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Diversity, biomass, covers, and NDVI of restored mangrove forests in Karawang and Subang Coasts, West Java, Indonesia

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Abstract. *Suwanto A, Takarina ND, Koestoer RH, Frimawaty E. 2021. Diversity, biomass, covers, and NDVI of restored mangrove forests in Karawang and Subang Coasts, West Java, Indonesia. Biodiversitas 22: 4115-4122.* Indonesia has been recognized as the country with greatest diversity of mangrove species with significant amount of carbon sink and biomass. In few recent decades, mangrove forests have been deforested significantly. One of the solutions to deal with mangrove deforestation is through restoration. West Java north coasts are one of the areas that have experienced deforestation, however, and mangrove restorations have been conducted mainly in Karawang and Subang coasts. Correspondingly this research aims to assess the mangrove diversity using index and biomass resulted from restoration programs in those coasts. To assess the mangrove diversity in each coast on June 2021, 6 sampling stations containing 3 replicated sample plots of size 10 m × 10 m were located. In total 8 species with 1549 trees were been sampled. In Subang the order of mangrove species from common to less-common species was *Avicennia marina* > *Rhizophora mucronata* > *Sonneratia caseolaris* > *Acanthus ilicifolius* > *Bruguiera gymnorhiza*. While the order in Karawang was *Avicennia marina* > *R. mucronata* > *Rhizophora apiculata* > *S. caseolaris* > *B. gymnorhiza*. The mangrove diversity (H)' was significantly different ($p = 0.000$, $F = 2.216$) with diversity in Subang Coast (average H' = 1.326, 95% CI: 1.15-1.5) was higher than in Karawang (average H' = 1.063, 95%CI: 0.934-1.2). Estimated restored mangrove covers in Subang were 3.612 km^2 and 0.46 km^2 in Karawang. *R. mucronata* was a mangrove species with the highest biomass with the value of 1337.91 mg ha^{-1} and the lowest was *A. marina* with a value of 14.3 mg ha^{-1}. The results suggest that restoration areas in Subang and Karawang have significant contributions to maintain mangrove diversity, biomass, and covers.

Keywords: Allometric model, biomass, dominance, mangrove diversity, NDVI, restoration, Shannon-Wiener index

INTRODUCTION

Mangrove forest area in Indonesia was estimated to be 3,112,989 ha or 22.6% of the total mangrove area globally (Giri et al. 2011). Mangrove forests alone have important biological wealth for Indonesia's coastal areas considering that mangrove forest is a transitional ecosystem in almost all coastal areas in the Indonesian Archipelago, ranging from Sumatra in the West to Papua Islands in the East. Despite the fact that mangroves cover such a huge area, Indonesia has 47 true mangrove species (Yudha et al. 2021), representing a higher species diversity than other countries in Southeast Asia.

Despite biodiversity, one of important parameters to evaluate mangrove assemblage is biomass. Mangrove biomass and their productivity are the two important parameters for indicating the material and nutrient inputs in the mangrove ecosystem. Consequently, many studies have developed biomass estimation methods for mangroves, including harvest, mean-tree, and allometric methods. This method is the most frequently used to estimate the mangrove forests biomass based on the diameter of mangrove tree trunks. Allometric models for mangroves biomass estimation vary greatly among the species and sites. In Panabo Park, Philippines, Alimbon and Manseguiao (2021) have measured the biomass for *Avicennia marina*, *Rhizophora mucronata* and *Sonneratia alba* of 46.30 mg ha^{-1}, 2.89 mg ha^{-1} and 27.98 mg ha^{-1} respectively. In the study of Analuddin et al. (2020), the measured *R. stylosa* biomass in Southeast Sulawesi ranged from 21.19 to 562.76 mg ha^{-1}. While, Zulhalifah et al. (2021), have recorded the biomass for *A. marina*, *Rhizophora apiculata* and *Sonneratia caseolaris* of 36.72 mg ha^{-1}, 148.92 mg ha^{-1}, and 127.76 mg ha^{-1} respectively in Lombok.

