

Estimation of aboveground biomass and carbon stock in Damas Beach, Trenggalek District, East Java, Indonesia

ALYA AFRA INAS NUR¹, KIRANA NURUL ARIFIANI¹, ANANDA RILO RAMADHANDI¹,
AGRA DEWI SABRINA¹, GILANG DWI NUGROHO², LIA KUSUMANINGRUM¹, DEVESEE RAMDHUN³,
TRAN QUANG BAO⁴, CHEE KONG YAP⁵, SUGENG BUDIHARTA⁶, AHMAD DWI SETYAWAN^{1,7}*

¹Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia. Tel./fax.: +62-271-663375, *email: volatileoils@gmail.com

²Biodiversitas Study Club, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia

³Department of Biosciences and Ocean Studies, Faculty of Science, University of Mauritius. Réduit 80837, Republic of Mauritius

⁴Vietnam National University of Forestry. Xuan Mai Town, Ha Noi, Vietnam

⁵Department of Biology, Faculty of Science, Universiti Putra Malaysia. 43400 UPM Serdang, Selangor, Malaysia

⁶Purwodadi Botanic Gardens. Jl. Surabaya-Malang Km. 65, Purwodadi, Pasuruan 67163, East Java, Indonesia

⁷Biodiversity Research Group, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia

Manuscript received: 31 July 2022. Revision accepted: 2 December 2022.

Abstract. Nur AAI, Arifiani KN, Ramadhandi AR, Sabrina AD, Nugroho GD, Kusumaningrum L, Ramdhun D, Bao TQ, Yap CK, Budiharta S, Setyawan AD. 2022. Estimation of aboveground biomass and carbon stock in Damas Beach, Trenggalek District, East Java, Indonesia. *Indo Pac J Ocean Life* 6: 80-86. Vegetation plays a vital role in providing environmental services in the form of storing carbon which can mitigate climate change. This study aimed to calculate Aboveground Biomass (AGB) and carbon stock in Damas Beach, Trenggalek District, East Java Province, Indonesia using an allometric equation. Biomass and carbon data at a tree (dbh >20 cm) and pole (dbh 10-20 cm) levels were collected using sampling plots distributed randomly at three stations, namely mangrove vegetation (Station I), coconut plantation (Station II), and agroforestry (Station III). The results showed that across the three research stations, there were a total of 23 plant species classified as tree and pole levels. At tree level, *Rhizophora stylosa* Griffith had the highest carbon stock with a value of 85.48 MgC/ha, while the lowest value was *Nypa fruticans* Wurm with 0.02 MgC/ha. Similarly, at the pole level, the species with the highest carbon stock was *R. stylosa*, with a value of 65.88 MgC/ha, and the lowest was *Theobroma cacao* L. with 0.11 MgC/ha. The mangrove vegetation (Station I) had the highest carbon stock value of 200.53 MgC/ha. In contrast, the coconut plantation vegetation (Station II) has the lowest total carbon stock, with a value of 84.68 MgC/ha. Conservation and management need to be improved in the Damas Beach area because if the area is disturbed, the ability of vegetation to absorb carbon will decrease.

Keywords: Allometric equation, environmental service, pole and tree, vegetation

INTRODUCTION

The increasing temperature of the earth leads to changing climate which causes changes in rainfall patterns, extreme weather, rising sea surfaces, and big waves. Among various causes of climate change, the accumulation of greenhouse gases in the atmosphere due to anthropogenic activities is considered the most important contributor, particularly since the industrial era began. Among greenhouse gases, carbon dioxide (CO₂) has the biggest influence on global warming (Pratama 2019). The increase of CO₂ concentration in the atmosphere is predicted to occur in the future in line with the increase of the human population and global industry (Shafiya et al. 2021). Large-scale burning of fossil fuels (e.g., oil, coal and natural gas) and carbon losses from Land Use, Land-Use Change and Forestry (LULUCF) are anthropogenic activities with the largest contribution to CO₂ emissions (Suwardi and Syamsuardi 2013).

Climate change has various negative impacts on human life since human activities highly depend on natural conditions (Nurhayati et al. 2020). Therefore, adaptation

and mitigation strategies are required to tackle the problems caused by the changing climate. In doing so, humans can be assisted by the natural environment itself, which is commonly referred to as environmental services. Environmental services are the benefits that society derived from the dynamic interrelationships among biotic (e.g., plants, animals and micro-organisms) and abiotic elements (e.g. soil, water and gases) of the environment. Environmental services can be in the form of direct/tangible benefits (e.g., timber, food, water) and indirect/intangible benefits (e.g., soil fertility, flood and erosion control, hydrological system, biodiversity, natural beauty, and carbon sequestration and storage) (Roslinda and Kartikawati 2019).

Environmental services in the form of carbon storage can mitigate the greenhouse effect (Rahardjanto et al. 2022). One of the carbon pools is in vegetation stored as biomass. Vegetation can play an important role in reducing greenhouse gases concentration by absorbing and accumulating CO₂ in the leaves, branches, stems, and roots as biomass, in the litter and soil organic matter (McPherson and Simpson 1999; Hikmatyar et al. 2015). Vegetation with high species diversity might have high carbon storage

capacity (Idris et al. 2013). Besides being increasingly studied in climate change research, plant biomass has been historically studied in plant physiology since it is an important indicator of growth and vegetation dynamics (Yan et al. 2013).

Vegetation can occur in various ecosystems, one of which is found in the coastal area. Coastal areas provide various human benefits, including serving as a carbon sink (Canu et al. 2015). Coastal areas have several ecosystem types with the mangrove ecosystem considered the most important ecological function. Regarding climate change mitigation, the existence of mangrove forests in coastal areas is very essential in reducing CO₂ gas in the atmosphere (Taillardat et al. 2018). Mangroves are one of the blue carbon elements because they play a role in utilizing CO₂ for photosynthesis and storing it in biomass and soil sediments (Suryono et al. 2018).

