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Assessing the seagrasses meadows status and condition: A case study of Wori Seagrass Meadows, North Sulawesi, Indonesia

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Abstract. *Sondak CFA, Kaligis EY. 2022. Assessing the seagrasses meadows status and condition: A case study of Wori Seagrass Meadows, North Sulawesi, Indonesia. Biodiversitas 23: 2156-2166.* Seagrass meadows play an important role in the coastal ecosystem through the services they provide, however, they are one of the most threatened ecosystems in the coastal environment due to anthropogenic influences and rapid environmental changes. Seagrass meadows extent is not validated and the health condition is left unmonitored and unreported. In Indonesia, the information about the current status of seagrass meadows' extent and health conditions is limited. We assess the seagrass meadow abundance, status, and health condition. We provide information about species abundance, density threats, and the health status of seagrass meadows in North Sulawesi, Indonesia, particularly in Wori District. This district has a vast extent of seagrass meadows but has been affected by the expansion of the industrial/tourism area within the region. This study found that seagrass meadows' coverages were *moderate,* but their health status was *unhealthy.* Six seagrass species are found in this area, including *Enhalus acoroides* (L.f.) Royle*, Thalassia hemprichii* (Ehrenb.) Aschers*, Cymodocea rotundata* (Asch. & Schweinf.)*, Halodule pinifolia* (Miki) Hartog*, Halophila ovalis* (R.Br.) Hook. F., and *Syringodium isoetifolium* (Asch.) Dandy. Our results highlight the communities' activities, including gleaning, boat propeller, anchoring, mooring, sedimentation, and the effects of climate change on the environment as factors that could affect seagrass meadows' extent and health condition in the study sites.

Keywords: North Sulawesi's seagrass condition, seagrass abundance, seagrass meadow assessment, seagrass monitoring system

INTRODUCTION

Seagrasses are shallow coastal flowering marine plants that can be formed as extensive meadows or beds (Short et al. 2007; Nugraha et al. 2021) which play an important role as they provide ecosystem services (ES) to the coastal marine environment (Duarte et al. 2013; Nordlund et al. 2018). Decreasing of seagrass area can affect the ecosystem surrounding areas such as loss of nursery ground for fishes, reduction the detritus producer, lack of coastline protection, increase in coastal erosion, decrease in water clarity improvement, changes in nutrient regulation and carbon sequestration (Costanza et al. 2014; Nordlund et al. 2016; Boudouresque et al. 2016; Unsworth et al. 2019). Seagrass bed is one of the three marine coastal ecosystems together with mangroves and corals as a barrier to the coastal area where damage to one ecosystem may have a negative impact on other ecosystems. In Indonesia, the seagrass bed (known as "lamun") can usually be found in line with mangrove forests and coral reefs in many coastal areas. However, in many cases, the seagrass meadows are either abandoned or are given less attention by the community, government, and policymakers, and sometimes being forgotten compared to coral reefs and mangrove forests (Potouroglou et al. 2020). In fact, the seagrass meadow is one of the most threatened ecosystems compared to corals and mangroves due to their significantly decreasing area worldwide (Xu et al. 2016). A recent study showed that the global seagrass area was only from 160,387 km^2 to 266.562 km^2 (McKenzie et al. 2020), which means the mitigation measurement and monitoring need to be taken seriously. However, one of the global problems for seagrass monitoring is the lack of basic information regarding the habitat, leading to unregulated, underestimated, and poorly presented updated data (Fortes et al. 2018; Rifai et al. 2022).

Before 1940, the area of seagrass beds worldwide decreased by 0.9% per year and the rate of decline increased to 7% per year in the 1990s (Waycott et al. 2009). Tropical seagrass meadows in Southeast Asia also show a decline in the area, leading to an average of 4,7% annually (Sudo et al. 2021). Data about the area of Indonesia's seagrass meadows are also lacking and need further validation. The estimated area of Indonesia's seagrass beds is approximately 1,15 million ha (11,500 km^2) with 22,31% considered *good,* 11,25% *moderate* and 13,42 % *damaged* (BPS, 2020). Validated data of Indonesia's seagrass area was 293,464 ha were, 284,660 ha in Eastern waters and 8,804 ha in Western waters (Sjafrie et al. 2018). Of 284,660 ha-validated seagrass meadows in Eastern Indonesia waters, 43% are in *good* condition, 50% are *moderate* 50% and 7% are *damaged* (Supriyadi et al. 2018a). However, data about the area of Indonesia's seagrass meadows are also lacking and unclear. North Minahasa has 5,962 ha of seagrass meadows (Suraji et al. 2015), but there is no information about their condition and health status.