Numerous assessments on mangrove biodiversity and biomass were already implemented, whereas, only a few studies were conducted in the North of West Java Coasts. At the same time, mangroves on this coast were experiencing ongoing deforestation. Sodikin et al. (2017) have shown that mangrove areas in Indramayu Coast, West Java were decreased by 2.345 ha and the worst damage was recorded in Cantigi areas. One of the solutions to mitigate deforestation in West Java is through restoration. In West Java, coastal restoration activities by mangrove planting have been started since 1990. From 1999 to 2003, these activities resulted in 7.890 ha restored mangrove areas whereas the success rate was still very low. Based on this result, the rate of mangrove forest restoration in West Java was known to be about 1.973 ha yr^{-1}.

Karawang and Subang were mid areas in West Java that were also experiencing deforestation. Realizing this condition, several restoration activities initiated by government and community have been conducted through mangrove seedling plantings. This research was aimed to evaluate the results of mangrove restoration in Karawang and Subang Coasts based on diversity, biomass, land covers and NDVI variables.

MATERIALS AND METHODS

Study area

The study was conducted in June 2021 in Tangkolak, Karawang District and Blanakan, Subang District of West Java Province, Indonesia. Tangkolak (Karawang) has a size of 7.32 km^2 and surrounded by mangrove forests on its northern coast. Fishponds dominated southern part of Tangkolak (Karawang). Blanakan (Subang) was located in the East of Tangkolak and it has area of 5.22 km^2. The mangrove forest in Blanakan (Subang) was restored by the community through mangrove seedling plantings inside the fish ponds.

Procedures

Mangrove diversity, density and dominance

Method to assess mangrove forest diversity was modified from Dangan-Galon et al. (2016) and Sreelekshmi et al. (2020) based on the transect method on direct observation in mangrove restoration areas Blanakan (Subang) and Tangkolak (Karawang) coasts. On each coast on June 2021, six sampling stations containing 3 replicated sample plots sizing 10 m × 10 m were located. Inside the 10 m × 10 m plot, mangrove species and numbers of mangrove trees with a trunk diameter (Diameter at Breast Height/DBH) ≥ 10 cm and height ≥ 1.5 m were recorded. The density was measured as numbers of trees within 1 ha and denoted as trees ha^{-1}.

The mangrove diversity was assessed using Shannon-Wiener (H') and Dominance (D') indices (Asuk et al. 2018; Rahmayanti et al. 2018; Kasim et al. 2019). The H' was calculated as follows:

$$H' = \Sigma[P_i \ln (P_i)],$$

Where: Pi is the proportion of the species i mangrove in total individuals. The H' range is from 0 (low diversity) to 1 (high diversity).

