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Short Communication: Diversity, biomass, and carbon stock of seagrass community in three coastal waters of Minahasa Peninsula, North Sulawesi, Indonesia

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Abstract. *Wagey BT, Paruntu C, Lasabuda R, Kambey A. 2023. Short Communication: Diversity, biomass, and carbon stock of seagrass community in three coastal waters of Minahasa Peninsula, North Sulawesi, Indonesia. Biodiversitas 24: 1793-1798.* Seagrasses are well-known for their ecological and economic importance. However, just like any other ecosystem, seagrass meadows around the world are threatened by anthropogenic activities. This paper aimed to analyze the seagrass abundance (expressed as shoot density), richness, diversity, biomass, and carbon stocks in three locations in the Minahasa Peninsula of North Sulawesi, Indonesia. Transect survey techniques were conducted in Bajo, Bolsel and Bunaken. The study recorded 8 species across the three locations with Bolsel having the highest number of species (7), followed by Bajo (6) and Bunaken (4). Seagrass species differed significantly in terms of shoot density across the sampling locations in which denser shoots were observed for the eelgrass (*Enhalus acoroides*) at Bolsel while the other two species (*Thalassia hemprichii* and *Cymodocea rotundata*) were least abundant at the Bunaken site. Seagrass cover did not vary significantly between sites. With the exception of Bunaken, above-ground and below-ground biomasses, as well as carbon stock, did not differ among locations. The lower species diversity as well as above-ground biomass and carbon stocks in Bunaken were likely due to grazing by herbivores (e.g., fish and sea urchins) and tourism activities (e.g., boat traffic, diving, snorkeling). Grazing effects and human tourism activities should be included in future investigations to monitor the dynamics of seagrass biomass and carbon stocks in the area. This study provides baseline information that can be used to better manage the seagrass ecosystems, not only in the Minahasa Peninsula but in Indonesian waters and even beyond.

Keywords: Biomass, carbon stock, coverage, Minahasa, seagrass, Sulawesi

INTRODUCTION

Seagrass is an aquatic flowering plant that plays a key role in the coastal ecosystem. The ecological as well as the economic benefits of seagrass meadows cannot be undermined (McKenzie et al. 2021). They have biological productivity equivalent to that of other aquatic systems (Cullen-Unsworth 2014). Seagrass meadows also serve as nursery and foraging grounds for many commercially important marine fishes and invertebrates (Unsworth 2019). Other ecological functions of seagrass beds include nutrient cycling, bottom water stabilization, sediment trapping, and erosion barriers (Christianen et al. 2023).

Globally, there are about 600,000 km^2 of seagrass meadows (Mazarrasa et al. 2015) of which Indonesia has about 8,812.9 km^2, about 1.5% of the global seagrass meadows and 24% of Southeast Asia (Fortes et al. 2018). Indonesia is a significant part of the center of global marine biodiversity known as the Coral Triangle, which comprises Indonesia, Malaysia, Papua New Guinea, Philippines, Solomon Islands, and Timor-Leste and covers an area of 5.7 million km^2 of the Pacific Ocean (Asaad et al. 2018). For example, of the 150 families of fish in the Coral Triangle, the majority are found in Indonesia (Al-Asif et al. 2022). Unfortunately, many marine ecosystems in Indonesia, including the seagrass meadows, are increasingly threatened because of unregulated human activities (Unsworth et al. 2018). Like anywhere else in the world, several human activities exist as a threat to seagrasses (Brodie et al. 2020), including the proliferation of macro-and microplastics (Bonanno and Bonaca 2020). Several studies (e.g., Lasut et al. 2018) highlighted this problem by stating that the Coral Triangle has become the 'Trash Triangle'. Two countries located in the Coral Triangle (i.e., Indonesia and the Philippines) are among the top polluters of plastics in the ocean (along with China as the top 3), largely due to their large human population and low-quality waste management systems (Jambeck et al. 2015). Seagrasses are known to trap large plastic debris, making them plastic sinks in the ocean (Unsworth et al. 2021; Sanchez-Vidal et al. 2021). There is early evidence that microplastics and nanoplastics affect the physiology and growth of seagrasses (Menicagli et al. 2022). The other threats to seagrass include sedimentation and eutrophication, which the effects can be amplified by global warming (Pazzaglia et al. 2020).