Considering the vital role of seagrass meadows, various efforts are needed to maintain their sustainability. One effort that can be made is by researching the current condition of seagrass beds, therefore it can be informed earlier whether the seagrass in the area is still in good condition, required actions, or urgent intervention is needed while the condition is already alarming. Furthermore, global reports of its losses have driven awareness for urgent action in mitigation, such as seagrass protection, regular monitoring, required risk assessment, management and restoration (Orth et al. 2006). Moreover, knowing and informing the seagrass status is important to raise government attention and the community and stakeholders' awareness on conservation for the sustainability of this ecosystem.

The activity of monitoring seagrass meadows for their health status plays a crucial role in the management and sustainability of the coastal environment (Rustam 2019). Data on seagrass conditions is important as this can provide references for appropriate management and conservation (Supriadi et al. 2012). Data and information regarding the status of seagrass meadows in Indonesia, especially in North Sulawesi waters, are still limited, therefore data from observations of their abundance, health status, and the extent of damaged and loss of seagrass meadows are very important. The lack of data could lead to underestimating seagrass resource role in certain locations (Brodie and N'Yeurt 2018), and mitigation for the improvement cannot be informed.

Wori District in North Sulawesi is located in Minahasa Peninsula and three-fourths of the area is located in the coastal area. The inhabitant's livelihood is mostly depending on fisheries and agricultural activities. Therefore, the seagrass meadow in this area is under threat mostly due to human activities (e.g., coastal development and tourism industries). This study is the first to be conducted in the selected area of North Sulawesi, where the seagrass meadows' condition and health status have not been monitored and informed. Therefore, the result of this study may provide initial information and can be used as baseline data for further monitoring, management, and conservation purposes. With this updated information, an understanding of the mitigation strategies and priority management can be highlighted either for conservation purposes or supporting the local community activity without losing its functionality. The objective of this study was to assess the current status of seagrass meadows in North Sulawesi, particularly in Wori District waters, including information about coverages area and species abundance, environment parameters and local community activity that may influence the health status and sustainability of the seagrass bed. In addition, the activity impact on the seagrass meadow function was identified as risks identification which is important as basic information and evidence for the local government's further mitigation in the area.

MATERIAL AND METHODS

Sampling location

The study was carried out in Wori District waters on the coast of North Sulawesi Peninsula, Indonesia (1°38'0" N-1°39'0" N and 124°55'0" E-124°56'0" E from August to September 2021 (Figure 1). Four stations (Wori, Bulo, Darunu, and Budo) within Wori waters were identified as study sites based on their seagrass meadows abundance and threats. All the study site areas were vegetated by mangroves, seagrass, and seaweed beds. The platform reef flat is vegetated by extensive seagrass, seaweeds and patches of coral reefs. Seagrass beds in the study area occur from rocky shores to the boundary of the mangrove forests. The seagrass bed can be found from the boundary between sub-tidal and intertidal areas extended to the mangrove forest. Currently, the most activity of the coastal community in the areas are fisheries, agriculture, water transportation, and gleaning, which may have a negative impact on the sustainability of the seagrass ecosystem and the ecosystem services due to the decrease of the area-bed coverages.