Damas Beach, located in Karanggandu Village, Watulimo Sub-district, Trenggalek District, East Java, Indonesia, is a coastal ecosystem with the potential for high carbon sequestration despite its importance for the local community as a source of livelihood from fisheries. Yet, no information is available regarding the amount of carbon stored in the vegetation that occurred on the beach. Therefore, this study aimed to estimate Aboveground Biomass (AGB) and carbon stock in Damas Beach. In doing so, a non-destructive method was used by employing allometric equations to avoid damage to the vegetation (Huff et al. 2017; Ibrahim and Muhsoni 2020). We expected the results of this study might enrich the existing literature on climate-related ecological studies to improve

the understanding of carbon sequestration from vegetation (Jara et al. 2015; Bhaskara et al. 2018), especially in the context of the coastal ecosystem.

MATERIALS AND METHODS

Study area

The study was conducted at Damas Beach, Karanggandu Village, Trenggalek District, East Java, Indonesia (Figure 1). Damas Beach is geographically located at 8°19'47"S and 111°41'39"E on June 2022. This beach is located 53 km from the center of the Trenggalek District. Damas Beach has a land area of 5.5 hectares with a coastal line of 2 km, and is 5 km southwest of Prigi Beach, a well-known tourist spot in Trenggalek and is located on the coast of Prigi Bay.

Data collection

The data collection was conducted in June 2022. Carbon storage in Damas Beach was estimated by calculating the weight of Aboveground Biomass (AGB). The AGB was calculated using an indirect non-destructive method, namely by allometric equations, to avoid damage to the Damas Beach ecosystem (Louhaichi et al. 2018). The sampling technique used was simple random sampling at three research stations. Station I consisted of mangrove vegetation, Station II was a coconut plantation and Station III was agroforest (i.e., land use management that combined timber trees with short-term agricultural crops).

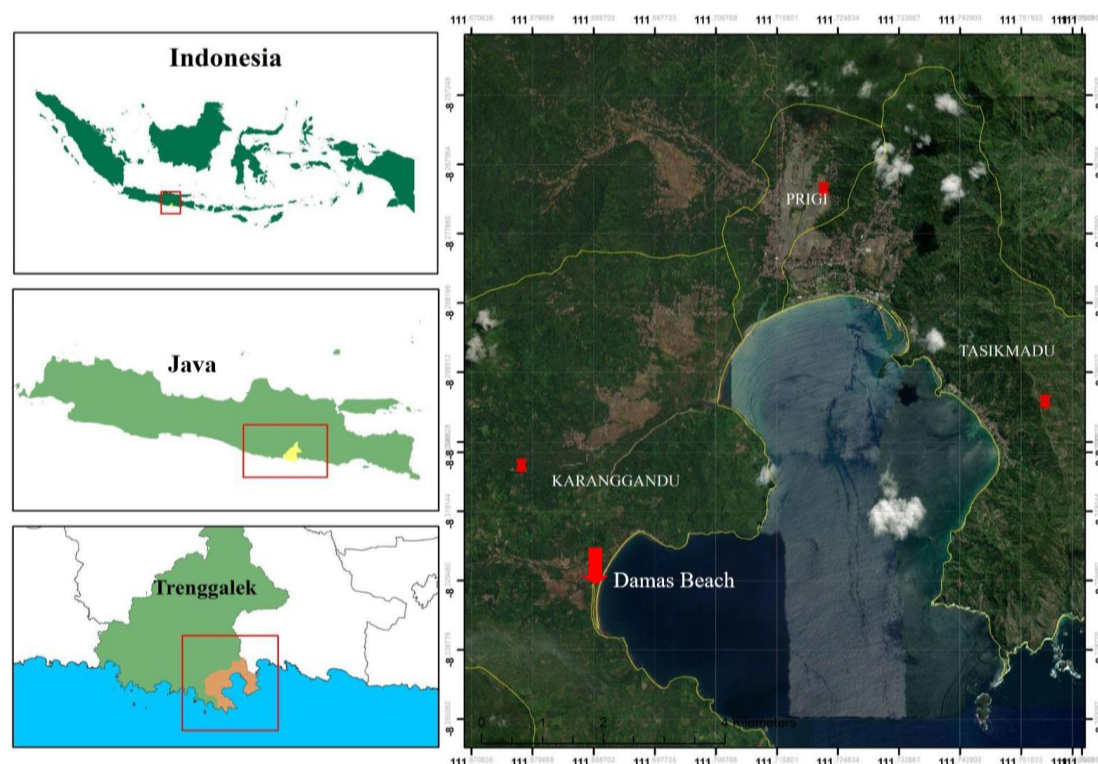


Figure 1. The map of the research location in Damas Beach, Karanggandu Village, Watulimo Sub-district, Trenggalek District, East Java, Indonesia

The estimation of aboveground biomass was focused on two vegetation levels, i.e., trees for vegetation with a diameter at breast height (dbh) >20 cm, and pole for dbh 10-20 cm. Biomass and carbon data were collected using sampling plots, established using simple random sampling to represent the species composition of each station. Sampling plots were divided into plots measuring 20x20 m² each to collect data for tree stands and 10x10 m² for pole stands. In total, 131 sampling plots were created. Local names of plants, dbh, and plant heights were recorded on a tally sheet, while secondary data included Latin names, allometric equations, and the specific gravity of wood.

Data analysis

Estimates of vegetation carbon storage at Damas Beach were inferred from the calculation of AGB biomass using specific allometric formulas for each plant species (Table 1). Then the total biomass per species was summed to obtain the total biomass of each species. Next, biomass was multiplied by 0.5 as a proportion of the carbon content of the plant species (Arsalan et al. 2020). Following the standardization of the National Standardization Agency (2011), the carbon content in the plots (poles and trees) was converted to carbon per hectare using the following equation:

$$C_n = \frac{C_x}{1.000} \times \frac{10.000}{l_{sub-plot}}$$

Where: C_n is carbon per hectare in each sub-plot in units of MgC/ha; C_x is carbon per sub-plot in units of kg; the $l_{sub-plot}$ is the total area of the sub-plot in m². Allometric calculations were calculated based on the wood density of each species, dbh and height (Purwiyanto and Agustriani 2017).

