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Estimated carbon stock of various mangrove zonation in Marsegu Island, West Seram, Maluku

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Abstract. This study aimed to determine the amount of carbon storage of various mangrove zonation formed on Marsegu Island, West Seram, Maluku. Marsegu Island is a Raised Coral Island which has 46.75% mangrove vegetation (112.29 ha) with the area of each zonation is 32.12 ha (proximal zone), 39.00 ha (middle zone) and 41.17 ha (distal zone). The calculation of stored carbon stocks of various mangrove zonation in Marsegu island used SNI guidelines (Indonesian National Standard) 7724:2011. Field measurements for estimation of forest carbon stocks (ground-based forest carbon accounting). The estimations of above-ground carbon stored in the proximal zone, middle zone and distal zone are as follows: 52.11 t/ha, 70.50 t/ha and 140.13 t/ha. Meanwhile, the below-ground (root) carbon storage is 10.62 t/ha, 13.48 t/ha and 24.36 t/ha. The potential amount of carbon of above and below ground plus dead trees and dead-wood (necromass), with estimation soil carbon storage up to 20 cm depth, are 234.07 t/ha for the proximal zone, 317.47 t/ha for middle zone and 406.58 t/ha for the distal zone. The estimated total carbon stock in Mangrove Forest of Marsegu Island is 36,637.02 tonnes.

1. Introduction

Climate change that occurs on earth affects many life aspects. Humans' efforts to reduce the damage caused by climate change are still continuing. Small islands are very vulnerable to climate change, especially the impact of sea level rise. It is estimated that many small islands are sinking due to sea level rise [1,2].

Sea level rise will cause changes in the structure and composition of vegetation species around the coastal areas, including mangroves that grow in small islands. The area of mangrove forests is predicted to shrink if the mangroves cannot adapt to the speed of sea level rise [3]. The width of the tidal zone factor will change with the occurrence of sea level. Although very vulnerable to sea level rise, mangrove forests provide great environmental services and benefits for coastal communities as it functions as high carbon storage [4,5]. Mangrove forest ecosystems are very productive with higher carbon storage compared to swamp forests, seagrass beds, tropical rainforests, boreal forests, and temperate forests [6,7].

Mangroves are woody plants that are able to survive and strengthen growth in a salty environment along tropical coastlines protected under the influence of wide tides [8]. In some areas, mangroves can also be found on shores protected from large waves, flat delta plains, and sandy or rocky coastlines



around small islands [4,9]. The adaptation response of mangroves to the surface height of seawater in a muddy coastal area has led to the formation of mangrove zonation. Zonation is an expression of the succession that occurs in mangroves and many mangrove studies around the world have interpreted zonation in the context of succession [8].

Marsegu Island is a raised coral island, meaning that there are mangrove plants that grow on the coral. The mangrove forest that grows on the coral islands of Marsegu appears to have characteristics with high salinity without river flow which can be divided into three zonations, namely proximal, middle, and distal [9]. Each zonation has a different vegetation structure and composition that affects the productivity differences occurring in the community [10].

This study aimed to: (1) calculate the potential carbon storage in each mangrove zonation on Marsegu Island. (2) find out the comparison of several carbon pools in each mangrove zonation on Marsegu Island. (3) estimate the potential of carbon stock in the mangroves of Marsegu Island which is classified in the raised coral island.

2. Methods

2.1. Research time and location

Field research was conducted in March 2020 on Marsegu Island, West Seram, Maluku. Marsegu Island is a protected forest area with an area of 240.24 ha and its waters are a Marine Nature Tourism Area, including a conservation area. Marsegu Island consists of several ecosystems including: Mangrove Forest, Rocky Secondary Forest, Beach Forest, and the *Imperata cylindrica* area [11].