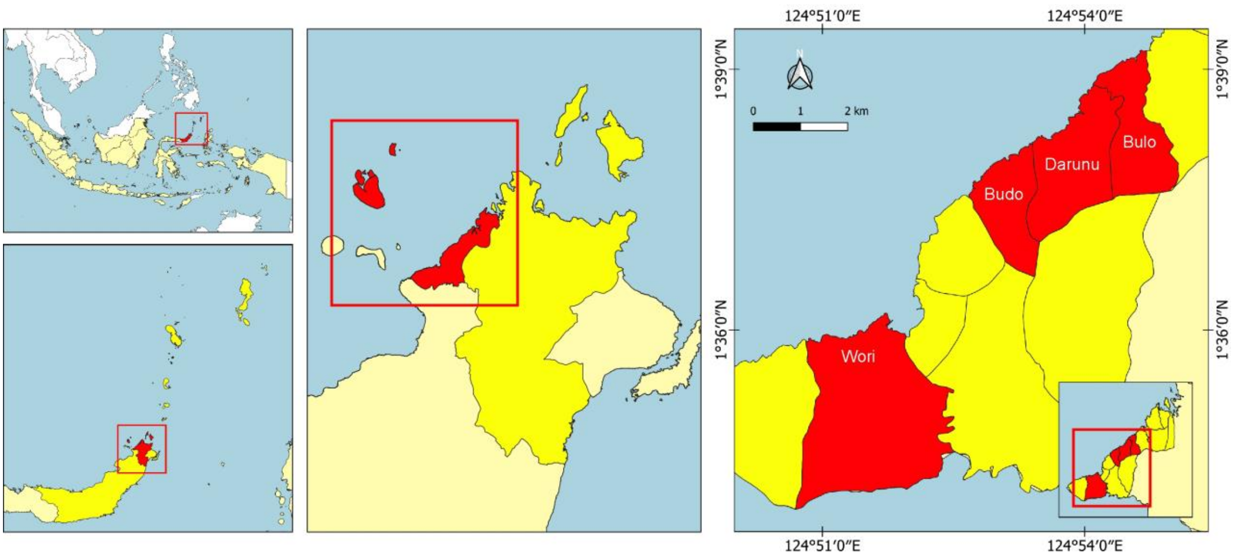

Figure 1. Map of sampling location in Wori District, North Sulawesi, Indonesia

Experimental design

The quadrant transect method used is a transect and a quadrant-shaped frame of 50 x 50 cm^2 (McKenzie et al. 2001; Rahmawati et al. 2014). Data was collected using line transects, where the length of each transect is 100 m from the coastline onward to the sea. There were four-line transects in each location. The quadrat frame (50 x 50 cm^2) was then placed on the right side of the transect line, where the distance between the frame was 10 m. Data collection includes; line transect coordinate point, seagrass species, seagrass percentage cover, seagrass species percentage cover, and type of substrate. In addition, individual seagrass species were identified and characterized based on morphology (McKenzie 2008; El Shaffai 2015).

Seagrass covered and health condition measurement

Measuring the seagrass percentage cover was used scientific literature based on Rahmawati et al. (2014), with the percentage covered of seagrass was categorized as rare (0-25%), *moderate* (25-50%), *dense* (51-75%) and *very dense* (76-100%). The health condition of seagrass was categorized based on the national regulation of the Minister of Environment Decree No. 200/2004 with the categorized as *healthy* if the seagrass cover in an area is reaching >60%, *less healthy* if it is 30-59.9% and *poor* if the cover percentage is between 0-29.9%. Identifying the seagrass bed risk was based on on-site findings, while mitigation measures were taken based on literature studies. Environmental factors were also measured at each location which may influence the health condition of the seagrass.

Environmental data collection

Environmental data, namely temperature, salinity, and pH data, were measured. Three measurements for each environmental factor have done within each study site. The environmental data measurements were taken on the surface of the seawater. The environmental factors values were then calculated and presented as their average on the table.

Data analysis

All data were analyzed using statistical analysis (IBM-SPSS Version 23). A Levene test was conducted before the analysis to ensure the data were distributed normally. Data coverage of seagrass in each location was compared to determine a significant difference. Due to not being normally distributed, a non-parametric Kruskall-Wallis test was conducted to analyze the data. The environmental parameter at each location was analyzed using the One-way Anova. A significant difference was obtained at p <.0.05.

RESULTS AND DISCUSSION

Seagrasses community and type of habitat

A total of six seagrass species were found at the sampling locations, including *Enhalus acoroides* (L.f.) Royle, *Thalassia hemprichii* (Ehrenb.) Aschers, *Cymodocea rotundata* (Asch. & Schweinf.), *Halodule pinifolia* (Miki) Hartog, *Halophila ovalis* (R.Br.) Hook. F., and *Syringodium isoetifolium* (Asch.) Dandy. (Figure 2; Table 1). The *E. acoroides* and *T. hemprichii* were the most common species found, as both formed extensive beds in all sites in the study area. All seagrass species were found to inhibit the intertidal zone to the boundary of the subtidal zone. Substrates in the study area are coral rubble, fine and coarse sand, massive dead rock coral, and muddy sand.

