RESEARCH PAPER

ECOLOGICAL ASSESSMENT OF THE ROLE OF MANGROVE TREES IN CARBON SEQUESTRATION AND BIODIVERSITY IN KARIMUNJAWA NATIONAL PARK INDONESIA

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ABSTRACT. Mangrove ecosystem has an important role in reducing carbon in the environment. There has been massive conversion of mangrove area into ponds and buildings in the current period. Therefore, the species diversity and carbon sequestration capacity of the mangrove ecosystem must be evaluated to monitor its function. This research aims to evaluate the species diversity and the sequestered carbon in the mangrove ecosystem of Karimunjawa National Park (KNP), Indonesia. The species analysis in the 3 research sites, 9 transects, and 27 plots (10 m × 10 m) that was obtained using the quadrat sampling method. Allometric equations, Shannon–Wiener, and evenness indices were used to estimate the standing biomass and carbon, species diversity, and distribution, respectively. The sediment samples were obtained at a depth of 100 cm and divided into three depths, namely, 0–33, 34–67, and 68–100 cm. The carbon content of mangrove sediments was analyzed in the laboratory using the Walkley–Black method. The results revealed that mangroves in the KNP have moderate diversity and even distribution. The estimated carbon in the mangrove stand was 146.22 t C ha^{-1} and the estimated carbon stock in the sediment was around 360.61 t C ha^{-1}. Although the mangrove ecosystem in Karimunjawa National Park is still in a stable condition, it is necessary to monitor its changes due to the anthropogenic activities.

KEYWORDS: Mangrove ecosystem, Emission reduction, Carbon Sequestration, Biodiversity, Vulnerable

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INTRODUCTION

Mangroves are currently recognized as crucial ecosystems that support the reproduction of fish and crabs as well as abrasion barriers against tsunamis. Mangroves are increasingly recognised as significant ecosystems that support the reproduction of aquatic life and can resist damage from extreme weather events. Mangroves also become carbon dioxide sinks that are more effective than peatlands or rainforests (Taillardat et al. 2018). The mangrove ecosystem is one of the most important ecosystems in the effort to maintain the stability of flora–fauna diversity and mitigate global warming, namely, as the best carbon storage compared with all other forest types on earth. Overexploitation for a variety of reasons, including commercial forestry, fuelwood, charcoal, and conversion to other land-uses, primarily aquaculture ponds, has been cited as a cause of mangrove losses (Kusmana 2015; Murdiyarso et al. 2015; Malik et al. 2017). Mangrove forests have a major role as carbon sinks and stores, which range from 4 gigatons C/year to 112 gigatons C/year (Cameron et al. 2019). Thus, efforts to sequester carbon in Indonesia are an important way to curb climate change and save living species from extinction (Roy et al. 2013). Indonesia is one of the countries that has the largest mangrove forest in the world, which can absorb more carbon than tropical forests or peatlands (Malik et al. 2015). Indonesia has 3.63 million hectares of mangrove ecosystems, which is 20.37 % of the world's total. The largest mangrove ecosystem is on the island of Papua, which is 1.63 million hectares. Sumatera is next with 892,835 hectares, and Kalimantan is third with 630,913 hectares (KKP 2021). Karimunjawa National Park (KNP), which is situated in Jepara Regency, Central Java, serves as a symbol of the sustainability of the region's ecosystem. As a conservation area that has very potential natural resources and high diversity, the mangrove ecosystem in Karimunjawa consists of Karimunjawa Island, Sintok, Mengawakan, Big Krakal, Small Krakal, Big Cemara, Small Cemara, Merican, and Kemujan. The largest mangrove forests are on Karimunjawa Island and Kemujan Island with an area of 396.90 ha. Karimunjawa was designated a national park on February 29, 1988 by the Ministry of Forestry, it is divided into nine zones, namely, core, jungle, marine protection, land use, marine tourism utilization, marine cultivation, religious cultural and historical, rehabilitation, and traditional fishing zones.

Karimunjawa is home to coral reefs, mangroves, coastal forests, and nearly 400 species of marine fauna, including 242 species of ornamental fish. The white-breasted sea eagle, hawksbill turtles, and green turtles are a few of the unusual animals that call this place home. Plants that characterize the KNP are dewadaru (*Crystocalyx macrophyla*), which are found in lowland rain forests (BTNKJ 2020). KNP consists of small islands in the middle of the Java Sea. Small islands generally have properties that are very vulnerable to environmental changes and pressures (Utami et al. 2017). Based on the natural resources and the fragile nature of the island, the existence of the KNP really needs to be maintained and protected. However, not all residents are aware of mangrove forests' role, particularly on tiny islands. Mangroves play an important role in protecting the island from eroding waves and ocean currents. Mangrove forests are systematically degraded due to human activities (Basu and Cetzal 2018). On Karimunjawa Island and Kemujan Island, there has been a massive conversion of mangroves to agricultural land and plantations. A total of 82.37 ha has been lost during the period 1992 – 2018 (Latifah et al. 2018). Mangrove forest functions are converted to achieve the decreased ability to absorb carbon in the atmosphere and the decomposition of stored carbon through the decomposition process into the atmosphere (Ha et al. 2014). The role of the mangrove ecosystem as an absorber and a reservoir for CO_2 turns into a contributor to CO_2 emissions. These circumstances exacerbate global climate change (Datta et al. 2012). Mangrove mud substrates have a high potential for carbon storage. Other studies related to the potential for mangrove carbon storage in other Southeast Asian countries, namely: in Banacon Island, Philippines, 145.6 t C ha^{-1} (Camacho et al. 2011), Panabo Philippines, 37.18 t C ha^{-1} (Alimbon and Manseguiao 2021), in Johor Park Malaysia of 50.68 t C ha^{-1}, the Kelantan delta Malaysia 99.13 t C ha^{-1} (Rozainah et al. 2018) and the carbon content of mangrove sediments in the Palawan Philippine forest area of 173.75 t C ha^{-1} (Abino et al. 2014) while the total C soil in Johor Park was 384.57 t C ha^{-1} and the Kelantan delta was 413.33 t C ha^{-1} (Rozainah et al. 2018). Therefore, the estimation of carbon storage in tree parts and mangrove mud substrate can be used as a basic reference in assessing the ecological benefits of mangroves in the form of environmental service commodities (Carugati et al. 2018). Sustainable management of mangrove forests is suitable for stabilizing air quality because carbon will be absorbed and stored in the mangrove ecosystem (Li et al. 2010). This study aimed to assess the species diversity and evenness and to estimate the carbon stored in both stands and sediments of mangroves ecosystem in Karimunjawa National Park, as a basis for sustainable management of mangrove ecosystem.

