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Mangrove forest inventory and estimation of Carbon Storage in Poteran Island, East Java, Indonesia

Muhammad Arif Asadi*, Sukandar Sukandar, Oktiyas Muzaky Luthfi, Muliawati Handayani, Citra satrya Utama Dewi, Dhira Kurniawan Saputra, Muhammad Reza Alfi Rahmandika

Department of Marine Science, University of Brawijaya, Malang, Indonesia

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Abstract

Mangrove forests support a wide range ecosystem services, including fisheries production and carbon storage. However, the areal extent of mangrove forests has degraded rapidly over the past five decades as a result of over harvesting, aquaculture and coastal development. Consequently, the decrease of available wood, fish, and crustacean as well as the loss of carbon (C) stored in the mangrove forests is inevitable. This study aimed to evaluate the structures of mangrove forests of Poteran Island, East Java, Indonesia as well as to quantify the above-ground and below-ground-root biomass and C stocks. Nine sampling transect quadrants with 10x10m, 5x5m, and 1x1m plots in each transect were carried out to identify, measure, and record the mangrove species and stands and their diameter breast height (DBH). Results showed that the diversity index of mangrove stands was low (H'=0.4) in which there were four mangrove species (*Rhizophora stylosa, Sonneratia alba, Osbornea octodonta, Excoecaria agallocha*). *R. stylosa* dominated the mangrove stands (97%) with IVI value of 246.01%. Although, the average DBH of this species was much lower than that of other species (4.39 ± 1.39cm), it had highest biomass and C stocks (170.38 ± 63.68Mg B ha^{-1} and 78.51 ± 29.32Mg C ha^{-1} respectively) which constituted 96.3% of total biomass and C stocks. In total, mangrove forests of Poteran Island substantially sequestered high amount of C (81.49 ± 29.94Mg C ha^{-1}) and therefore management action should be implemented to protect its mangrove forest.

***Corresponding Author:** Muhammad Arif Asadi ✉ asadi@ub.ac.id

Introduction

Mangrove forests are among the most diverse and productive ecosystems on earth. They are recognized for their wide range of ecosystem services, including spawning and nursery grounds for many fish and invertebrates, ecotourism, wood production, nutrient cycling and carbon (C) storage. Although, mangrove ecotones comprise only 0.7% of the world's tropical forest areas, they contribute 10% of the global anthropogenic carbon dioxide (CO_2) emissions from tropical deforestation (Abino *et al.*, 2014; Asadi *et al.*, 2017; Donato *et al.*, 2011). Moreover, mangroves have been shown to contain significant C pools globally, sequestering more than three times the carbon of upland forests. With an extent of 2.9 Mha, the estimated total carbon sequestration of mangrove forests in Indonesia could be as much as 3.14 ± 1.1 PgC (Murdiyarso *et al.*, 2015).

Indonesia has the highest diversity of mangrove species in which at least 45 species out of 70 true mangroves species found in this archipelago. They have salt filtration systems to cope with salt intrusion as well as a complex root system to adapt with low oxygen environment of waterlogged mud. Therefore, mangroves successfully thrive in intertidal areas of Indonesia in which this country represents about 20% of all mangroves on Earth (Asadi *et al.*, 2018; Donato *et al.*, 2011). However, in Indonesia as well as in other countries, mangroves have been degraded in alarming speed. Over just 20 years, mangrove forest along Indonesia's coastline had declined about 26% from 4.2 Mha in 1980 to 3.1 in 2000 (Giri *et al.*, 2011).

Based on FAO data, annual deforestation rate of mangrove forests in Indonesia was 1.24% in which cumulatively it had lost around 30% of its mangroves between 1980 and 2005 (Malik *et al.*, 2016).

The main cause of those rapid mangroves loss was the expanding of aquaculture development in which only between 1997 and 2005, 0.65% Mha mangrove forests were converted to shrimp ponds (Murdiyarso *et al.*, 2015). Although export revenues from the shrimp industries approached 40% of the total revenues of fisheries sector in Indonesia, the loss of mangrove forests has devastating economic and environmental consequences for the coastal communities.

The conversion of mangrove forests for aquaculture and other coastal developments will also increase the emissions as well as reduce the capacity of mangrove ecosystem in sequestering CO_2 in the atmosphere (Murdiyarso *et al.*, 2015; Polidoro *et al.*, 2010). The conversion of mangrove forest for coastal developments has also occurred in most mangrove areas in East Java, Indonesia.