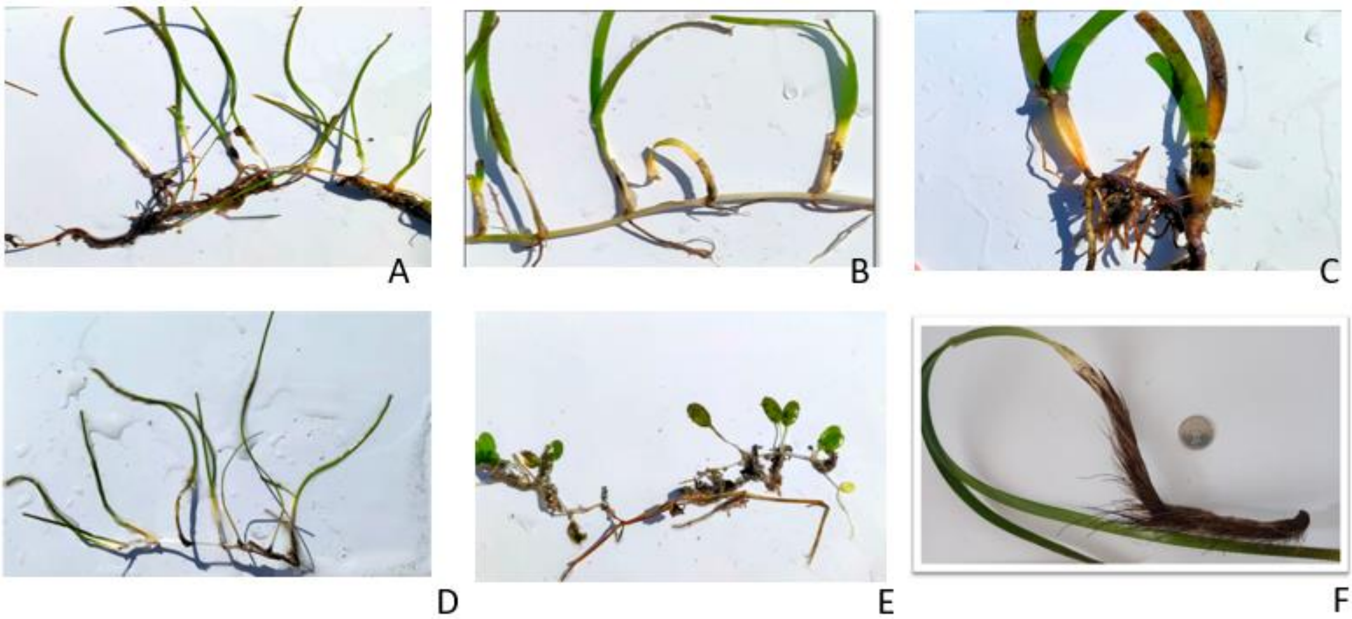

Figure 2. Seagrass species: A. *Syringodium isoetifolium*; B. *Cymodocea rotundata*; C. *Thalassia hemprichii*; D. *Halodule pinifolia*; E. *Halophila ovalis*; F. *Enhalus acoroides*

Table 1. Available seagrass species at each location

Species	Common name	Location			
		Bl	Bd	Dr	Wr
Enhalus acoroides (L.f.) Royle	Tape seagrass	√	√	√	√
Thalassia hemprichii (Ehrenb.) Aschers	Turtle grass	√	√	√	√
Halophila ovalis (R.Br.) Hook. F.	Spoon/dugong grass	√	-	√	√
Halodule pinifolia (Miki) Hartog	Narrowleaf seagrass	√	-	√	√
Cymodocea rotundata (Asch. & Schweinf.)	Manatee grass	√	√	√	√
Syringodium isoetifolium (Asch.) Dandy	Noddle grass	√	√	√	√

Note: Bl = Bulo, Bd = Budo, Dr = Darunu, Wr = Wori

Types of seagrass beds vegetation in the study area are single and mixed vegetation. Four out of six species can be found in all sites, while two species of *H. ovalis* and *H. pinifolia* were not found in Budo station. *E. acoroides* was found in the lower intertidal zone and extended to the mangrove forest area. The species was preferred to grow on mixed fine sand and muddy substrates to form single vegetation and mixed vegetation with *T. hemprichii* and *H. ovalis*. In addition, *T. hemprichii* occurred in all study sites and was mostly found in mixed fine and coarse sand, rubble substrates, and dead rock coral. This species formed mixed vegetation with *E. acoroides* and *C. rotundata* in the intertidal zone. Moreover, *T. hemprichii* discovered in the Budo site formed dense mixed vegetation with *E, acoroides*, and macroalgae *Bornetella* sp.

