Ecological Valuation of Mangrove Trees From Karimunjawa National Park as a Role in Carbon Sequestration to Maintain the Stability of Biodiversity

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Abstract

The diversity of species in the mangrove ecosystem can be threatened if there is no database on what and how much content is in it. The research conducted in the mangrove ecosystem of Karimunjawa National Park has the objective of assessing species diversity and calculating the estimated carbon sequestration from stands and sediments. Inventory of species using quadrant sampling method consisting of 3 stations, 9 transects and 27 plots (10m x 10m). Allometric equations, Shannon-Wiener index, and evenness index were used to calculate stand biomass and carbon, species diversity and distribution. The sediment samples were taken at a depth of 100 cm and divided into 3 depths, namely 0-33 cm, 34 - 67 cm, and 68 - 100 cm. The species diversity is moderate and the evenness of the species is in the stable category. The estimated standing carbon was in the range of 146.22 t C ha^{-1} and the estimated carbon stock in the sediment was around 360.61 t C ha^{-1}. Although the diversity and even distribution of mangrove species in Karimunjawa National Park is still in a stable condition, it is necessary to monitor its changes due to the anthropogenic activities.

Introduction

Until now, mangroves are known as abrasion barriers against tsunamis and as important ecosystems that support the breeding of fish and crabs, but mangroves are also known to have an important function as a more effective absorber of carbon dioxide emissions when compared to rainforests or peatlands (Taillardat et al. 2018). Carbon dioxide emissions that make the earth warmer, encourage climate change and the loss of biodiversity, can come from motor vehicle fumes or various activities that use fossil fuels, such as electricity use, tourism and industrial activities (Wan et al. 2012). So, efforts to sequester carbon especially through rainforests and peatlands in Indonesia, are an important way to curb climate change and save living species from extinction (Roy et al. 2013).

Indonesia is indeed rich in forests and peatlands that are able to absorb carbon, but Indonesia is also one of the countries that has the largest mangrove forest in the world that is able to absorb more carbon than tropical forests or peatlands (Malik et al. 2015). It is noted that Indonesia has around three million hectares of mangrove forest or represents more than 20 percent of the world's mangroves, while Australia and Brazil in the second and third positions, only have about 900 thousand hectares (Huxham et al. 2015). Karimunjawa National Park is located in Jepara Regency, Central Java, is a representation of the integrity of the ecosystem of the northern coast of Java. 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, 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 and is divided into nine zones, namely core zone, jungle zone, marine protection zone, land use zone, marine tourism utilization zone, marine cultivation zone, religious cultural and historical zone, rehabilitation zone, 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. Some of the rare fauna that live here are the White-breasted Sea Eagle, hawksbill turtles, and green turtles. Plants that characterize the Karimunjawa National Park are dewadaru (*Crystocalyx macrophyla*) which are found in lowland rain forests (BTNKJ 2020). Mangrove forests have a major role as carbon sinks and stores, which are around 4 gigatons C/year to 112 gigatons C/year (Cameron et al. 2019). Unfortunately, not all residents are aware of the importance of the function of the mangrove forest. On the other hand, mangrove forests are systematically degraded due to human interests (Basu and Cetzal 2018). There is a conversion of mangrove forest functions so that it has an impact on decreasing the 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 conditions contribute to climate change in the world (Datta et al. 2012). The potential for carbon storage in mangrove mud substrates is very large. Therefore, the estimation of carbon storage in the tree part 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). Therefore, it is important to assess the level of diversity and evenness of mangrove species and to know the estimated carbon content stored in stands and sediments, which can later become a database so that in the future they can implement sustainable management of mangrove ecosystems.

Materials And Methods

Study Area

This research was conducted in the mangrove ecosystem of Karimunjawa National Park which is geographically located in 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). With a land area of ± 1,500 hectares and waters of ± 110,000 hectares. Sampling was in the mangrove area of Karimunjawa Island, Kemujan Island, and Menjangan Island. The sampling location was chosen based on the island which has a mangrove ecosystem and its condition is still natural.