MATERIALS AND METHODS

Study Area

This research was conducted in the mangrove ecosystem of Karimunjawa National Park which is geographically located at 5°49´9´´S 110°27´32´´E. Karimunjawa National Park is an archipelago in the Java Sea which is included in Jepara Regency, Central Java (Fig. 1). It has a land area of ± 1,500 ha and waters of ± 110,000 ha (BTNKJ 2020). Sampling was done performed in the mangrove area of Karimunjawa Island (Station 1), Kemujan Island (Station 2), and Menjangan Besar Island (Station 3). Based on the presence and health of respective mangrove ecosystems, the sampling sites were chosen. In locations where sampling and selection of various mangrove conditions are not difficult. Because location 1 is in the national park area. Location 2 is near settlements, plantations, and location 3 is on an uninhabited island.

Data Collection

Nondestructive sampling was carried out in August 2021. This study sample consisted of 3 stations, 9 transects, and 27 plots (10 m × 10 m), with a distance of 10–20 m between plots. The species of mangrove trees in the sample plots were identified, and their diameter at breast height (DBH) was also measured (Komiyama et al. 2008). A minimum height of 1.3 metres from the ground is required for the tree to enter the DBH measurement. Then the diameter is measured using a roll meter. Fig. 2 shows details and images from several mangrove roots with height differences.

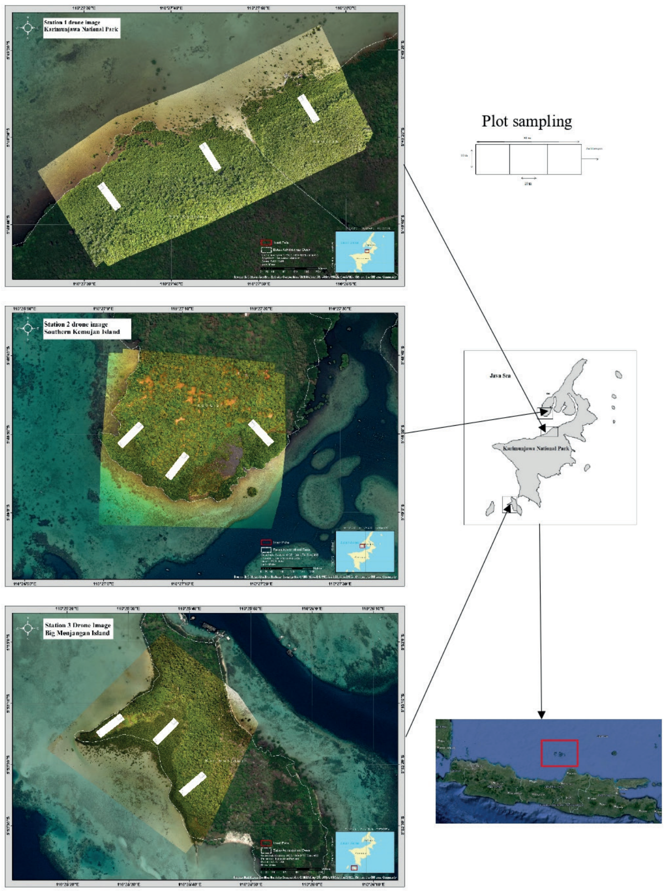

Fig. 1. Maps of (a) Karimunjawa National Park Area, Jepara Regency, Central Java, (b) Karimunjawa Island, (c) Kemujan Island, and (d) Menjangan Besar Island

Meanwhile, the data on the height of mangrove trees were obtained from the height of the observer's eye from the ground and the results of measurement of the distance of the observer from the tree and angle of inclination between the eye of the observer and the treetop (Weyerhaeuser and Tennigkeit 2000). The measurement of mangrove tree stand height was carried out in each plot. The tree category included a diameter of more than 10 cm, and a tree height of more than 2 m (Hadiyanto et al. 2021). Mangrove sediment samples were obtained from three stations using a hand corer type sediment core with a length of 100 cm. The core sediments were divided into three depths, namely, 0–33, 34–67, and 68–100 cm. The level of sediment depth affected the amount of carbon content.

Data Analysis

To obtain the importance value index (IVI) of each species, determined the sum of relative density, relative frequency, and relative dominance. Then, the Shannon–Wiener equation was used to find the value of the diversity index (H') of a species:

$$N' = -\sum_{i=1}^{S} Piln(Pi) \quad (1)$$

H' = Shannon diversity, s = number of species, and pi = abundance.