Therefore, inventories of mangrove properties in this province are also necessary to obtain the information of mangrove diversity and their biomass. In this study, the capacity of mangrove forest in sequestering C in the Poteran Island, Sumenep, East Java, Indonesia would be measured, and the mangrove diversity in the island would also be accessed.

Materials and methods

Study area

Poteran Island is located at Sumenep regency, East Java province, Indonesia. The island had a total population of 41.107 with a total area of 49.8km^2 (KKP, 2018). As the impact of population pressure, the mangrove ecosystems in this island have been under anthropogenic threats such as wood exploitation, habitat degradation, and coastal development. The mangrove forests of the Poteran Island are fragmented into small patches of forest along the island's coastline which in turn increase the vulnerability of its mangrove forest.

The study was conducted on October 2016 during the end of rain season. For the study of mangrove diversity and C stocks, we sampled mangroves at three distinct stations with 3 transects in each station, totaling 9 quadrant transects. Station selections were primarily based on random selection along the Poteran Island coastlines. Geographic coordinates, mangrove species, and the map of research areas are summarized in Fig. 1 and Table 1 respectively.

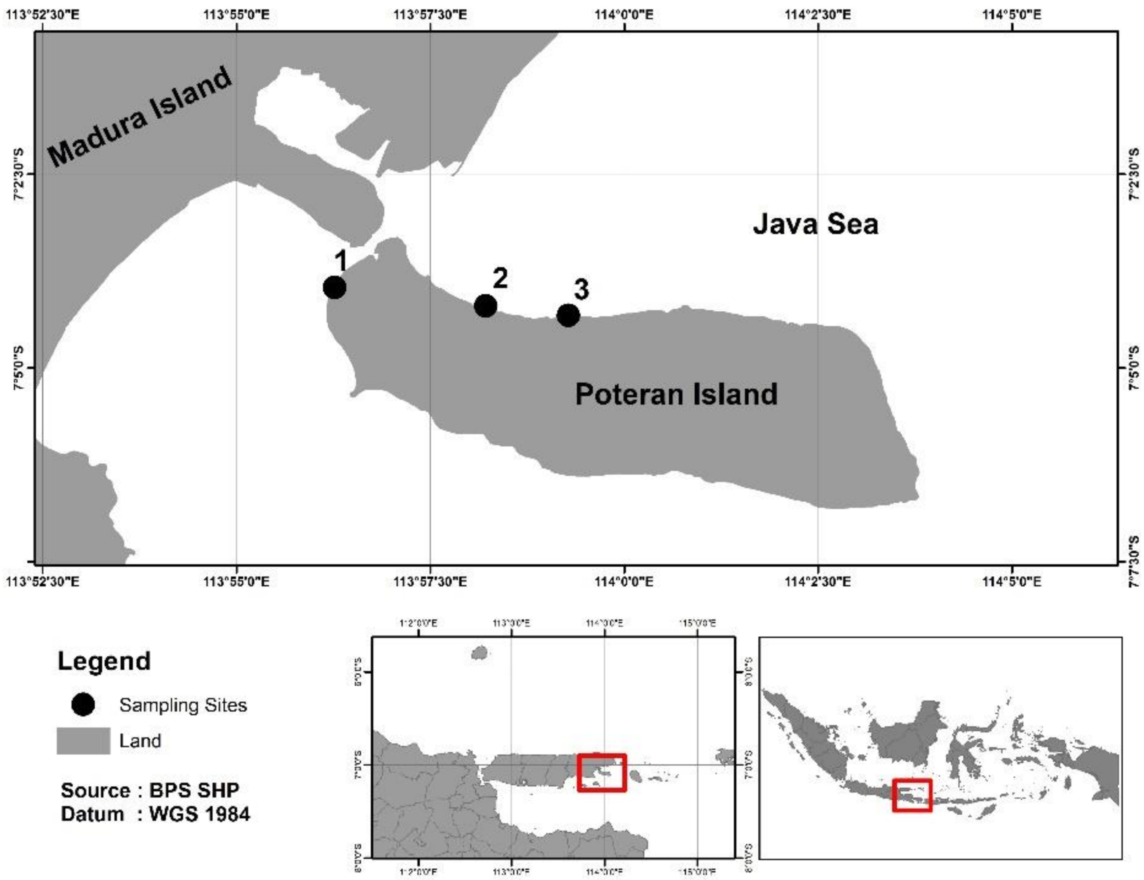

Fig. 1. Location map of the study sites in Poteran Island, Sumenep, East Java, Indonesia.