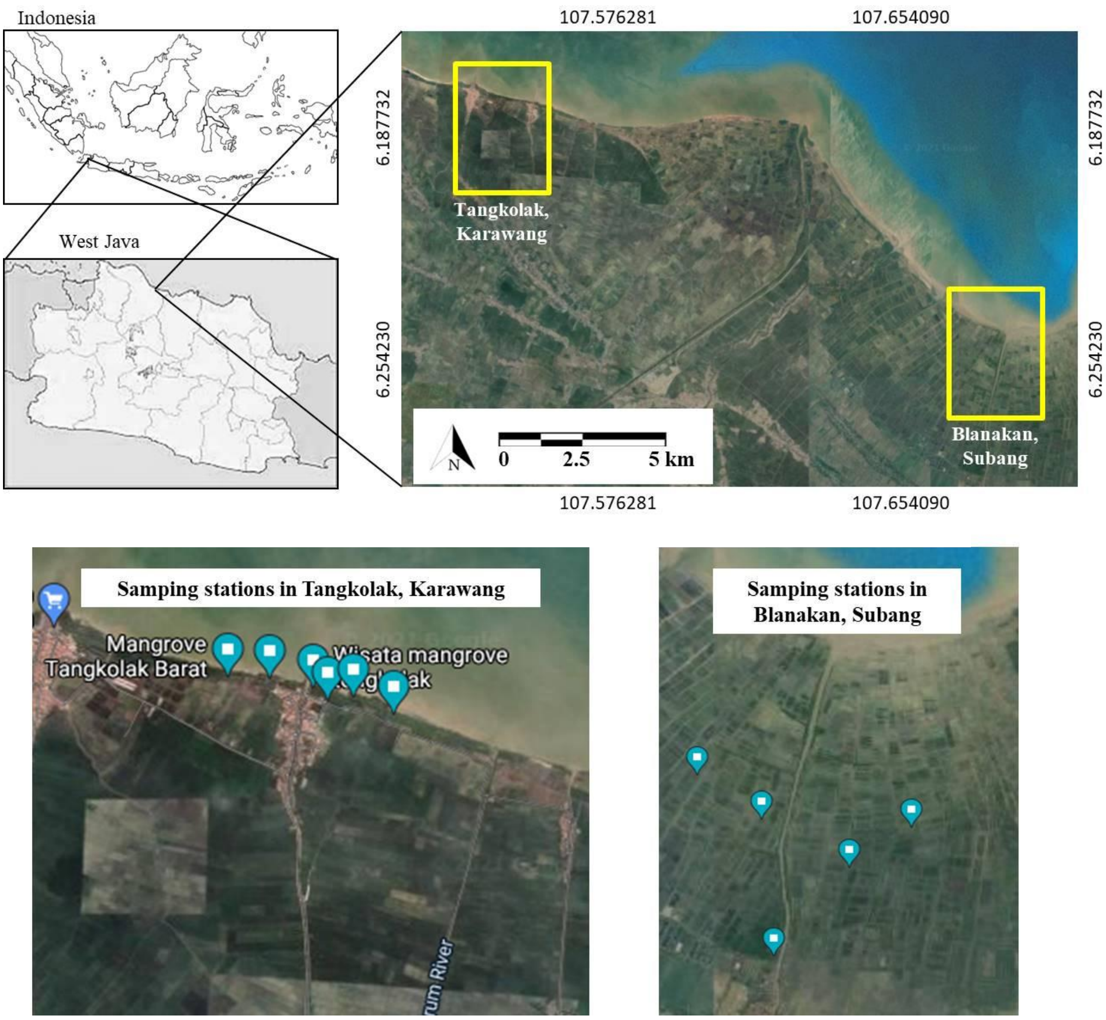

Figure 1. Map of study area and sampling stations in Tangkolak, Karawang and Blanakan, Subang Coasts, West Java. In each study area, 6 stations with 3 replicated 10 m × 10 m sampling plots were located

The D' was calculated following:

D' = 1-[(Σi ni (ni-1)/N (N-1)],

Where: ni is the number of the species i mangrove in total individuals (N).

Mangrove cover and NDVI

Mangrove cover classification was performed using Geographical Information System (GIS) analysis. A Landsat 8 satellite imagery (Landsat 8 Operational Land Imager (OLI) acquisition date: June, 24 2021) was retrieved and classified using supervised classification to determine the land cover types. The categories for land cover classifications were mangrove, settlement, ponds, and water. The sizes of each land cover category were measured to determine the land cover compositions denoted as percentage (%).

The method to measure mangrove NDVI was modified from Alatorre et al. (2016), Ibharim et al. (2015), and Rhyma et al. (2020). The NDVI is described as a simple graphical indicator that can be used to analyze remote sensing measurements, often from a space satellite platform, assessing whether the observed target contains live green vegetation. The NDVI was measured by analyzing the wavelength of satellite images retrieved from Landsat 8 containing vegetation images, which was mangrove in this study. This measurement is possible since cell structure of the vegetation leaves strongly reflects near-infrared light wavelength ranges from 0.7 to 1.1 µm. The calculation of NDVI for each pixel of vegetation pixel was as follows:

NDVI = near-invisible red wave length-red wavelength / near-invisible red wavelength + red wavelength

The NDVI was denoted as 0 (no vegetation) to 1 (high vegetation density). The NDVI rasters were then overlayed into Blanakan (Subang) and Tangkolak (Karawang) land cover layers using GIS. The mangrove covers are then categorized and classified by using NDVI as follows (Hanan et al. 2020):

if 0 < NDVI < 0.32 then mangrove covers < 50%
if 0.32 < NDVI < 0.43 then mangrove covers are 50-69%
if 0.43 < NDVI < 1.0 then mangrove covers are 70-100%

Mangrove biomass

The mangrove biomass for each recorded species was calculated using allometric methods. In this method, allometric models were established using independent variables of DBH. The allometric models for biomass estimation of each species were available in Table 1 (Clough and Scott 1989; Comley and McGuinness 2005; Analuddin et al. 2018; Kusmana et al. 2018).