According to Wagey (2018), while numerous studies on seagrass biology and ecology have been conducted in Indonesian waters, there appears to be a general paucity in terms of more recent but specialized studies that can be used to highlight the role of Indonesian seagrass meadows as part of the world's carbon sink. Although one recent study (Tilaar et al. 2019) emphasized the significance and role of seagrasses as carbon sinks in Sulawesi and the rest of the Indonesian archipelago, quantifying and monitoring parameters for calculating seagrass carbon stocks on a large spatial scale in Indonesia remains a massive task. Seagrass meadows are one component of what is termed BCE or Blue Carbon Ecosystem along with mangroves and tidal marshes due to their significant role as a carbon sink by sequestering atmospheric carbon dioxide (Beaumont et al. 2014; Duarte and Krause-Jensen 2017). Because of their importance, monitoring relevant seagrass biological aspects, like diversity, abundance, growth, and productivity, will be extremely beneficial to inform the ecological health and integrity of seagrass meadows. Monitoring the health of the seagrass ecosystem is also important for assessing the potential impacts of any coastal developments (Cullen-Unsworth and Unsworth 2016), such as coastal engineering infrastructures, to better inform the public and policymakers (Fortes et al. 2018; Hyder et al. 2015).

Asaad et al. (2018) have delineated the marine bioregion of Indonesia and stated that the northern tip of Sulawesi Island is among the top priority areas for conservation. Based on such rationale, this paper is aimed to provide a more comprehensive assessment of the seagrass abundance (expressed as shoot density), richness, diversity, biomass, and carbon stocks in three locations in the Minahasa Peninsula of North Sulawesi, Indonesia. We expected the results of this study might serve as baseline data for monitoring purposes in the future and be used to develop management strategies aimed at conserving the seagrass ecosystems not only in the study area but even beyond Indonesian waters.

MATERIALS AND METHODS

Study area

Sampling of seagrasses was done at three stations in the Minahasa Peninsula, North Sulawesi, Indonesia (Figure 1). Specific sampling locations, as marked with a hand-held GPS (Yucom trek 100G), are as follows: Bunaken (1.601700°N; 124.769045°E); Bajo (1.269328°N; 124.561811°E); and Bolsel (0.398477°N; 124.276285°E). These sampling locations were pre-selected based on prior knowledge in these areas, such as similarity in the extent of seagrass coverage and general benthic components (sandy-muddy). These sites also represented two seas (Celebes and Molucca seas). The station in Bunaken is located within the tourist destination and a protected marine park (Bunaken National Park).

Data collection procedure

Physico-chemical parameters

Prior to sampling, the following physico-chemical parameters were measured in situ with the use of a multi-parameter water quality monitoring device (HORIBA U50 series) between 14 August to 10 December 2022: temperature of the water, pH of the water; turbidity; dissolved oxygen (DO), and salinity.