Table 1. Location coordinates, Hydro-geomorphic setting, and mangrove species of Poteran Island, East Java, Indonesia

Site	Latitude	Longitude	Hydro-geomorphic setting	Mangrove species
1	-7.066077°	113.937766°	Fringe mangroves	*Rhizophora stylosa, Sonneratia alba, Avicenia marina*
2	-7.070307°	113.970255°	Fringe mangroves	*Rhizophora stylosa, Sonneratia alba, Osbornea octodonta, Excoecaria agallocha*
3	-7.072079°	113.988037°	Fringe mangroves	*Rhizophora stylosa, Rhizophora apiculata, Sonneratia alba, Avicenia marina*

Data Collection

In each station, three transects with three plots (10 x 10m, 5 x 5m, and 1 x 1m) in each transect were laid out parallel to the coastline to determine the species structure and composition of the mangrove forests in the Poteran Island, Sumenep, East Java, Indonesia. The sampling was a non-destructive technique with a distance of each transect between 5 and 20 m depending on the mangrove ecosystem characteristics. The mangroves with a diameter of at least 5cm and 2.5cm in 10 x 10m and 5 x 5m plots respectively were identified according to Giesen *et al.* (2006), and the diameter breast height (DBH) of the mangroves were also measured in situ. The DBH of Rhizophora was measured at 30cm above the highest prop root. The DBH of other mangrove species were measured at 130cm above the ground (Abino *et al.*, 2014; Asadi *et al.*, 2018).

Data Analysis

The importance value index (IVI) is the structural importance of each species in a community. The percentage values of relative frequency (RF), relative density (RD), and relative dominance (RDom) were determined and the sum of those values were added to obtain the IVI, where:

$$RF = \frac{Frequency\ of\ a\ species}{Total\ frequency\ of\ all\ species}\ X\ 100$$

$$RD = \frac{Density\ of\ a\ species}{Total\ density\ of\ all\ species}\ X\ 100$$

$$RDom = \frac{Dominance\ of\ a\ species}{Total\ dominance\ of\ all\ species}\ X\ 100$$

Shannon-Wiener's diversity index (Shannon & Weaver, 1963) was determined in this study. It indicates a quantitative description of mangroves in terms of species evenness and distribution. Shannon-Wiener's Index was calculated using the following form:

$$H' = -\sum Pi\ \ln Pi$$

Where $H'$is the diversity index, Pi is the proportion of individuals i^{th} species to total species individuals, and ln is the natural logarithm (Abino *et al.*, 2014; Asadi *et al.*, 2018; Nguyen *et al.*, 2014).

Furthermore, above-ground biomass (AGB) and below-ground-root biomass (BGB) from the data of DBH of mangroves were estimated using the general allometric equations for Indo-West Pacific (0.251 x ρ (wood density of the species, g cm^{-3}) x $D^{2.46}$ and 0.199 x $\rho^{0.899}$ x $D^{2.22}$ for AGB and BGB respectively). The biomasses of those calculation results were then multiplied by 0.47 and 0.39 to determine above-ground carbon (AGC) and below-ground-root carbon (BGC) respectively (Kauffman and Donato, 2012; Komiyama *et al.*, 2008).

Result

Vegetation structure

There were six mangrove species from five families recorded in the Poteran Island, Sumenep, East Java, Indonesia (Table 1). However, only four species had DBH higher than 2.5cm namely *R. stylosa* from Rhizophoraceae family, *S. alba* from Lythraceae family, *O. octodonta* and *E. agallocha* from Myrtaceae and Euphorbiaceae family respectively.

Station 2 had the highest diversity of mangroves in which all species of mangrove stems found in the research areas stood in this station. Meanwhile, the minimum DBH of the stands was 2.55 cm, and the maximum was 17.17cm (Table 2).

Table 2. Species composition and DBH of the mangrove trees in the Poteran Island, Sumenep, East Java, Indonesia.