Data and statistical analysis

The analysis was using ANOVA test with significant values p < 0.05. This test was used to measure the significant differences in mangrove density, diversity, and biomass between restoration areas in Tangkolak (Karawang) and Blanakan (Subang) coasts.

Table 1. Allometric model for mangrove species

Species name	Allometric model
Avicennia marina	$0.308(DBH)^{2.11}$
Rhizophora mucronata	$0.143(DBH)^{2.52}$
Sonneratia caseolaris	$0.258(DBH)^{2.28}$
Bruguiera gymnorhiza	$0.186(DBH)^{2.31}$

RESULTS AND DISCUSSION

Mangrove diversity and density

Mangrove in Blanakan (Subang) and Tangkolak (Karawang) coasts was remarkably different (Table 2). Mangroves of Blanakan (Subang) were more diverse with 6 species from 5 families. While in Tangkolak (Karawang) there were only 5 mangrove species from 3 families. *R. apiculata* was absent in Blanakan (Subang) while *Acanthus ilicifolius* and *Terminalia catappa* were absent in Tangkolak (Karawang). In Blanakan (Subang) the order of mangrove species from common to less common species was *A. marina* > *R. mucronata* > *S. caseolaris* > *A. ilicifolius* > *B. gymnorhiza*. While the order in Tangkolak (Karawang) was *A. marina* > *R. mucronata* > *R. apiculata* > *S. caseolaris* > *B. gymnorhiza*. All the mangrove tree species in Subang and Karawang were categorized as the least concern (IUCN 2021). Figure 2 presents the rarefaction curves. The curve demonstrated that the observed mangrove species richness tends to increase as observed in Subang and Karawang, indicating that further sampling would recover more mangrove species.

Figure 3 shows the average density of each mangrove species in every hectare in Blanakan (Subang) and Tangkolak (Karawang) coasts. In total the mangrove density in Karawang was higher. Despite having only 5 species, the mangrove density in Karawang was 5188.9 trees ha^{-1} which was higher than Subang with only 3416.7 trees ha^{-1} yet had 6 species. In both locations, *A. marina* and *R. mucronata* were the most common species. Figure 4 presents the diversity and dominance index. The mangrove diversity (H)' was significantly different (p = 0.000, F = 2.216) with diversity in Subang coast (average H' = 1.326, 95% CI: 1.15-1.5) was higher than in Karawang (average H' = 1.063, 95% CI: 0.934-1.2).

Mangrove covers and NDVI

Figure 5 shows the land cover distribution and compositions in study areas. In Karawang, restored mangrove areas were fragmented and available only on the coasts. The restoration areas were bordered directly with settlements and fishponds in the south parts. These conditions were very different compared to Blanakan (Subang). Here, mangrove restoration areas were distributed and mixed with the fishponds. As a result of restoration mangrove implemented inside the ponds, the land cover composition (Figure 6) order in Blanakan (Subang) was in order of mangrove > settlement > pond. While in Tangkolak (Karawang), the order was pond > mangrove > settlement. Estimated restored mangrove covers in Subang were 3.612 km^2 and 0.46 km^2 in Karawang.

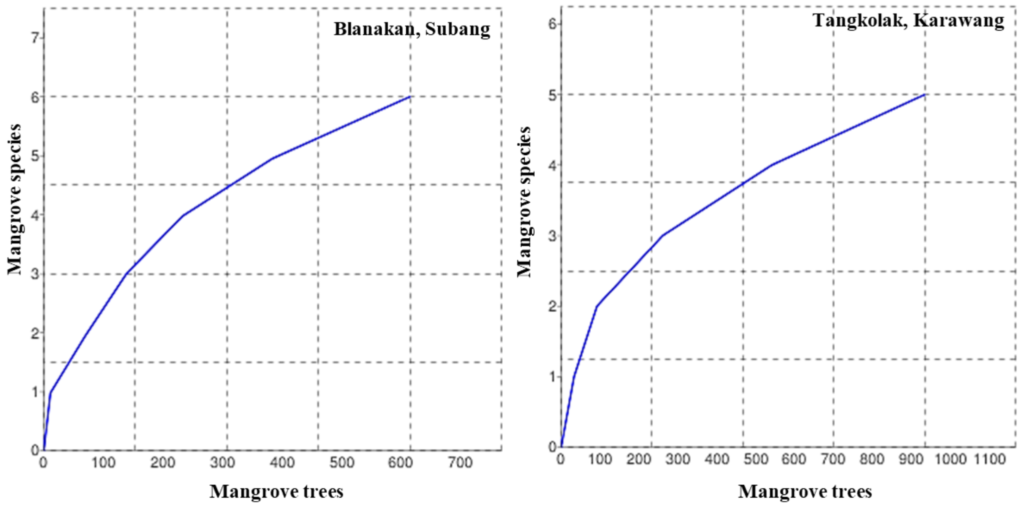

Figure 2. Rarefaction curve of mangrove species and total numbers of trees in Blanakan, Subang and Tangkolak, Karawang, West Java, Indonesia