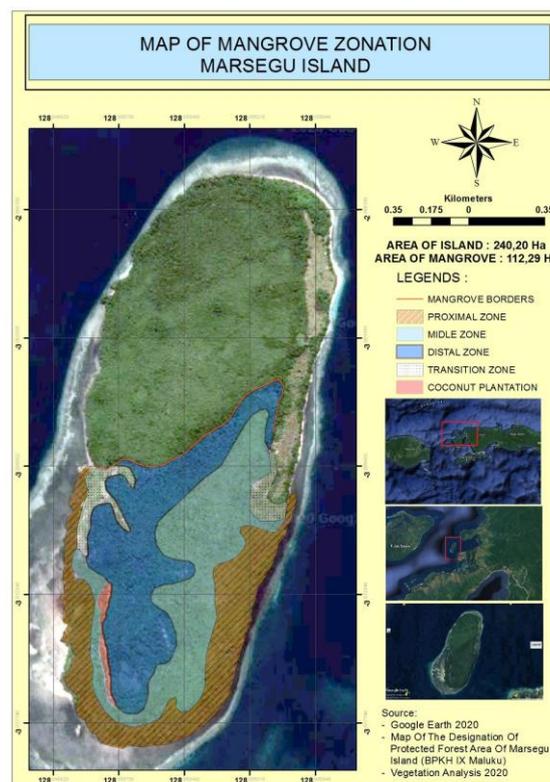


Figure 1. Map of mangrove zonation on Marsegu Island.

Mangrove forest located in the southern part of Marsegu Island is divided into three zonations, namely proximal zone, middle zone, and distal zone. The Proximal Zone is a mangrove area adjacent to the sea, next to the middle zone and the backward is the distal zone (figure 1). Each zonation has an area

as follows: proximal 32.12 ha, Middle 39.00 ha and distal 41.17 ha so that the total area of the Marsegu Island mangrove forest is 112.29 ha [9].

2.2. Growth stages and sample plots size

The growth stages and sample plots in the line transect method are shown in the figure 2, as follows:

- Trees $\varnothing \geq 20$ cm : 20m x 20m x 5 = 2,000 m² = 0.2 ha
- Poles $\varnothing \geq 10$ to <20 cm : 10m x 20m x 5 = 1,000 m² = 0.1 ha
- Saplings $\varnothing \geq 2$ to <10 cm : 10m x 10m x 5 = 500 m² = 0.05 ha
- Seedlings up to 1.5 m high : 2m x 2m x 5 = 20 m² = 0.002 ha

Observation of seedlings was used to determine natural regeneration and biodiversity in mangrove forests.

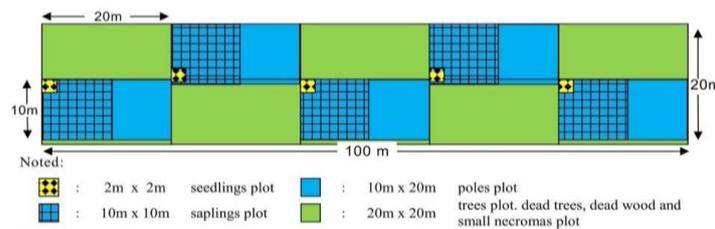


Figure 2. Sample plots size and design.

The azimuth points of the three lines transect sampling are as follows: proximal zone 3°00'57,1"S 128°03'18,2"E and 285° of direction; middle zone 3°00'55,8"S 128°03'12,9"E and 285° of direction; distal zone 3°00'26,2"S 128°03'12,1"E and 180° of direction. Plots design of soil organic carbon sampling, understorey and soil to calculate bulk density [12], are shown in the figure 3:

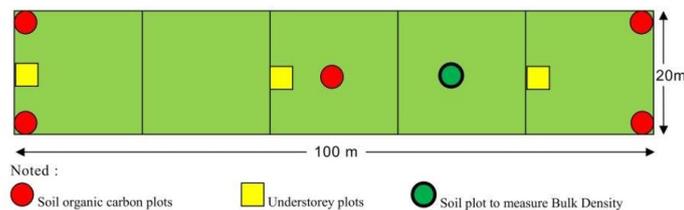


Figure 3. Soil and understorey sample plots.

2.3. Equipment and materials

The equipment used in the field study were: Garmin GPS Personal Navigator, compass, diameter tree tape, hagameter, roll meter, digital camera, caliper, analytical scale, *Eijkelpamp* soil drill, ring soil sampler, saw and machete. Data analysis and tabulation used Microsoft Office Excel software.

2.4. Measurement and calculation of carbon stocks

Measurement and calculation of stored carbon stocks of various mangrove zonation in Marsegu island used SNI guidelines (Indonesian National Standard) 7724:2011. Field measurements for estimation of forest carbon stocks (ground-based forest carbon accounting).

Measurement and calculation of forest carbon stocks were carried out in five carbon pools where biomass and organic matter are stored, namely above-ground biomass, below-ground biomass, dead-wood, litter, and soil organic matter. The measurement of litter in mangrove forests is not carried out because the tidal factor in sea water causes the measured litter not to come entirely from the mangrove stands at the location [13].