Species diversity is a characteristic that can be used to express community structure. It can also be used to measure community stability, which refers to the ability of a community to maintain itself stable despite disturbances to its components (Fachrul 2007). The range of values of the diversity index scale according to the Magguran (2004) is as follows: H'<1 = low diversity; 1<H'<3 = medium diversity; H'>3 = high diversity.

The value of species evenness index can describe the stability of a community. The evenness index value (E) ranges from 0–1. The smaller or closer to zero value of E, the more uneven the distribution of species in the community, which is dominated by certain species. Conversely, the greater or closer to one value of E, the more evenly spread of species in the community (Sholiqin et al. 2021). The equation for the evenness index is as follows:

$$E = N'/LogS \quad (2)$$

E = species evenness, and H' = Shannon diversity (the log of the number of species).

Calculation of biomass was done using allometric formulas. The allometric equation used is based on the reference from the Forestry Research and Development Agency No.P.01/VIII-P3KR/2012 using the approach to the availability of a tree biomass allometric model, which is appropriate for the type/forest ecosystem where the object is located but not the specific location of the object.

After the biomass had been determined, it was then multiplied by 0.47 to determine the carbon content, which was then converted into a unit area (ton ha^{-1}) (IPCC 2006). The conversion of carbon stock to total CO_2 absorption can use the relative atomic mass ratio C which can be formulated as follows: CO_2 equivalent = C x 3.67 (Azzahra et al. 2020). The carbon content of mangrove sediments was analyzed in the laboratory using the Walkley–Black method (ton ha^{-1}) (Walkley and Black 1934). Then, the sediment layer samples were analyzed to obtain the sediment grain–size data. The results of sediment size analysis laboratory were used to determine each size class based on the Wenworth scale. In addition, the grain size of the resulting sediment was used to determine the types of sediment in the study area based on the sheppard triangle (Shepard 1954).

RESULTS

Mangrove Diversity in Karimunjawa National Park

Species composition, number of trees, average DBH and average tree height of the Karimunjawa National Park mangrove ecosystem are shown in Table 2. Each research station comprised mangrove species including *Rhizophora apiculata, Rhizophora mucronata, Ceriops tagal, Rhizophora*

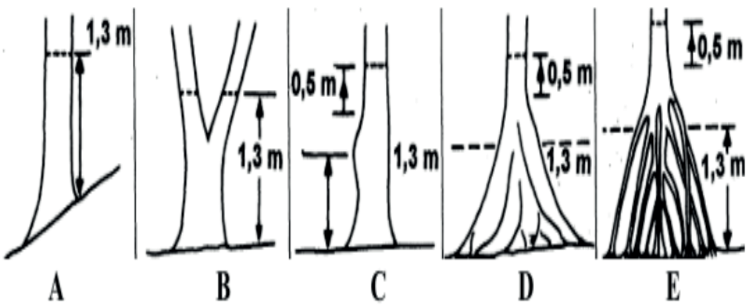

Fig. 2. How to measure DBH based on root state

Fig. 1. Allometric Equation

Species	Allometric
Rhizophora stylosa	B = 0.097 (DBH)$^{2.68}$
Rhizophora apiculata	B = 0.043(DBH)$^{2.63}$
Rhizophora mucronata	B = 0.128(DBH)$^{2.60}$
Xylocarpus molucensis	B = 0.1832(DBH)$^{2.21}$
Sonneratia caseolaris	B = 0.825(DBH)^{2,2}
Cerriops tagal	B = 0.168* ρ*(DBH)$^{2.47}$

B=Biomass; DBH=Diameter Breast High; ρ=density *stylosa* and *Xylocarpus moluccensis*. The distribution was even because these species are natural mangrove species in the KNP.

The results of the analysis of the relative density of mangroves in Karimunjawa National Park (Table 3) showed that Station I had the highest and lowest relative density values. *R. apiculata* had the highest value of 43.42%, whereas *X. moluccensis* had the lowest value (2.91%). The high relative density of *R. apiculata* was due to its high adaptability, which allows to develop well. According to the information in Table 3 the diversity index (H') ranged from 1.47 to 1.62. Referring to the work of Odum (1996), the diversity of mangrove species in the study area was in the moderate category at all stations. The diversity index value can be used to determine the level of stability of a community towards the environment (Odum 1996). Thus, the mangrove ecosystem in Karimunjawa National Park is stable and has a moderate diversity. The value of diversity in a community depends on the numbers of species and individuals in the community. The species diversity of a community is high if the community is composed of many species, and no species dominates (Rahmila and Halim 2018). Conversely, a community has a low species diversity if the community is composed of a few species, and a dominant species persists (Canty et al. 2022). The relationship between Biomass-Carbon, DBH, and Density is presented in the regression analysis (Fig 3).