RESULTS AND DISCUSSION

In total, there were 23 species of 17 families across the three research stations (Tables 2 and 3). The most dominant species in Station I or mangrove vegetation was *Rhizophora stylosa* Griffith. The dominance of *R. stylosa* in mangrove vegetation was also found in several areas in Indonesia, including Weh Island, Aceh (Dewiyanti 2010), Kemujan Island, Karimunjawa (Wirasatriya et al. 2022), and Pacitan, East Java (Irwansyah et al. 2021; Sholiqin et al. 2021; Wiraatmaja et al. 2022). This is understandable since *R. stylosa* can grow at habitats with low to high salinity. This species can optimize nutrients and sunlight in the growth process, making it highly adaptable to various environmental conditions (Heriyanto and Subiandono 2012). At Station II, or coconut plantation, the most dominating species was *Cocos nucifera* L. While at Station III with agroforestry vegetation, the most dominating species was *Durio zibethinus* Murray. The *C. nucifera* and *D. zibethinus* were the dominant species in Stations II and III because they were the main plantation commodities for communities in Damas Beach. The existence of species dominance in an area shows that the physical and environmental conditions favor the species.

The biomass gain of vegetation is affected by the density of vegetation, the diversity of its diameter and the distribution of its specific gravity; where land use consisting of trees with species that have a high wood density value and large diameter, the biomass will be higher when compared to land that has species with low wood density values such as poles (Hairiah and Rahayu 2007). Poles are young trees with a diameter of 10 to less than 20 cm which have a high rate of photosynthesis so they have the potential to absorb carbon. Poles can contribute to carbon stock storage, although smaller than tree vegetation (Hopkins and Huner 2009). The effect of main contribution of biomass lies in the stem so that the carbon stored in the pole is smaller than the carbon stored in trees with a larger diameter than the pole.

Table 1. Species-specific allometric equations to calculate aboveground biomass in Damas Beach, Trenggalek, Indonesia

Species	Equation	References
<i>Acacia auriculiformis</i> A.Cunn. ex Benth.	$0,0775 \times (D^{2,14})^{0,9018}$	(Mugiono 2009)
<i>Aegiceras corniculatum</i> (L.) Blanco	$0,251 \times 0,6784 \times D^{2,46}$	(Komiya et al. 2005)
<i>Albizia chinensis</i> (Osbeck) Merr.	$0,0272 \times D^{2,831}$	(Sugiharto 2002)
Branched tree	$0,11 \times \rho \times D^{2,62}$	(Ketterings et al. 2001)
<i>Casuarina equisetifolia</i> L.	$-1,17 + 2,119 \times (\ln \ln D)$	(Brown 1997)
<i>Cocos nucifera</i> L.	$(3,14 \times \rho \times h \times D^2)$ Δn	(Hairiah et al. 2001)
<i>Nypa fruticans</i> Wurmb	$\log B = 0,85 \log D^2 \times L + 1,54$	(Matsui et al. 2014)
<i>Rhizophora stylosa</i> Griffith	$0,9789 \times D^{2,6948}$	(Clough and Scott 1989)
<i>Sonneratia alba</i> Sm.	$0,251 \times 0,475 \times D^{2,46}$	(Komiya et al. 2005)
<i>Swietenia mahagoni</i> (L.) Jacq.	$0,048 \times D^{2,3}$	(Adinugroho and Sidiyasa 2001)
<i>Tectona grandis</i> L.f.	$0,290091 \times D^{2,3}$	(Hendri 2001)
<i>Terminalia catappa</i> L.	$\rho \times (-1499) + 2,148 \times \ln D + 0,207 \times \ln D^2 - 0,0281 \times \ln D^3$	(Chave et al. 2005)
<i>Theobroma cacao</i> L.	$0,012088 \times D^{1,98}$	(Yuliasmara et al. 2009)

Note: D is the diameter at breast height (dbh); L is the length of the frond; ρ is the wood density (World Agroforestry 2022)

At the pole stands, 19 species were found from 15 different families (Table 2). Most species were found at Station III with a total of 12 species. The largest AGB and carbon stock per hectare in pole level with dbh of 10-20 cm at the study site was dominated by *R. stylosa* with an AGB of 131 MgB/ha, equating to carbon stock of 65.88 MgC/ha (Table 2). Besides the high dominance of *R. stylosa*, the relatively high carbon stock contributed by this species was because mangrove plants can store more biomass than other plants (Dinilhuda et al. 2018). The high biomass was also contributed by *Aegiceras corniculatum* (L.) Blanco with an AGB of 54.65 MgB/ha or 27.33 MgC/ha.

Meanwhile, at Station II which is a coconut plantation, 4 species were found at the pole level with the largest AGB value coming from the species *Pandanus utilis* Bory with a value of 4.02 MgB/ha or equivalent to carbon stock of 2.01 MgC/ha. Followed by *C. nucifera* with an AGB value of 2.86 MgB/ha (equal to 1.43 MgC/ha). At Station III, which is an agroforestry, the species *Artocarpus heterophyllus* Lam. is the species with the largest AGB, namely 20.03 MgB/ha or equivalent to 10.01 MgC/ha (Table 2).

For the tree level (vegetation with dbh of more than 20 cm), 20 species were found (Table 3). Most species were found in Station III or agroforestry, comprising 13 species. The highest AGB and carbon stock per hectare in tree level was also contributed by *R. stylosa* from Station I with AGB of 170.96 MgB/ha, or equivalent to carbon stock of 85.48 MgC/ha (Table 3). Similarly in South Sulawesi, based on research by Analuddin et al. (2020), the carbon stock of the *R. stylosa* forest in South Sulawesi, Indonesia, is much higher than other mangrove vegetations in several regions of the world, with a value of 264.50 MgC/ha.