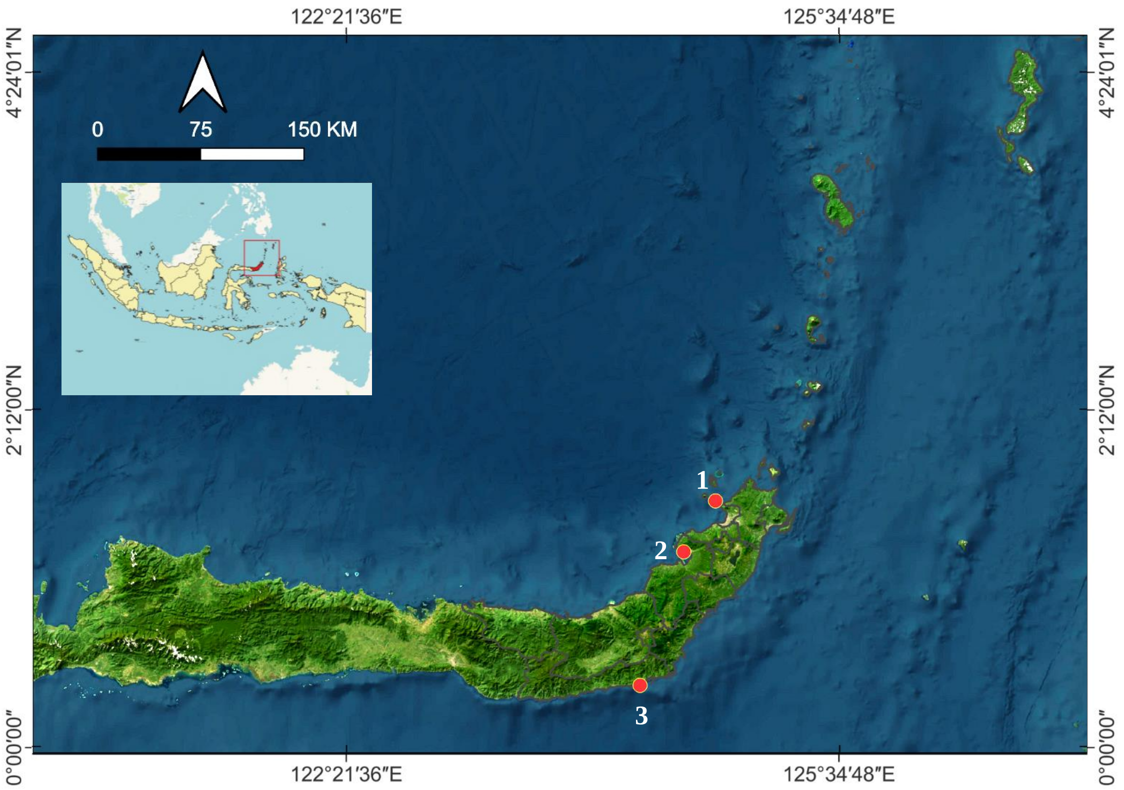

Figure 1. Location of the sampling stations in the Minahasa Peninsula, North Sulawesi, Indonesia. 1. Bunaken, 2. Bajo, 3. Bolsel

Seagrass sampling

The field procedures described by Inving et al. (2013) and Wagey (2019) were used to collect seagrass samples. Three 50-m transect lines were laid perpendicular to the shoreline at each sampling site, and coordinates were recorded using a Garmin® GPS (Geographic Positioning System) device. In each transect, six square quadrats with size 1 m^2 each were randomly placed (resulting in a total of 33 quadrats per location and 99 quadrats for all locations), and seagrass coverage (%) and the total count of shoots of each species was recorded. Photographs were also taken, especially for samples requiring species identification verification. Species identification was based on taxonomic references that were available (El Shaffai 2016; BFAR 2022).

Each quadrat's seagrass samples were cleaned of epiphytes, sediments, and debris. They were then separated into species and above-ground and below-ground parts for further laboratory processing and analysis. A portable electronic balance was used to measure wet weight (nearest grams) (AND EJ 610).

Determination of biomass and carbon

At the laboratory, samples collected from each quadrat (separated into above-ground and below-ground categories) were air-dried for a minimum of five days before being oven-dried at 60°C for 1 day (24 hours). For determining the biomass, the oven-dried samples were weighed on an analytical balance. This study used the LOI (lost on ignition) method, as described in previous studies, to determine the total carbon of the samples (g C m^{-2}) (Kondoy 2017; Hulopi et al. 2017).

Data analysis

One-Way Analysis of Variance (ANOVA) or Kruskal-Wallis test was applied to test the difference in physico-chemical parameters between the sampling stations using R statistical software (R Core Team, 2020). The parametric One-Way ANOVA was used to test for significance in shoot density. Prior to analysis, data were subjected to normality tests with the Shapiro-Wilk test, QQ-plot, and outliers with the boxplot using ggplot2 in R. To qualify for the parametric test, data were log-transformed if the variable violated the normality assumptions. Because the quadrat-level shot density data contains 0s, the entire dataset was log(x+1) transformed to conform to the ANOVA parametric assumptions.

The community structure for each site was measured using diversity measures: species richness (number of species and using Margalef's richness index), diversity (Shannon-Weiner Index), and Simpson's dominance index. The three indices were calculated as follows:

Margalef's Richness Index (D):

$$D = \frac{s-1}{\ln N}$$

Where: s refers to the number of species per transect; N is the number of individuals per transect; ln - natural logarithm

Shannon-Weiner Diversity Index (H'):

$$H' = \sum_{i-1}^{N} pi \ln pi$$

Where: *pi* refers to the proportion of individuals of each species; N-total number of individuals; ln-natural logarithm. The diversity index is classified as low if H' < 1, medium if 1 ≤ H ' ≤ 3 and high if H ' > 3 (Fitrian et al. 2017).

