

# Mangrove species diversity and carbon stock in silvofishery ponds in Deli Serdang District, North Sumatra, Indonesia

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**Abstract.** Harefa MS, Nasution Z, Mulya MB, Maksu A. 2022. Mangrove species diversity and carbon stock in silvofishery ponds in Deli Serdang District, North Sumatra, Indonesia. *Biodiversitas* 23: 655-662. Mangrove-based silvofishery ponds are promoted as a win-win solution for biodiversity conservation, climate change mitigation as well as income generation for coastal communities. This study aimed to analyze the species diversity and carbon stock of mangrove vegetation in silvofishery ponds in Tanjung Rejo Village, Percut Seituan Sub-district, Deli Serdang District, North Sumatra, Indonesia. Data of the mangrove species were obtained using vegetation analysis, and the potential carbon stock was estimated based on allometric equations of both above- and below-ground tree biomass. For this purpose, plot samples from 22 silvofishery ponds were taken by establishing 5 aligned circular plots, each with a radius of 5.64 m, perpendicular to the coastline and with a distance of 15 meters between their perimeters. The results show that the mangrove species with the highest Importance Value Index (IVI) was *Rhizophora apiculata* (122.05%), followed by *Excoecaria agallocha* (42.29%) and *Avicennia marina* (36.84%), and the lowest IVI was *Sonneratia caseolaris* (1.48%). Higher IVI values indicate a larger carbon deposit from mangrove vegetation in silvofishery ponds. Our results indicate that mangrove area coverage of 44-80% per hectare in silvofishery ponds can deposit 40-50 tonnes of carbon per hectare and have greater potential carbon stock compared to coverage below 40%. The mangrove management activities with the silvofishery scheme have a good impact on the community's economy and also maintain the existence of mangroves as carbon storage.

**Keywords:** Carbon stock, mangroves, silvofishery ponds

## INTRODUCTION

Mangroves are dicotyledonous woody shrubs or trees that are almost predominately found in the tropics. They commonly form a dense intertidal forest that dominates muddy intertidal shores, with patches or bands that are almost entirely monospecific (Hogarth 2015). The existence of the mangrove ecosystem is crucial because it provides a variety of ecosystem services along the coastline (Alongi et al. 2016). Mangrove forests serve as a protective line against erosion and abrasion, wind and wave breakers, and seawater intrusion. They are also an important habitat for various types of fauna and ideal places for various types of fish, shrimp, crabs, and other marine biotas to forage, spawn, and breed. Mangrove forests absorb CO<sub>2</sub> and produce O<sub>2</sub> at a relatively high rate compared to other forest types (Hossain and Nuruddin 2016). In addition, mangroves have high adaptability when combined with an anaerobic environment and conditions (Oddsson 2020), resulting in significant long carbon storage potential (Murdiyarto et al. 2015).

Mangrove forests are continuously disturbed as a consequence of human and environmental impacts, as is well known. These disturbances such as land cover change will increase their vulnerability to climate change impacts

such as the sea-level rise and ecosystem degradation (Akbar et al. 2017). The loss of mangrove forest cover also reduces forest biomass, emitting carbon into the atmosphere (Eid and Shaltout 2016; Perez et al. 2018). However, the extent of mangrove ecosystems, which are critical for providing local environmental services as well as global climate change mitigation, is declining at an alarming rate every year (Barbier 2012; Wiwatthanapornchai et al. 2014).

Various mangrove management schemes such as rehabilitation, a silvofishery system, social forestry and land subject to agrarian reform or land reform (TORA) have been implemented on the Indonesian island of Java, Sumatra and other islands (Musa et al. 2020). Silvofishery is one of the most widespread land-use systems in mangrove areas in Indonesia (Hastuti and Budihastuti 2016). In general, silvofishery is an aquaculture activity by integrating ponds with mangrove trees to generate economic benefits while also ensuring environmental sustainability (Sari et al. 2014). In silvofishery, mangroves can absorb organic matter from anthropogenic activities, improving the quality of pond water (De-León-Herrera et al. 2015). Many studies have found that mangrove trees can absorb these materials (Barraza et al. 2013; Dauda et al. 2019; De-León-Herrera et al. 2015). Microbial activity in

mangrove sediments also plays an important role in the removal of organic matter and nutrients from wastewater (Ouyang and Guo 2016; Tian et al. 2018).

Silvofishery, also known as intercropping ponds, is perfectly suited with social forestry policy in Indonesia, especially in densely populated mangrove forests and is similar to the agroforestry system promoted in terrestrial areas. According to the Decree of the Minister of Fisheries and Marine Affairs No. 28 of 2004, the silvofishery model is defined as the use of mangrove vegetation in aquaculture activities without disturbing the sustainability of the mangroves by constructing ponds as much as possible to avoid damage or elimination of the natural functioning of mangrove forests. The use of mangroves in silvofishery can benefit coastal communities' economies and environmental services (Suwanto et al. 2015). Essentially, silvofishery-based pond management employs water as the primary medium for fish cultivation and fish-catching activities, which is supported by mangrove vegetation in the ponds (Harefa et al. 2019). In addition, the mangrove ecosystem also has a dual function as a habitat for aquatic and terrestrial biota (Serosero et al. 2020).