Station III had the largest total AGB at tree level with a value of 233.73 MgB/ha or equivalent to 116 MgC/ha. The largest value at Station III came from the species *Tectona grandis* L.f. with an AGB of 64.31 MgB/ha (equal to 32.15 MgC/ha). This value is much smaller than *R.*

stylosa at Station I. However, the amount of AGB and carbon stock produced at the tree level at Station I was lower than in Station III (Table 4). This happened because there were few mangroves at the tree level found in the research site and a large number of trees at Station III.

The average of AGB from 3 stations at Damas Beach, Trenggalek was 302.27 MgB/ha or equivalent to 151.13 MgC/ha (Table 4). The average from 3 stations at tree stands was 199.90 MgB/ha (equal to 99.95 MgC/ha), meanwhile, the average at pole stands was 102.36 MgB/ha (equal to 51.18 MgC/ha). As for each station, Station I had the highest carbon sequestration with a value of 200.53 MgC/ha, followed by Station III with a value of 168.18 MgC/ha and Station II was the lowest with a carbon storage value of 84.68 MgC/ha (Table 4).

Discussion

The average AGB in Damas Beach was 302.27 MgB/ha, or equivalent to a carbon sequestration of 151.13 MgC/ha (Table 4). In general, the value of biomass and carbon stock of each species is different and is influenced by the sequestration ability, which can be inferred from dbh tree, density value tree, and height tree using allometric equation (Ariani et al. 2016). Plants absorb CO₂ from the air through photosynthesis and then convert it into organic matter (Handoyo et al. 2020).

The value of carbon stocks in other parts of Indonesia also varies. According to Kusumaningtyas et al. (2019) and Pricillia et al. (2021), the average carbon stock was 68.1 MgC/ha in Nusa Lembongan, Bali and 15.8 MgC/ha in Segara Anakan Lagoon, Central Java. Meanwhile, in other Asian regions, such as China, the average value is around 355.25 ± 82.19 MgC/ha (Liu et al. 2014). Then, Rozainah et al. (2018) reported that the mean aboveground carbon in Peninsular Malaysia was 156.35 MgC/ha in Delta Kelantan and 70.17 MgC/ha in Johor Park, Malaysia.

Table 2. Aboveground biomass and carbon stock of vegetation at pole layer with diameter at breast height of 10-20 cm

Station	Family	Local name	Scientific name	AGB (MgB/ha)	Carbon stock (MgC/ha)
Station I (Mangrove)	Primulaceae	Gedangan	<i>Aegiceras corniculatum</i> (L.) Blanco	54.65	27.33
	Lythraceae	Perepat	<i>Sonneratia alba</i> Sm.	10.20	5.10
	Rhizophoraceae	Bakau	<i>Rhizophora stylosa</i> Griffith	131.76	65.88
Station II (Coconut tree)	Arecaceae	Kelapa	<i>Cocos nucifera</i> L.	2.86	1.43
	Casuarinaceae	Cemara Laut	<i>Casuarina equisetifolia</i> L.	0.64	0.32
	Combretaceae	Ketapang	<i>Terminalia catappa</i> L.	0.33	0.16
	Pandanaceae	Pandan laut	<i>Pandanus utilis</i> Bory	4.02	2.01
Station III (Agroforestry)	Anacardiaceae	Mangga	<i>Mangifera indica</i> L.	9.08	4.54
	Euphorbiaceae	Macaranga	<i>Macaranga</i> sp.	8.14	4.07
	Fabaceae	Petai Cina	<i>Leucaena leucocephala</i> (Lam.) de Wit	7.89	3.95
	Fabaceae	Sengon	<i>Albizia chinensis</i> (Osbeck) Merr.	6.01	3.01
	Fabaceae	Akasia	<i>Acacia auriculiformis</i> A.Cunn. ex Benth.	11.45	5.73
	Fabaceae	Jengkol	<i>Pithecellobium jiringa</i> (Jack) Prain	11.73	5.86
	Lamiaceae	Jati	<i>Tectona grandis</i> L.f.	6.95	3.48
	Malvaceae	Kakao	<i>Theobroma cacao</i> L.	0.22	0.11
	Malvaceae	Durian	<i>Durio zibethinus</i> Murray	9.93	4.96
	Moraceae	Nangka	<i>Artocarpus heterophyllus</i> Lam.	20.03	10.01
	Myrtaceae	Cengkeh	<i>Syzygium aromaticum</i> (L.) Merr. & Perry	5.20	2.60
	Sapindaceae	Rambutan	<i>Nephelium lappaceum</i> L.	7.08	3.54

Note: AGB: Aboveground biomass

Table 3. Aboveground biomass and carbon stock of vegetation at tree layer with diameter at breast height of 20 cm