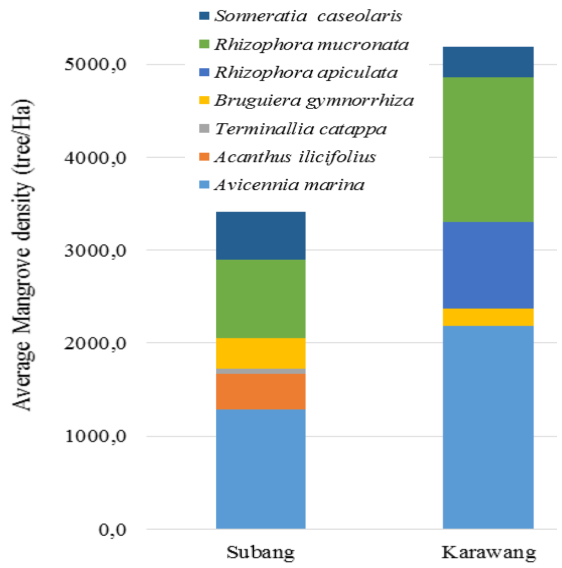

Figure 3. Average mangrove density (trees/Ha) in each station and total station (accumulative) in Blanakan, Subang and Tangkolak, Karawang, West Java, Indonesia

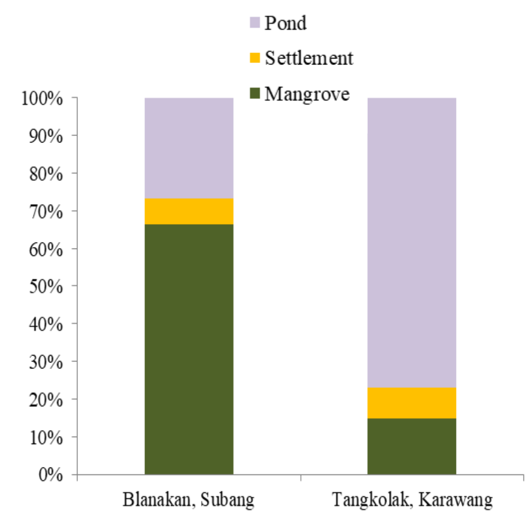

Figure 6. Restored mangrove and land cover compositions in Blanakan, Subang and Tangkolak, Karawang, West Java, Indonesia

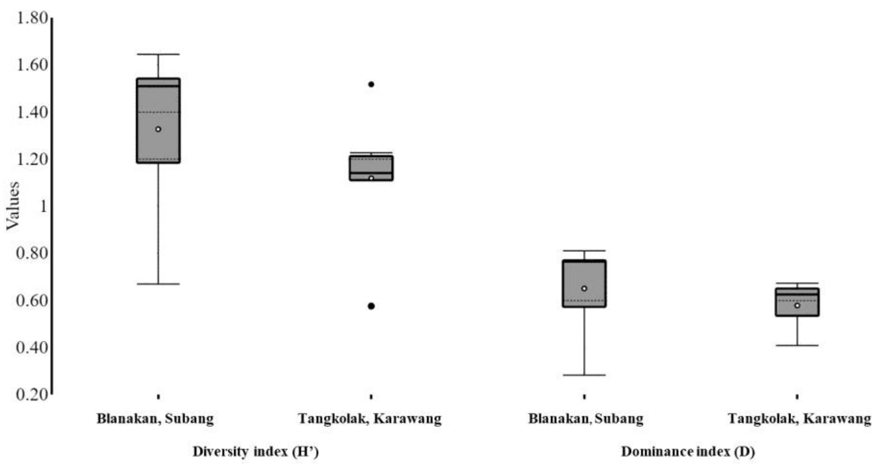

Figure 4. Boxplot of average diversity (H') and dominance (D') indexes of mangrove in Blanakan, Subang and Tangkolak, Karawang, West Java, Indonesia