The species *C. rotundata* grows in mixed fine sand and coarse sand areas and lives side by side with *T. hemprichii*. This species can be found in the mid-intertidal area to the sub-tidal area. The narrow-leafed seagrass *H. pinifolia* was discovered to live on coarse sand and coral rubble with *T. hemprichii* and *C. rotundata*. However, *S. isoetifolium* was mostly found within *E. acoroides* and *T. hemprichii* but mostly consisted of only 2-4 stands. The manatee grass *H. ovalis* was also found to live between *E. acoroides* and *T. hemprichii* or formed small dense vegetation in mixed sand and muddy substrates adjacent to *E. acoroides* and *T. hemprichii*.

Seagrass coverages

Seagrass coverages, on average at all sites, were varied with a range from 36.65 ± 25.5% to 46.28 ± 27.6%. Budo site had the highest percentage cover among all the study sites, 46.28 ± 27.6%, while Wori had the lowest with only 36.65 ± 25.5% (Figure 3). In Bulo and Darunu areas, the coverage was 46.28 ± 27.6% and 43,78 ± 28.5%, respectively. The statistical analysis showed no significant difference in the seagrass coverages among four sampling locations ($p > 0.05$; Kruskal-Wallis $p = 0.34$).

Seagrass species abundance within sites shows differences in percentage covered (Table 2). At Bulo and Budo locations, species of *T. hemprichii* were measured to have the highest species coverages, about 23% and 24%, respectively, while *E. acoroides* become the second higher of the species coverages. E. acoroides are highly covered wori sites with a percentage covered of 24%. At the same time, other species such as *T. hemprichii*, *C. rotundata*, *S. isoetifolium*, and *H. ovalis* were found with small coverages, which are less than 10%. In the Darunu location, *T. hemprichii* and *E. acoroides* were similar percentage coverages, given the location has the most abundance of species covered in the area. Species *H. pinifolia* and *H. ovalis* were rarely found in the locations and were absent in Budo and Wori areas.

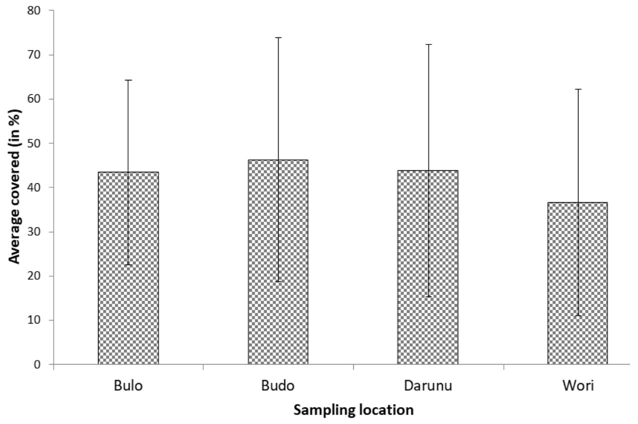

Figure 3. Average of seagrass percent cover in each sampling location (error bar is SD ± mean)

Table 2. Seagrass species coverage at each location

Location	Ea (%)	Th (%)	Cr (%)	Hp (%)	Ho (%)	Si (%)
Bulo	15,41	22,39	5,66	0,14	0,12	2,62
Budo	16,51	23,50	5,06	-	-	0,93
Darunu	22,65	22,76	10,63	2,25	0,78	1,69
Wori	24,21	6,68	5,18	-	0,06	1,52

Note: Ea= *Enhalus acoroides*, Th= *Thalassia hemprichii*, Cr= *Cymodocea rotundata*, Hp= *Halodule pinifolia*, Ho= *Halophila ovalis*, Si= *Syringodium isoetifolium*

Seagrass health condition measurement

The percentage cover category of seagrass meadows in the Wori District was measured at 42.75%, which indicated a *moderate* coverage by two works of literature assessment (Table 3). By the coverage condition, the health status of seagrass meadows in each location was categorized as *unhealthy*. The environmental parameters were reported to similar values at all locations. The temperature ranged from 29 to 31ºC, salinity ranged from 29 to 31‰, and pH ranged from 7.9 to 8.2. No significance difference of the temperature (p = 0.16; F = 2.22), salinity (p = 0.06; F = 3.89), and pH (p = 0.12; F = 2.67) among locations (Table 4). The Tukey HSD as a post-hoc test noted that salinity between Darunu and Wori has a significant difference. The risks identified at each location were categorized based on the majority of activity that may disturb the condition and coverages of the seagrass (Table 5).