Station	Family	Local name	Scientific name	AGB (MgB/ha)	Carbon stock (MgC/ha)
Station I (Mangrove)	Arecaceae	Nipah	<i>Nypa fruticans</i> Wurm	0.05	0.02
	Lythraceae	Perepat	<i>Sonneratia alba</i> Sm.	8.14	4.07
	Primulaceae	Gedangan	<i>Aegiceras corniculatum</i> (L.) Blanco	25.30	12.65
	Rhizophoraceae	Bakau	<i>Rhizophora stylosa</i> Griffith	170.96	85.48
Station II (Coconut tree)	Arecaceae	Kelapa	<i>Cocos nucifera</i> L.	160.81	80.41
	Casuarinaceae	Cemara Laut	<i>Casuarina equisetifolia</i> L.	0.46	0.23
	Combretaceae	Ketapang	<i>Terminalia catappa</i> L.	0.26	0.13
Station III (Agroforestry)	Achariaceae	Keluak	<i>Pangium edule</i> Reinw.	24.92	12.46
	Anacardiaceae	Mangga	<i>Mangifera indica</i> L.	9.31	4.65
	Fabaceae	Petai Cina	<i>Leucaena leucocephala</i> (Lam.) de Wit	5.34	2.67
	Fabaceae	Sengon	<i>Albizia chinensis</i> (Osbeck) Merr.	11.56	5.78
	Fabaceae	Akasia	<i>Acacia auriculiformis</i> A.Cunn. ex Benth.	9.26	4.63
	Fabaceae	Jengkol	<i>Pithecellobium jiringa</i> (Jack) Prain	9.67	4.83
	Fabaceae	Petai	<i>Parkia speciosa</i> Hassk.	5.40	2.70
	Lamiaceae	Jati	<i>Tectona grandis</i> L.f.	64.31	32.15
	Malvaceae	Kakao	<i>Theobroma cacao</i> L.	0.15	0.07
	Malvaceae	Durian	<i>Durio zibethinus</i> Murray	39.50	19.75
	Meliaceae	Mahoni	<i>Swietenia mahagoni</i> (L.) Jacq.	18.20	9.10
	Moraceae	Nangka	<i>Artocarpus heterophyllus</i> Lam.	29.97	14.98
	Sapindaceae	Rambutan	<i>Nephelium lappaceum</i> L.	6.17	3.09

Note: AGB: Aboveground biomass

Table 4. Total aboveground biomass and plant carbon stock at each station

Station	Biomass and carbon stock				Total	
	Tree		Pole		AGB (MgB/ha)	Carbon stock (MgC/ha)
	AGB (MgB/ha)	Carbon stock (MgC/ha)	AGB (MgB/ha)	Carbon stock (MgC/ha)		
Station I (Mangrove)	204.45	102.22	196.62	98.31	401.06	200.53
Station II (Coconut tree)	161.53	80.76	7.84	3.92	169.37	84.68
Station III (Agroforestry)	233.73	116.87	102.63	51.32	336.37	168.18
Average	199.90	99.95	102.36	51.18	302.27	151.13

Note: AGB: Aboveground biomass

In this study, tree stands with a dbh of more than 20 cm had an average AGB of 199.90 MgB/ha or could absorb carbon of 99.95 MgC/ha, while pole stands with a value of 102.36 MgB/ha or were able to absorb carbon of 51.18 MgC/ha (Table 4). The dimension (i.e., diameter, height) of plants will affect the total biomass and carbon stored. The carbon stored at the tree level was greater than that at the poles, which is in agreement with the studies by Purwiyanto and Agustriani (2017) and Purwanto et al. (2021).

Mangrove vegetation at Station I had the highest AGB value and carbon stock per hectare compared to other stations, which stored 401.06 MgB/ha or equal to 200.53 MgC/ha (Table 4). Among the carbon sequestered in the world, about 55% is captured by organisms living in the ocean (blue carbon) (Lovelock and Duarte 2019). Blue carbon is a term for carbon pools in coastal and marine ecosystems. Coastal ecosystems can absorb more carbon than terrestrial ecosystems. The ecosystems considered blue carbon pools include mangroves, tidal swamps, seagrasses, etc. The sediments in the coastal ecosystem

where mangroves grow store a large amount of nutrients. This is because, the litter from mangroves including dead trees, leaves, propagules, and twigs as well as roots, becomes a source of organic carbon in the sediments of mangroves (Alongi 1998). This causes mangroves as very productive ecosystems and has high potential as a global carbon sink (Dittmar and Lara 2001; Alongi 2007).

At Station II, coconut plantations consisted of 4 species, namely *C. nucifera* and the rest were *Casuarina equisetifolia* L., *Terminalia catappa* L. and *P. utilis*. The total AGB at Station II was 169.37 MgB/ha or stored carbon as much as 84.68 MgC/ha (Table 4). Coconut (*C. nucifera*) was the dominant species at this station, with a total AGB of trees and poles of 163.67 MgB/ha and a carbon stock of 81.84 MgC/ha. The AGB value and carbon stock in the coconut plantation were smaller than those in the other stations (Table 4). This result is in line with the research by Ikhwan (2021) in Lubuk Kertang, North Sumatra, Indonesia, in which coconut stands had only 19 MgC/ha while other vegetation reached 158 MgC/ha. The low carbon stock in coconut plantations was also found in

Honda Bay, the Philippines, by Castillo et al. (2018) with 11.9-12 MgC/ha.

At Station III, a forest area with an agroforestry system, the plant species found were *D. zibethinus*, *Syzygium aromaticum* (L.) Merr. & Perry, *T. grandis*, *Theobroma cacao* L., *Albizia chinensis* (Osbeck) Merr. and others (Tables 2 and 3). Station III had a total AGB of 336.36 MgB/ha, equivalent to carbon sequestration of 168.18 MgC/ha (Table 4). The result of this study is within the range of carbon stock in agroforestry systems in Southeast Asia have the potential to store carbon from 12 MgC/ha to 228 MgC/ha (Murthy et al. 2013). The result of this study is greater when compared to carbon stock in the agroforestry system in Kurushetra, North India with 131.65 Mg/ha (Kumar 2017) and in Central Sulawesi, Indonesia, with a value of 42.42 MgC/ha (Wardah et al. 2011).

In conclusion, the coastal ecosystem in Damas Beach has the ability to provide environmental services in the form of storing carbon. The species at tree layer with the highest carbon stock was *R. stylosa* with a value of 85.48 MgC/ha, while the lowest was *Nypa fruticans* Wurm with 0.02 MgC/ha. Similarly, the species at the pole level with the highest carbon stock was *R. stylosa* with a value of 65.88 MgC/ha and the lowest value was *T. cacao* with 0.11 MgC/ha. The area with the highest biomass was Station I or mangrove vegetation with a carbon stock value of 200.53 MgC/ha, while the station with the lowest total carbon stock was Station II, or coconut plantation, with a value of 84.68 MgC/ha. Conservation and management need to be improved in the Damas Beach area because if there is a disturbance in the area, either due to anthropogenic factors or natural factors such as natural disasters, the number of stored carbon stocks will decrease or even disappear, causing carbon emissions not to be absorbed.

