Diversity and biomass of mangrove forest within Baluran National Park, Indonesia

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Abstract. Mangrove forests in Java Island have been systematically exploited, mainly for aquaculture development. However, in some remote areas and national parks, mangrove forests are still well preserved. This study aimed to assess the community structure and species diversity of the primary mangrove forest of Bama Resort, Baluran National Park, Indonesia. Twenty-one plots with a size of 10x10 m were established to identify and measure the trees' diameter at breast height (DBH). Shannon-Wiener's Index and common allometric equations were applied to determine the diversity index and the mangrove biomass, respectively. Results showed that there were eight species of true mangroves, with a diversity index of 1.31; some species were only represented by less than three individuals. *Rhizophora stylosa* and *Ceriops tagal* had the highest IVI values (124.6% and 66%, respectively). The overall means of biomass and C-stocks of the mangrove stands in the whole research area were 533.1±566.7 MgB ha^{-1} and 239.8±256.9 MgC ha^{-1}, respectively. Stored carbon was equivalent to CO_2 sequestration of 880±942.8 Mg ha^{-1} CO_2. These findings suggest that some mangrove species of Bama Resort may still be under threat from habitat loss. The primary mangrove forest of Bama Resort has the capacity to sequester a substantial amount of atmospheric carbon dioxide; therefore, this important ecosystem requires protection and conservation.
Key Words: Bama Resort, *Rhizophora stylosa, Ceriops tagal,* C stocks, biomass.

Introduction. Mangrove forest is an ecotone ecosystem that is widely distributed throughout tropical coastlines (Ardiansyah et al 2019; Asadi et al 2018; Kauffman & Donato 2012). Mangrove forests cover only 0.5% of the Earth's coastal areas, and yet they contribute significantly to the provision of ecosystem services (Alongi 2014; Kauffman & Donato 2012). Mangroves provide nursery, refuge, and feeding grounds for a wide array of marine species from invertebrates to fish (Giri et al 2011; Lovelock et al 2015), while protecting human communities against storms, hurricanes, waves, and floods, preventing soil erosion, and maintaining water quality (Aslan et al 2016; Valiela et al 2001).

Globally, mangrove forest cover has decreased by 1.4% annually since the 1980s (Widyastuti et al 2018). Between 1980 and 2005, a total of 20% of mangrove area was lost and converted to aquaculture and other coastal developments (Craft 2016). Moreover, in Indonesia, it is estimated that a total of 40% of mangrove cover has been lost in the last three decades (Murdiyarso et al 2015). Mangroves are also threatened by increases in sea surface temperature and sea level rise due to global climate change (Kauffman et al 2016; Lovelock et al 2015).

Restoration and rehabilitation of degraded mangroves have been carried out in many regions with the aim of protecting and stabilizing coastal and shoreline areas, as well as to enhance coastal biodiversity and to generate income for local communities (Brander et al 2012; Valiela et al 2001). Recently, trading carbon credits, like the REDD+ scheme, have been included as the objective of mangrove conservation and restoration (Donato et al 2011; Wylie et al 2016). However, REDD+ and other carbon credit schemes require robust monitoring of C pools and emissions estimation (Donato et al 2011).

Mangrove forests are known for their high capacity in sequestering CO_2 and otherwise storing C. They store up to three times more organic C than typical terrestrial forests (Kauffman et al 2016), and are known as the most important form of blue carbon

(Alongi 2014). However, there is still a lack of study on carbon storage of mangrove ecosystem in many areas (Donato et al 2011; Brander et al 2012). In Java Island of Indonesia, where rapid coastal development have reduced mangrove covers (Asadi et al 2018), some mangrove forests are still well preserved, including in Bama Resort, Baluran National Park (BNP). Therefore, the aims of this study were to estimate biomass and assess the structure of the mangrove forest of Bama Resort, BNP.