Fig. 2. Composition of Mangrove Species in Karimunjawa National Park

Station	Species	Mean DBH	Mean Height
1	*Rhizophora apiculata*	22.26	9.40
	Rhizophora mucronata	22.46	7.70
	Ceriops tagal	22.84	6.10
	Rhizophora stylosa	13.83	6.80
	Sonneratia caseolaris	13.36	6.50
	Xylocarpus moluccensis	14.9	7.10
	Value	18.27	7.26
2	*Rhizophora apiculata*	15	8.20
	Rhizophora mucronata	14.64	6.00
	Ceriops tagal	10.23	6.40
	Rhizophora stylosa	14	6.60
	Xylocarpus moluccensis	11.87	6.80
	Sonneratia caseolaris	15.53	5.50
	Value	13.54	6.58
3	*Rhizophora apiculata*	15.25	7.70
	Rhizophora mucronata	15.1	7.20
	Ceriops tagal	10.79	7.25
	Rhizophora stylosa	15.35	7.00
	Xylocarpus moluccensis	11.22	6.60
	Value	13.54	7.15

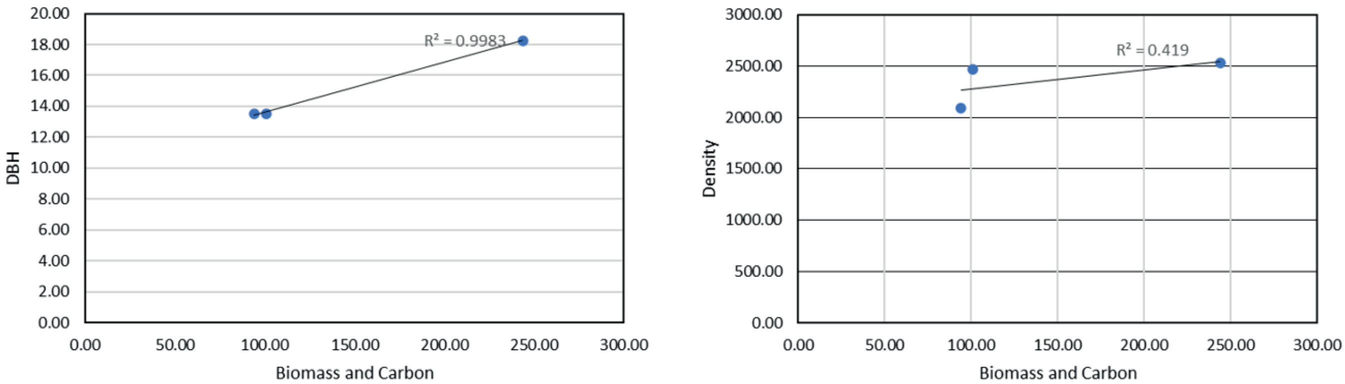

Fig. 3. Regression analysis of the relationship between Biomass-Carbon, DBH, and Density

Fig. 3. Value of IVI, Diversity Index, and Evenness Index

No	Species	Important Value Index (%)			IUCN
		Station 1	Station 2	Station 3	
1	*Rhizophora apiculata*	113.25	69.05	74.01	LC
2	*Rhizophora mucronata*	55.69	61.43	67.67	LC
3	*Ceriops tagal*	44.21	49.05	57.25	LC
4	*Rhizophora stylosa*	52.80	47.13	58.48	LC
5	*Sonneratia caseolaris*	18.20	35.33	-	LC
6	*Xylocarpus moluccensis*	15.82	38.00	42.59	LC
Σ Species		6	6	5	
Diversity index H’		1.47	1.62	1.54	
Evenness Index E		0.82	0.90	0.95	

Sediment Characteristics

According to Fig. 4, silt sediment accounted for an average of 58% of the different types of sediment detected at the three research sites. At a depth of 0–100 cm, the sediment had a texture like that of sandy mud with some clay. *Rhizophora sp*, given their robust roots and efficient sand traps, can thrive in sandy loam textures (Komiyama et al. 2005). Mangroves have a sandy loam substrate because the location of the mangrove ecosystem is not extremely close to the beach, which has high currents or waves. According to Indah et al. (2010), the root forms of *Rhizophora sp.*, namely, anchoring, and tight, also cause formation. This substrate formation is strongly influenced by the presence of currents in tidal and ebb conditions which carry the particles deposited at low tide.

Currents and depth are Oceanographic factors that affect sediment distribution (Wickramasinghe et al. 2009). Waters that have relatively calm currents and shallow water depths between 16 and 20 cm have similar types of sediments distributed in the mangrove ecosystem (Santen et al. 2007). This condition is due to the anchored and tight root forms of *Rhizophora sp.*, which also causes substrate formation (Ortega-Pacheco et al. 2018). These roots allow the excellent capturing process of dust particles in *Rhizophora sp* (Morton 2016). When a backflow exists, the dust particles are blocked by the roots. This condition shows the sediment characteristics that are suitable for the growth of mangroves in the Karimunjawa National Park, which is dominated by *Rhizophora sp.*

Biomass, C-Stock stand, and C-Stock Soil

Table 4 shows the stand biomass yield, stand carbon content, and sediment carbon content. Station 1 has the highest above ground biomass and C-Stock among other stations. The community structure of *R. apiculata* which is spread in all stations and dominates each transect influences the amount of carbon content.