Data Collection

Sampling was carried out non-destructively, which was carried out in August 2021. This study consisted of 3 stations, 9 transects and consisted of 27 plots (10m x 10m) with a distance between plots of 10-20 m to facilitate inventory. The species of mangrove trees in the sample plot were identified and their diameter measured based on DBH (diameter of breast high) (Komiyama et al. 2008). The tree category includes a diameter of more than 10 cm and a tree height of more than 2 meters. Mangrove sediment samples were taken at 3 stations using a sediment core with a length of 100 cm. The core sediments are divided into 3 depths, namely 0-33 cm, 34-67 cm, 68-100 cm. The level of sediment depth affects the amount of carbon content.

Data Analysis

To find out the important value index of an ecosystem, the sum of relative density, relative frequency, and relative dominance is done. Then to find the value of the diversity index (H') of a species, the Shanon Wiener equation is used:

H' = $-\sum$ Pi In (Pi)…………………… (1)

H' = Shannon diversity, s = number of species, pi = proportion of the ith species.

Species diversity is a characteristic of community level based on their biological organization. Species diversity can be used to express community structure. Species diversity can also be used to measure community stability, namely the ability of a community to maintain itself stable despite disturbances to its components.

The value of the species evenness index can describe the stability of a community. Evenness index value (E) ranged from 0-1. The smaller the value of E or close to zero, the more uneven the distribution of organisms in the community which is dominated by certain species and conversely the greater the value of E or close to one, the organisms in the community will spread evenly. The equation for the evenness index is:

E= H' / Log S) …………………………. (2)

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

Calculation of biomass using the allometric formula by measuring the diameter at breast height (DBH). The allometric equation used is based on the reference from the Forestry Research and Development Agency No.P.01/VIII-P3KR/2012 by using the approach to the availability of a tree biomass allometric model that is appropriate to the type/forest ecosystem where the object is located but not at the location of the object. After the biomass is known, it is then multiplied by 0.47 to determine the carbon content, then converted into a unit area (ton ha^{-1}). The carbon content of mangrove sediments was analyzed in the laboratory using the Walkley & Black method (ton ha^{-1}), then the sediment layer samples were analyzed for the purpose of obtaining sediment grain size data. The results of the sediment size analysis carried out in this laboratory are used to determine each size class based on the Wenworth scale. In addition, the grain size of the resulting sediment is also used to determine the type of sediment in the study area based on the Sheppard triangle.

Results And Discussion

Species Mangrove in Karimunjawa National Park

The composition of species, the number of trees, the average diameter at breast height and the average tree height of the mangrove ecosystem of Karimunjawa National Park are shown in Table 1. This study was divided into three stations focused on three islands, namely Karimunjawa Island, Kemujan Island, and Menjangan Island. Each island or observation station consists of three transects. It can be seen in Table 1 that at each research station there are mangrove species *Rhizophora apiculate*, *Rhizophora mucronate, Ceriops tagal, Rhizophora stylosa and Xylocarpus moluccensis*. The distribution is even because these species are natural mangrove species in the Karimunjawa National Park. The order of the total number of trees from the most to the least is station one (228 trees), station three (222 trees), station two (188 trees). The species that dominated the highest number of trees in all research locations was *Rhizophora apiculata*. According to Wetlands International, this species grows in silty, smooth, deep soil and is flooded during normal tides (Andradi et al. 2013). Prefers tidal waters that have a strong permanent influence of fresh water input. *Rhizophora apiculate* has a dominance level that reaches 90% of the vegetation that grows in a location. This is in accordance with the substrate conditions in the mangrove ecosystem of Karimunjawa National Park where many *Rhizophora apiculate* species grow and develop because their habitat is very suitable. The type and magnitude of the substrate percentage at each station can be seen in Fig. 2.

Table 1
Composition of Mangrove Species in Karimunjawa National Park

Station	Species	No. of trees	Mean DBH	Mean Height
1	*Rhizophora apiculata*	99	22,26	9,40
	Rhizophora mucronata	38	22,46	7,70
	Ceriops tagal	41	22,84	6,10
	Rhizophora stylosa	36	13,83	6,80
	Sonneratia caseolaris	9	13,36	6,50
	Xylocarpus moluccensis	5	14,9	7,10
2	*Rhizophora apiculata*	59	15	8,20
	Rhizophora mucronata	49	14,64	6,00
	Ceriops tagal	34	10,23	6,40
	Rhizophora stylosa	23	14	6,60
	Xylocarpus moluccensis	12	11,87	6,80
	Sonneratia caseolaris	11	15,53	5,50
3	*Rhizophora apiculata*	65	15,25	7,70
	Rhizophora mucronata	52	15,1	7,20
	Ceriops tagal	52	10,79	7,25
	Rhizophora stylosa	33	15,35	7,00
	Xylocarpus moluccensis	20	11,22	6,60