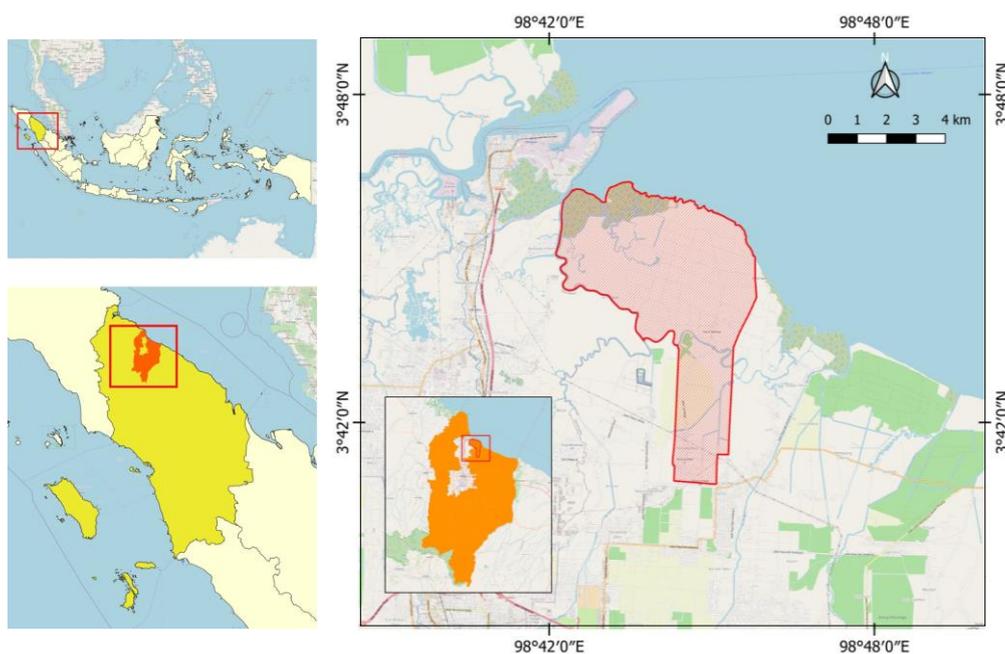
The wide variety of environmental services provided by mangroves is expected to support aquaculture activities. The physical, chemical, and biological properties of mangrove forests are expected to benefit pond businesses while also raising public awareness about the importance of mangroves. Mangroves play a physical role in sediment capture (Gunawan et al. 2011), reducing the pollutant entering the pond and absorbing nutrients as well as the organic matter that benefit the cultured fish (Mandari et al. 2016). When allowed to grow along the pond, mangroves might serve as spawning grounds, nursery grounds, and feeding grounds for a variety of aquatic biota (Kaiser et al. 2015; Widyastuti et al. 2018).

The destruction of mangrove forests clearly affects aquaculture activities. For example, the 2004 earthquake and tsunami resulted in damages to many ponds in Tanjung Rejo Village, Deli Serdang District, North Sumatra, Indonesia. Prior to the 2004 tsunami, pond management was mostly intensive with no or limited mangrove forest cover. Currently, the village applies the silvofishery system, thus it is critical to understand the current state of mangroves and their carbon potential. The purpose of this research is to determine the species diversity and potential carbon stocks in silvofishery ponds in Tanjung Rejo Village, Percut Sei Tuan Sub-district, Deli Serdang District. The diversity and biomass data obtained in this study will serve as a reference regarding environmental services delivered from sustainable silvofishery management.

## MATERIALS AND METHODS

### Research area

The study was carried out in 22 silvofishery ponds located in Tanjung Rejo Village, Percut Sei Tuan Sub-district, Deli Serdang District, North Sumatra Province, Indonesia (Figure 1). This village was chosen as it was the only location applying a silvofishery system in Deli Serdang District. Tanjung Rejo Village is made up of 13 hamlets, including 10 hamlets with dominant land uses of irrigated rice fields and 3 hamlets of the hermitage area, ponds, and rainfed rice fields. The air temperature in Deli Serdang District ranges between 25<sup>o</sup> and 27<sup>o</sup> C, with an annual rainfall of 2,400 mm/year. Tanjung Rejo Village has a relatively flat topography and is generally classified as a lowland area with an elevation of 0-10 meters above sea level.



**Figure 1.** Map of research location in Tanjung Rejo Village, Percut Sei Tuan Sub-district, Deli Serdang District, North Sumatra Province, Indonesia

Quantitative research was conducted in silvofishery community ponds. Non-probability convenience sampling was used to select the 22 ponds for study. The selected silvofishery ponds included milkfish aquaculture and crab-rearing ponds, as well as non-cultivated fish and shrimp ponds. Each pond had a water gate with growing mangroves, and the water discharge was influenced by tides. The characteristics of the ponds in this study were consistent with the size of the ponds and the extent of mangrove areas in the larger research area, which had no numerical or percentage similarities. The mangrove areas of the 22 ponds varied from 1.15 to 12.4 ha, accounting for 0.26-6.33% of the pond area. Table 1 shows that the silvofishery ponds also had varying percentages of mangroves coverage, ranging from 14.21% to 81.05%.

### Research methods

The sources of the data were mangrove vegetation in silvofishery ponds and data collected were as follow: (i) Mangrove species identification through observation and the involvement of local farmers and experts; (ii) measurements of mangrove diameters to obtain biomass for determining carbon stocks; and (iii) number of individuals to calculate mangrove density, frequency, dominance, and index of importance at the observation site. Mangrove vegetation was observed in plots, and measurements were carried out in sample ponds using the method developed for mangrove forests (Donato et al. 2011) (Figure 2). In

total, 5 measurement plots were created in a circular pattern, each with a radius of 5.64 m, aligned 15 meters from each other and perpendicular to the coastline. The area of one plot of measurement was 99.85 m<sup>2</sup>, or the rough equivalent of 100 m<sup>2</sup>.

### Data analysis

Vegetation analysis was conducted in accordance with Soerianegara and Indrawan (1998), which involved calculating the relative values of density (RD), frequency (RF), basal area (RBA), and Importance Value Index (IVI). The estimation of above-ground carbon stock was determined using the allometric equations of tree biomass above ground (Table 2).