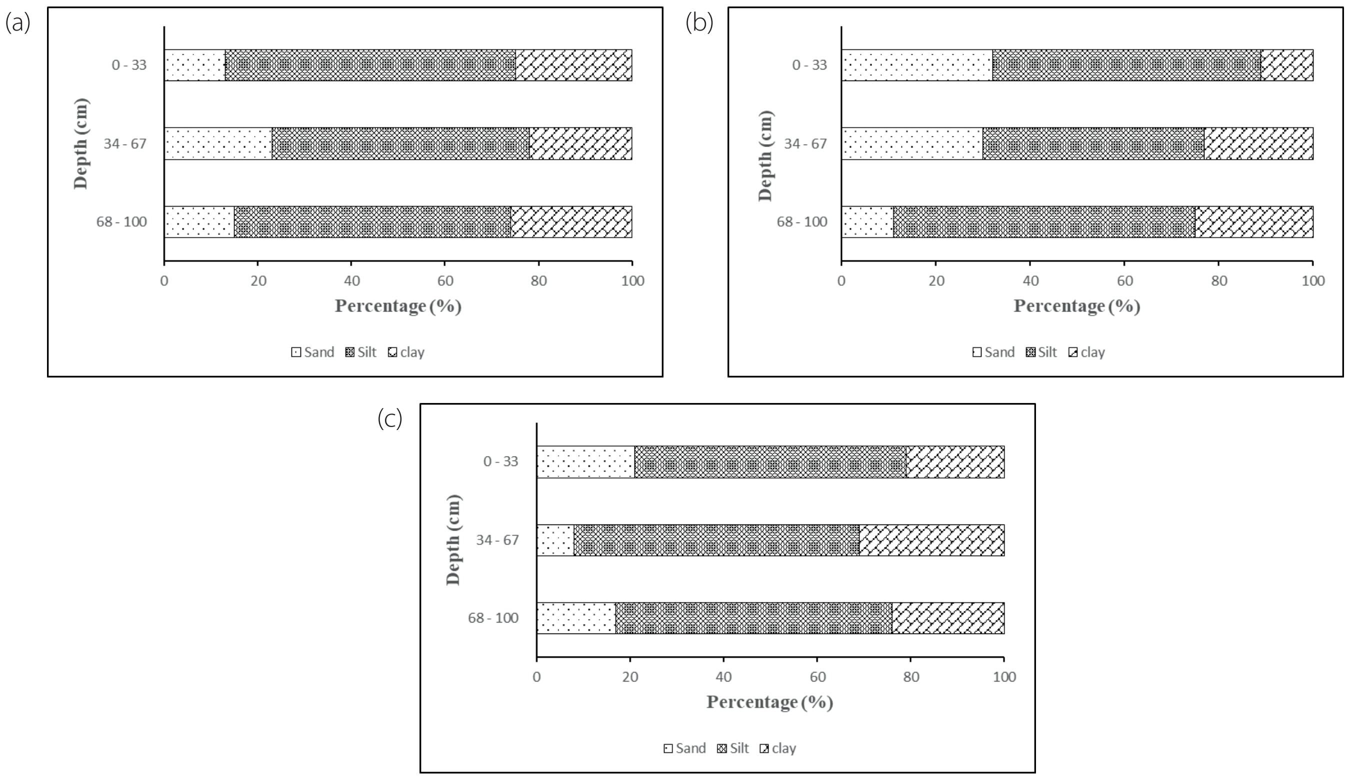

Fig. 4. Type and amount of sediment percentage based on depth. (a) Station 1, (b) Station 2, (c) Station 3

Table 4. Value of Biomass, C-Stock, and Average C-Stock

	Transect	Above-ground Biomass (t ha $^{-1}$)	C-Stock (t C ha $^{-1}$)	Average C-Stock (t C ha $^{-1}$)
St 1	1	638.79	300.23	243.73
	2	427.8	201.07	
	3	489.13	229.89	
St 2	4	240.29	112.93	94.01
	5	177.75	83.54	
	6	182.04	85.56	
St 3	7	244.27	114.80	100.92
	8	193.37	90.88	
	9	206.58	97.09	

The total individual, density value and DBH of *R. apiculata* at Station I showed that this community affected the carbon content at Station I was higher than at other stations. At Station 2, the density of mangrove trees has the lowest value compared to other stations. The dominant mangrove species at stations 2 and 3 is *R. Apiculata* and these two stations have the same average DBH value, which is 13.54 m. The level of diversity at all stations is still in the range of 1<H<3. Which means the level of diversity is included in the medium category. Even though in the case at Station 2 there was land conversion, the damage did not reduce the diversity of mangroves at Station 2. However, with density values, number of individuals in plot plots, and small DBH values compared to stations 1 and 3, the biomass content and carbon stock at Station 2 were the lowest (94.01 t C ha^{-1}). The value of the regression analysis between biomass-carbon and DBH shows 0.998. This demonstrates a directly proportional relationship. While the relationship between biomass-carbon and density shows a relationship that tends to be weak, the value is 0.419 (Fig. 5). The number of vegetation and diameter size indicate the amount of biomass and carbon stored (Datta et al. 2010). In addition, Station 1 is in the National Park area, allowing for natural mangrove conditions and optimal carbon absorption. This case is different from that at Station 2. The condition of mangroves located on the southern coast of Kemujan Island has been damaged considerably. This is presumably because there are residents around the mangrove area which caused the conversion of mangrove land to agricultural land.

Organic carbon in sediments is one of the constituents of organic compounds in waters. Organic carbon is a priority for soil improvement and for carbon storage. The ability to store carbon is higher than the mangrove tree itself. A high potential for emissions was observed due to the disruption of large carbon stores (Burdige 2007). The measurements of carbon content at the three stations based on depth yielded different results for carbon storage (Fig. 5). The carbon storage was measured vertically with three different depths.