2.4.1. Measurement of above-ground biomass. Above-Ground Biomass (AGB) is all biomass of tree parts that live and grow above the ground including trunks, branches, twigs, leaves, flowers, and fruits that are usually expressed in kilograms (kg) or tonnes. The usual above-ground biomass is intended for

trees that store the largest forest carbon stocks and thus constitutes a very important carbon pool. Measurement of *tree life form* starting at saplings stage ($\varnothing \geq 2$ to <10 cm), poles ($\varnothing \geq 10$ to <20 cm), and trees ($\varnothing \geq 20$ cm). Afterwards, the trees' species are recorded and measured the diameter at breast height (DBH) [14].

The calculation of tree biomass used the allometric method according to the tree species with the equation in the table 1.

Table 1. Allometric by species for calculating AGB.

No	Mangrove Species	Allometric AGB	Equation in MS Excel	Source
1	<i>Bruguiera gymnorhiza</i> (L.) Lam.	$\log \text{AGB} = -0.552 + 2.244 * \log(D)$	$\text{AGB} = 10^{(-0.552 + 2.244 * \text{LOG}(D))}$	[15]
2	<i>Ceriops tagal</i> (Perr.) C.B.Rob.	$\text{AGB} = 0.168 \rho D^{2.471}$	$\text{AGB} = 0.168 * \rho * D^{2.471}$	[16]
3	<i>Rhizophora apiculata</i> Blume	$\log \text{AGB} = -1.315 + 2.614 * \log(D)$	$\text{AGB} = 10^{(-1.315 + 2.614 * \text{LOG}(D))}$	[17]
4	<i>Rhizophora mucronata</i> Lam.	$\text{AGB} = 0.045 * D^{2.868}$	$\text{AGB} = 0.045 * (D)^{2.868}$	[18]
5	<i>Rhizophora stylosa</i> Griff.	$\text{AGB} = 0.045 * D^{2.868}$	$\text{AGB} = 0.045 * (D)^{2.868}$	[18]
6	<i>Xylocarpus granatum</i> J. Koenig	$\log \text{AGB} = -0.763 + 2.23 * \log(D)$	$\text{AGB} = 10^{(-0.763 + 2.23 * \text{LOG}(D))}$	[19]
7	<i>Xylocarpus moluccensis</i> (Lam.) M.Roem.	$\log \text{AGB} = -0.763 + 2.23 * \log(D)$	$\text{AGB} = 10^{(-0.763 + 2.23 * \text{LOG}(D))}$	[19]

Noted: D = Diameter, ρ = Wood Density <http://db.worldagroforestry.org/>.

2.4.2. Measurement of dead trees biomass. Necromass is a part of a dead tree that is either standing upright or falling on the not-yet-rotted ground, including stumps, branches, and twigs [20]. This study used the terms of large necromass and small necromass. Large necromass are dead trees and dead-wood that have a diameter of ≥ 10 cm, while small necromass have a diameter of >5 to <10 cm.

The dead tree biomass calculation used the allometric equation of the diameter at breast height and multiplied by the correction factor for the integrity stage of the dead tree, which are 0.7; 0.8 and 0.9 [13]. The shape of the tree integrity stage and the correction factors are seen in the figure 4:

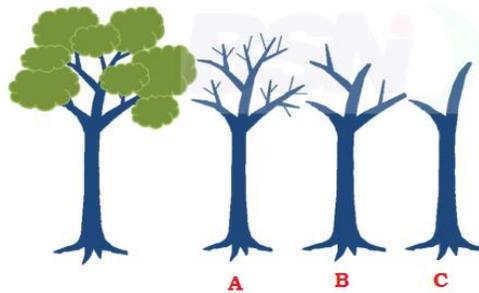


Figure 4. The stages of dead tree integrity.

where:

- A. Tree integrity stage with a correction factor of 0.9 (Dead tree without leaves).
- B. Tree integrity stage with a correction factor of 0.8 (Dead tree without leaves and twigs).
- C. Tree integrity stage with a correction factor of 0.7 (Dead tree without leaves, branches and twigs).