To estimate the below-ground tree biomass, this study used the formula developed by Komiyama et al. (2008):

$$B_{BT} = 0,199 * \rho^{0,899} * (D)^{2,22}$$

Note:

$B_{BT}$  : Below-ground tree biomass (kg)

$D$  : Diameter at breast height (cm)

$\rho$  : Specific gravity of wood

Furthermore, carbon was estimated as 46% of the above-ground tree biomass (Kauffman et al. 2012). To calculate the carbon stock in the pond, the carbon stock per hectare in the sample plot was multiplied by the pond area:

$$\text{Carbon stock in ponds} \left( \frac{\text{Tonnes}}{\text{Area n}} \right) = \text{Carbon reserves tonnes per hectare} \times \text{Pond area (ha)}$$

**Table 1.** Characteristics of ponds based on the mangrove coverage in Tanjung Rejo Village, Percut Sei Tuan Sub-district, Deli Serdang District, North Sumatra Province, Indonesia

Pond number	Coordinates		Pond area (ha)	Mangrove area (ha)	Pond area (ha)	Mangrove cover (%)	Pond surface (%)
	Longitude	Latitude					
1	98°43'13.30"E	3°44'34.10"N	7.81	6.33	1.48	81.05	18.95
2	98°43'58.66"E	3°45'60.13"N	2.43	1.95	0.48	80.25	19.75
3	98°44'00.37"E	3°45'22.44"N	1.9	1.49	0.41	78.42	21.58
4	98°44'60.12"E	3°45'12.70"N	2.4	1.87	0.53	77.92	22.08
5	98°43'33.01"E	3°44'51.76"N	4.1	2.72	1.38	66.34	33.66
6	98°43'18.62"E	3°44'57.67"N	4.64	3.05	1.59	65.73	34.27
7	98°43'43.81"E	3°44'43.88"N	6.1	3.22	2.88	52.79	47.21
8	98°43'59.18"E	3°45'80.11"N	1.15	0.56	0.59	48.70	51.30
9	98°42'59.83"E	3°44'37.18"N	7.22	3.24	3.98	44.88	55.12
10	98°43'32.90"E	3°44'46.79"N	4.72	2.11	2.61	44.70	55.30
11	98°43'50.70"E	3°45'10.88"N	8.4	3.62	4.78	43.10	56.90
12	98°43'56.60"E	3°45'20.10"N	1.62	0.66	0.96	40.74	59.26
13	98°42'57.94"E	3°45'60.61"N	8.51	3.41	5.1	40.07	59.93
14	98°44'10.08"E	3°45'12.92"N	2.19	0.82	1.37	37.44	62.56
15	98°43'21.32"E	3°45'20.78"N	1.74	0.64	1.1	36.78	63.22
16	98°42'56.97"E	3°45'16.62"N	12.4	3.5	8.9	28.23	71.77
17	98°43'59.56"E	3°44'49.43"N	2.11	0.59	1.52	27.96	72.04
18	98°43'56.13"E	3°44'46.86"N	0.98	0.26	0.72	26.53	73.47
19	98°43'18.62"E	3°44'57.67"N	4.35	0.93	3.42	21.38	78.62
20	98°43'59.55"E	3°45'10.98"N	1.36	0.26	1.1	19.12	80.88
21	98°42'56.52"E	3°44'47.64"N	5.1	0.78	4.32	15.29	84.71
22	98°43'50.24"E	3°44'50.24"N	3.87	0.55	3.32	14.21	85.79

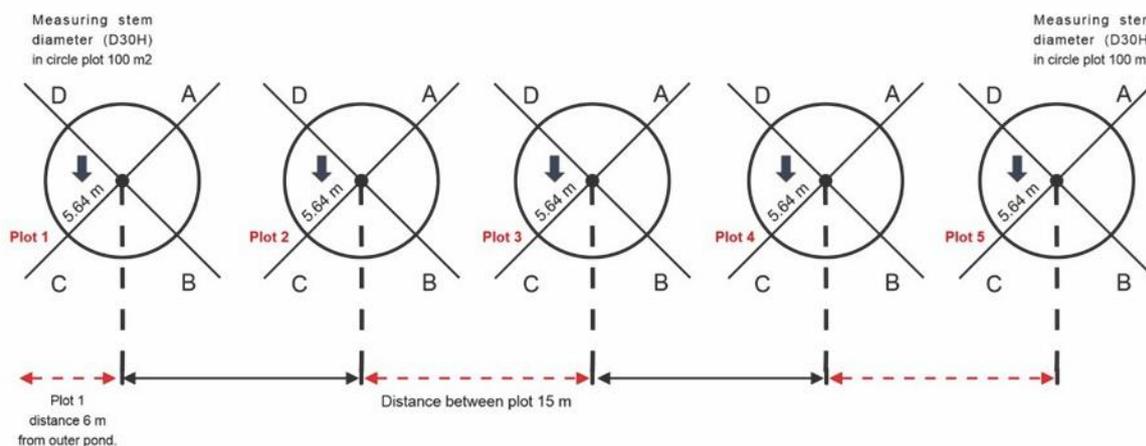


Figure 2. Schematic plot for measuring mangrove vegetation in the pond

Table 2. The allometric equation for calculating above-ground tree biomass

Species	BAT (kg)	Reference
<i>Avicennia marina</i>	$0.1848D^{2.3524}$	Dharmawan and Siregar, 2008
<i>Avicennia officinalis</i>	$0.1848D^{2.3524}$	Siregar CA and IWS Dharmawan 2009
<i>Bruguiera cylindrica</i>	$(0.0754D^{2.505 * p}) + (0.0679D^{1.4914})$	Kauffman and Cole, 2010
<i>Bruguiera gymnorhiza</i>	$(0.0754D^{2.505 * p}) + (0.0679D^{1.4914})$	Kauffman and Cole, 2010
<i>Bruguiera sexangula</i>	$(0.0754D^{2.505 * p}) + (0.0679D^{1.4914})$	Kauffman and Cole, 2010
<i>Excoecaria agallocha</i>	$0.251 * p * D^{2.46}$	Komiyama et al. 2005
<i>Lumnitzera racemosa</i>	$0.251 * p * D^{2.46}$	Komiyama et al. 2005
<i>Rhizophora apiculata</i>	$0.043D^{2.63}$	Putz and Chan, 1986
<i>Rhizophora mucronata</i>	$0.043D^{2.63}$	Putz and Chan, 1986
<i>Sonneratia alba</i>	$0.251 * p * D^{2.46}$	Komiyama et al. 2005
<i>Sonneratia caseolaris</i>	$0.251 * p * D^{2.46}$	Komiyama et al. 2005
<i>Xylocarpus granatum</i>	$0.1832D^{2.21}$	Tarlan 2008

Note: BAT: Above-ground tree biomass (kg); D: Diameter at breast height (cm); ρ: Specific gravity of wood

## RESULTS AND DISCUSSION

### Species diversity in Tanjung Rejo mangrove silvofishery ponds

Human activity and the environment each play a significant role in the diversity of vegetation in the mangrove ecosystem (Alavaisha and Mangora 2016). The ability to adapt to environmental factors such as temperature, salinity, and pH influences the diversity of species in mangrove forests (FAO 1994). Human activities affecting land use also have an impact on mangrove diversity (Gillerot et al. 2018). The density of each type of mangrove varies. The physical condition of mangrove vegetation can reveal the density of an ecosystem. These conditions take the form of an environment, which can be identified using a variety of parameter values such as stem diameter, height, dominance, relative dominance, frequency, relative frequency, and canopy area (Prasetyo et al. 2017).