Simpson's Dominance Index (SDI):

$$D = \sum_{i-1}^{N} (pi)^2$$

Where: *pi* = Proportion of species of the i-th of the total number. The dominance index ranges from 0 (low dominance; 0-0.5) to 1 (high dominance) (Fitrian et al. 2017).

RESULTS AND DISCUSSION

Physico-chemical parameters

As shown in Table 1, the physico-chemical data measured during the sampling did not differ significantly among the three sampling locations (Kruskal-Wallis tests; P>0.05). This might be due to the apparent similarity in the substrates of the sampling sites.

Table 1. Physico-chemical parameters at three sampling locations in the Minahasa Peninsula, North Sulawesi, Indonesia

Parameters	Site			KW-test	Quality standard (seagrass)
	Bolsel	Bunaken	Bajo		
Temperature (°C)	29.85	30.33	32.49	ns	28 -30
Salinity (‰)	32.82	30.23	31.84	ns	33-34
pH	7.58	7.76	6.48	ns	7-8.5
Dissolved Oxygen (mg/L)	6.67	6.44	6.01	ns	> 5
Turbidity (NTU)	3	2	4	ns	< 5

Note: *significance at 0.05 alpha level; n.s.: not significant; KW: test referred to Kruskal-Wallis test

Seagrass cover, biomass, and carbon stock

Seagrass cover ranged from 51.57±7.26% to 66.67±6.01% with site Bolsel having the highest coverage. Statistically, however, these values did not vary significantly (Kruskal-Wallis; P>0.05; Figure 2). Seagrass above-ground biomass ranged from 70 g dry weight·m^{-2} (Bunaken) to 850 g dry weight·m^{-2} (Bolsel) as shown in Figure 3. Above-ground biomass between sites did not differ from each other (P = 0.172). Similarly, below-ground biomass was highest at Bolsel and lowest at Bunaken, but the observed differences between sites did not vary significantly (Kruskal-Wallis; P=0.252). The trend in seagrass carbon stock was very similar to that of seagrass biomass (Figure 4), with the smallest value derived from 23.52 gC·m^{-2} while the highest value was observed in Bolsel at 285 gC·m^{-2}. However, these differences are not statistically significant (Kruskal-Wallis; P>0.05).

Diversity

There were 8 species of seagrass documented in this study. Bolsel had the highest number of species with 6-7 species per transect, followed by Bajo with 5-6 species, while Bunaken had the lowest with only 1-4 species. A similar trend was also observed on Margalef's richness index (highest in Bolsel with 0.8-0.9), Shannon-Weiner's H' index (1.61 in Bolsel, 1.3-1.4 in Bajo, and only 0-.8 in Bunaken), and Simpson's index (highest in Bolsel with 0.77-0.79) (Table 2). The ranges of such indices indicate that the sampling sites had low to medium species diversity and in terms of dominance in which Bolsel and Bajo both had moderate dominance as compared to Bunaken.

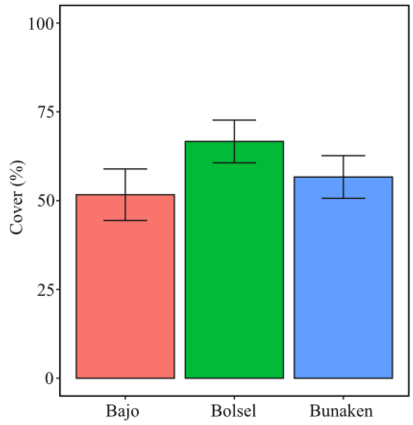

Figure 2. Seagrass cover (mean±SE; in %) at three sampling locations in Minahasa Peninsula, North Sulawesi, Indonesia