2.4.3. Measurement of deadwood biomass. Dead-wood is wood lying on the ground, dead roots, and stumps with a diameter of ≥ 10 cm. Deadwood biomass calculations are carried out by measuring the diameter of the base, end and length of the deadwood. Furthermore, it is calculated using a modification of the Brereton and Hairiah equations [13,21], as follows:

$$B_{dw} = 0,25\pi \left[\frac{db+de}{2 \times 100} \right]^2 \times l \times \rho \times \% \text{ decomposition} \quad (1)$$

where:

- B_{dw} : biomass of deadwood; l : length of deadwood;
- db : diameter of the base;
- de : diameter of the end;

π : 22/7 or 3.14

ρ : deadwood density (kg/m^3), Usually deadwood density about 0.4 g/cm^3 (400 kg/m^3), however, depending on the level of decomposition. The higher the level of wood decay, the lower the wood density

2.4.4. Measurement of small necromass biomass. Measurement of small necromass biomass ($\varnothing > 5$ to < 10 cm) used direct weighing by collecting all deadwood on a 20×20 m sub-plot and taking a 300 gram sample for carbon content analysis in the laboratory. Testing the sample of carbon content was carried out at The Biochemistry laboratory of Universitas Pattimura.

2.4.5. Measurement of soil organic carbon. Measurement of soil organic carbon (SOC) content in mangrove areas was conducted by taking soil samples at five points, the four plot angles and one point in the middle of the plot. Soil sampling was taken with the composite method using an *Eijkelkamp* soil drill by mixing soil samples from the five soil sample points at a depth of 20 cm. Soil samples were taken to calculate Bulk Density using a ring soil sampler. Analysis of the percentage of carbon in soil samples was carried out at the Laboratory of the Center for Agricultural Technology Studies (BPTP) South Sulawesi. Soil carbon calculation used the following formula [13]:

$$C_s = D_s \times \rho \times \%C_{\text{organic}} \quad (2)$$

where:

C_s : soil carbon content (g/cm^2);
 D_s : soil sampling depth (cm);
 ρ : bulk density (g/cm^3);
 $\%C_{\text{organic}}$: percentage of carbon content.

2.4.6. Measurement of below-ground biomass. Below-Ground Biomass (BGB) is the biomass from the roots of living trees to a size greater than 2 mm. Roots smaller than 2 mm in diameter are often overlooked because they cannot be distinguished from soil organic matter or litter.

Root stem ratio is the ratio between root biomass and above-ground biomass (AGB). The equation for obtaining the root biomass estimation (*Root biomass density*) used equation [22] as follows:

$$RBD = EXP [-1.0587 + 0.8836 \times LN(AGB)] \quad (3)$$

where:

RBD : Root Biomass / BGB (tonnes/ha), AGB : Above-Ground Biomass (tonnes/ha).

3. Results and discussion

Mangrove growth and development depends on the age of the vegetation community which determines the level of productivity. At the beginning of establishing themselves in coastal areas or in the succession stage, mangrove plants have a slightly large diameter [8]. At the final stage of the succession, there are larger trees with a greater mix of species compared to the initial stage of succession. The appearance of a succession of mangrove plants can be seen in the growth zones formed, such as the proximal zone, middle zone and distal zone. Zonation in mangrove forests is an expression of succession stage changes that have occurred [8].

3.1. Above-ground biomass (AGB)

The proximal zone is the area adjacent to the sea which is dominated by the poles stage ($\varnothing \geq 10$ to < 20 cm) from a mixture of *Rhizophora stylosa* and *Rhizophora mucronata* with a density of 820 poles per hectare (AGB of 66,243 kg/ha). The middle zone begins to be dominated by tree stage ($\varnothing \geq 20$ cm) by *Bruguiera gymnorhiza*, *Rhizophora apiculata*, *Ceriops tagal*, and *Xylocarpus granatum* with a density of 105 trees per hectare (AGB of 70,900 kg/ha). The distal zone is dominated by the tree stage by *Bruguiera gymnorhiza*, *Ceriops tagal*, *Rhizophora apiculata*, and *Xylocarpus moluccensis* with a density of 300 trees per hectare (AGB of 212,270 kg / ha).

The number of trees per hectare and above-ground biomass for each mangrove zonation are shown in the table 2.

Table 2. Above-ground biomass (AGB) for each mangrove zonation.

Mangrove Zonation	Saplings		Poles		Trees		Total kg/ha
	$\text{Ø} \geq 2$ to < 10 cm		$\text{Ø} \geq 10$ to < 20 cm		$\text{Ø} \geq 20$ cm		
	N/ha	kg/ha	N/ha	kg/ha	N/ha	kg/ha	
Proximal	1,120	13,322	820	66,243	115	31,299	110,864
Middle	2,920	28,991	530	50,105	105	70,900	149,996
Distal	2,620	23,834	610	62,046	300	212,270	298,151

The highest AGB was in the distal zone of 298,151 kg/ha, then the middle zone of 149,996 kg/ha and the lowest was the proximal zone of 110,864 kg/ha. More trees density with large diameters in the distal zone causes the highest AGB when compared to the middle and proximal zones.