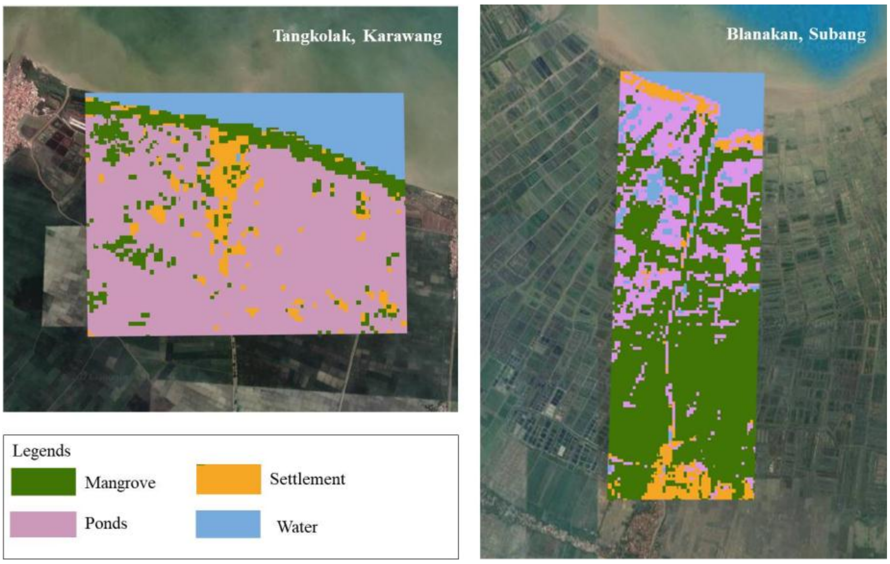

Figure 5. Restored mangrove and land cover distributions in Blanakan, Subang and Tangkolak, Karawang, West Java, Indonesia

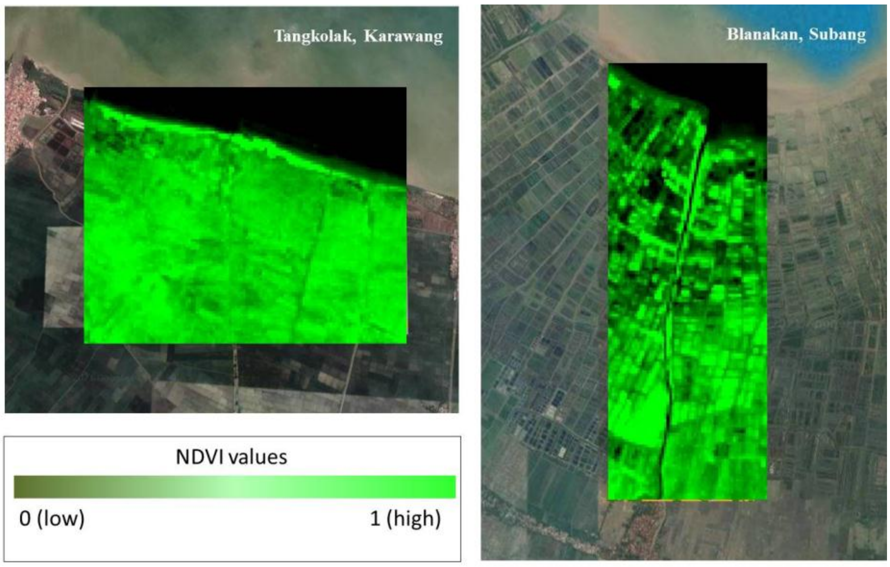

Figure 7. Mangrove NDVI values in Blanakan, Subang and Tangkolak, Karawang, West Java, Indonesia