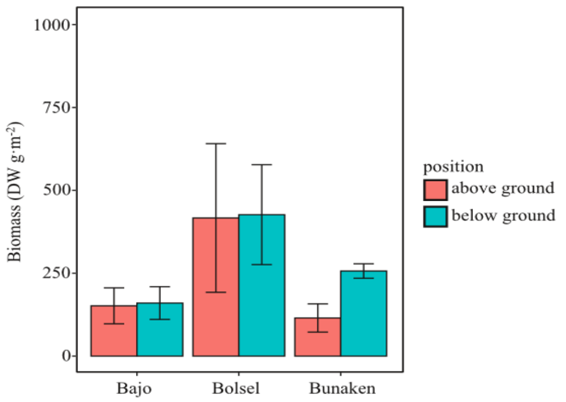

Figure 3. Seagrass biomass (mean±SE; in g dry weight·m^{-2}) at three sampling locations in Minahasa Peninsula, North Sulawesi, Indonesia

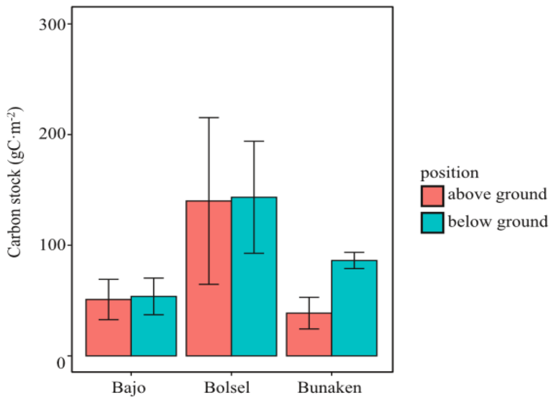

Figure 4. Seagrass carbon stock (mean±SE; in gC·m^{-2}) at three sampling locations in Minahasa Peninsula, North Sulawesi, Indonesia

Table 2. Biodiversity parameters of seagrass community at three sampling locations in the Minahasa Peninsula, North Sulawesi, Indonesia

Site	Transect	No. of species	Index		
			Margalef (D)	Shannon-Weiner (H')	Simpson (SDI)
Bajo	T1	5	0.7	1.42	0.73
	T2	6	0.83	1.3	0.66
	T3	6	0.84	1.44	0.71
Bolsel	T1	6	0.81	1.66	0.79
	T2	6	0.81	1.61	0.78
	T3	7	0.99	1.61	0.77
Bunaken	T1	4	0.64	0.81	0.41
	T2	2	0.22	0.56	0.37
	T3	1	0	0	0

Table 3. List of species and shoot density at three sampling locations in the Minahasa Peninsula, North Sulawesi, Indonesia

Species	Site		
	Bajo	Bolsel	Bunaken
Enhalus acoroides	1.73±2.48	4.21±4.57	6.06±6.96
Thalassia hemprichii	9.09±9.78	13.33±10.07	0.39±1.62
Cymodocea rotundata	6.67±8.4	9.34±6.33	0.36±1.19
Cymodocea serrulata	1.36±3	x	x
Halophila ovalis	12.94±10.94	3.27±6.64	0.79±1.96
Halophila minor	1.85±3.51	0.52±1.35	x
Halodule pinifolia	x	3.22±6.54	x
Syringodium isoetifolium	x	9.82±14.5	x

Note: The error bars represent the standard error of the means (n=33 quadrats/site); X means that the species was absent

Shoot density

Among the species found in all there sites, only *Enhalus acoroides* had the lowest shoot density (<10 shoots m^{-2}) while *Thalassia hemprichii* and *Cymodocea rotundata* had similar shoot density values across all sites (see Table 3). Based on One-Way ANOVA, shoot density of *E. acoroides* differed significantly among the sites (P = 0.011). For the two species, *T. hemprichii* and *C. rotundata*, shoot densities between sites significantly differ was also observed, probably due to reduced values in Bunaken (ANOVA; P<0.001).

Discussion

The physico-chemical parameters observed in this study were not significantly different among the three locations, implying that the observed variations in seagrass community structure (density, diversity, etc.) and biomasses most likely did not affect these factors. However, due to the limited sampling plots and duration of monitoring, these physico-chemical data should be interpreted with caution. Although seagrasses are known to be limited in terms of phosphorus content (Brodersen et al. 2017), growth rate and thus biomass are expected to be higher in areas such as Bunaken where the amount of this element was higher (according to preliminary data) which might promote the growth of seagrass plant. However, nutrient levels were not monitored in this experiment but will be conducted in the near future.