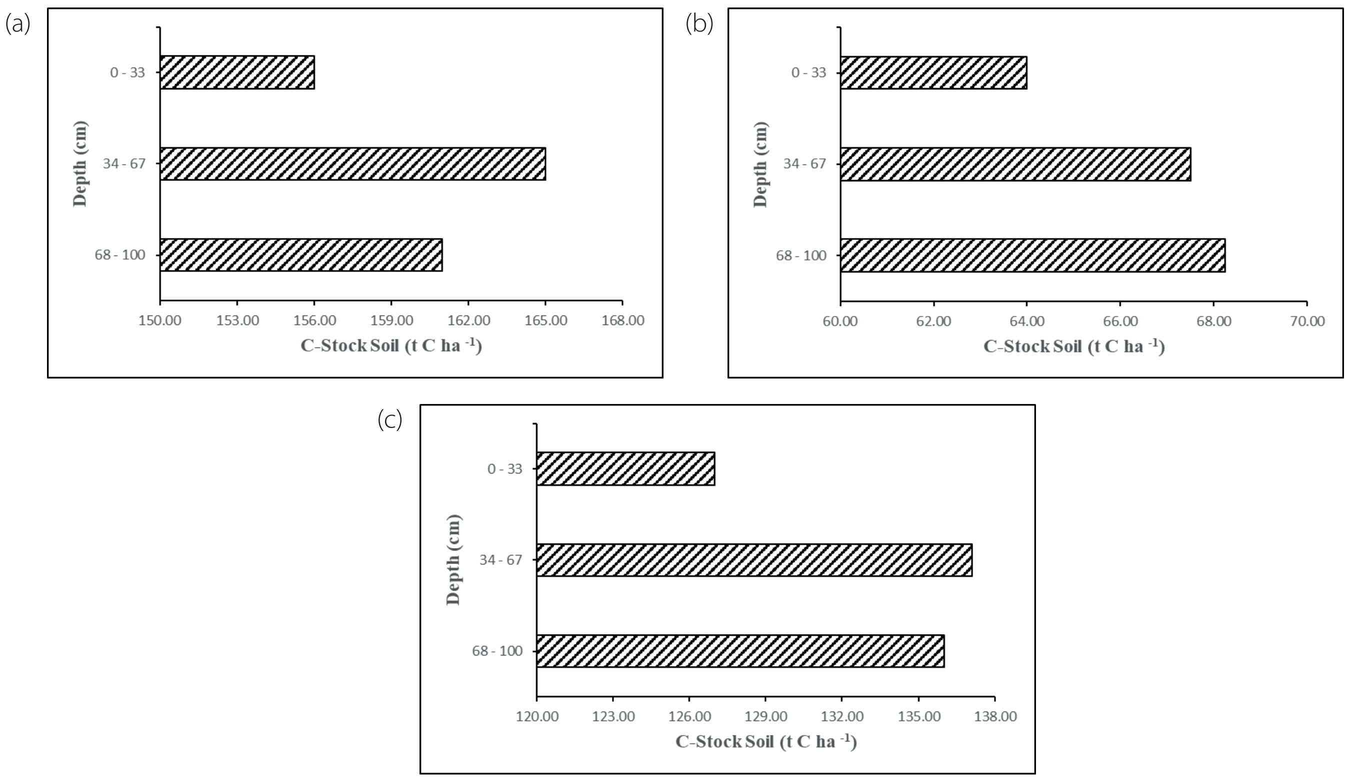

Fig. 5. Comparison of total soil C-stock values based on depth at all stations. (a) Station 1, (b) Station 2, (c) Station 3

Discussion

The order of the total number of trees from the most to the least was as follows: Station 1 (228 trees) > Station 3 (222 trees) > and Station 2 (188 trees). *R. apiculata* dominated the highest number of trees in all research locations. According to Wetlands International, this species grows in silty, smooth, deep soil and is flooded during normal tides (Andradi-Brown et al. 2013). It prefers tidal waters that have a strong permanent influence of freshwater input (Utami et al. 2021). *R. apiculata* has a dominance level that reaches 90% of the vegetation that grows in a location. This finding is in accordance with the substrate conditions in the mangrove ecosystem of Karimunjawa National Park, where many *R. apiculata* species grow and develop because of their very suitable habitat. Fig. 2 displays the type and magnitude of the substrate percentage at each station.

Importance Value Index (IVI) is calculated based on the number obtained to determine the level of species dominance in a plant community (Pollisco and Simorangkir 2013). From the results of calculations that have been carried out at the three observation stations, the difference in the index values among mangrove species was evident. *R. apiculata* found at Station I had the highest IVI of 113.25% while *X. moluccensis* of the same station had the lowest IVI of 15.82%. The IVI shows the range of indices that describe the community structure and distribution pattern of mangroves (Owuor et al. 2019). The difference in the IVI of mangrove vegetation is due to competition between each species for nutrients and sunlight at the study site. In addition, other factors that cause differences in mangrove vegetation density are the type of sediment and tides (Sarker et al. 2019). Gnanappazham and Selvam (2011) argued that the dominant species in a plant community will have a high IVI. Raymond et al. (2010) added that species with a high IVI have a high cumulative value of mastery and excellent control over their habitat. These species will be superior in utilizing resources or more adaptable to the environment. Furthermore, the difference in the IVI illustrates that the influence of a species in the mangrove community is different. This condition is influenced by a high species density value, resulting in a high IVI. According to Odum (1993), the influence of a population on communities and ecosystems not only depends on the species of the organizations involved but also on the number or density of the population. Sandy mud substrate conditions and water conditions, which are always inundated, were strongly suspected to affect the survival of *R. apiculata* (Rahim et al. 2017). The low relative density of *X. moluccensis* was thought to be due to the inaccessibility of the sampling plot. Sampling did not reach the land area. Thus, only a few tree samples were detected in the plot. This species prefers aquatic habitats that with low salinity and is often found on riverbanks (Dasgupta et al. 2010).