Station	Transect	No. of trees	Species	DBH (cm) Mean	Min.	Max.	SD
1	1	68	Rs, Sa	4.48	2.55	11.14	1.79
	2	50	Rs	5.18	2.55	9.23	1.69
	3	60	Rs	5.5	2.55	11.46	2.16
2	1	43	Rs, Sa, Oo, Ea	4.49	2.55	14	2.14
	2	50	Rs	4.47	2.55	7.96	1.71
	3	52	Rs	3.18	2.55	7	1.18
3	1	22	Rs, Sa	5.27	2.55	17.17	3.12
	2	11	Rs, Sa	4.26	2.55	11.3	3.19
	3	3	Rs	2.71	2.55	2.86	0.16

Note: Rs = *R. stylosa,* Sa= *S. alba,* Oo = *O. Octodonta,* Ea = *E. Agallocha.*

More than 97% of individual mangrove stems found in the entire study areas was *R. stylosa* (Table 3). It stood in all research stations and quadrant transects (Table 2), comprising 60% of relative RF in the whole mangrove forests of the island. Meanwhile, this species also had highest RD and Rdom with the values of 97.25% and 88.86% respectively making up 246.01% of IVI. *E. Agallocha* which had only one stand and found only in the station 2 had IVI of 9.03%. As *R. stylosa* dominated the mangrove stands in whole research areas, the Shannon's diversity index was low with the value of only 0.4.

The density of the stands was also dominated by *R. Stylosa* with 12172 trees per hectare (Table 3).

Mangrove Biomass and C Stocks

Although *R. Stylosa* had the lowest average DBH with only 4.39 ± 1.64cm, the AGB and BGB of this species had the highest values with 109.3 ± 40.83 and 61.08 ± 22.85Mg B ha^{-1} respectively. With a total biomass of 170.38 ± 63.68Mg B ha^{-1}, *R. Stylosa* stands in the Poteran Island sequestered as much as 78.51 ± 29.32Mg C ha^{-1}. Meanwhile, *O. octodonta and E. agallocha* that had DBH 7.72 and 14.01cm respectively only sequestered 0.97 and 0.6Mg C ha^{-1} respectively. In total, the mangrove stands of Poteran Island had biomass of 176.79 ± 65.02Mg B ha^{-1} and sequestered 81.49 ± 29.94Mg C ha^{-1} (Table 4).

Table 3. Analysis of importance value index (IVI) and the Shannon's diversity index of the mangrove forest of Poteran Island, Sumenep, East Java, Indonesia.

Family	Species	No. of Individuals	RF (%)	Rdom (%)	RD (%)	IVI (%)	H'	Density (Ind ha^{-1})
Rhizophoraceae	*R. stylosa*	349	60	88.86	97.21	246.0179 943	0.58	12172
Lythraceae	*S. alba*	5	26.67	6.47	1.39	34.51	- 0.08	55
Myrtaceae	*O. octodonta*	4	6.67	2.66	1.12	10.44	- 0.07	44
Euphorbiaceae	*E. agallocha*	1	6.67	2.08	0.28	9.03	-0.02	11
	Total	359	100	100	100	300	0.40	12282

Table 4. The mean of DBH, AGB, AGC, BGB, and BGC of mangrove stands in Poteran Island, Sumenep, Indonesia. Two-way ANOVA showed statistically significant differences (p < 0.05) in DBH, AGB, AGC, BGB, and BGC of mangrove stands among different species.

Species	DBH (cm)	AGB (Mg B ha^{-1})	AGC (Mg C ha^{-1})	BGB (Mg B ha^{-1})	BGC (Mg C ha^{-1})	Total (Mg B ha^{-1})	Total (Mg C ha^{-1})
R. stylosa	4.39 ±	109.3 ± 40.83	54.65 ±	61.08 ±	23.86 ± 8.91	170.38 ±	78.51 ±
S. alba	8.41 ±	2.05 ± 0.54	1.02 ± 0.27	1 ± 0.26	0.39 ± 0.10	3.05 ± 0.80	1.41 ± 0.37
O. octodonta	7.72 ±	1.39 ± 0.36	0.7 ± 0.18	0.69 ± 0.18	0.27 ± 0.07	2.08 ± 0.54	0.97 ± 0.25
E. agallocha	14.01	0.88	0.44	0.40	0.16	1.28	0.6
Total	-	113.63 ± 41.72	56.81 ±	63.27 ±	24.67 ± 9.08	176.79 ±	81.49 ±

Discussion

Poteran Island had been known rich in seagrass biodiversity and biomass (Dewi and Sukandar, 2017). With clay and silt substratum dominated the intertidal areas of the island, it once might have a massive mangrove covers. However, the expanding aquaculture development during the last few decades extremely reduced mangrove habitat in most areas of Indonesia, including in the Poteran Island and other coastal areas of East Java (Asadi *et al.*, 2017; Murdiyarso *et al.*, 2015)