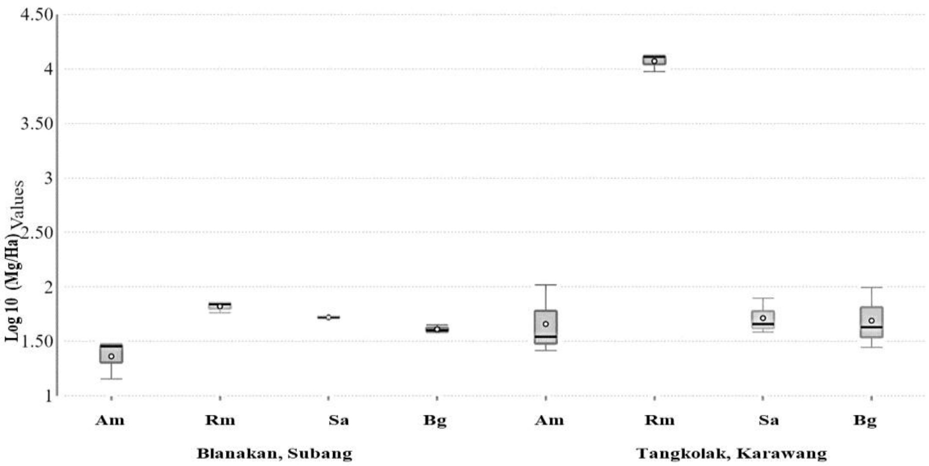

Figure 8. Mangrove biomass (log 10 mg ha^{-1}) in Blanakan, Subang and Tangkolak, Karawang, West Java, Indonesia. (Am: *Avicennia marina*, Rm: *Rhizophora mucronata*, Sa: *Sonneratia caseolaris*, Bg: *Bruguiera gymnorhiza*)

Table 2. Mangrove species and total numbers of trees in Blanakan, Subang and Tangkolak, Karawang, West Java, Indonesia

Family	Species	Local name	IUCN Redlist Status	Blanakan	Tangkolak
Avicenniaceae	*Avicennia marina*	*Api api*	LC	231	393
Acanthaceae	*Acanthus ilicifolius*	*Jeruju*	LC	69	-
Combretaceae	*Terminalia catappa*	*Ketapang*	LC	11	-
Rhizophoraceae	*Bruguiera gymnorhiza*	*Tancang*	LC	59	33
	Rhizophora apiculata	*Bakau*	LC	-	169
	Rhizophora mucronata	*Bakau*	LC	151	280
Sonneratiaceae	*Sonneratia caseolaris*	*Pidada*	LC	94	59
Total trees				615	934
Grand total				1549	

Note: IUCN Reldist Status: LC: least concern

Table 3. H' and D' values of mangrove locations of present study in comparison to other locations

Location	Numbers of species	H'	D'	Resources
Blanakan, Subang	6	1.326	0.650	*Present study*
Tangkolak, Karawang	5	1.063	0.577	*Present study*
Banaybanay, Philippines	33	3.145	0.056	Pototan et al. (2021)
Panabo Park, Philippines	5	1.027	-	Alimbon and Manseguiao (2021)
Surabaya East Coast	7	1.1	0.626	Susanto et al. (2018)
Segara Anakan	16	2.615	-	Widyastuti et al. (2018)

Figure 7 presents the NDVI values of mangroves in Karawang and Subang. In Karawang, the NDVI clearly informed high NDVI values in the mangrove restoration areas. Whereas, the NDVI values were decreasing in the areas that were classified as settlements and ponds. In Subang, areas with NDVI values were more scattered. This condition considering that in Subang, restoration areas were mixed and combined with the fishponds.

Mangrove biomass

Comparison of mangrove biomass in Karawang and Subang restoration areas was presented in Figure 8. In Subang, the highest biomass was recorded in *R. mucronata* with average biomass of 72.32 mg ha^{-1} and the lowest was *A. marina* with value of 14.3 mg ha^{-1}. *R. mucronata* species also had the highest biomass in Karawang with value of 1337.91 mg ha^{-1}. *A. marina* was also observed to have the lowest biomass in Karawang with value of 26.05 mg ha^{-1}.