Material and Method

Study sites. This study was performed in the natural mangrove forest of Bama Resort, BNP, situated at the north-eastern extremity of Java Island, Indonesia (Figure 1). The park is bordered by Bali Strait to the east and Madura Strait to the north, between 7°29′10′′ S and 7°55′55′′ S latitude, and 114°29′10′′ E and 114°39′10′′ E longitude (Sabarno 2001). This area has a typical monsoon climate with a long dry season (Wianti 2014).

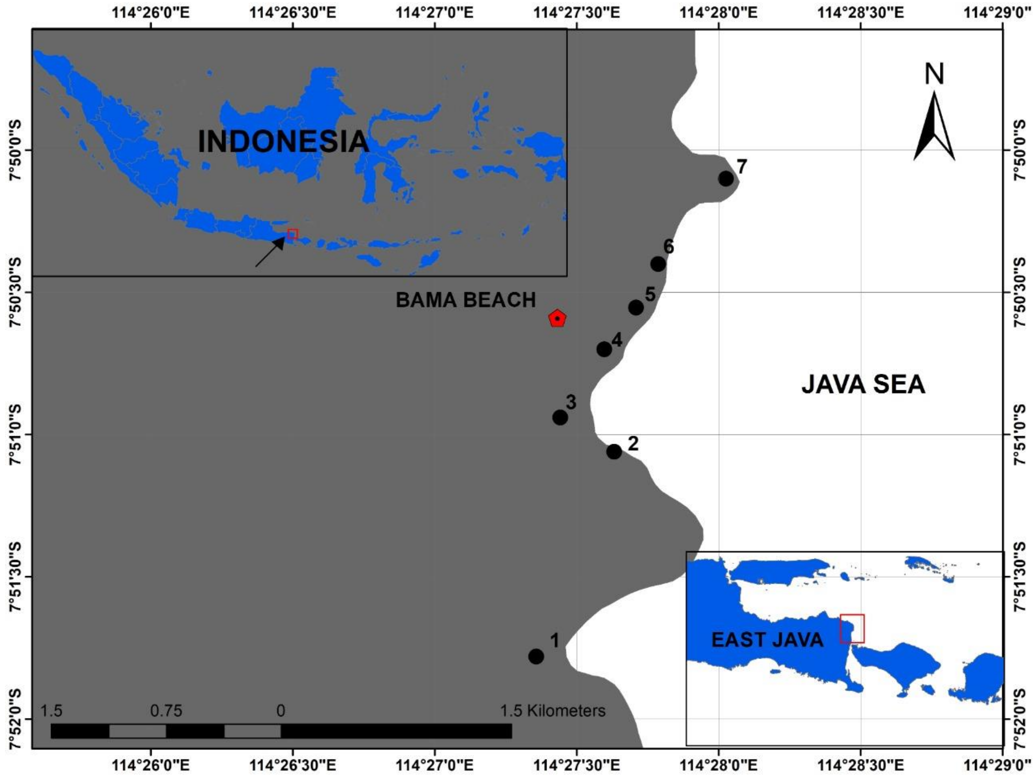

Figure 1. Map of the study area showing the sampling locations along the mangrove forest of Bama Resort, BNP.

BNP is among the first National Parks in Indonesia, declared in 1980 during the World Conservation Strategy Day (van Balen et al 1995; Wianti 2014). In 2016, BNP, along with Kawah Ijen nature reserve, Alas Purwo and Meru Betiri national parks, was declared the Belambangan Biosphere Reserve by UNESCO. It comprises both terrestrial and marine ecosystems, including savannah, seagrass beds, and coastal forests (UNESCO 2016).

During the initial field study, it was revealed that the pattern of tides in the BNP was mixed semidiurnal tide (unpublished data). The salinity and soil pH of the research stations ranged from 20.6‰ to 31‰ and 6.1 to 7.1, respectively. Dissolved oxygen (DO) ranged from 3.1 to 3.6 and temperature from 28.3 to 30.3°C. The geographic coordinates and the environmental parameters of the sampling stations are summarized in Table 1.