A total of 12 mangrove species (Table 3) were found in the research area, of which 40.94% (957 trees) were *Rhizophora apiculata* and, with the least representation was *Sonneratia caseolaris* with only 0.05% (1 tree). *Rhizophora apiculata* is commonly planted by the community in the middle and at the edge of the pond because it is capable of producing a high growth of phytoplankton, which indirectly provides good nutrition for

the fish. This is related to Kurniadi and Koeslulata (2020) observation on the island of Timor, Indonesia, that people are willing to plant mangroves if they feel there are benefits, especially in terms of economy. *R. apiculata*-dominated ponds are more suitable for plankton growth and can provide more nutrients than other types of mangrove stands. *Rhizophora* roots do not impede pond development, and the leaves can be used as animal feed for cattle and goats (Basyuni et al. 2018). The presence of *R. apiculata* and *A. marina* in ponds is very suitable because they serve as a natural predator repellent as well as a source of natural food for fish growth through the decomposition process of leaves, twigs, and fruit litter, which results in the formation of detritus. Their suitability is consistent with the findings of Malik et al. (2019), who report that mangrove rehabilitation in Southeast Asian countries is primarily focused on planting one or two species, particularly *Rhizophora* or red mangroves.

Based the analysis, *Rhizophora apiculata* had the highest IVI (122.05%), followed by *Excoecaria agallocha* (42.29%) and *Avicennia marina* (36.84%), while the lowest IVI was *Sonneratia caseolaris* (1.48%). Species with the highest IVI can be categorized as the most important species in the location (Noraimy et al. 2014). IVI can be used to determine each species' overall importance in the community structure (Ismail et al. 2017). The significance

of the dominance value indicates the vegetation's ability to compete with nutrients, groundwater, and soil water. Adequate nutrition encourages healthy shoot growth. Good shoot growth increases the species' ability to compete for light as the primary energy source, affecting the growth of all organs, including the growth of stems, leaves, and roots. The findings of this study are consistent with Ginting et al. (2016), who discovered that the fulfillment of ecological factors in habitat allows the species to grow well and dominate at every level of growth. Because *R. apiculata* and *A. marina* have habitats in high salinity areas, salinity influences their growth. Other mangrove vegetation, by contrast, is mostly planted by the surrounding community. The ideal salinity range for mangrove development and growth is 0.5-35 (Hamran et al. 2014).

### Biomass and carbon stock potential

Because it is non-destructive, the allometric method is widely used to predict the biomass of a vegetation community (Kridiborworn et al. 2012; Kusmana et al. 2018). The allometric equation in this study followed Komiyama et al. (2005) and used trunk diameter and wood density as dependent variables (Njana et al. 2015), making the field measurement easier. These two factors are known to have a significant relationship with the biomass and carbon stock of each individual species. Carbon is known to be well stored in the leaves, branches, stems, roots, and soil (Hemati et al. 2015; Hong et al. 2017). The potential for storage is proportional to the amount of biomass in the vegetation (Siteo et al. 2014).

Table 4 shows the biomass pools, carbon stocks, and equivalent CO<sub>2</sub> in different species. Based on the accumulation of above-ground biomass and roots of each tree in the mangrove forest of Tanjung Rejo Village, Sei Tuan Sub-district, the estimated total biomass was between 12.67 and 138.25 tons/ha. Among the sample plots, pond number 2 had the largest total biomass, at 138.25 tons/ha, with a pond area of 2.43 ha and a mangrove area of 1.95 ha, followed by pond number 1, which had total biomass of 100.13 tons/ha and a pond area of 7.81 ha. However, based on the percentage of mangrove cover, pond number 2, with

only 80.25% coverage, did not have the highest percentage of cover. This can be attributed to the recorded tree basal area of each pond (Table 4) and the circumference (2.37-25.32 cm) in the plot (Table 3). Although pond 2 had the largest total biomass, pond 2 did not have the largest mangrove area. Furthermore, above-ground biomass ranged from 3.71 to 67.73 tons/ha, while below-ground biomass ranged from 8.51 to 79.99 tons/ha.

In this study, 74% biomass was attributed to above-ground biomass, with roots accounting for the remaining 26%. The biomass estimation results from this study ranged from 12.67 to 138.25 tons/ha. Our estimation of natural mangrove stand biomass in Percut Sei Tuan Sub-district is comparable to the value obtained by Camacho et al. (2011) on *R. stylosa*-dominated mangrove forests and community-managed stands in Bohol, Philippines. Camacho et al. (2011), who also used Komiyama et al. (2005)'s general allometric equation, found that the total biomass ranged from 173.9 to 948.0 tons/ha, compared to 59.73-1091.53 tons/ha in our study. According to Komiyama et al. (2008)'s multi-year study of mangrove forest biomass in various countries, variations in biomass estimates depend on species and ecological conditions and geographical location. The t/R ratio of mangroves is significantly lower than that of the upland forest because a large amount of biomass tends to be allocated in the root system to maintain the shape of the trees' underside so that they can stand upright in wet and soft mud (Chandra et al. 2011).