REFERENCES

- Adinugroho W.C, Sidiyasa K. 2001. Model pendugaan biomassa pohon mahoni (*Swietenia macrophylla* King) diatas permukaan tanah. Jurnal Penelitian Hutan dan Konservasi Alam 3 (1): 103-117. DOI: 10.20886/jphka.2006.3.1.103-117. [Indonesian]
- Alongi DM. 1998. Coastal Ecosystem Processes. CRC Press Boca Raton, New York.
- Alongi DM. 2007. Mangrove forest: Resilience, protection from tsunamis, and responses to global climate change. Estuar Coast Shelf Sci 76: 1-13. DOI: 10.1016/j.ecss.2007.08.024.
- Analuddin K, La Ode K, La Ode MYH, Andi S, Idin S, La S, Saban R, La Ode AF, Kazuo N. 2020. Aboveground biomass, productivity and carbon sequestration in *Rhizophora stylosa* mangrove forest of Southeast Sulawesi, Indonesia. Biodiversitas 21 (4): 1316-1325. DOI: 10.13057/biodiv/d210407.
- Ariani E, Ruslan M, Kurnain A, Kissinger. 2016. Analisis potensi simpanan karbon hutan mangrove di area PT. Indocement Tunggal Prakarsa. EnviroSciencetea 12 (3): 312-329. DOI:10.20527/es.v12i3.2456. [Indonesian]
- Arsalan A, Gravitiani E, Irianto H. 2020. Biomassa di atas tanah dan penghitungan simpanan karbon Hutan Kalibiru Kabupaten Kulon Progo. Bioeksperimen 6 (1): 1-8. DOI: 10.23917/bioeksperimen.v6i1.10426. [Indonesian]
- Bhaskara DR, Qurniati R, Duryat D, dan Banuwa IS. 2018. Carbon stock in Repong Damar Agroforest at Pahungan Village, Pesisir Tengah Sub-District, Pesisir Barat Regency. J Sylva Lestari 6 (2): 32-40. DOI: 10.23960/jsl2632-40. [Indonesian]
- Brown S. 1997. Estimating Biomass and Biomass Change of Tropical Forests: Primer. In Fao Forestry Paper; Fao, Rome, Italy.
- Canu DM, Ghermandi A, Nunes PA, Lazzari P, Cossarini G, Solidoro C. 2015. Estimating the value of carbon sequestration ecosystem services in the Mediterranean Sea: An ecological economics approach. Glob Environ Change 32: 87-95. DOI: 10.1016/j.gloenvcha.2015.02.008.
- Castillo JAA, Apan AA, Maraseni TN, Salmó III SG. 2018. Tree biomass quantity, carbon stock and canopy correlates in mangrove forest and land uses that replaced mangroves in Honda Bay, Philippines. Reg Stud Mar Sci 24: 174-183. DOI: 10.1016/j.rsma.2018.08.006.
- Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, Fölster H, Fromard F, Higuchi N, Kira T, Lescure JP, Nelson BW, Ogawa H, Puig H, Riera B, Yamakura T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145 (1): 87-99. DOI 10.1007/s00442-005-0100-x.
- Clough BF, Scott K. 1989. Allometric relationship for estimating aboveground biomass in six mangrove species. For Ecol Manag 27: 117-127. DOI: 10.1016/0378-1127(89)90034-0.
- Dewiyanti I. 2010. Litter decomposition of *Rhizophora stylosa* in Sabang-Weh Island, Aceh, Indonesia; Evidence from mass loss and nutrients. Biodiversitas 11 (3): 139-144. DOI: 10.13057/biodiv/d110307.
- Dinilhuda A, Akbar AA, Jumiati J. 2018. Peran ekosistem mangrove bagi mitigasi pemanasan global. Jurnal Teknik Sipil 18 (2): 1-8. DOI: 10.26418/jtsft.v18i2.31233. [Indonesian]
- Dittmar T, Lara RJ. 2001. Driving forces behind nutrient and organic matter dynamics in a mangrove tidal creek in North Brazil. Estuar Coast Shelf Sci 52: 249-259. DOI: 10.1006/ecss.2000.0743.
- Hairiah K, Rahayu S. 2007. Pengukuran Karbon Tersimpan di Berbagai Macam Penggunaan Lahan. World Agroforestry Centre Bogor, Bogor. [Indonesian]
- Hairiah K, Sitompul SM, Noordwijk MV, Palm C. 2001. Methods for Sampling Carbon Stocks Above and Below Ground. ASB Lecture Note ICRAF, Bogor.
- Handoyo E, Amin B, Elizal. 2020. Estimation of carbon reserved in mangrove forest of Sungai Sembilan Sub-District, Dumai City, Riau Province. Asian J Aquat Sci 3 (2): 123-134. DOI: 10.31258/ajoa.3.2.123-134.
- Hendri. 2001. Analisis Emisi dan Penyerapan Gas Rumah Kaca (Baseline) dan Evaluasi Teknologi Mitigasi Karbon Di Wilayah Perum Perhutani. [Master Thesis]. Program Pasca Sarjana Institut Pertanian Bogor, Bogor. [Indonesian]
- Heriyanto NM, Subiandono E. 2012. Komposisi dan struktur tegakan, biomasa, dan potensi kandungan karbon hutan mangrove di Taman Nasional Alas Purwo. J Penelitian Hutan dan Konservasi Alam 9 (1): 023-032. DOI: 10.20886/jphka.2012.9.1.023-032. [Indonesian]
- Hikmatyar MF, Ishak TM, Pamungkas AP, Soffie S, Rijaludin, A. 2015. Estimasi karbon tersimpan pada tegakan pohon di Hutan Pantai Pulau Kotok Besar, Bagian Barat, Kepulauan Seribu. Al-Kauniyah Jurnal Biologi 8 (1): 40-45. [Indonesian]
- Hopkins WG, Huner NPA. 2009. Introduction to plant physiology 4th edition. John Wiley & Sons Inc., Ontario.
- Huff S, Ritchie M, Temesgen H. 2017. Allometric equations for estimating aboveground biomass for common shrubs in Northeastern California. For Ecol Manag 398: 48-63. DOI: 10.1016/j.foreco.2017.04.027.
- Ibrahim A, Muhseni FF. 2020. Estimasi stok karbon pada ekosistem hutan mangrove di Desa Lembung Paseser, Kecamatan Sepuluh, Kabupaten Bangkalan. Juvenil: Jurnal Ilmiah Kelautan dan Perikanan 1 (4): 498-507. DOI: 10.21107/juvenil.v1i4.8947. [Indonesian]
- Idris MH, Latifah S, Aji IML, Wahyuningsih E, Indriyatno I, Ningsih RV. 2013. Studi vegetasi dan cadangan karbon di Kawasan Hutan Dengan Tujuan Khusus (KHDTK) Senaru, Bayan Lombok Utara. J Ilmu Kehutanan 7 (1): 25-36. DOI: 10.22146/jik.6135. [Indonesian]
- Ikhwan, M. 2021. Potensi Stok Karbon Hutan Mangrove dan Tutupan Lahan Lainnya di Lubuk Kertang, Sumatera Utara. [Thesis]. Departemen Budidaya Hutan Fakultas Kehutanan, Universitas Sumatera Utara, Medan. [Indonesian]
- Irwansyah RM, Azzahra SIN, Darmastuti SA, Ramadhani AR, Firdaus O, Daeni F, Safitri N, Fajri OPA, Nugroho GD, Naim DM, Setyawan AD. 2021. Crab diversity and crab potential as support ecotourism in Teleng Ria, Grindulu and Siwil Beach, Pacitan, East Java, Indonesia. Intl J Bonorowo Wetlands 11: 75-83. DOI: 10.13057/bonorowo/w110204.
- Jara MC, Henry M, Réjou-Méchain M, Wayson C, Zapata-Cuartas M, Piotto D, Westfall J. 2015. Guidelines for documenting and reporting