Frequency is one of the parameters that can show the distribution pattern of vegetation types in an ecosystem (Ha et al. 2012). Species frequency also describes the probability of species that can grow and be found in a location. The frequency of mangrove species is influenced by the number of plots where the species is found. Finding mangrove species is more likely to occur when there are more plots (Sidik et al. 2018). The results of the analysis of the relative frequency of mangroves that have been carried out in the mangrove ecosystem of Karimunjawa National Park at the highest tree level are at Station 3, which is the same for all species at 20%. The species found were *R. apiculata, R. mucronata, C. tagal, R. stylosa,* and *X. moluccensis*. Meanwhile, the lowest relative frequency at the tree level was that of *S. caseolaris* (11.76 %) at Station 2. The large number of *R. apiculata* was due to the condition of the sediment substrate at the study site in the form of sandy silt, which can support mangrove growth, allowing this type of mangrove to survive and develop well. The silt substrate that is spread in almost all stations contained a huge amount of organic matter when compared with the type of sediment in sand form, which only contains minerals (Sarathchandra et al. 2018). Furthermore, the typical life cycle of Rhizophora with seeds that can germinate when they are still on the parent plant is very supportive of the wide distribution process of this species in the mangrove ecosystem (Thatoi et al. 2012).

R. apiculata at Station I had the highest relative dominance of 51.08 % due to its root system that is well-adapted in obtaining more nutrients when compared with other species. Meanwhile, *X. moluccensis* of the same station had the lowest relative dominance at 1.13 % due to its uneven distribution and the level of habitat suitability. The substrate type in the Karimunjawa mangrove ecosystem is mostly silt-sand type, whereas *X. moluccensis* prefers a harder substrate. The mangrove vegetation found showed varying zonings at each station. These mangroves do not fully form zoning based on their tolerance to salinity and periods of inundation, as suggested by many mangrove experts. In this study, mangroves grow from the edge of the sea to the mainland. The part near the sea is dominated by *R. apiculata*, which is very dominant along the coastlines of Karimunjawa Island, Kemujan Island, and Menjangan Besar Island. *S. caseolaris, C. tagal, R. stylosa* and *R. mucronata* were also found in the zone after *R. apiculata. Meanwhile, X. moluccensis* belongs to a minor mangrove group that is far from the coast and prefers aquatic habitats that are not too salty (Jugale et al. 2009).

Based on the description above, differences existed in the mangrove zoning at each research station, especially for the rear zoning. The front zoning tends to be uniform and is dominated by *Rhizophora sp*. There are different findings regarding the presence of *Avicennia Marina* in KNP. According to the research of Ulyah et al. (2022), there are *Avicennia Marina* species in all research locations (Menjangan Besar Island and Kemujan Island), while according to Susilo (2017), the existence of Avicennia Marina is not in the research location. It is suspected that this difference is caused by the size of the study area and the different sampling locations. Zoning that occurs in mangrove forests is influenced by several factors, including the frequency of inundation, salinity, dominance of plant species, tidal water movements and the openness of the mangrove forest location to wind and waves, as well as the distance of plants from the shoreline (Bunt 1996). According to (Odum 1972) the structure of the mangrove ecosystem in KNP is the estuary type of mangrove formation. In this type of the influence of sea water is as strong as the influence of river water. Estuary mangroves are characterized by the presence of *Rhizophora sp. At the edge of the groove, followed by a mixed commu*nity of Rhizophora – Bruguiera and ending with a pure community of *Nypa sp*. This is what makes *Avicennia sp* species not found in this study. Because the sampling location is in the estuary area, while *Avicennia sp* species enters the coastal mangrove. According to the conservation status of the International Union for Conservation of Nature (IUCN) Red List, all mangrove species found in the study in Karimunjawa National Park are classified as least concern (LC). Although it is still classified as low risk, in the next few years, the number of species may be threatened along by the increase in anthropogenic activities in Karimunjawa National Park. Conservation efforts still need to be carried out. Furthermore, the evenness index value at each research station ranged from 0.82 to 0.95. This shows that the species found at each research station tend to have uniformity, meaning that no species dominates a station. If the value of the evenness index is small, then the species uniformity in the community is lacking, meaning that the number of individuals for each species is not the same, so there is a tendency to be dominated by certain species (Zhila et al. 2014). On the other hand, the higher the uniformity index value, the higher the distribution pattern in the community and no species is dominant.

Distribution patterns in clusters are generally found in nature, due to the need for the same environmental factors (Syahid et al. 2020). Several reasons explain why plants show a clumped distribution (Mangora 2011). Most of the mangrove seeds/fruits are not consumed by animals. Thus, the ripe fruit will fall near the parent tree and grow into an adult tree. According to Santos et al. (2014), the formation of a clustered distribution pattern is related to the pattern or way of eating because certain areas have abundant food sources. In addition, external reproduction factors and substrate characteristics that are suitable for mangrove growth are one of the factors for the formation of a group distribution pattern. At stations 1 – 3, the carbon content increased with the increase in depth. The high organic matter in the surface layer (0 cm) was due to the high litter production from each station, where the mangrove density also affected the level of organic matter content. This result is in accordance with the opinion of Oliver et al. (2012), who stated that the decomposition process of litter (leaves/branches/twigs) only occurs on the soil surface, whereas at a depth of more than 20 cm, the effect of this process is not significant (Moriizumi et al. 2010). The condition of the sustainability of subsurface carbon stocks is still poorly understood, but evidence from this study shows that land clearing, drainage, and/or conversion to ponds/agriculture, in addition to having an impact on vegetation biomass, significantly reduces the carbon content of mangrove soils (Duan and Kaushal 2013).