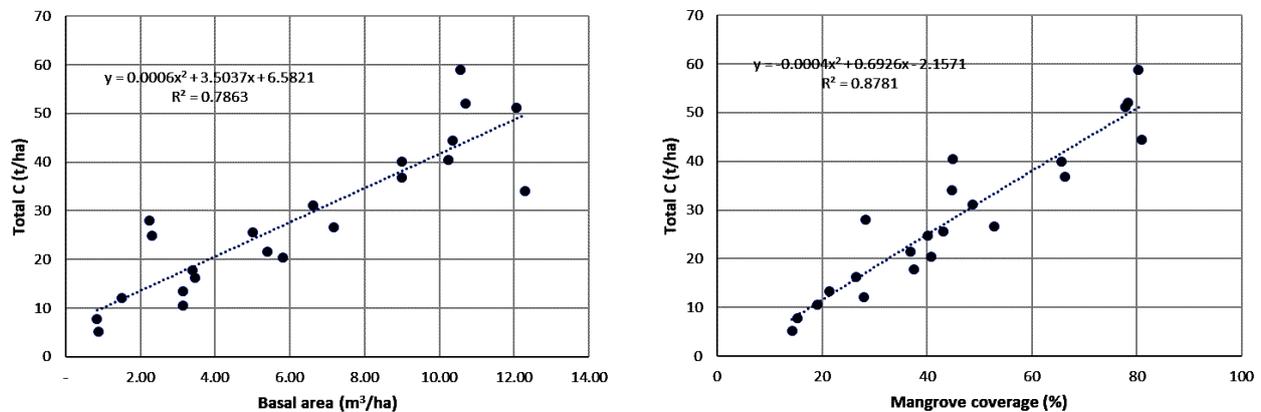
Silvofishery ponds with more than 40% mangrove cover have higher carbon stocks than ponds with less than 40% mangrove cover. In this study, five ponds with the highest carbon content had more than 40% mangrove cover. The trend of the total carbon stock among the ponds seems highly related to the basal area and mangrove coverage. Figure 3 shows that the basal area and mangrove coverage have a strong relationship with total carbon stock, indicated by high determination coefficients (R<sup>2</sup>) of 0.79 and 0.88, respectively. This result confirms a study by Siarudin et al. (2021), who reported that basal area is a good predictor of carbon stock in various agroforestry systems in West Java Province, including silvofisheries.

**Table 3.** The IVI values of mangrove species in silvofishery ponds in Tanjung Rejo Village, Percut Sei Tuan Sub-district, Deli Serdang District, North Sumatra Province, Indonesia

Mangrove species	Pond	Diameter range (cm)	Tree number	Relative value			
				Density (%)	Freq. (%)	Basal area (%)	IVI (%)
<i>Avicennia marina</i> (Forssk.) Vierh.	4,6,7,8,9,11, 14, 18,19, 21	2.49-25.32	214	9.83	17.57	9.45	36.84
<i>Avicennia officinalis</i> L.	18	6.37	3	0.14	1.35	0.12	1.61
<i>Bruguiera cylindrica</i> (L.) Blume	9	2.37	146	6.70	1.35	1.59	9.64
<i>Bruguiera gymnorrhiza</i> (L.) Lam.	18	10.83	4	0.18	1.35	0.48	2.02
<i>Bruguiera sexangula</i> (Lour.) Poir.	1,2,3,5,6,7, 12,19	2.23-7.85	261	11.98	10.81	7.44	30.23
<i>Excoecaria agallocha</i> L.	1,2,5,6,7, 12,13,17, 19,20,21	2.49-10.11	281	12.90	14.86	14.53	42.29
<i>Lumnitzera racemosa</i> Willd.	2,3,6,12,16	3.82-5.19	221	10.15	6.76	4.72	21.62
<i>Rhizophora apiculata</i> Blume	2,3,4,5,6,7,8,9,10,11, 14,15, 18, 20,21,22	4.37-14.01	957	43.94	22.97	55.14	122.05
<i>Rhizophora mucronata</i> Lam.	4,5,7,8,10,11,12,19	4.38-9.14	59	2.71	10.81	3.93	17.45
<i>Sonneratia alba</i> Sm.	3,5,6,7	6.29-10.03	7	0.32	5.41	0.45	6.17
<i>Sonneratia caseolaris</i> (L.) Engl.	18	9.24	1	0.05	1.35	0.08	1.48
<i>Xylocarpus granatum</i> J.Koenig	3,6,17,19	3.98-10.08	24	1.10	5.41	2.08	8.59

**Table 4.** The biomass pools and carbon stocks in different species in silvofishery ponds in Tanjung Rejo Village, Percut Sei Tuan Sub-district, Deli Serdang District, North Sumatra Province, Indonesia

Pond number	Pond area (ha)	Mangrove area (ha)	Biomass (tonnes/ha)			Basal area (m <sup>3</sup> /ha)	Mangrove coverage (%)	Mangrove carbon stock (tonnes/ha)		
			Above ground	Below ground	Total			Above ground	Below ground	Total
1	7.81	6.33	67.73	32.41	100.13	10.37	81.05	31.83	12.64	44.47
2	2.43	1.95	61.96	76.29	138.25	10.56	80.25	29.12	29.75	58.87
3	1.9	1.49	53.61	68.96	122.57	10.70	78.42	25.20	26.90	52.09
4	2.4	1.87	42.46	79.99	122.45	12.06	77.92	19.96	31.20	51.15
5	4.1	2.72	33.79	53.60	87.40	9.00	66.34	15.88	20.91	36.79
6	4.64	3.05	51.45	40.66	92.11	9.00	65.73	24.18	15.86	40.04
7	6.1	3.22	36.64	24.13	60.77	7.16	52.79	17.22	9.41	26.63
8	1.15	0.56	26.48	47.75	74.23	6.63	48.70	12.45	18.62	31.07
9	7.22	3.24	45.25	49.07	94.33	10.23	44.88	21.27	19.14	40.41
10	4.72	2.11	25.64	56.41	82.05	12.30	44.70	12.05	22.00	34.05
11	8.4	3.62	28.11	31.62	59.74	5.00	43.10	13.21	12.33	25.55
12	1.62	0.66	20.18	28.04	48.22	5.80	40.74	9.49	10.94	20.42
13	8.51	3.41	36.43	19.75	56.18	2.30	40.07	17.12	7.70	24.82
14	2.19	0.82	14.63	28.15	42.78	3.39	37.44	6.87	10.98	17.85
15	1.74	0.64	18.57	32.79	51.36	5.40	36.78	8.73	12.79	21.51
16	12.4	3.5	41.17	22.05	63.21	2.23	28.23	19.35	8.60	27.95
17	2.11	0.59	17.27	10.20	27.47	1.51	27.96	8.12	3.98	12.10
18	0.98	0.26	19.99	17.48	37.47	3.46	26.53	9.40	6.82	16.21
19	4.35	0.93	16.90	13.97	30.88	3.15	21.38	7.94	5.45	13.39
20	1.36	0.26	8.94	16.19	25.13	3.13	19.12	4.20	6.32	10.52
21	5.1	0.78	9.41	8.51	17.92	0.84	15.29	4.42	3.32	7.74
22	3.87	0.55	3.71	8.96	12.67	0.88	14.21	1.74	3.50	5.24