Table 1
Geographic coordinates and the environmental parameters of each sampling station

Station	*Latitude*	*Longitude*	*Temperature (°C)*	*pH*	*Salinity (‰)*	*DO (mg L^{-1})*
1.	7º51'46.68'' S	114º27'21.52" E	28.6±0.6	7.1±0.1	20.6±0.6	3.1±0.1
2.	7º51'5.30" S	114°27'38.00" E	30.3±0.6	6.1±0.1	21±1	3.5±0.1
3.	7º50'56.70'' S	114º27'26.60" E	28.3±0.6	7±0.1	28.6±0.6	3.3±0.1
4.	7º50'43.60'' S	114º27'35.90" E	28.3±0.6	6.5±0.1	31.3±1.5	3.2±0.1
5.	7º50'36.26'' S	114º27'44.03" E	29.6±0.6	6.1±0.1	31.3±1.5	3.6±0.1
6.	7º50'22.53'' S	114º27'47.31" E	29.3±0.6	6.5±0.1	30.3±0.6	3.6±0.1
7.	7º50'7.63'' S	114º28'1.60" E	29.6±0.6	6.8±0.1	30.3±0.6	3.3±0.1

Inventory design. Field work was performed over two field seasons, in October 2018 and March 2019. The sampling approach used a nondestructive quadrat technique to determine species composition and structure. At each station, three plots with a size of 10x10 m were established perpendicular to the shore, with a plot distance of between 5 and 20 m depending on the width of the forest. In each plot, all trees with a diameter at breast height (DBH) at least 2.5 cm were identified and counted in order to determine the forest biomass. The DBH of the genera *Rhizophora* and *Bruguiera* were measured 30 cm above the highest prop root and the buttress, respectively. The diameters of other genera were measured 130 cm above the ground (Abino et al 2014). Temperature, salinity, pH, and DO were measured in situ using an AAQ 1183 water quality profiler.

Forest structure analysis and biomass calculation. The Shannon–Wiener diversity index (*H*) was used to determine the species diversity of mangrove communities in the Bama Resort, BNP. The index is a measure of diversity that combines relative abundance and species richness (species number in a given area) which is broadly used to compare diversity in many ecosystems, including mangrove forest (Abino et al 2014; Tang et al 2012). The index was computed using the following formula:

$$\mathrm{H}' = -\sum pi \ln pi,$$

Where: *H'* stands for the diversity index and *pi* is the value of a species as a proportion of all species.

The inventory of mangrove forest of Bama Resort, BNP was also assessed using the importance value index (IVI) which calculated by adding three values: relative density (RD), relative dominance (Rdom), and relative frequency (RF).

Estimation of the biomass of mangrove stands was made using the general and species-specific allometric equations developed by Komiyama et al (2005) and Comley & McGuinness (2005). The species-specific allometric equations for *Avicennia marina* were $0.308xD^{2.11}$ and $1.28xD^{1.17}$ (DBH, cm) for above-ground biomass (AGB) and root biomass (RB), respectively (Comley & McGuinness 2005). For other species, the common allometric equations were 0.251xρ (wood density of each species, g cm^{-3})$xD^{2.46}$ and $0.199x\rho^{0.899}$ for AGB and RB respectively (Komiyama et al 2005). To calculate above-ground C (AGC) and root C (RC), AGB and RB were multiplied by 0.47 and 0.39, respectively (Kauffman & Donato 2012).