The highest carbon storage on average was at a depth of 34–67 cm, with values ranging from 67.5 t C ha^{-1} to 165 t C ha^{-1}. The lowest value was found in the upper layer (0–33 cm) at Station 2 with a value of 64 t C ha^{-1}. This condition was thought to be the surface layer being heavily affected by currents, waves, and tides, which cause the organic content, including carbon, to be carried along with the movement of water (Halim et al. 2018). The layer beneath reveals solid forms that have been held together over years by sedimentation. In theory, from the sedimentation process, a biogeochemical process occurs which causes the carbon content at the bottom to increase with increasing depth. But in this study, at stations 1 and 3 the carbon content only increased after a depth of 33 cm leading to a depth of 67 cm. After a depth of 67 to 100 cm the carbon content decreases. Only Station 2 has an increase in carbon content with increasing depth. One reason for this is that it is suspected that the sample at a depth of 68 - 100 cm contains sand type sediments. At Station 3 the sand content increased after a depth of 67 cm. Whereas at station 1 it is slightly different, because the sand content at a depth of 68 - 100 cm is less than at a depth of 34 - 67 cm. At Station 1 at a depth of 34 - 67 the sediment conditions are very dark black, while at a depth of 68 - 100 cm the sediment is not as dense as at a depth of 34 - 67 cm. According to Ati et al. (2014), the proportion of the particle size of sand, silt and clay affects the permeability, fertility, and salinity of the soil. The presence of nutrients is also influenced by the composition of the sediment. Sediments that contain a lot of silt are generally richer in organic matter than sandy sediments. Sari et al. (2017) in their research located in West Kalimantan where sediment research was carried out based on a depth range of 0-5 cm, 5-10 cm, 10-20 cm and 20-30 cm. where at a depth of 0-5 cm it has a carbon stock value of 1705.27 t C ha^{-1} and has increased to 8899.62 t C ha^{-1} at a depth of 10-20 cm, but at a depth of 20-30 it has decreased by 6745.22 t C ha^{-1}. The soil organic carbon content in the 0-5 cm layer is in an active weathering process and often changes. According to (Lorenz and Lal 2005) soil organic carbon reserves in the top layer often experience rapid decomposition by increased microbial activity near the soil surface and fluctuations in soil temperature. Soil organic carbon stocks in the lower layers are protected in soil aggregates and have a low decomposition rate. The total average value of C-Stock stands and C-Stock soil at all observation stations was 438.66 t C ha^{-1} and 1081.85 t C ha^{-1}, respectively. This value is equivalent to the absorption of CO_2 from the atmosphere of 1,609.88 t C ha^{-1} and 3,970.38 t C ha^{-1}. Efforts to increase the contribution of emission reduction in KNP can be achieved by conducting emission reduction interventions. One form of intervention that can be done is to reduce emissions due to changes in mangrove land by rehabilitating or planting mangroves that can increase carbon sequestration and storage. In addition, conservation of mangrove ecosystems is also to prevent increased emissions in the land-based sector. This effort can be considered in the mitigation actions of Central Java Province.

The biogeochemical cycle is the transfer of organic and inorganic elements/compounds (Alongi 2020). The biogeochemical cycle maintains life on earth. The total average value for the estimated carbon of mangrove stands was 146.22 t C ha^{-1}, and for the estimated carbon stock in sediments, the value was around 360.61 t C ha^{-1}. The estimated carbon of mangrove stands in Karimunjawa National Park is lower than the carbon content in the coastal village of Botoc, Philippines (Abino et al. 2013). On a national scale, the carbon content in the mangrove sediments of Karimunjawa National Park is higher than that of mangrove forests in Mangunharjo (Hadiyanto et al. 2021), Baturapa (Marbun et al. 2020), the northern part of the mangrove ecosystem of Bunaken National Park (Verisandria et al. 2018), and Jembrana Bali (Mahasani et al. 2015). According to Komiyama et al. (2008), in a study of mangrove forest biomass in various countries that was carried out for several years, variations in biomass estimates not only depended on species but also on ecological conditions and geographical locations. Based on research by Latifah et al. (2018), there has been deforestation of 82.37 ha of mangroves in Karimunjawa during the period 1992 - 2017. That means that there has been a decrease in mangroves by 0.3 ha per year. Meanwhile in this study, the value of the carbon content of the stands was 146.22 t C ha^{-1} or a CO_2 equivalent of 1609.88 t CO_2 ha^{-1}. So, we can assume that if the reduction in area in the research of Latifah et al. (2018) is combined with our carbon research, the result is that the mangrove ecosystem in Karimunjawa loses an average of 48.74 t C ha^{-1} of carbon stock each year or a CO_2 equivalent absorption of 536.62 t CO_2 ha^{-1} due to anthropogenic activities. The Karimunjawa mangrove habitat has a reasonably high-density value, which means that the potential for litter fall is also to be very significant. Carbon content is influenced by the number and density of trees, tree species, and environmental factors, including sunlight, water content, temperature, and soil fertility, which affect the rate of photosynthesis (Alongi 2002).

CONCLUSIONS

Karimunjawa National Park has a stable mangrove ecosystem and sufficient species diversity. The condition of the mangrove ecosystem, which was still good at the time of sampling in August 2021, requires special attention in sustainable management. The potential for carbon sequestration is high in stands (146.22 t C ha^{-1}) and sediments (360.61 t C ha^{-1}). The main factors that influence this potential are the density of species and diameter of mangrove trunks. Deforestation of mangrove land causes the release of carbon in the atmosphere. It is suspected that there has been a loss of mangrove carbon stocks in Karimunjawa with an average of 48.74 t C ha^{-1}/year or CO_2 equivalent absorption of 536.62 t CO_2 ha^{-1}/year.

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