Sediment Characteristics

Based on Fig. 2 above, the type of sediment found in the three research sites is dominated by silt sediment, an average of 58%. Sediment conditions at a depth of 0-100 cm tend to be textured like sandy mud with a little clay. According to Komiyama et al (2005) the type of mangrove *Rhizophora* sp can grow well with a sandy loam texture. Because of the strong roots of *Rhizpora* and effective in sand traps. The condition of mangroves has a sandy loam substrate, this is because the location of the mangrove ecosystem is not too close to the beach which has high currents or waves. According to Indah et al (2008), which stated that the root forms of *Rhizophora* sp. anchoring and tight also causes the formation of a substrate. The formation of this substrate is strongly influenced by the presence of currents in tidal and ebb conditions which carry the particles deposited at low tide. Oceanographic factors that affect the distribution of sediments are currents and depth (Wickramasinghe et al. 2009). Waters that have relatively calm currents and shallow water depths between 16-20 cm so that the types of sediments distributed in the mangrove ecosystem are similar. This is due to the anchored and tight root forms of *Rhizophora* sp which also causes the formation of a substrate (Ortega et al. 2018). These roots make the process of capturing dust particles in *Rhizophora* sp stands run perfectly (Morton 2016). When there is a backflow, the dust particles are blocked by the roots. This shows the characteristics of the sediments that are suitable for the growth of mangroves in the Karimunjawa National Park which are dominated by *Rhizophora* sp.

Mangrove Species Diversity

Important Value Index (INP) is an index that is calculated based on the amount obtained to determine the level of species dominance in a plant community (Pollisco and Simorangkir 2013). To determine the Important Value Index in mangrove vegetation trees can be obtained from the sum of the relative frequency, relative density, and relative dominance of a vegetation expressed in percent (%). From the results of calculations that have been carried out at the three observation stations, it can be seen that there are differences in the value of the Important Value Index for each type of mangrove, where *Rhizophora apiculata* found at station I has the highest Important Value Index, which is 113.25% while the lowest important value index is owned by vegetation. *Xylocarpus moluccensis* mangrove species found in station I amounted to 15.82%. The Important Value Index shows the range of the index that describes the community structure and distribution pattern of mangroves (Owuor et al. 2019). The difference in the index of the importance of mangrove vegetation is due to competition in each species to get nutrients and sunlight at the research site. Apart from nutrients and the sun, other factors that cause differences in the density of mangrove vegetation are the type of sediment and tides (Sarker et al. 2019).

The results of the analysis of the relative density of mangroves in Karimunjawa National Park presented in Table 2 shows that at the tree level the highest relative density is *Rhizophora apiculata*, which is 43.42% at station I, while the lowest relative density is *Xylocarpus moluccensis*, which is 2, 91% of which are at station I as well. The high relative density of *Rhizophora apiculata* is because this mangrove has a high ability to adapt so that it can develop well. The low density of *Xylocarpus moluccensis* is due to the fact that this species is not covered by the study area and is more commonly found near land.

Species frequency is one of the vegetation parameters that can show the distribution pattern or distribution of plant species in the ecosystem or show the distribution pattern of plants. The frequency value is influenced by the value of the plot where mangrove species are found. The more the number of squares found, the higher the frequency of the presence of mangrove species (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 III, which is the same as 20%. The species are *Rhizophora apiculate, Rhizophora mucronate, Ceriops tagal, Rhizophora stylosa, and Xylocarpus moluccensis*. Meanwhile, the lowest relative frequency at the tree level is Sonneratia caseolaris, which is 11.76% at station II. The large number of *Rhizophora apiculate* species is due to the condition of the sediment substrate at the study site in the form of sandy silt which is able to support mangrove growth so that this type of mangrove can survive and develop well. The silt substrate that is spread in almost all stations contains a lot of organic matter when compared to the type of sediment in the form of sand because it 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).