- tree allometric equations. *Ann For Sci* 72 (6): 763-768. DOI: 10.1007/s13595-014-0415-z.
- Ketterings QM, Coe R, Noordwijk MV, Ambagau Y, Palm CA. 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forest. *For Ecol Manag* 146: 199-209. DOI 10.1016/S0378-1127(00)00460-6.
- Komiyama AS, Pongpan, Kato S. 2005. Common allometric equations for estimating the tree weight of mangroves. *J Trop Ecol* 21 (4): 471-477. DOI: 10.1017/S0266467405002476.
- Kumar M. 2017. Carbon Sequestration in a agroforestry system at Kurukshetra in Northern India. *Intl J Theor Appl Sci* 9 (1): 43-46. DOI: 10.13140/RG.2.2.29629.00486.
- Kusumaningtyas MA, Hutahaean AA, Fischer HW, Pérez-mayo M, Ransby D, Jennerjahn TC. 2019. Variability in the organic carbon stocks, sources, and accumulation rates of Indonesian mangrove ecosystems. *Estuar Coast Shelf Sci* 218: 310-323. DOI: 10.1016/j.ecss.2018.12.007.
- Liu H, Ren H, Hui D, Wang W, Liao B, Cao Q. 2014. Carbon stocks and potential carbon storage in themangrove forests of China. *J Environ Manag* 133: 86-93. DOI: 10.1016/j.jenvman.2013.11.037.
- Louhaichi M, Hassan S, Clifton K, Johnson DE. 2018. A reliable and non-destructive method for estimating forage shrub cover and biomass in arid environments using digital vegetation charting technique. *Agrofor Syst* 92 (5): 1341-1352. DOI: 10.1007/s10457-017-0079-4.
- Lovelock CE, Duarte CM. 2019. Dimensions of blue carbon and emerging perspectives. *Biol Lett* 15: 1-5. DOI: 10.1098/rsbl.2018.0781.
- Matsui N, Okimori Y, Takahashi F, Matsumura K, Bamroongruga N. 2014. Nipa (*Nypa fruticans* Wurmb) sap collection in Southern Thailand II. Biomass and soil properties. *Environ Nat Resour Res* 4 (4): 89-100. DOI: 10.5539/enr.v4n4p89.
- McPherson EG, Simpson JR. 1999. Carbon dioxide reduction through urban forestry: Guidelines for professional and volunteer tree planters. Gen. Tech. Rep. PSW-GTR-171. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA, US. DOI: 10.2737/PSW-GTR-171.
- Mugiono IS. 2009. Allometric from Various Type of Tree for Estimating Biomass and Carbon Content in Community Forest. BPKH Wilayah XI Jawa-Madura and Forest Governance and Multi stakeholder Forestry Programme (MFP II), Yogyakarta. [Indonesian]
- Murthy IK, Gupta M, Tomar S, Munsil M, Tiwari R, Hegde GT, Ravindranath NH. 2013. Carbon sequestration potential of agroforestry systems in India. *J Earth Sci Climate Change* 4 (1): 1-7. DOI: 10.4172/2157-7617.1000131.
- National Standardization Agency. 2011. Standar Nasional Indonesia No. 7724 Tentang Pengukuran dan Penghitungan Cadangan Karbon- Pengukuran Lapangan untuk Penaksiran Cadangan Karbon Hutan (ground based forest carbon accounting). Jakarta. [Indonesian]
- Nurhayati D, Dhokhikah Y, Mandala M. 2020. Persepsi dan strategi adaptasi masyarakat terhadap perubahan iklim di kawasan Asia Tenggara. *PROTEKSI: J Lingkungan Berkelanjutan* 1 (1): 39-44. [Indonesian]
- Pratama R. 2019. Efek rumah kaca terhadap bumi. *Buletin Utama Teknik* 14 (2): 120-126. [Indonesian]
- Pricillia CC, Patria MP, Herdiansyah H. 2021. Environmental conditions to support blue carbon storage in mangrove forest: A case study in the mangrove forest, Nusa Lembongan, Bali, Indonesia. *Biodiversitas* 22 (6): 3304-3314. DOI: 10.13057/biodiv/d220636.
- Purwanto RH, Mulyana B, Sari PI, Hidayatullah MF, Marpaung AA, Putra ISR, Putra AD. 2021. The environmental services of Pangarengan mangrove forest in Cirebon, Indonesia: Conserving biodiversity and storing carbon. *Biodiversitas* 22: 5609-5616. DOI: 10.13057/biodiv/d221246.