3.2. Below-ground biomass (BGB)

Below-ground biomass is the biomass of all living roots with a diameter of > 2 mm for each zonation are shown in the table 3.

Table 3. Below-ground biomass for each zonation.

Mangrove Zonation	Saplings (kg/ha)	Poles (kg/ha)	Trees (kg/ha)	Total (kg/ha)
Proximal	3,351	13,619	5,625	22,595
Middle	7,416	10,099	11,161	28,677
Distal	6,154	12,459	33,226	51,838

The highest BGB was in the distal zone of 51,838 kg/ha, then the middle zone was 28,677 kg/ha and the lowest was the proximal zone of 22,595 kg/ha. The highest BGB has the same yield pattern as AGB because BGB was an allometric calculation of AGB.

3.3. Biomass of dead tree, dead-wood, and small necromass

In the proximal zone line transect, there were no dead trees standing upright since they had fallen and classified as dead-wood. In the middle and distal zones, there were found dead tree biomass of 77,855 kg/ha and 77,414 kg/ha, are shown in the table 4.

Table 4. Biomass of dead tree and wood (kg/ha).

Mangrove Zonation	Dead Trees (kg/ha)	Dead-Wood (kg/ha)
Proximal	-	137
Middle	77,855	6,110
Distal	76,414	4,183

The highest dead-wood biomass value was in the middle zone (6,110 kg/ha), while the lowest was in the proximal zone (137 kg/ha). The high dead-wood biomass in the middle zone was the result of tree cutting carried out by the community, but the dead-wood biomass in the distal zone (4,183 kg/ha) came from old trees that died naturally.

The value of small necromass biomass was the result of weighing the small necromass in the sub-plot multiplied by the density of the sample analyzed in the laboratory. Small necromass biomass per hectare is completely shown in the table 5.

Table 5. Biomass of small necromass.

Mangrove Zonation	Weight of Small Necromass (kg/ha)					Average (kg/ha)	Dry/Wet Weight of Sample	Biomass (kg/ha)
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5			
Proximal	264	277	508	464	449	392	0.66	259
Middle	326	396	500	653	423	460	0.69	316
Distal	376	523	322	580	608	482	0.72	345

3.4. The presence of seedlings and understorey in various mangrove zonation

The presence of seedlings as regeneration determines the regeneration of mangrove forests to grow and develop in the future. The species of seedlings found in the proximal zone were *Bruguiera gymnorhiza* and *Rhizophora stylosa* with a density of 1,500 seedlings/ha. The middle zone had a higher seedling density, namely 11,000 seedlings/ha of the *Bruguiera gymnorhiza* and *Ceriops tagal* species. Whereas for the distal zone, only *Bruguiera gymnorhiza* species were found with a density of 2,000 seedlings/ha.

The understorey was not found in the predetermined research plot transect since vegetation was difficult to grow in flooding and tick mud conditions. In addition, the canopy cover factor in the distal zone and the tight of mangrove stilt roots in the proximal zone dominated the growing area. The middle zone had a canopy gap due to tree cutting, but the area was inundated with muddy soil thus there was no understorey but seedlings were found. The presence of understorey can be found in drier and more open soil conditions where *Acrostichum speciosum* is growing. The understorey is one of the components of the pool above-ground biomass, but the carbon content is very small compared to trees. In certain forest types, understorey can be ignored [23].

3.5. Carbon stocks of above and below ground

The carbon content obtained from above-ground and below-ground biomass multiplied by the carbon percentage of 0.47 [13] are shown in the table 6.

Table 6. Carbon stocks of above and below ground.

Mangrove Zonation	Biomass (kg/ha)		Carbon (%)*	Carbon Stocks (kg/ha)	
	Above Ground	Below Ground		Above Ground	Below Ground
Proximal	110,864	22,595	47.00	52,106	10,620
Middle	149,996	28,677	47.00	70,498	13,478
Distal	382,843	62,893	47.00	179,936	29,560

Noted : * SNI 7724:2011.

The highest above-ground carbon stock was in the distal zone of 179,936 kg/ha followed by carbon stock in the middle zone of 70,498 kg/ha and the lowest was in the proximal zone of 52,106 kg/ha. Similarly, the highest below-ground was in the distal zone of 29,560 kg/ha followed by carbon stock in then the middle zone of 13,478 kg/ha and the lowest was in the proximal zone of 10,620 kg/ha.