At the tree level, the highest relative dominance value was occupied by *Rhizophora apiculate* with a dominance value of 51.08% at station I. This was because *Rhizophora apiculate* was able to compete to obtain more nutrients than other species due to the adaptation of its root system. Meanwhile, the dominance value which is relatively low is *Xylocarpus moluccensis*, which is 1.13%. This is due to the uneven distribution of *Xylocarpus* *moluccensis* and the level of habitat suitability, where the substrate type in the Karimunjawa mangrove ecosystem is mostly silt-sand type, while *Xylocarpus moluccensis* prefers a harder substrate.

Table 2
Value of Relative Frequency, Relative Dominance, Relative Density, Important Value Index, Diversity Index, and Evenness Index

St	Species	Total Individual	Relative values (%)			Importance value (%)	H'	E	IUCN
			Frequency	Dominance	Density				
1	*Rhizophora apiculata*	99	18,75	51,08	43,42	113,25	0,36	0,82	LC
	Rhizophora mucronata	38	18,75	20,27	16,66	55,69	0,29		LC
	Ceriops tagal	41	18,75	7,48	17,98	44,21	0,30		LC
	Rhizophora stylosa	36	18,75	18,26	15,78	52,80	0,29		LC
	Sonneratia caseolaris	9	12,5	1,76	3,94	18,20	0,12		LC
	Xylocarpus moluccensis	5	12,5	1,13	2,19	15,82	0,08		LC
	Total	**228**	**100**	**100**	**100**	**300**	**1,47**		
2	*Rhizophora apiculata*	59	17,64	20,02	31,38	69,05	0,36	0.90	LC
	Rhizophora mucronata	49	17,64	17,72	26,06	61,43	0,35		LC
	Ceriops tagal	34	17,64	13,32	18,08	49,05	0,31		LC
	Rhizophora stylosa	23	17,64	17,25	12,23	47,13	0,26		LC
	Xylocarpus moluccensis	12	17,64	13,97	6,38	38,00	0,18		LC
	Sonneratia caseolaris	11	11,76	17,72	5,85	35,33	0,17		LC
	Total	**188**	**100**	**100**	**100**	**300**	**1,62**		
3	*Rhizophora apiculata*	65	20	24,73	29,28	74,01	0,36	0,95	LC
	Rhizophora mucronata	52	20	24,25	23,42	67,67	0,34		LC
	Ceriops tagal	52	20	13,82	23,42	57,25	0,34		LC
	Rhizophora stylosa	33	20	23,61	14,86	58,48	0,28		LC
	Xylocarpus moluccensis	20	20	13,58	9,01	42,59	0,22		LC

St	Species	Total Individual	Relative values (%)			Importance value (%)	H’	E	IUCN
			Frequency	Dominance	Density				
	Total	222	100	100	100	300	1,54		

The diversity of mangrove species in the study area based on the Shannon-Wienner diversity index (H') was in the moderate category at all stations. The data in Table 2 shows that for tree growth rates, the diversity index (H') ranges from H' 1.47 to 1.62. This shows that the mangrove ecosystem has moderate diversity, the condition of the ecosystem is quite balanced, the water conditions are still stable, and the ecological pressure is moderate. The value of diversity in a community depends on the number of species and the number of individuals in the community. The species diversity of a community will be high if the community is composed of many species and no species dominates (Rahmila and Halim 2018). Conversely, a community has a low value of species diversity, if the community is composed of a few species and there is a dominant species. The mangrove vegetation found showed varying zoning 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 *Rhizophora apiculata*. This species is very dominant along the coastline of Karimunjawa Island, Kemujan Island, Menjangan Island. *Sonneratia caseolaris, Ceriops tagal, Rhizophora stylosa* and *Rhizophora mucronata* are at the rear, while *Xylocarpus moluccensis* and other minor component mangrove species fill the rear zone. This mangrove vegetation profile diagram shows that there are differences in mangrove zoning at each research station, especially for the rear zoning, while the front zoning tends to be uniform, dominated by *Rhizophora apiculate*. According to the conservation status of the IUCN red list, all mangrove species found in the study in Karimunjawa National Park are included in the least concern (LC) category. Although it is still classified as low risk, it is not impossible that in the next few years the number of species will be threatened along with the increase in anthropogenic activities in Karimunjawa National Park. So that conservation efforts need to be carried out