According to the data from this study on the seagrass species found in these sampling sites in Northern Sulawesi, the overall differences in seagrass cover, biomass, or carbon stocks between sampling sites were negligible. The similarity in physico-chemical characteristics and substrates between sampling sites may be related to this. Seagrass densities, on the other hand, specifically *T. hemprichii* and *C. rotundata*, were noticeably lower at Bunaken. Other factors that although not included in this study (e.g., grazing, turbidity and total sediment loading, boat traffic due to tourism and fishing activities), may potentially be responsible for variations in seagrass shoot density and even growth and eventually biomass (Ramili et al. 2018). It is noteworthy that the above-ground biomass as well as carbon stocks were slightly lower in Bunaken. One possible explanation is the effect of grazing by herbivores such as fish (Scott et al. 2021) and sea urchins (Burnell et al. 2013). In general, data on shoot densities were similar to those from other regions (e.g., Indonesia and the Philippines; see Fitrian et al. 2017).

Previous studies found that there were no discernible differences in seagrass carbon stocks between the intertidal and subtidal zones (Lavery et al. 2013 and Gullström et al. 2018). Other aspects, such as the impact of the substrate on biomass variability and carbon storage (Katuuk et al. 2018), should also be taken into account. The carbon content of the soil was not included in this analysis, but it should be in the project's later stages.

There are currently at least 13 different species of seagrass in Indonesia, and this study was able to identify 8 of them, with Bolsel having 7 species. This is comparable to other Indonesian regions (e.g., Fitrian et al. 2017; Wagey 2018). The number of species observed varied between this study and other surveys, including those conducted in the Celebes Sea and North Sulawesi areas, which may have resulted from variations in sampling (e.g. methodologies and coverage of sampling). This study demonstrated that despite its protected status, Bunaken (located inside the Bunaken National Park), had lower diversity and species richness in the coastal waters surrounding the Minahasa peninsula than the other two stations (Bolsel and Bajo). The lower species diversity as well as above-ground biomass and carbon stocks in Bunaken were likely due to grazing by herbivores (e.g., fish and sea urchins) and tourism activities (e.g., boat traffic, diving, snorkeling). Therefore, grazing effects and human tourism activities should be included in future investigations to monitor the dynamics of seagrass biomass and carbon stocks in the area.

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REFERENCES

Al-Asif A, Kamal AH, Hamli H, Idris MH, Gerusu GJ, Ismail J, Bhuiyan MK, Abualreesh MH, Musa N, Wahid ME, Mishra M. 2022. Status, biodiversity, and ecosystem services of seagrass habitats within the Coral Triangle in the Western Pacific Ocean. Ocean Sci J 57 (2):147-73. DOI: 10.1007/s12601-022-00068-w.

Asaad I, Lundquist CJ, Erdmann MV, Costello MJ. 2018. Delineating priority areas for marine biodiversity conservation in the Coral Triangle. Biol Conserv 222: 198-211. DOI: 10.1016/j.biocon.2018.03.037.

Beaumont NJ, Jones L, Garbutt A, Hansom JD, Toberman M. 2014. The value of carbon sequestration and storage in coastal habitats. Estuar Coast Shelf Sci 137: 32-40. DOI: 10.1016/j.ecss.2013.11.022.

BFAR. 2022. Field Guide on Seagrasses. https://www.bfar.da.gov.ph/wp-content/uploads/2022/05/Field-Guide-on-Seagrass.pdf

Bonanno G, Orlando-Bonaca M. 2020. Marine plastics: what risks and policies exist for seagrass ecosystems in the Plasticene?. Mar Pollut Bull 158: 111425. DOI: 10.1016/j.marpolbul.2020.111425.

Brodersen KE, Koren K, Moßhammer M, Ralph PJ, Kühl M, Santner J. 2017. Seagrass-mediated phosphorus and iron solubilization in tropical sediments. Environ Sci Technol 51 (24): 14155-14163. DOI: 10.1021/acs.est.7b03878.

Brodie G, Holland E, Antoine De Ramon NY, Soapi K, Hills J. 2020. Seagrasses and seagrass habitats in Pacific small island developing states: Potential loss of benefits via human disturbance and climate change. Mar Pollut Bull 160: 111573. DOI: 10.1016/j.marpolbul.2020.111573.