3.6. Carbon stocks of dead trees, dead-wood, and small necromass

The carbon stocks obtained from dead trees and wood biomass (large biomass) multiplied by the carbon percentage of 0.47 [13] are shown in the table 7.

Table 7. Carbon stocks of dead trees and wood.

Mangrove Zonation	Biomass (kg/ha)		Carbon (%)*	Carbon stocks (kg/ha)		
	Dead tree	Dead-wood		Dead trees	Dead-wood	Total
Proximal	-	137	47.00	-	64	64
Middle	77,855	6,110	47.00	36,592	2,872	39,464
Distal	76,414	4,183	47.00	35,914	1,966	37,881

Noted : * SNI 7724:2011.

The highest carbon stock of dead trees and wood was in the middle zone, namely 39,464 kg/ha. The distal zone contained carbon from dead trees and wood of 37,881 kg/ha, came from old trees that had died. The carbon stock of small necromass from direct weighing in the field was multiplied by the carbon content percentage from the analysis of the Biochemistry laboratory of Universitas Pattimura. The calculation can be seen in the table 8. The largest carbon stock of small necromass was in the distal zone of 77 kg/ha followed by carbon stock in the middle zone of 64 kg/ha and the smallest was in the proximal zone of 38 kg/ha.

Table 8. Carbon stock of small necromass.

Mangrove Zonation	Small Necromass (kg/ha) Ø>5 to < 10 cm	Carbon (%)**	Carbon stocks (kg/ha)
Proximal	259	14,60	38
Middle	316	20,13	64
Distal	345	22,40	77

Noted : ** Analysis of the Biochemistry Laboratory of Universitas Pattimura.

3.7. Soil organic carbon (SOC)

Organic material in mangrove soil is the result of the decomposition of dead trees, trunks, twigs, and leaves that are buried under the soil surface. The older the mangrove forest is, the more organic material is stored and buried in it. Soil organic matter becomes a source of macro and micro nutrients for tree growth and other organisms.

Soil fertility depends on the biological, physical, and chemical properties that are formed and processed in the soil. The process of soil development in mangrove areas is also influenced by several factors, such as salinity and limited oxygen levels in flooding. Soil carbon stock of each mangrove zonation can be seen in the table 9.

Table 9. Soil organic carbon in various mangrove zonation.

Mangrove Zonation	Bulk Density (g/cm ³)	Soil Depth (cm)	Carbon (%) ***	SOC (g/cm ²)	SOC (t/ha)
Proximal	0.4648	20	18.42	1.71	171.25
Middle	0.5055	20	19.18	1.94	193.91
Distal	0.5520	20	18.49	2.04	204.13

Noted : *** Analysis of BPTP laboratory Sulawesi Selatan.

The highest soil organic carbon at a depth of 0-20 cm was in the distal zone. Weathering of organic matter that settles, accumulates, and is confined with weak currents is difficult to bring out into the open seas. The estimated soil carbon stock for the depth of 20 cm per zonation is as follows 171.25 t/ha (proximal), 193.91 t/ha (middle), and 204.13 t/ha (distal). This carbon potential will be even higher if calculated with a soil depth of more than 20 cm.

3.8. Carbon stock of various mangrove zonation in Marsegu Island

The total carbon stock of all calculated mangrove carbon pools shows that soil is the largest store of carbon. The second rank is the above-ground (trees), followed by dead trees, below-ground (roots), dead-wood, and small necromass. The comparison of carbon stock per hectare for each pool of various zonation shown in the figure 5.