Furthermore, the evenness index value at each research station ranged from 0.82 - 0.95. Based on the evenness index criteria, this value is stable for all stations. This shows that the species found at each research station tend to have uniformity, meaning that no particular 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. 2013). On the other hand, the higher the uniformity index value, the higher the distribution pattern in the community and no particular 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). There are a number of reasons why plants show a clumped distribution (Mangora 2011). Most of the mangrove seeds/fruits are not consumed by animals, so the ripe fruit will fall near the parent tree and will grow into an adult tree. According to Santos et al (2014), that the formation of a clustered distribution pattern is related to the pattern or way of eating because in certain areas there are many food sources. In addition, external reproduction factors and the characteristics of the substrate that are suitable for mangrove growth are one of the factors for the formation of a group distribution pattern.

Biomass and C-Stock

Table 3 shows the stand biomass yield, stand carbon content, and sediment carbon content. The value of biomass and carbon in the stand is directly proportional because the larger the diameter of the stand and the greater the density, the greater the biomass and carbon content. It can be seen that station 1 has the highest carbon content among the other stations. This is because at station 1 the mangrove ecosystem is included in the national park area, so that the condition of the stands and the condition of the surrounding environment are still very natural. This case is different from what happened at station 2. The condition of mangroves located on the southern coast of Kemujan Island has been damaged a lot. This is presumably because there are residential residents around the mangrove area which causes the conversion of mangrove land to agricultural land. There is agricultural land for tropical crops such as rice and coconut plantations which can be seen in Fig. 1. Organic carbon in sediment is one of the constituents of organic compounds in the 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. There is a high potential for emissions due to disruption of large carbon stores. Table 4 shows the carbon content based on depth and total carbon content in the Karimunjawa mangrove ecosystem.

At stations 1 – 3, the carbon content increases with increasing depth. The high organic matter in the surface layer (0 cm) is due to the high litter production from each station, where the mangrove density also affects the level of organic matter content. This is in accordance with Oliver et al (2012) opinion, which states that the decomposition process of litter (leaves/branches/twigs) only occurs on the surface of the soil, 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 in particular 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, also significantly reduces the carbon content of mangrove soils.

Table 3
Value of Above-ground Biomass, C-stock, and Average C-stock at All Station

	Transek	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	

Table 4
Value of Carbon Content by Depth

Station	Depth	Total Soil C-Stock	Total Soil C-Stock (t C ha $^{-1}$)
1	Depth 0 - 33 cm	156,00	482
	Depth 34 - 67 cm	165,00	
	Depth 68 - 100 cm	161,00	
2	Depth 0 - 33 cm	64,00	199,75
	Depth 34 - 67 cm	67,50	
	Depth 68 - 100 cm	68,25	
3	Depth 0 - 33 cm	127,00	400,1
	Depth 34 - 67 cm	137,10	
	Depth 68 - 100 cm	136,00	

The results of measurements of carbon content at the three stations based on depth have different results of carbon storage (Fig. 3). The carbon storage value was measured vertically with five different depths while the measured depths were 0-33 cm, 34-67 cm, 68-100 cm. Where each depth has a different carbon storage value. The highest carbon storage on average is at a depth of 34-67 cm with values ranging from 67.5 to 165 t C ha^{-1}. The lowest value was found in the upper layer (0-33cm) at station 2 with a value of 64 t C ha^{-1}. This condition is thought to be because the surface layer is heavily affected by currents, waves, and tides which cause organic content including carbon to be carried along with the movement of water (Halim et al. 2018). While the layer below it has been in the form of solids that have fused over the years through the sedimentation process. From the sedimentation process, there is a biogeochemical process that causes the carbon content at the bottom to increase with increasing depth. The biogeochemical cycle is the transfer of elements/compounds involving organic and inorganic (Alongi 2020). The function of the biogeochemical cycle is to maintain life on earth. The total average value for the estimated carbon of mangrove stands is 146.22 t C ha^{-1} and for the estimated carbon stock in sediments it is 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). However, the estimated carbon content of sediments in Karimunjawa National Park is almost twice as high as 360.61 t C ha^{-1}. 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), 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 did not only depend on species but also on ecological conditions and geographical locations. With a relatively high density value in the Karimunjawa mangrove ecosystem, the potential for litter fall is also expected to be very high. Different values of carbon content are influenced by the number and density of trees, tree species, environmental factors including sunlight, water content, temperature, and soil fertility that affect the rate of photosynthesis (Alongi 2002). 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 to all other forest types on earth.