With the identification of the abundance, species formed the seagrass-bed in Wori District Water, this finding was corroborated by the previous finding 6-10 species within and nearby North Minahasa (Patti and Rifai 2013; Rustam et al. 2015; Suraji et al. 2015; Kamaruddin et al. 2016; Kusumaningtyas et al. 2016; Bongga et al. 2021). About 10 species from the Eastern part of Indonesia (Supriyadi et al. 2018b), 8 species in Ternate (Makatipu et al. 2015), 6 species in Biak-Numfor, Papua (Giyanto et al. 2016), and 15 species were recorded in Indonesia (Sjafrie et al. 2018). The *T. hemprichii* and *E. acoroides* were the most abundant among the species discovered. This finding supports the claim that both species are the most common species in Indonesia waters (Hernawan et al. 2017; Sjafrie et al. 2018). From 423 study sites across Indonesia, *T. hemprichii* was found in 371 locations, while *E. acoroides* were found in 357 locations (Hernawan et al. 2017; Sjafrie et al. 2018).

Environmental parameters such as temperature, salinity and tidal current affected seagrass growth and reproduction (McKenzie 2008; Rahman et al. 2016). Environmental parameters recorded in the study site are still acceptable for seagrass to grow. The temperature range found in this present study, 29.67-30.67ºC, is still in the range of optimal growth for tropical/subtropical species 23ºC-32ºC (Lee et al. 2007). In addition, a decrease in salinity could cause a decline in the seagrass growth rate (Lamit and Tanaka 2021). Salinity can affect seagrass growth, structure, function and distribution (Salo et al. 2014). However, the average salinity in the study area was similar among all sites. Marine plants, including primary seagrass productivity, were affected by temporal variation in pH (Mvungi et al. 2012). The low seawater pH inhibited the physiological activity of seagrass leaves (Andika et al. 2020).

Globally, the disappearance of seagrass meadows is not balanced by conservation and restoration efforts (e.g., seedling and planting) (Devault and Pascaline 2013). The rate of damage to seagrass ecosystems globally is unpredictable, but the dominant cause of damage is anthropogenic activity (Potouroglou et al. 2017; Unsworth et al. 2019). For example, the decrease in seagrass beds in Indonesia resulted from human activities and natural factors in the coastal environment, including waves, strong currents, storms, earthquakes, tsunamis, and climate change (Sjafrie et al. 2018; Sudo et al. 2021). In addition, threats from sedimentation and nutrient runoff processes, physical disturbances, species invasion, disease, destructive commercial fishing practices, gleaning, unsustainable marine aquaculture, and global warming are factors originating from human activities that can contribute to the degradation of seagrass on a large scale of square meters to hundreds of square kilometers (Orth et al. 2006; Unsworth et al. 2018; Unsworth et al. 2019). Seagrass damage is mostly caused by fishing boats, development activities, and the increasing number of people living in coastal areas (Potouroglou et al. 2017).

Table 3. Seagrass species status at each location

Location	Percentage cover (%)	COREMAP CTI LIPI Percent Cover Category (Rahmawati et al. 2014)	Ministry of Environment 200/2004 Health Status Category
Bulo	43.44 ± 20.9	Moderate	Unhealthy
Budo	46.28 ± 27.6	Moderate	Unhealthy
Darunu	43,78 ± 28.5	Moderate	Unhealthy
Wori	36.55 ± 25.5	Moderate	Unhealthy

Table 4. Current environment parameters

Location	Temperature (º C)	Salinity (‰)	pH
Bulo	30.67 ± 0.5	30.0 ± 0	8.0 ± 0
Budo	29.67 ± 0.5	30.33 ± 0.5	8.10 ± 0.1
Darunu	30.0 ± 0	30.67 ± 0.5	8.0 ± 0
Wori	30.33 ± 0.5	29.33 ± 0.5	7.97 ± 0.1

Table 5. Identification of potential risks of the seagrass-bed ecosystem in Wori District, Indonesia areas including the community activities (modified from seaweed farming risks; Kambey et al. 2021)