Burnell OW, Russell BD, Irving AD, Connell SD. 2013. Eutrophication offsets increased sea urchin grazing on seagrass caused by ocean warming and acidification. Mar Ecol Prog Ser 485: 37-46. DOI: 10.3354/meps10323.

Christianen MJ, Smulders FO, Vonk JA, Becking LE, Bouma TJ, Engel SM, James RK, Nava MI, de Smit JC, van der Zee JP, Palsbøll PJ. 2023. Seagrass ecosystem multifunctionality under the rise of a

flagship marine megaherbivore. Glob Chang Biol 29 (1): 215-30. DOI: 10.1111/gcb.16464.
Cullen-Unsworth LC, Nordlund LM, Paddock J, Baker S, McKenzie LJ, Unsworth RK. 2014. Seagrass meadows globally as a coupled social-ecological system: implications for human wellbeing. Mar Pollut Bull 83 (2): 387-397. DOI: 10.1016/j.marpolbul.2013.06.001.
Cullen-Unsworth LC, Unsworth RK. 2016. Strategies to enhance the resilience of the world's seagrass meadows. J Appl Ecol 53 (4): 967-972. DOI: 10.1111/1365-2664.12637.
Duarte CM, Krause-Jensen D. 2017. Export from seagrass meadows contributes to marine carbon sequestration. Front Mar Sci 4: 13. DOI: 10.3389/fmars.2017.00013.
El Shaffai A. 2016. Field Guide to Seagrasses of the Red Sea. In: Rouphael A, Abdulla A (eds). First Edition. Gland, Switzerland: IUCN and Courbevoie, France: Total Foundation. https://www.researchgate.net/publication/266031410_Field_Guide_to_Seagrasses_of_the_Red_Sea. [02-02-23]
Fitrian T, Kusnadi A, Persilitte RN. 2017. Seagrass community structure of Tayando-Tam Island, Southeast Moluccas, Indonesia. Biodiversitas 18 (2): 788-794. DOI: 10.13057/biodiv/d180246.
Fortes MD, Ooi JLS, Tan YM, Prathep A, Bujang JS, Yaakub SM. 2018. Seagrass in Southeast Asia: a review of status and knowledge gaps, and a road map for conservation. Bot Mar 61 (3): 269-288. DOI: 10.1515/bot-2018-0008.
Gullström M, Lyimo,LD, Dahl M, Samuelsson GS, Eggertsen M, Anderberg E, Rasmusson LM, Linderholm HW, Knudby A, Bandeira S. 2018. Blue carbon storage in tropical seagrass meadows relates to carbonate stock dynamics, plant- sediment processes, and landscape context: Insights from the western Indian Ocean. Ecosystems 21: 551-566. DOI: 10.1007/s10021-017-0170-8.
Hulopi M, Tuahatu JW, Tuhumury N C. 2017 Seagrass potency as blue carbon source in Galala and Tanjung Tiram waters, Ambon Island, Indonesia. AACL Bioflux 10 (5): 1019-1025.
Hyder K, Townhill B, Anderson LG, Delany J, Pinnegar JK. 2015. Can citizen science contribute to the evidence-base that underpins marine policy?. Mar Policy 59: 112-120. DOI: 10.1007/s10021-017-0170-8.
Inving AD, Tanner JE, Gaylard SG. 2013. An integrative method for the evaluation, monitoring, and comparison of seagrass habitat structure. Mar Pollut Bull 66 (1-2): 176-84. DOI: 10.1016/j.marpolbul.2012.10.017.
Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL. 2015. Plastic waste inputs from land into the ocean. Science 347 (6223):768-71. DOI: 10.1126/science.1260352.
Katuuk V, Wagey BT, Mantiri D, Gerung G, Bucol LA. 2018. Variation in morphological parameters of the seagrass *Thalassia hemprichii* (Ehrenberg) Ascherson) across substrate types and locations in Northern Sulawesi, Indonesia. Intl J Ecol Dev 33 (3): 64-72.
Kondoy KI. 2017 Seagrass as carbon holder in Waleo coastal waters, North Sulawesi, Indonesia. AACL Bioflux 10 (5): 1342-1350.