Conclusion

Karimunjawa National Park has a stable mangrove ecosystem and sufficient species diversity. With conditions that are still natural, special attention is needed in sustainable management. The potential for carbon sequestration on a national scale is quite high both in stands (146.22 t C ha^{-1}) and in sediments (360.61 t C ha^{-1}). The main factors that influence this are the density of species and the diameter of mangrove trunks. However, there is a threat from anthropogenic activities and the impact of climate change that can make the mangrove ecosystem vulnerable.

Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the conception and design of the study. Material preparation, data collection and analysis were carried out by M. Arief Rahman Halim, Tri Retnaningsih Soeprobowati, and Hadiyanto. The initial draft of the manuscript was written by M. Arief Rahman Halim and all authors commented on the previous version of the manuscript. All authors read and approved the final manuscript.

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request

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Figures

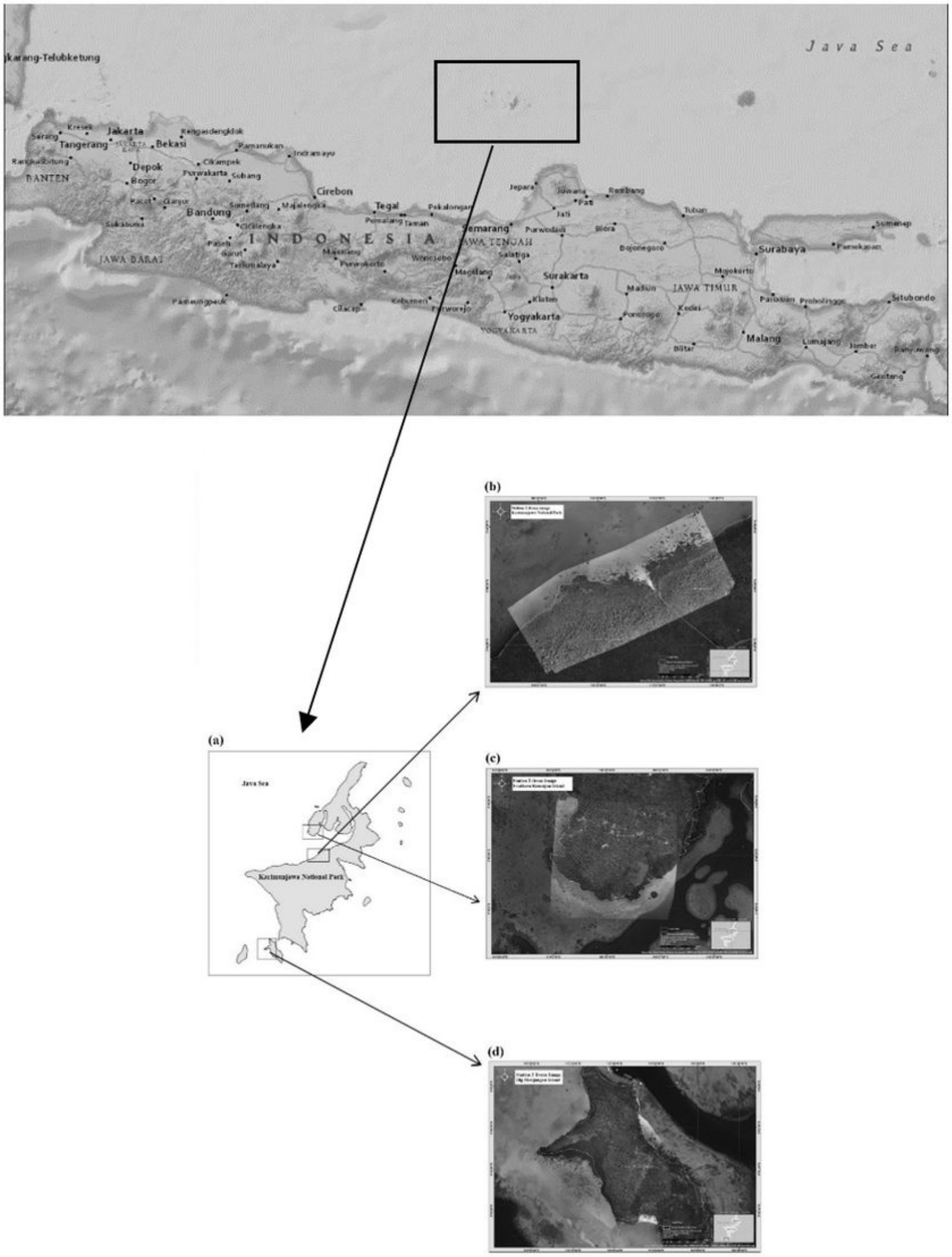

Figure 1

Map of (a) Karimunjawa National Park Area, Jepara Regency, Central Java (b) Karimunjawa Island (c) Kemujan Island (d) Menjangan Islan