Although there were six species of mangrove in the research areas, namely *A. marina, R. apiculata, R. stylosa, S. alba, O. octodonta, E. agallocha,* only four latter species were included in the IVI determination and biomass calculation. The two former species were not considered in the inventories as both species found in the research areas were in the form of saplings. Most studies of mangrove inventories measured and tagged all trees with a DBH of 5cm or greater (Donato *et al.*, 2011; Kauffman *et al.*, 2016; Nam *et al.*, 2016). In this research areas, most trees had DBH less than 5cm; therefore, mangrove with a DBH of at least 2.5 were tagged for the inventories. Abino *et al.* (2014) also considered mangroves with a DBH of 2.5cm or greater to be included in the biomass calculation as well as forest structure determination.

Furthermore, 349 out of 359 mangrove trees were *R. Stylosa* which also constituted 97% of all mangrove stands in the whole research areas. Structurally, the species was also the most important species in the island. It was expressed in its high IVI (246.01%) representing 82% of the total IVI.

It seemed that the dominance of *R. Stylosa* might be caused by forestation programs in the Island. It was reflected by the high density of this species in the most research areas which on average it was as many as 12172 trees per hectare. During the field work, it was clearly seen that the trees were neatly planted confirming that the high density and dominance of *R. Stylosa* were due to plantation programs in the research areas. Density is a primary factor determining the individual growth and therefore high density of mangroves might limit the growth of trees as the habitat competition become greater in those mangrove ecosystems (Pachas *et al.*, 2018). Moreover, the forest density is among environmental factor or property that highly correlated with tree's diameter in which the DBH of *R. Stylosa* in the Poteran Island, on average, was below 5cm (Ramananantoandro *et al.*, 2016).

Although *S. alba* had only 5 individuals or 1.39% of all mangrove stands, It had relatively high IVI (34.51%) or 11.5% of the total IVI. It was due to the relatively high RF (26.67%) possessed by this species which was driven by the occurrence of this species in 4 out of 9 transects. In contrast, *O. Octodonta* had IVI only 10.44%; although, the number of individuals of this species were almost as many as *S. alba*. It was due to the fact that *O. Octodonta* was only found in 1 out of 9 transects; therefore the RF was relatively low (6.67%) compared to that of *S. alba*. Even though, the average DBH of *R. Stylosa* was much lower than that of other species, it constituted 96.3% of all mangrove's biomass and C. The value was relative high for such a low DBH; however, *R. Stylosa* has higher wood density than that of the other species which contributed higher biomass and C stocks (Abino *et al.*, 2014; Komiyama *et al.*, 2008). The C stock of mangrove forest in Poteran Island was higher than that of found in mangrove forest of Labuhan, East Java, and Totok Bay, North Sulawesi, Indonesia which had values of 74.7 and 17.1Mg C ha^{-1} respectively (Asadi *et al.*, 2018; Rumengan *et al.*, 2018). It was lower compared to that of primary mangrove forest of Can Gio Mangrove Forest Park, Vietnam and Sarawak mangrove forest, Malaysia 102 and 117Mg C ha^{-1} respectively (Abino *et al.*, 2014; Dung *et al.*, 2016).

Primary forests usually have higher biomass than that of secondary forest as the stands are older and therefore they have higher values of DBH (Asadi *et al.*, 2017). The C stock of mangrove forest of the Poteran Island would be continuing to increase as time passes as long as anthropogenic threats to mangrove ecosystems like poaching and land conversion could be minimalized. Satellite data showed that at some areas of Poteran Island including in the station 1, the mangroves had been poached or converted for coastal development. Therefore, the authorities and local communities should preserve the mangrove ecosystem of this island.

Conclusion

The study was the first mangrove forest inventories of the Poteran Island, East Java, Indonesia. The island harbored 6 true mangrove species but there were only 4 species with DBH higher than 2.5cm, namely *R. stylosa*, *S. alba*, *O. octodonta* and *E. agallocha*. *R. stylosa* had the highest IVI with the value of 246.01%, followed by *S. alba* and *O. octodonta* (34.51% and 10.44% respectively). *R. stylosa* also had the highest density and biomass. The C stock of the mangrove stands was 81.49 ± 29.94Mg C ha^{-1} in which it was equivalent to sequestration of 299.06 ± 109.87Mg CO_2 ha^{-1} from the atmosphere.

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