- Purwiyanto AIS, Agustriani F. 2017. Estimasi stok karbon mangrove (aboveground) di Tanjung Api-Api, Sumatera Selatan. *J Ilmu dan Teknologi Kelautan Tropis* 9 (2):761-770. DOI: 10.29244/jitkt.v9i2.19308. [Indonesian]
- Rahardjanto A, Sari URK, Waluyo L, Husamah H. 2022. Ecological functions of mangrove based on carbondioxide abilities and carbon storage at Cengkong Beach, Trenggalek Regency. *Jurnal Biosilampari: Jurnal Biologi* 4 (2): 33-52. DOI: 0.31540/biosilampari.v4i2.1516. [Indonesian]
- Rozainah MZ, Nazri MN, Sofawi AB, Hemati Z, Juliana WA. 2018. Estimation of carbon pool in soil, above and below ground vegetation at different types of mangrove forests in Peninsular Malaysia. *Mar Pollut Bull* 137: 237-245. DOI: 10.1016/j.marpolbul.2018.10.023.
- Shafiya RW, Djunaedi A, Ario R. 2021. Estimasi biomassa dan simpanan karbon pada vegetasi lamun di Perairan Pantai Jepara. *J Mar Res* 10 (3): 446-452. DOI: 10.14710/jmr.v10i3.30998. [Indonesian]
- Sholihqin M, Pramadaningtyas PS, Solikah I, Febriyanti S, Pambudi MD, Mahartika SB, Umam AF, Liza N, Setyawan AD. 2021. Analysis of the diversity and evenness of mangrove ecosystems in the Pacitan Coast, East Java, Indonesia. *Intl J Bonorowo Wetlands* 11: 84-94. DOI: 10.13057/bonorowo/w110205.
- Sugiharto C. 2002. Kajian Aluminium sebagai Faktor Pembatas Pertumbuhan Akar Sengon (*Paraserianthes falcataria* L. Nelson). [Thesis]. Jurusan Tanah, Fakultas Pertanian, Universitas Brawijaya, Malang. [Indonesian]
- Suryono S, Soenardjo N, Wibowo E, Ario R, Rozy EF. 2018. Estimasi kandungan biomassa dan karbon di Hutan Mangrove Perancak Kabupaten Jembrana, Provinsi Bali. *Buletin Oseanografi Marina* 7 (1): 1-8. DOI: 10.14710/Buloma.V7i1.19036. [Indonesian]
- Suwardi AB, Syamsuardi EMD. 2013. Perubahan populasi pohon dan cadangan karbon selama tiga dekade di hutan Ulu Gadut, Sumatera Barat. *Biospectrum* 9 (3): 157-166. [Indonesian]
- Taillardat P, Friess DA, Lupascu M. 2018. Mangrove blue carbon strategies for climate change mitigation are most effective at the national scale. *Biol Lett* 14 (10): 20180251. DOI:10.1098/rsbl.2018.0251.
- Wardah, Toknok B, Zulkhaidah. 2011. Carbon stock of agroforestry systems at adjacent buffer zone of Lore Lindu National Park, Central Sulawesi. *J Trop Soils* 16 (2): 123-128. DOI: 10.5400/jts.2011.16.2.123.
- Wiraatmaja MF, Hasanah R, Dwirani NM, Pratiwi AS, Riani FE, Hasnaningtyas S, Nugroho GD, Setyawan AD. 2022. Structure and composition molluscs (bivalves and gastropods) in mangrove ecosystem of Pacitan District, East Java, Indonesia. *Intl J Bonorowo Wetlands* 12: 1-11. DOI: 10.13057/bonorowo/w120101.
- Wirasatriya A, Pribadi R, Iryanthony SB, Maslukah L, Sugianto DN, Helmi M, Ananta RR, Adi NS, Kepel TL, Ati RNA, Kusumaningtyas MA, Suwa R, Ray R, Nakamura T, Nadaoka K. 2022. Mangrove aboveground biomass and carbon stock in the Karimunjawa-Kemujan Islands estimated from unmanned aerial vehicle-imagery. *Sustainability* 14 (2): 706. DOI: 10.3390/su14020706.
- World Agroforestry. 2022. Wood Density. <http://db.worldagroforestry.org/wd>. [31-7-2022]
- Yan F, Wu B, Wang YJ. 2013. Estimating aboveground biomass in Mu Us Sandy Land using landsat spectral derived vegetation indices over the past 30 years. *Jarid Land* 5 (4): 521-530. DOI: 10.1007/s40333-013-0180-0.
- Yuliasmara A, Wibawa AA, Prawoto. 2009. Karbon tersimpan pada berbagai umur dan sistem pertanaman kakao: Pendekatan allometrik. *Pelita Perkebunan* 25 (2): 86-100. DOI: 10.22302/iccri.jur.pelita-perkebunan.v25i2.132. [Indonesian]