Results

Forest structure. The species composition of primary mangrove forest of Bama Resort, BNP is shown in Table 2. A total of 192 trees from eight species and five families of true mangroves was recorded from 21 (10x10 m) plots. *Rhizophora stylosa* was observed in 13 of 21 plots, with 88 total individuals and a mean DBH of 14.7 cm. *R. stylosa* had the highest RF (46.4%), with Rdom of 32.4% and RD of 45.8%, resulting in the highest IVI (124.6%). *Ceriops tagal* was observed in 3 plots, 60 individuals with an average DBH of 15.4 cm. *C. tagal* had the second highest IVI (66%) with RF, Rdom, and RD of 10.7%, 24%, and 31.3%, respectively. There was only one individual each of *Lumnitzera racemosa* and *Aegiceras corniculatum*, and two individuals of *A. marina* observed in the whole research area. Those species contributed to the diversity of mangroves in Bama Resort, BNP, with a total Shannon–Weiner diversity index (*H'*) of 1.31.

Table 2

IVI and Shannon–Weiner diversity index of mangroves belonging to five families in the primary mangrove forest of Bama Resort

Family	*Species*	*Mean DBH*	*No. of individuals*	*RF (%)*	*Rdom (%)*	*RD (%)*	*IVI (%)*	*H'*
Acanthaceae	*A. marina*	14.3	2	3.6	0.7	1.0	5.3	0.05
Combretaceae	*L. racemosa*	7.6	1	3.6	0.1	0.5	4.2	0.03
Lythraceae	*S. alba*	56.7	6	14.3	32.6	3.1	50.0	0.11
Rhizophoraceae	*R. apiculata*	13.4	28	14.3	8.6	14.6	37.4	0.27
	R. mucronata	11.5	6	3.6	1.4	3.1	8.0	0.11
	R. stylosa	14.7	88	46.4	32.4	45.8	124.6	0.35
	C. tagal	15.4	60	10.7	24.0	31.3	66.0	0.36
Primulaceae	*A. corniculatum*	13.1	1	3.6	0.3	0.5	4.4	0.03
Total		15.9	192	100	100	100	300	1.31

Mangrove biomass and C stock estimation. AGB, RB and the total biomass (TB) of each station were significantly different (p<0.05), with an average TB of 533.1±566.7 MgB ha^{-1}. Stations 3 and 5 had the highest and lowest TB, with respective values of 1743±787.5 MgB ha^{-1} and 77.1±55.4 MgB ha^{-1}. The average of total C (TC) was 239.8±256.9 MgC ha^{-1}, with highest and lowest TC values of 789.6±357.6 MgC ha^{-1} and 34.5±24.9 MgC ha^{-1} at stations 3 and 5, respectively (Table3).

Table 3

Species relative frequency, tree biomass, biomass and C stocks of mangroves at each station (mean±standard error)

Station	*Species relative frequency*	*AGB* *(MgB ha^{-1})*	*RB* *(MgB ha^{-1})*	*TB* *(MgB ha^{-1})*	*AGC* *(MgC ha^{-1})*	*RC* *(MgC ha^{-1})*	*TC* *(MgC ha^{-1})*
1	Rs (100%)	295.7±97.6	123.4±45.4	419.1±141.3	139±45.8	48.1±17.7	187.1±62.9
2	Rs (100%)	122.4±64.6	66.1±16	188.5±69.2	57.5±30	25.8±6.2	83.3±32.1
3	Sa (75%), Lr (25%)	1372.9±630.9	370.1±156.6	1743±787.5	645.3±296.5	144.3±61.1	789.6±357.6
4	Rs (47%), Ra (53%)	274.2±168.8	110±49.9	384.1±218.6	128.8±79.3	42.8±19.4	171.7±98.7
5	Rs (100%)	56±40.9	21.5±6.3	77.1±55.4	26.1±19.2	8.4±5.6	34.5±24.9
6	Ct (81%), Ra (11%), Rm (8%)	469.9±197.1	202.9±70.3	672.8±265.8	220.8±92.6	79.1±27.4	299.9±119.4
7	Rs (53%), Ra (29%), Sa (9%), Am (6%), Ac (3%)	205.3±169.5	42.1±19.2	247.4±165	96.4±79.1	16.4±7.5	112.9±77.8
	Mean	399.7±447.2	133.7±120.3	533.1±566.7	187.7±211.2	52.1±46.9	239.8±256.9