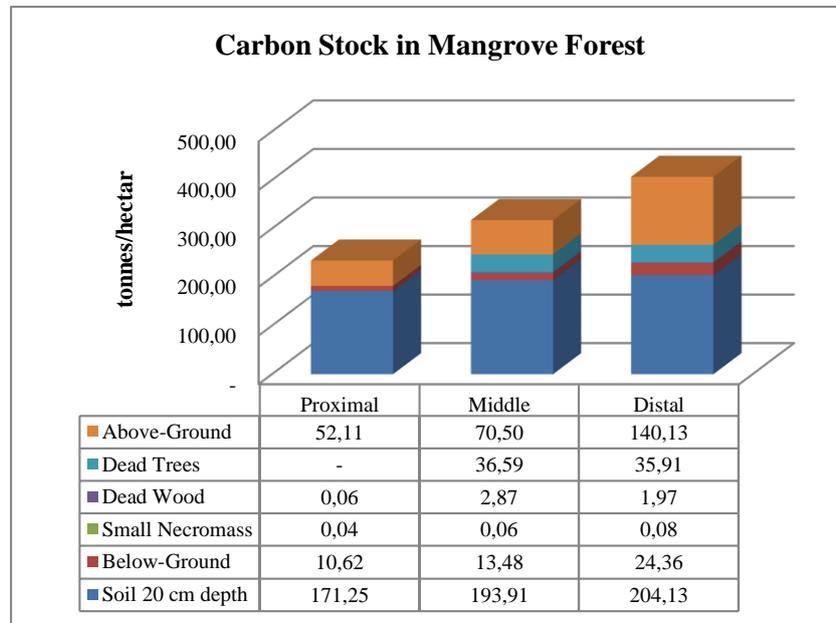


Figure 5. Carbon stock in mangrove forest (t/ha).

The highest carbon stock per hectare is in the distal zone of 406.58 t/ha followed by carbon stock in the middle zone of 317.42 t/ha and proximal zone of 234.07 t/ha, are shown in the table 10. This shows that the distal zone is the area with the last succession stage. The more trees and organic matter accumulation in the soil, the greater the carbon stock in the zone is.

Table 10. Carbon stock of various mangrove zonation in Marsegu Island.

Mangrove Zonation	Carbon Stock (t/ha)	Area of Mangrove (ha)	Carbon Stock (tonnes)
Proximal	234.07	32.12	7,518.42
Middle	317.42	39.00	12,379.49
Distal	406.58	41.17	16,739.12
Total		112.29	36,637.02

Carbon stock according to the zonation area of mangrove forests are as follows: 7,518.42 tonnes in the proximal zone, 12,379.49 tonnes in the middle zone, and 16,739.12 tonnes in the distal zone. The total estimated carbon stock of mangrove forests on Marsegu Island was 36,637.02 tonnes.

4. Conclusions

- The highest above-ground carbon stock was in the distal zone of 140,131 kg/ha followed by carbon stock in the middle zone of 70,498 kg/ha and the lowest was in the proximal zone of 52,106 kg/ha. Similarly, the highest below-ground was in the distal zone of 24,364 kg/ha followed by carbon stock in then the middle zone of 13,478 kg/ha and the lowest was in the proximal zone of 10,620 kg/ha.
- The highest carbon stock of dead trees and wood was in the middle zone, namely 39,464 kg/ha. The distal zone contained carbon from dead trees and wood of 37,881 kg/ha, came from old trees that had died.

- The largest carbon stock of small necromass was in the distal zone of 77 kg/ha followed by carbon stock in the middle zone of 64 kg/ha and the smallest was in the proximal zone of 38 kg/ha.
- The estimated soil carbon stock for the depth of 20 cm per zonation is as follows 171.25 t/ha (proximal), 193.91 t/ha (middle), and 204.13 t/ha (distal). This carbon potential will be even higher if calculated with a soil depth of more than 20 cm.
- The total carbon stock of all calculated mangrove carbon pools shows that soil is the largest store of carbon. The second rank is the above-ground (trees), followed by dead trees, below-ground (roots), dead-wood, and small necromass.
- Carbon stock according to the zonation area of mangrove forests are as follows: 7,518.42 tonnes in the proximal zone, 12,379.49 tonnes in the middle zone, and 16,739.12 tonnes in the distal zone. The total estimated carbon stock of mangrove forests on Marsegu Island was 36,637.02 tonnes.