**Figure 3.** Relationship between basal area (left) and mangrove cover (right) with total carbon stock in silvofishery ponds in Tanjung Rejo Village, Percut Sei Tuan Sub-district, Deli Serdang District, North Sumatra Province, Indonesia

This finding is also consistent with Githaiga et al. (2020) and Kauffman et al. (2012), who concluded that carbon stocks in mangrove forests are higher than carbon stocks in other forest types, with mangrove sediments containing the most carbon. As a result, the higher the density of mangroves in the silvofishery pond area, the higher the level of carbon production in the pond. Similarly, Li et al. (2015) found that as canopy cover and mangrove density increased, so did carbon stocks. Besar et al. (2020) similarly found that greater mangrove cover leads to greater amounts of carbon stock.

The result of this study indicates that mangrove cover in Sei Tuan Sub-district silvofisheries stored large amounts of

CO<sub>2</sub>. Of course, from an economical perspective, this is valuable information given the synergy between mangrove conservation and the livelihood of the surrounding community. This is because mangroves are important habitats for mangrove crab that have high economic value. On the other hand, mangrove ecosystems also can sequester and store carbon in plant parts and sediments at a greater rate than terrestrial ecosystems (Liu et al. 2014). The existence of a blue carbon fund scheme to reduce emissions from deforestation and forest degradation in coastal areas provides an excellent opportunity for development in this area. This opportunity for carbon trading, through a variety of ecosystem services and

ecological functions, has the potential to result in impactful climate change mitigation strategies. In terms of climate change mitigation, the underrecognized mangrove ecosystem services are now receiving significant attention around the world.

In conclusion the silvofishery ponds in Tanjung Rejo Village consisted of 12 mangrove species with the highest IVI was found in *R. apiculata* (122.05%) followed by *Excoecaria agallocha* (42.29%) and *Avicennia marina* (36.84%) and the lowest was in *Sonneratia caseolaris* (1.48%). The existence of mangroves in silvofishery ponds contributed to carbon stocks with strong positive correlation between mangrove area and carbon stocks, implying that the greater the number, type, and diameter of mangrove trees in the pond, the larger the carbon stock. Silvofishery ponds with 44-80% mangrove cover can produce 40-59 tonnes of carbon per hectare. According to existing research, the presence of mangroves in ponds can not only increase pond production but also contribute to carbon absorption.

