganas et al. 2020).

As shown in Figure 5 and 6, *A. marina* and *A. alba* were found in the area with a salinity of 6-28 ppt. *A. marina* has formed its own group in the shoreline, and *A. alba* has grown together with other species in the middle area of Pangarengan mangrove forest. Rather than direct planting, a vertical aquaponic system can be applied to ensure the survival, growth, and distribution of *A. marina* and *A. alba*. Hilmi et al. (2022) reported that this system had increased the survival rate of *R. mucronata, R. apiculata, R. stylosa, A. marina,* and *S. caseolaris* seedlings in North Jakarta.

The mangrove habitat is affected by salinity and its substrate. In general, mangroves grow in the estuarine area with muddy soil. Mud thickness exhibits a different pattern of salinity. In this work, salinity distribution gradually changed from the shoreline to the settlement area, and mud thicknesses showed an irregular pattern. Mud thickness near the settlement ranged between 55 and 135 cm, and deep mud was located close to the sea areas (136-175 cm). *R. mucronata* can grow in a wide range of mud thickness, *S. caseolaris* and *S. alba* were found in the mangrove area with mud thickness ranging 55-135 cm.
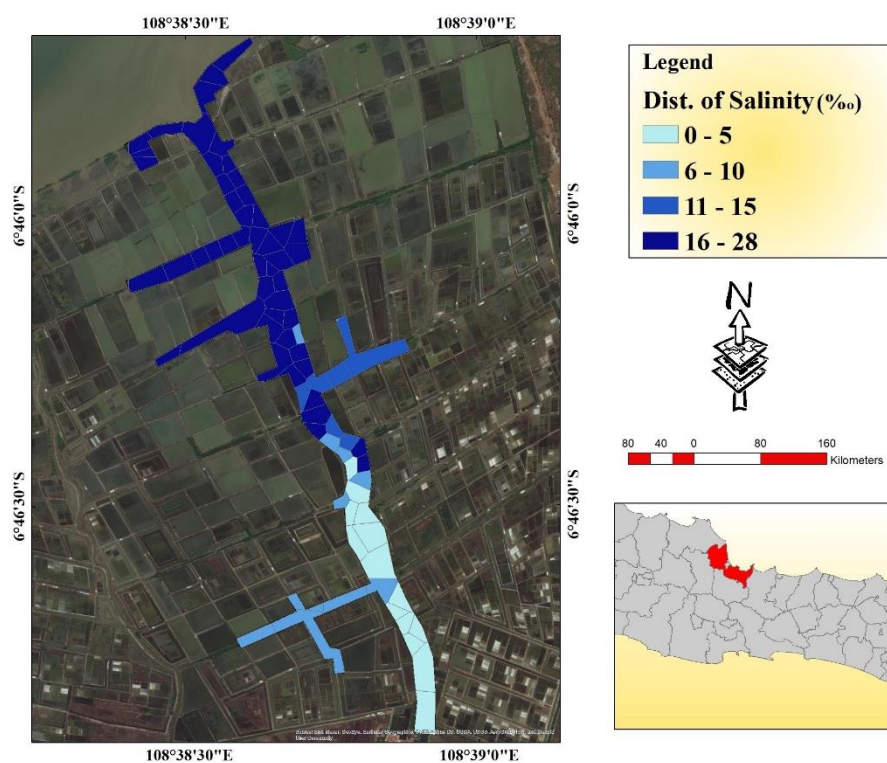
Figure 6. Spatial distribution of salinity level in Pangarengan mangrove forest, Cirebon District, West Java Province, Indonesia
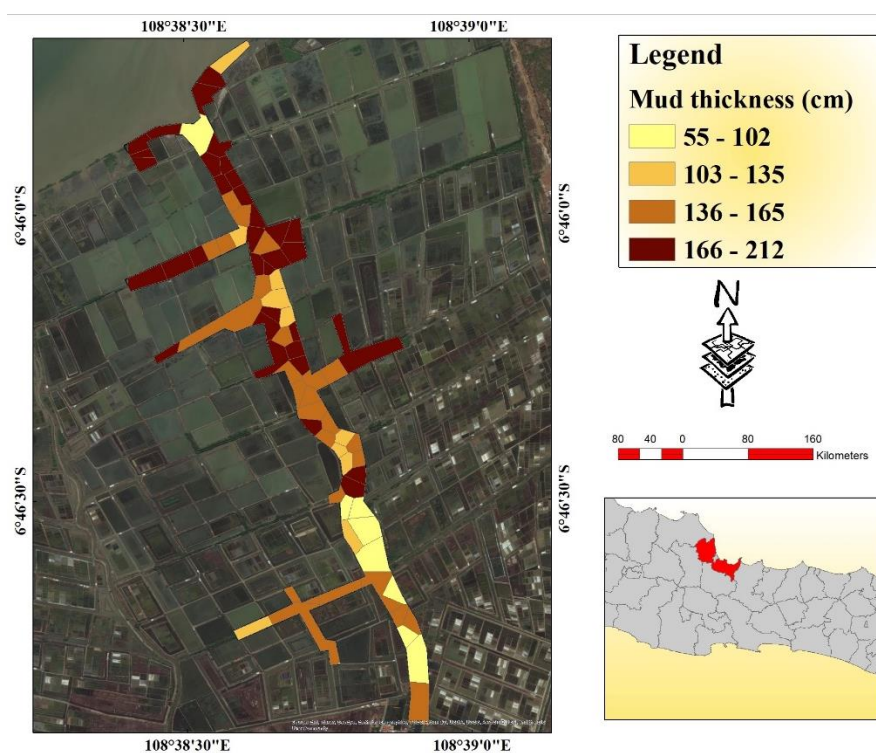

Figure 7. Spatial distribution of mud thickness in Pangarengan mangrove forest, Cirebon District, West Java Province, Indonesia

In conclusion, the Pangarengan mangrove forest was dominated by *R. mucronata* followed by *A. marina, A. alba, S. caseolaris, S. alba,* and *N. fructicans.* The dominance of *R. mucronata* occurred in all life stages (seedlings, saplings, poles, and trees). The salinity in During high tide, the salinity in Pangarengan mangrove forest ranged 0-28 ppt with a regular pattern and decreased gradually from sea area to settlement area. Mud thickness did not show a regular pattern. Stakeholders who will plan rehabilitation programs in the Pangarengan mangrove forest should consider these findings on species distribution, salinity gradient, and mud thickness. Given that *R. mucronata* was already abundant, the rehabilitation program must propose to enrich planting for other species such as *S. caseolaris* and *S. alba.*

ACKNOWLEDGEMENTS

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