Discussion

In this study, *A. marina*, *R. apiculata*, *R. mucronata*, and *S. caseolaris* were common mangroves and had high density. While *B. gymnorhiza* and *A. ilicifolius* were less common. This result was in line with other studies on mangrove communities (Table 3). Pototan et al. (2021) recorded that those species were having high frequencies and dominance. Susanto et al. (2018) have informed that in Surabaya East Coast, *A. marina* was the most common species. This could be because this species has a high tolerance limit to waters with extreme conditions, including high salinity and muddy substrate conditions, and unique root system known as pneumatophore. *Avicennia* can tolerate over a wide range of salinity compared to other genera of mangrove and this leads to *A. marina* adaptability to grow well in salinity close to 90 ‰. Two species of mangroves including *R. apiculata* and *R. mucronata* were more common in Karawang considering that most mangrove restoration programs in Southeast Asian countries mainly focused on planting common mangrove species such as *Rhizophora* sp. (Akbar et al. 2017). *Rhizophora* was preferred due to the ability of this species to protect coastal areas from erosion, high waves, and storms. Besides that, this species also possesses a higher capability to trap the sediment than other species and *Rhizophora* seedlings are easy to collect around restoration areas (Malik et al. 2020). The maximum richest taxa in genus and species levels observed in Rhizophoraceae (family of *Rhizophora*) considering that this family always has the richest taxa in most mangrove ecosystems in the world (Yessoufou and Stoffberg 2016) and as recorded in the present study, this family is referred to as the true mangrove family.

In Karawang there were two *Rhizophora* and in Subang only one *Rhizophora* species. This condition was also related to the restoration areas. According to Figure 5, restoration areas in Karawang were located in the coast. While in Subang, the restored areas were located in the fishponds and far from coasts. Restoration areas on the coast have mud substrate that is important for mangrove species to grow (Irawan et al. 2021). In this case, *Rhizophora* prefers to grow closest to the sea and inundated substrate conditions for long time.

According to Table 2, the diversity index of mangrove restoration areas was above H' values in Panobo Park and Surabaya East Coast, whereas below H' values of Segara Anakan. Panabo Park and Surabaya were an open spaces meaning those locations can be accessed by the public. While Karawang and Subang were designated restored areas with limited access, this resulted in higher H' values. Whereas, the comparisons with mangroves in Segara Anakan show H' values in Karawang and Subang to be lower. Segara Anakan was protected areas and intact forests. In contrast, mangroves in Karawang and Subang resulted from mangrove seedlings initiated in 1990.

In terms of density, mangroves in Karawang had higher density than in Subang. Mangrove in Karawang resulted from restoration through mangrove planting program initiated by the community. Whereas the available areas designated for the mangrove restoration were narrow considering the land covers in Karawang were dominated by the ponds. Since the restoration was implemented in the limited space and mangrove planting has low planting spacing and mangrove seedlings were planted close to each other. In contrast, despite high density, mangroves in Karawang had lower diversity as indicated by lower H' in comparison to mangrove in Subang, which may be due to plantation of less number of mangrove species in Karawang. Asuk et al. (2018) have identified several factors that may affect mangrove diversity in certain areas. Those factors include population growth, clearing for firewood and agriculture, and unsustainable extraction of nontimber forest products for food, local craft, and commerce. Mangrove forests located near settlements were more vulnerable to those activities that led to the diversity reductions. Settlements surrounded restoration areas in Karawang and this condition may explain the lower mangrove diversity in the Karawang.

High biomass of *R. mucronata* mainly found in Karawang indicated existence of old-age mangrove trees with high DBH, particularly resulting from good conservation practices of mangrove areas in Karawang. Higher biomass is ascribed to larger trunk diameter (mainly DBH) and tree height (Sheil et al. 2017; Scales and Friess 2019). Notably, the accounted aboveground living biomass of the study site can only be attributed to four species, namely (in order of contribution): *R. mucronata*, *S. caseolaris*, *B. gymnorhiza*, and *A. marina*. Out of the said four species, *R. mucronata*, was the most important, having the greatest contribution due to its stem diameter and biomass.

This study brings the results in showing differences in mangrove restoration patterns based on factors of density, index of diversity (H'), biomass in coastal areas. Based on those factors, Karawang and Subang have different patterns. Karawang has lower H' value but higher density and large biomass, while in Subang has higher H' value but lower density and small biomass. Furthermore, this study confirmed that two species of *R. mucronata* and *A. marina* had higher biomass values compared to other species. The estimated value of restored mangroves in Subang and Karawang differs greatly based on the NDVI value. This research is expected to provide an overview of mangrove management. H' values observed in Karawang and Subang have indicated progress in mangrove restoration activities. While mangrove plantings combined with fishponds have also contributed to the areas of mangrove covers in Subang. Restoration of mangroves in both Karawang and Subang may have contributed to the mangrove assemblages in West Java Coasts.

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