TB: total biomass, AGB: above-ground biomass, RB: root biomass, Total AGC: above-ground C, RC: root C, TC: total C. Ac: *A. corniculatum*; Am: *A. marina;* Ct: *C. tagal*; Lr: *L. racemosa*; Rs: *R. apiculata*; Rs: *R. mucronata*; Rs: *R. stylosa*; Sa: *S. alba.*

Discussion

Forest structure. Mangrove forests are highly threatened and depleted in many parts of the world. The lack of a good knowledge of mangrove community structure is hampering conservation efforts (Quadros & Zimmer 2017). Currently, there are 55 species of mangroves considered "true" mangroves, of which Indonesia has by far the highest diversity (Quadros & Zimmer 2017; Aslan et al 2016). True mangroves are woody halophytes that are adapted to saline, waterlogged and anaerobic environments; their habitat does not extend into terrestrial plant communities (Asadi et al 2018; Polidoro et al 2010).

Mangrove forests of Bama Resort and other parts of BNP are among the few primary mangrove forests remaining in Java Island. Most mangroves in the area have been degraded or converted for coastal development and aquaculture (Asadi et al 2017; van Oudenhoven et al 2015). Those threats inevitably affect the biodiversity of mangrove species on the island. Therefore, monitoring and studying the biodiversity of the remaining primary mangrove forests on Java Island is necessary to support conservation efforts, rehabilitation and restoration projects (Quadros & Zimmer 2017). Though the primary mangrove forests of Java Island are facing anthropogenic threats and a lack of good management, there is still a lack of research on mangrove biodiversity and community structure in those forests (Asadi et al 2018).

In this study, *R. stylosa* and *C. tagal* were found to be the dominant species, with their respective IVIs of 124.6% and 66.4% (Table 2). The IVI indicates the ecological importance of a species in a community, and was developed to calculate the ecological success of a species with a single value (Mishra 1968). In most mangrove forests, members of *Ceriops* and *Rhizophora* are among the major components, and therefore commonly have high IVI values. On the other hand, *A. corniculatum* had an IVI of only 4.4%. This species commonly has a low IVI, being a minor component of mangrove forests (Quadros & Zimmer 2017).

Fourteen mangrove species have been recorded in the Segara Anakan lagoon of Central Java, home to the biggest mangrove forest in Java Island (Widyastuti et al 2018). In the primary mangrove forest of Labuhan, Lamongan, East Java, nine mangrove species were recorded in only 90 hectare of mangrove forest (Asadi et al 2018). In this study, the mangrove forest of Bama Resort, BNP, was found to be home to eight mangrove species, with a higher Shannon—Wiener diversity index the primary mangrove forest of Palawan, the Philippines (*H'*=0.1.31 and *H'*=0.99, respectively) as there were only 5 mangrove species in the latter forest (Abino et al 2014). Meanwhile, the mangrove forest of Labuhan, Lamongan, had higher diversity index (*H'*=1.51), with a species diversity greater than the Bama Resort (Asadi et al 2018).

In contrast to their terrestrial counterparts, mangrove forests typically have very low species diversity, as only true mangroves have the unique adaptations required to survive in the harsh intertidal environment (Quadros & Zimmer 2017). In this study, three species of mangroves (*A. marina*, *L. racemosa* and *A. corniculatum*) were represented by fewer than three individuals, and therefore methods to insure the long-term persistence of the mangrove biodiversity should be considered as part of efforts to conserve the mangrove forest of Bama Resort, BNP.