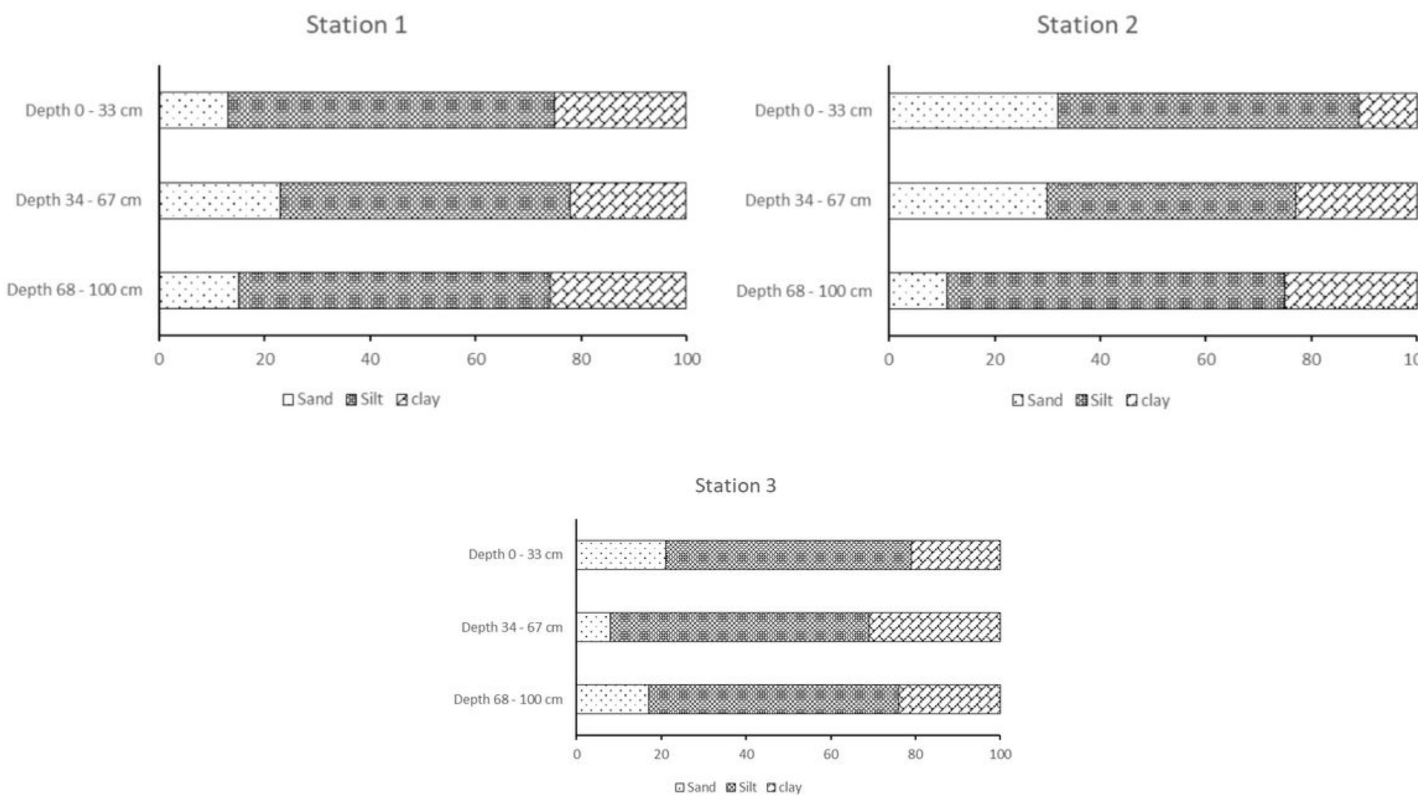

Figure 2

Type and amount of sediment percentage based on depth