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#### REFERENCES

- Apbar AA, Sartohadi J, Djohan TJS, Ritohardoyo S. 2017. The breakwater role on the rehabilitation of coastal and mangrove forests in West Kalimantan, Indonesia. *Ocean Coast Manag* 138: 50-59. DOI: 10.1016/j.ocecoaman.2017.01.004.
- Alavaisha E, Mangora MM. 2016. Carbon stock in the small estuarine mangrove of Geza and Mtimbwani, Tanga, Tanzania. *Intl J For Res* 1-11. DOI: 10.1155/2016/2068283.
- Alongi DM, Murdiyarto D, Fourqurean JW, Kauffman JB, Hutahaean A, Crooks S, Lovelock CE, Howard J, Herr D, Fortes M, Pidgeon E, Wagey T. 2016. Indonesia's blue carbon: a globally significant and vulnerable sink for seagrass and mangrove carbon. *Wetlands Ecol Manage* 24 (1): 3-13. DOI: 10.1007/s11273-015-9446-y.
- Barraza-Guardado RH, Arreola-Lizárraga JA, López-Torres MA, Casillas-Hernández R, Miranda-Baeza A, Magallón-Barrajas F, Ibarra-Gómez C. 2013. Effluents of shrimp farms and its influence on the coastal ecosystems of Bahía de Kino, Mexico. *Sci World J* 2013: 306370. DOI: 10.1155/2013/306370.
- Barbier EB. 2012. Progress and challenges in valuing coastal and marine ecosystem services. *Rev Environ Econ Pol* 6: 1-19. DOI: 10.1093/reep/rer017.
- Basyuni M, Nasution KS, Slamet B, Sulistiyono N, Bimantara Y, Putri LAP, Yusraini E, Hayati R, Lesmana I. 2018. Introducing of a silvofishery pond on sapling and seedling density based in Lubuk Kertang Village, North Sumatra. *IOP Conf Ser: Earth Environ Sci* 260: 012115 DOI: 10.1088/1755-1315/260/1/012115.
- Basyuni M, Gulton K, Fitri A, Susetya IE, Wati R, Slamet B, Sulistiyono N, Yusraini E, Blake T, Bunting P. 2018. Diversity and habitat characteristics of macrozoobenthos in the mangrove forest of Lubuk Kertang Village North Sumatra Indonesia. *Biodiversitas* 19 (1): 311-17. DOI: 10.13057/biodiv/d190142.
- Besar NA, Suardi H, Phua MH, James D, Mokhtar M, Ahmed MF. 2020. Carbon stock and sequestration potential of an agroforestry system in Sabah, carbon stock and sequestration potential of an agroforestry system in Sabah, Malaysia. *Forests* 11 (2): 210. DOI: 10.3390/f11020210.
- Camacho LD, Gevana DT, Carandang AP, Camacho SC, Combalicer EA, Rebugio LL, Youn YC. 2011. Tree biomass and carbon stock of a community-managed mangrove forest in Bohol, Philippines. *For Sci Technol* 7 (4): 161-167. DOI: 10.1080/21580103.2011.621377.
- Chandra IA, Seca G, Abu Hena MK. 2011. Aboveground biomass production of *Rhizophora apiculata* Blume in Sarawak mangrove forest. *Am J Agric Biol Sci* 6 (4): 469-474. DOI: 10.3844/ajabssp.2011.469.474.
- Dauda AB, Ajadi A, Tola-Fabunmi AS, Akinwale AO. 2019. Waste production in aquaculture: Sources, components and managements in different culture systems. *Aquacult Fish* 4 (3): 81-88. DOI: 10.1016/j.aaf.2018.10.002.
- De-León-Herrera R, Flores-Verdugo F, Flores-de-Santiago F, González-Farías F. 2015. Nutrient removal in a closed silvofishery system using three mangrove species (*Avicennia germinans*, *Laguncularia racemosa*, and *Rhizophora mangle*). *Mar Pollut Bull* 91 (1): 243-248. DOI: 10.1016/j.marpolbul.2014.11.040.
- Dharmawan IWS, Siregar CA. 2008. Soil carbon and carbon estimation of *Avicennia marina* (Forsk.) Vierh. stand at Ciasem, Purwakarta. *Jurnal Penelitian Hutan dan Konservasi Alam* V (4): 317-328. [Indonesian]
- Eid EM, Shaltout KH. 2016. Distribution of organic carbon soil in the mangrove *Avicennia marina* (Forsk.) Vierh. along the Egyptian Red Sea coast. *Reg Stud Mar Sci* 3: 76-82. DOI: 10.1016/j.rsma.2015.05.006.
- Food and Agriculture Organization (FAO) of The United Nations. 1994. *Mangrove Forest Management Guidelines*. FAO, Rome.
- Gillerot L, Vlaminc E, Ryck DJRD, Mwasaru DM, Beeckman H, Koedam N. 2018. Inter and intraspecific variation in mangrove carbon fraction and wood specific gravity in Gazi Bay, Kenya. *Ecosphere* 9 (6): 1-17. DOI: 10.1002/ecs2.2306.
- Ginting ZA, Marunung TF, Sisillia L. 2017. Vegetation analysis in village forest areas in Nanga Yen Village, Hulu Gurung Sub-district, Kapuas Hulu District. *Sustain For* 5 (3): 713-720. DOI: 10.26418/jhl.v5i3.21464.
- Githaiga MN, Kotut K, Kariuki F, Kairo JG. 2020. Structure and biomass accumulation of natural mangrove forest at Gazi Bay, Kenya. *Bonorowo Wetl* 10 (1): 18-32. DOI: 10.13057/bonorowo/w100102.
- Hamran, Linda R, Lovadi I. 2014. Analysis of mangrove vegetation in Sebus Village, Paloh Sub-district, Sambas District. *Protobiont* 3 (2): 201-208.
- Harefa MS, Nasution Z, Mulya MB, Maksum A. 2019. The effort to maintain mangrove forest through the development of silvofishery pond. *Proceedings of the 1st International Conference on Social Sciences and Interdisciplinary Studies* 2019.
- Hastuti ED, Budihastuti R. 2016. Potential of mangrove seedling for utilization in maintenance of environment quality within silvofishery ponds. *Biotropia* 22 (1): 58-63. DOI: 10.11598/btb.2016.23.1.606.
- Hemati Z, Hossain M, Emenike CU, Rozainah MZ. 2015. Rate of carbon storage in soil of natural and degraded mangrove forest in Peninsular Malaysia. *Clean-Soil Air Water* 43 (4): 614-619. DOI: 10.1002/clen.201400034.
- Hong LC, Hemati ZH, Zakaria RM. 2017. Carbon stock evaluation of selected mangrove forest in Peninsular Malaysia and its potential market value. *Environ Sci Manag* 20 (2): 77-87.
- Hogarth P J. 2015. *The Biology of Mangroves and Seagrasses*. Third edition, Oxford University Press, United Kingdom.
- Hossain MD, Nuruddin AA. 2016. Soil and mangrove: A review. *J Environ Sci Technol* 9 (2): 198-207. DOI: 10.3923/jest.2016.198.207
- Ismail MH, Fuad MFA, Zaki PH, Jemali NJN. 2017. Analysis of importance value index of unlogged and logged peat swamp forest in Nenasi Forest Reserve, Peninsular Malaysia. *Bonorowo Wetl* 7 (2): 74-78. DOI: 10.13057/bonorowo/w070203.
- Kaiser D, Kowalski N, Böttcher ME, Yan B, Unger D. 2015. Benthic nutrient fluxes from mangrove sediments of an anthropogenically impacted estuary in Southern China. *J Mar Sci Eng* 3 (2): 466-491. DOI: 10.3390/jmse3020466.