Components	Potential risk observed	Risk mitigation measures	Risk challenge
Seagrass habitat	No zoning system for industrial and tourism within the area which may potential scarified of the seagrass habitat for developing the area	Need a Risk assessment of the ecosystem for proving the evidence of the functionality of the seagrass-bed service (Rifai et al. 2022). The Marine Spatial Planning for the areas should incorporate environment-based management (Rifai et al. 2022)	Lack of strong evidence-based studies for the further decision of management by the government, the competent authority, and policymaker to have a local regulation
Species	Decrease and loss of many important and economical marine species	Need a Risk assessment of the ecosystem for proving the evidence of the functionality of the seagrass meadow (Sudo et al. 2021).	Need further studies to prove with evidence
Gleaning	Trampling and walking could cause damage to seagrass meadows	Need a Risk assessment of the ecosystem for proving the evidence of the damage to the seagrass meadows (Furkon et al. 2019).	Some fisher's livelihood depends on fish caught from seagrass meadows
Anchoring, mooring and boat propeller	Boat anchor and propeller could cause damage to seagrass meadows	Need a Risk assessment of the ecosystem for proving the evidence of damage to the seagrass meadow (La Manna et al. 2015).	The only waterway transportation to some islands nearby and fisher boats
Sedimentation	The High sedimentation rate causes damage to seagrass meadows	Need a Risk assessment of the ecosystem for proving the evidence of sedimentation in the seagrass meadow (Potoroglou et al. 2017)	Sediment sources are from agricultural activities
Environment and climate change	Decrease area and loss of many ecosystem services	Need a risk assessment on the impacts of climate change on the seagrass ecosystem (Kendrick et al. 2019)	Lack of strong evidence-based studies

Seagrass meadows are declining globally, therefore effort on monitoring this ecosystem is important and urgent. The measurement of changes in extent cover, biomass, or densities of seagrass abundance reflects natural and human disturbances in seagrass meadow and is therefore commonly used by many monitoring programs (Neckles et al. 2012; Congdon et al. 2018). Furthermore, monitoring seagrass health can help mitigate food demand and stabilize the climate (Unsworth et al. 2019). Therefore, seagrass monitoring action is a valuable tool for improving management practices and providing information about seagrass beds' status and condition, indicating whether they are stable, decreasing, or increasing (McKenzie et al. 2001). Through P2O LIPI (Coremap-CTI project), the Indonesian government has initiated a program for monitoring Indonesian seagrass beds' current status and condition. Currently, 423 sites across Indonesia have been monitored (Hernawan et al. 2017). Validated data from 110 monitoring stations across Indonesia reports that the seagrass area covers from 2015 to 2017 were 46%, 37,58 and 42,23%, respectively (Sjafrie et al. 2018). The overall status is unhealthy when categorized following the Minister of Environment Decree No. 200/2004. Taking into consideration, this trend is in line with the results from the present study, as we found that the current status of 4 seagrass beds in the Wori District is *unhealthy*.

This study also identified several potential risks of the seagrass meadows ecosystem in the Wori District related to coastal communities' activities. Several risks have been recognized, such as no zoning system on seagrass use related to tourism industries, damage on seagrass meadows caused by anchoring, mooring, and boat propeller, gleaning, sedimentation and climate change impact. These risks, if not managed properly, may be led to local seagrass meadows degradation and species loss. As seagrass species are degraded, biodiversity loss could lead to serious repercussions for human and marine diversity (Short et al. 2011).

Since there is no study recorded in our study sites, we cannot compare the past conditions to the current conditions of the seagrass ecosystem in determining whether it is stable, declining, or improving. We realized that seagrass ecosystems are dynamics where their condition cannot be the same all the time as environmental factors affect their growth to be either increasing or declining. As a result, the seagrass area in one location can change every time (Sjafrie et al. 2018). However, regular monitoring of percentage cover is one effort to detect changes in seagrass meadows area over time (Congdon et al. 2018). Therefore, assessing seagrass status using percent cover is a suitable parameter to detect changes and determine the status of seagrasses at the site up to the species level (Short et al. 2006). The percentage of seagrass cover in the study site was found to be *moderate* and the health status is *unhealthy*. We assumed that several factors could drive these findings. Gleaning, tourism activities (boat anchoring and mooring), sedimentation, and the effect of climate change are among potential threats that could cause damage and decline in seagrass meadows abundance in the study area.

Gleaning

The condition of seagrass meadows was assumed to be affected by anthropogenic threats in the study sites. The high rate of human activity in the area, such as gleaning on marine biota during low tide, could have negatively impacted the seagrass. Seagrass beds have important roles for local communities (e.g., fishing and gleaning). In all the study sites, these types of activities were practiced by local communities to catch invertebrates and fishes and also treated as a food source as well as an additional income source. Gleaners' daily activities include gleaning in a seagrass bed and mangrove forest and searching for gastropods, bivalves, and fishes. Gleaning can support a community's livelihood, however, this activity can also potentially cause damage to seagrass. For example, people will accidentally step and tramp on seagrass, which can inhibit the growth and reproduction of seagrass. Trampling by gleaners is considered to cause damage to seagrass meadows (Furkon et al. 2019; Unsworth et al. 2019). Moreover, the trampling can cause fragmentation of seagrass and result in the reproductive output of *E. acoroides* (Vermaat et al. 2006). Apart from that, walking activities at this location can result in the uncovering of sediments in water bodies, resulting in high turbidity of the waters, thereby potentially reducing light penetration. This can cause disturbances to the primary productivity of seagrass ecosystems because seagrass requires high light intensity for photosynthesis. Bivalves harvesting also significantly impacted seagrass meadows as their declines can affect water qualities (Congdon et al. 2018; Fales et al. 2020) and lose their role as epiphytes cleaner in seagrass leaves (Peterson and Heck 2001).