Biomass and C-stocks of mangroves. Among the mangrove stands, 75% of the total biomass was credited to the above-ground (399.7±447.2 MgB ha^{-1}) while 25% was attributed to the roots (133.7±120.3 MgB ha^{-1}). In terrestrial forests, roots commonly account for just 10% of the total tree's biomass. However, in the intertidal areas, the soft muddy soils and the waterlogged environments mean that the mangrove trees need large underground or aerial root systems to support them (Sinacore et al 2017).

In comparison with mangrove stands of Palawan, in the Philippines, mangroves of Bama Resort had lower total biomass. This results from the fact the dominant species of Bama Resort, *R. stylosa*, only had an average DBH of 14.7 cm, while the dominant species of Palawan, *R. apiculata* had an average DBH of 39.5 cm (Abino et al 2014). Lower-biomass mangrove stands (114.68 MgB ha^{-1}) have been reported from the mangrove forest of Labuhan, Lamongan, East Java (Asadi et al 2018). The mangroves of both Labuhan and Resort Bama are fringe mangroves, which grow along the coast. Typically, stands of fringe mangroves have a lower biomass than their interior counterparts (Nam et al 2016; Tue 2014).

Station 3 which had only four individual mangrove trees (2% of total trees) accounted for almost 50% of the total biomass among all research stations. Station 3 was dominated by *S. alba*, the average DBH of this species was much higher than that of other species. At this station, individual *S. Alba* was recorded with a mean DBH of 56.7 cm. In contrast, the average DBH of mangrove stands in the entire research area was only 15.9 cm (Table 2).

The mean C-stocks of mangrove stands at the stations in this study ranged from 34.5±24.9 to 789.6±357.6 MgC ha^{-1}, with a mean across all stations of 239.8±256.9 MgC ha^{-1}. The C-stock was much higher than that of Micronesian fringe mangroves, which have been reported to range from 104 MgC ha^{-1} (Palau) to 169 MgC ha^{-1} (Yap) (Kauffman et al 2011). Mangrove forest in Bama Resort, BNP may sequester as much as 880±942.8 $MgCO_2$ ha^{-1} (Figure 2); the high C-stock of the mangrove stands demonstrate that the forest may play an important role in sequestering carbon dioxide from the atmosphere.

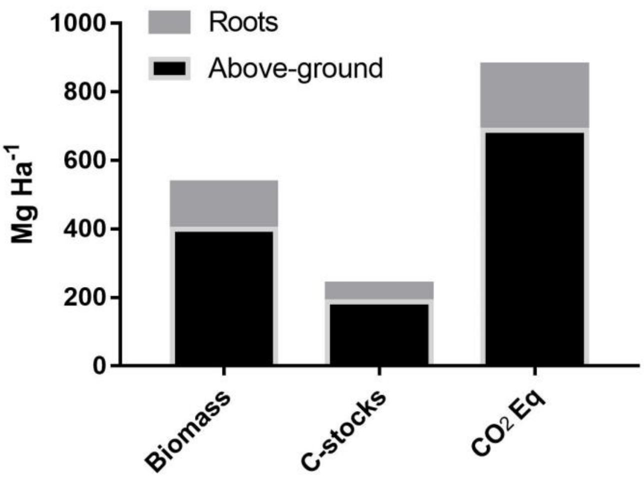

Figure 2. Biomass, C-stocks, and CO_2 sequestration of mangrove stands of Bama Resort, Baluran National Park, Indonesia.

Conclusions. Stands of primary mangrove forest in Bama Resort, BNP had significant differences in terms of biomass and C-stocks at each station. Station 3 showed the highest biomass and C-stocks, as the mangroves grew as a relatively thick fringe along the coast, supporting stands with high DBH. Though the mangrove stands of Bama Resort stored a high amount of C, some species were represented by only a few individuals. Therefore, protection and conservation of mangrove forests is required to maintain and preserve the biodiversity and C pools of this region. Furthermore, as mangrove soils commonly store a high amount of C, more attention should be given to estimation of C-stocks of soils in this forest with the aim of conserving large soil pools as part of the whole mangrove ecosystem.

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