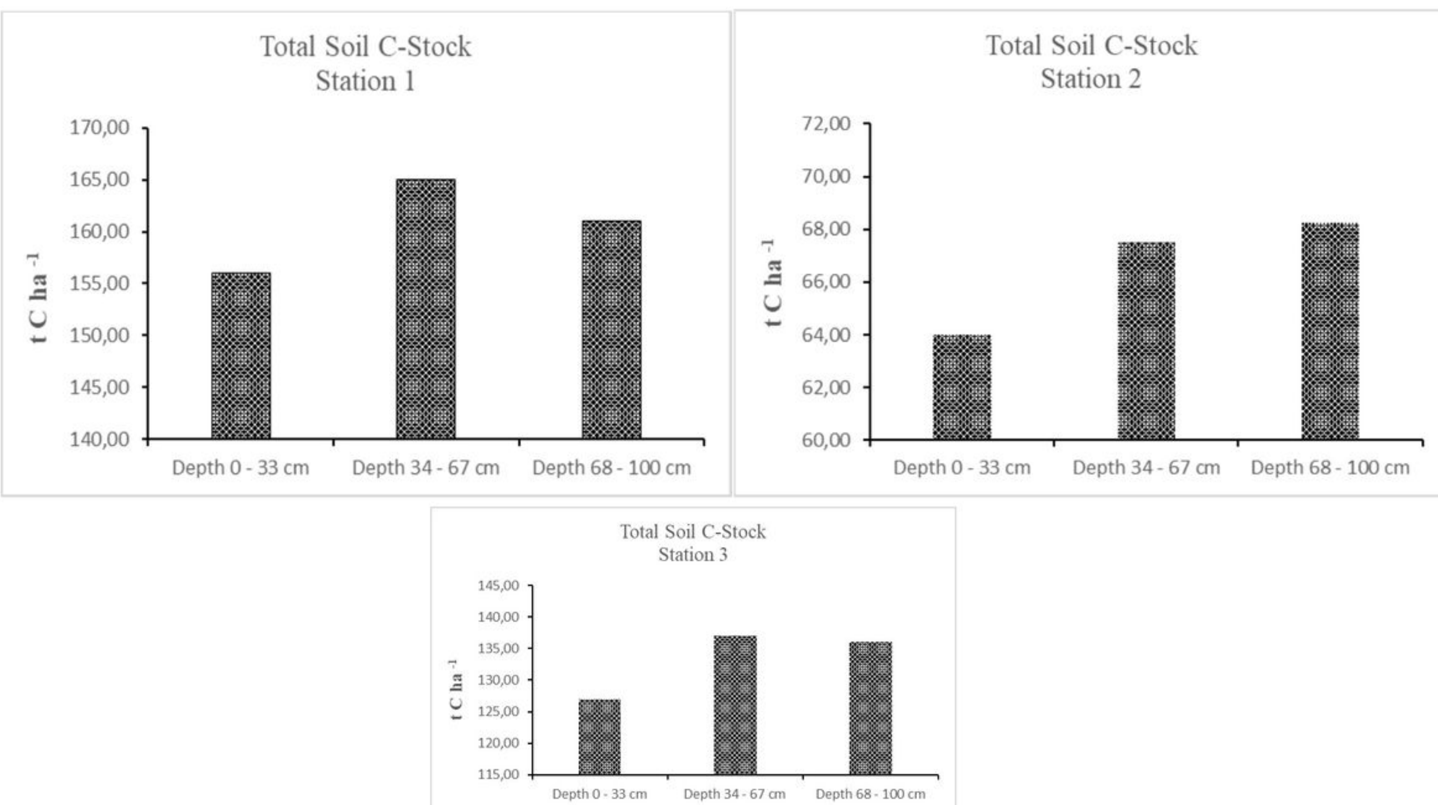

Figure 3

Comparison of total soil C-stock values based on depth at all stations