- Kauffman JB, Cole TG. 2010. Micronesian mangrove forest structure and tree responses to a severe typhoon. *Wetlands* 30 (6): 1077-1084. DOI: 10.1007/s13157-010-0114-y.
- Kauffman JB, Donato DC. 2012. Protocols for the measurement, monitoring and reporting of structure, biomass, and carbon stocks in mangrove forests. Center for International Forestry Research. DOI: 10.17528/cifor/003749.
- Komiyama A, Pongpam S, Kato S. 2005. Common allometric equations for estimating the tree biomass of mangroves. *J Trop Ecol* 21: 471-477.
- Komiyama A, Ong JE, Pongpam S. 2008. Allometry, biomass, and productivity of mangrove forests: A review. *Aquat Bot* 89 (2): 128-137. DOI: 10.1016/j.aquabot.2007.12.006.
- Kridiborworn P, Chidthaisong A, Yuttitham M, Tripetchkul S. 2012. Carbon sequestration by mangrove forest planted specifically for charcoal production in Yeasarn, Samut Songkram. *J Sustain Energy Environ* 3: 87-92.
- Kurniadi R, Koeslulata. 2020. Short Communication: Willingness to participate in planting and protecting mangrove forest: community response related to mangrove fruit product utilization in Pariti, Timor Island, Indonesia. *Trop Dry* 4 (1): 1-4. DOI: 10.13057/tropdrylands/t040101.
- Kusmana C, Hidayat T, Tiryanita T, Rusdiana O, Istomo. 2018. Allometric models for above-and below-ground biomass of *Sonneratia* spp. *Global Ecol Conserv* 15: e00417. DOI: 10.1016/j.gecco.2018.e00417.
- Lawrence A. 2012. Blue Carbon A new concept for reducing the impacts of climate change by conserving coastal ecosystems in the Coral Triangle. WWF Australia. Queensland, Australia.
- Li N, Chen P, Qin C. 2015. Density, storage and distribution of carbon in mangrove ecosystem in Guangdong's Coastal Areas. *Asian Agric Res* 7 (2): 62-73. DOI: 10.22004/ag.econ.202107.
- Liu H, Ren H, Sharks D, Wang W, Liao B, Cao Q. 2014. Carbon stocks and potential carbon storage in the forest of China. *J Environ Manag* 133: 86-93. DOI: 10.1016/j.jenvman.2013.11.037.
- Malik A, Rahim A, Sideng U, Rasyid A, Jamaluddin J. 2019. Biodiversity assessment of mangrove vegetation for the sustainability of ecotourism in West Sulawesi, Indonesia. *AAEL Bioflux* 12 (4): 1458-1466.
- Murdiyarto D, Purbopuspito J, Kauffman JB, Warren MW, Sasmito SD, Donato DC, Manuri S, Krisnawati H, Taberima S, Kurnianto S. 2015. The potential of Indonesian mangrove forest for global climate change mitigation. *Nature Climate Change, Cifor*. DOI: 10.1038/NCLIMATE2734.
- Musa M, Mahmudi M, Arsad S, Buwono NR. 2020. Feasibility study and potential of pond as silvofishery in coastal area: Local case study in Situbondo Indonesia. *Reg Stud Mar Sci* 33: 100971. DOI: 10.1016/j.rsma.2019.100971.
- Njana MA, Eid T, Zahabu E, Malimbwi R. 2015. Procedures for quantification of belowground biomass of three mangrove tree species. *Wetlands Ecol Manag* 23 (4): 749-764. DOI: 10.1007/s11273-015-9417-3.
- Noraimy R, Mohd Hasmadi I, Norizah K, Pakhriazad HZ. 2014. Effect of skid trails on the regeneration of commercial tree species at Balah Forest Reserve, Kelantan, Malaysia. *Biodiversitas* 15 (2): 239-243. DOI: 10.13057/biodiv/d150218.
- Oddsson GV. 2020. A definition of aquaculture intensity based on production functions-the aquaculture production intensity scale (APIS). *Water* 12 (3): 765. DOI: 10.3390/w12030765.
- Ouyang X, Guo F. 2016. Paradigms of mangroves in treatment of anthropogenic wastewater pollution. *Sci Tot Environ* 544: 971-979. DOI: 10.1016/j.scitotenv.2015.12.013.
- Perez A, Machado W, Gutierrez D, Borges AC, Patchineelam SR, Sanders CJ. 2018. Carbon accumulation and storage capacity in mangrove sediments three decades after deforestation within a eutrophic bay. *Mar Pollut Bull* 126: 275-280. DOI: 10.1016/j.marpolbul.2017.11.018.
- Putz FE, Chan HT. 1986. Tree growth dynamics, and productivity in a mature mangrove forest in Malaysia. *For Ecol Manag* 17: 211-230. DOI: 10.1016/0378-1127(86)90113-1.
- Sari M, Hatta M, Permana A. 2014. Ecological status and development of silvofishery for increasing peoples economy (The Case of RPH-Tegal Tangkil, KPH Purwakarta, Blanakan Subang East Java). *Acta Aquat* 2 (1): 41-47.
- Serosero RH, Abubakar S, Hasan S. 2020. Distribution and community structure of mangrove in Donrotu, Guratu and Manomadehe islands, West Halmahera District, North Maluku. *Jurnal Ilmu dan Teknologi Kelautan Tropis* 12 (1): 151-166. DOI: 10.29244/jitkt.v12i1.26929 [Indonesian]
- Siarudin M, Rahman SA, Artati Y, Indrajaya Y, Narulita S, Ardha MJ, Larjavaara M. 2021. Carbon sequestration potential of agroforestry systems in degraded landscapes in West Java, Indonesia. *Forests* 12 (6): 714. DOI: 10.3390/f12060714.
- Siregar CA, Dharmawan IWS. 2009. Biomassa Karbon Pada Hutan Tanaman Mangrove. Laporan Hasil Penelitian. Pusat Penelitian Hutan dan Konservasi Alam, Bogor. [Indonesian]
- Sitoe AA, Mandlate LJC, Guedes BS. 2014. Biomass and carbon stocks of Sofala bay mangrove forests. *Forests* 5 (8): 1967-1981. DOI: 10.3390/f5081967.
- Soerianegara I, Indrawan A. 1998. *Ekologi Hutan Indonesia*. IPB, Bogor [Indonesian]
- Suwarto, Lahjie AM, Ruchaemi A, Simorangkir BDAS, Mulyadi F. 2015. Ecological aspect of non productive fishponds at Mahakam Delta area: revitalization with silvofishery system. *GJAR* 3 (1): 27-37.
- Tian Y, Chen G, Tang F, Zheng C, Ye Y. 2018. Effects of different types of nutrient effluent from shrimp ponds on the seedling growth of *Kandelia obovata*. *Acta Oceanol Sin* 37 (6): 112-120. DOI: 10.1007/s13131-018-1207-3.
- Widyastuti A, Yani E, Nasution EK, Rochmatino. 2018. Diversity of mangrove vegetation and carbon sink estimation of Segara Anakan Mangrove Forest, Cilacap, Central Java, Indonesia. *Biodiversitas* 19 (1): 246-252. DOI: 10.13057/biodiv/d190133.
- Wiwatthanapornchai S, Piputsitee C, Boonyawat S. 2014. The economic value of Laem Phak Bia mangrove ecosystem services in Phetchaburi Province, Thailand. *Modern Appl Sci* 8: 36-58. DOI: 10.5539/mas.v8n5p36.