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References

- [1] Walshe R A and Stancioff C E 2018 Small island perspectives on climate change *Island Studies Journal* **13** (1) 13-24
- [2] Kelman I 2018 Islandness within climate change narratives of small island developing states (SIDS) *Island Studies Journal* **13** (1) 149-166
- [3] Murdiyarto D, Purbopuspito J, Kauffman J B, Warren M W, Sasmito S D, Donato D C, Manuri S, Krisnawati H, Taberima S and Kurnianto S 2015 The potential of Indonesian mangrove forests for global climate change mitigation *Nature Climate Change* **5** (12) 1089-1092
- [4] Costa M T, Salinas-de-León P and Aburto-Oropeza O 2019 Storage of blue carbon in isolated mangrove forests of the Galapagos' rocky coast *Wetlands Ecology and Management* **27** (4) 455 – 463
- [5] Paembonan S A, Bachtiar B and Ridwan M 2020 Sustainable forest management through natural mangrove regeneration on Pannikiang Island, South Sulawesi *IOP Conference Series: Earth and Environmental Science* Vol. **486** (1) p 012082
- [6] Alongi D M 2012 Carbon sequestration in mangrove forests *Carbon Management* **3** (3) 313-322
- [7] Alongi D M 2014 Carbon cycling and storage in mangrove forests *Annual Review Of Marine Science* **6** 195-219
- [8] Snedaker S C 1982 Mangrove species zonation: why? *Contributions to the Ecology of Halophytes* (Dordrecht: Springer) pp 111-125
- [9] Irwanto I, Paembonan S A, Oka N P and Maulany R I 2020 Growth characteristics of the mangrove forest at the raised coral island of Marsegu, West Seram, Maluku *International Journal of Innovative Science and Research Technology (IJISRT)* **5** (10) 211-219
- [10] Jennerjahn T C, Gilman E, Krauss K W, Lacerda L D, Nordhaus I and Wolanski E 2017 Mangrove ecosystems under climate change *Mangrove ecosystems: a global biogeographic perspective* (Cham: Springer) pp 211-244
- [11] Irwanto I 2014 *Pulau Marsegu. Studi Ekologi. Pengelolaan Pulau Kecil Kabupaten Seram Bagian Barat Provinsi Maluku* (Ambon: Badan Penerbit Fakultas Pertanian Universitas Pattimura)
- [12] Rusolono T, Tiryana T, Purwanto J and Sumantri H 2015 *Panduan Survei Cadangan Karbon dan Keanekaragaman Flora di Sumatera Selatan* (Palembang: GIZ Biodiversity and Climate Change (BIOCLIME) Project Deutsche Gesellschaft für Internationale Zusammenarbeit)
- [13] BSN 2011 *Pengukuran dan Penghitungan Cadangan Karbon–Pengukuran Lapangan untuk*

- Penaksiran Cadangan Karbon Hutan (Ground Based Forest Carbon Accounting)* (Jakarta Pusat: Badan Standarisasi Indonesia SNI, 7724)
- [14] Manuri S, Putra C A S and Saputra A D 2011 *Tehnik Pendugaan Cadangan Karbon Hutan* (Palembang: Merang REDD Pilot Project, German International Cooperation–GIZ)
- [15] Krisnawati H, Adinugroho W C, Dharmawan I W S and Imanuddin R 2012 Allometric models for estimating above ground biomass of *Bruguiera gymnorrhiza* L. (Lamk.) at Kubu Raya mangrove forest, Indonesia (Manuscript)
- [16] Chave J, Andalo C, Brown S, Cairns M A, Chambers J Q, Eamus D, Folster H, Fromard F, Higuchi N, Kira T, Lescure J P, Nelson B W, Ogawa H, Puig H, Riera B and Yamakura T 2005 Tree allometry and improved estimation of carbon stocks and balance in tropical forests *Oecologia* **145** 87–99
- [17] Amira S 2008 *Pendugaan Biomassa Jenis Rhizophora apiculata Bl. di Hutan Mangrove Batu Ampar Kabupaten Kubu Raya, Kalimantan Barat* Skripsi (Bogor: Fakultas Kehutanan Institut Pertanian Bogor)
- [18] Gevana D and Im S 2016 Allometric models for *Rhizophora stylosa* Griff. in dense monoculture plantation in the Philippines *Malaysian Forester* **79** (1&2) 39-53
- [19] Talan M A 2008 *Persamaan Penduga Biomasa Pohon Jenis Nyirih (Xylocarpus granatum Koenig. 1784) dalam Tegakan Mangrove Hutan Alam Di Batu Ampar, Kalimantan Barat*. Skripsi (Bogor: Departemen Konservasi Sumberdaya Hutan, Fakultas Kehutanan, Institut Pertanian Bogor)
- [20] Hairiah K and Rahayu S 2007 *Pengukuran karbon tersimpan di berbagai macam penggunaan lahan* (Bogor: World Agroforestry Centre - ICRAF) p 77
- [21] Hairiah K, Ekadinata A, Sari R R and Rahayu S 2011 *Pengukuran Cadangan Karbon: dari Tingkat Lahan ke Bentang Lahan Petunjuk Praktis Edisi Kedua* (Bogor: World Agroforestry Centre – ICRAF) pp 1-88
- [22] Cairns M A, Brown S, Helmer E H and Baumgardner G A 1991 Root biomass allocation in the world's upland forests *Oecologia* **111**(1) 1-11
- [23] Penman J, Gytarsky M, Hiraishi T, Krug T, Kruger D, Pipatti R, Buendia L, Miwa K, Ngara T, Tanabe T and Wagner F 2003 *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (Hayama, Kanagawa: The Institute for Global Environmental Strategies (IGES) for the IPCC)