Lasut MT, Weber M, Pangalila F, Rumampuk ND, Rimper JR, Warouw V, Kaunang ST, Lott C. 2018. From Coral Triangle to Trash Triangle-How the Hot spot of Global Marine Biodiversity Is Threatened by Plastic Waste. In: Cocca M, Di Pace E, Errico M, Gentile G, Montarsolo A, Mossotti R (eds). Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea. Springer Water. Springer, Cham. DOI: 10.1007/978-3-319-71279-6_15.
Lavery PS, Mateo MÁ, Serrano O, Rozaimi M. 2013. Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. PLoS One 8 (9): e73748. DOI: 10.1371/journal.pone.0073748.
Mazarrasa I, Marbà N, Lovelock CE, Serrano O, Lavery PS, Fourqurean JW, Kennedy H, Mateo MA, Krause-Jensen D, Steven AD, Duarte CM. 2015. Seagrass meadows as a globally significant carbonate reservoir. Biogeosciences 12 (16): 4993-5003. DOI: 10.5194/bg-12-4993-2015.
McKenzie LJ, Yoshida RL, Aini JW, Andréfouet S, Colin PL, Cullen-Unsworth LC, Unsworth RK. 2021. Seagrass ecosystem contributions to people's quality of life in the Pacific Island Countries and Territories. Mar Pollut Bul 167: 112307. DOI: 10.1016/j.marpolbul.2021.112307.
Menicagli V, Castiglione MR, Balestri E, Giorgetti L, Bottega S, Sorce C, Spanò C, Lardicci C. 2022. Early evidence of the impacts of microplastic and nanoplastic pollution on the growth and physiology of the seagrass *Cymodocea nodosa*. Sci Tot Environ 838: 156514. DOI: 10.1016/j.scitotenv.2022.156514.
Pazzaglia J, Santillán-Sarmiento A, Helber SB, Ruocco M, Terlizzi A, Marín-Guirao L, Procaccini G. 2020. Does warming enhance the effects of eutrophication in the seagrass *Posidonia oceanica*?. Front Mar Sci 7: 564805. DOI: 10.3389/fmars.2020.564805.
R Core Team. 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/
Ramili Yunita, Bengen DG, Madduppa, HH, Kawaroe Mujizat. 2018. Morphometric characteristics of two seagrass species (*Enhalus acoroides* and *Cymodocea rotundata*) in four small islands in North Maluku, Indonesia. Biodiversitas 19 (6): 2035-2043. DOI: 10.13057/biodiv/d190608.
Sanchez-Vidal A, Canals M, De Haan WP, Romero J, Veny M. 2021. Seagrasses provide a novel ecosystem service by trapping marine plastics. Sci Rep 11 (1):1-7. DOI: 10.1038/s41598-020-79370-3.
Scott AL, York PH, Rasheed MA. Spatial and temporal patterns in macroherbivore grazing in a multi-species tropical seagrass meadow of the Great Barrier Reef. Diversity 13 (1): 12. DOI: 10.3390/d13010012.
Tilaar FF, Wagey BT, Katuuk V, Salaki MS, Sondakh SJ, Mantiri DM, Kepel RC, Gaol JL. 2019. Potential carbon stocks of seagrass species in Bunaken Island, North Sulawesi, Indonesia. Advan Environ Sci 11 (2): 59-66.
Unsworth RK, Ambo-Rappe R, Jones BL, La Nafie YA, Irawan A, Hernawan UE, Cullen-Unsworth LC. 2018. Indonesia's globally significant seagrass meadows are under widespread threat. Sci Tot Environ 634: 279-286. DOI: 10.1016/j.scitotenv.2018.03.315.
Unsworth RK, Higgs A, Walter B, Cullen-Unsworth LC, Inman I, Jones BL. 2021. Canopy accumulation: are seagrass meadows a sink of microplastics? Oceans 2 (1): 162-178. DOI: 10.3390/oceans2010010.
Unsworth RKF, NordlundLM, Cullen-Unsworth LC. 2019. Seagrass meadows support global fisheries production. Conserv Lett 12: e12566. DOI: 10.1111/conl.12566.
Wagey BT. 2018. Studies on seagrasses of North Sulawesi, Indonesia and adjacent waters: a critical review. e-Journal Budidaya Perairan 6 (2): 1-6. DOI: 10.35800/bdp.6.2.2018.20152. [Indonesian]
Wagey BT. 2019. Buku Penuntun Praktikum Hilamun (Seagrass). Unsrat Press, Manado. [Indonesian]