Anchoring, mooring and boat propeller

Coastal inhabitants in this district use seagrass meadows in many ways, such as a source for food (fishing and gleaning), waterway, and boat mooring and anchoring area. All study sites have jetties for boats, and this condition could potentially damage seagrass meadows. Wori sites had the lowest percent cover compared to other sites. This is due to human activities in the seagrass surrounded area and the run-off from the river. Crowded waterway transportation, from small to big boats and driven of sediment and freshwater from the river to seagrass meadows area are among human activities. Moreover, in Wori and Budo, the jetties are also used as an alternative harbor to travel to Bunaken Marine National Park and the nearby islands. Boat propeller, mooring, and anchoring from those activities could cause damage to seagrass meadows (Demers et al. 2013; Unsworth et al. 2017; Luff et al. 2019). Anchor and mooring on seagrass meadows cause direct physical damage (Cullen-Unsworth and Unsworth 2018). Boat propeller scarring can harm leaves and roots, while anchoring and mooring can uproot or expose delicate seagrass roots (La Manna et al. 2015). The impact of damage is different in spatial scale. Still, it will mostly lead to the elimination of seagrass above and below-ground biomass and the transformation of cover and formation of seagrass meadows (Reed and Hovel 2006). Anchors of small and large boats can cause scars and dig deep into the sediment and remove massive sediment blocks (Boudouresque et al. 2012). Boat anchor can cause turbidity then leads to a reduction in light in the water column, particularly low light penetration to the deeper edge of seagrass beds which could affect their growth (Poedjirahajoe et al. 2013; Kirkman 2014; Rustam et al. 2014; Browne et al. 2017).

Sedimentation

Hills surround the Wori District area in the land, and some villagers practice agriculture. The clearing of forests, land intensification and extensification of new agriculture areas for planting coconuts, bananas, cassavas, fruits, and vegetables are agricultural activities that could treat seagrass meadows downstream. Land-use practices were thought to be one of the threats to marine ecosystems, including seagrass meadows (Saunders et al. 2017). Land-based activities affected seagrass meadows in terms of exporting organic and inorganic materials (Quiros et al. 2016). Terrestrial forest clearing drives soil erosion and sediment transport through rivers and streams and dumps in estuaries and coastal waters (Bjork et al. 2008). Sediment load to the coastal area can cause a problem for seagrass meadows. Sediment loading to seagrass meadows from watersheds, deforestation and mangrove clearing are among the biggest impacts on tropical seagrass decline (Duarte et al. 2008). In addition, watershed size, human development, and farmland had a negative impact on the seagrass state (Quiros et al. 2016). Equally, dredging activities inland can also increase sediment erosion and eutrophication in coastal waters and as a resulting decline and degradation of seagrass meadows (Waycoat et al. 2009). Erosion and sediment transport can cause a change in light attenuation penetration, leading to seagrass elimination (Duarte et al. 2008; Browne et al. 2017). Sediment discharge in the form of fine sediment has a negative impact on seagrass meadows as it can reduce light penetration (Zabarte-Maeztu et al. 2020). Likewise, seagrass decline is also collectively responsible for various pressures from coastal development, nutrient run-off from the land, and climate change (Potouroglou et al. 2020).

Climate change

Climate change causes changes in the seagrass population and community structure (Pergent et al. 2014; Kendrick et al. 2019; Salimi et al. 2021). Even though the further examination is needed on the study sites, climate change has significant impacts on seagrass meadows globally, including on our study sites. Sea level rise, increase in temperature, a rise in CO_2 level, increase in storm events, and wave energy power is among the effects of climate change (Brodie and N'Yeurt 2018). As the most severe threat among the global climate factors, ocean warming causes losses of dominant macrophytes, including seagrass along their equatorial range boundaries and range extensions into polar regions (Duarte et al. 2018). The global temperature predicted will be increased between 2-4oC by 2100 (IPCC 2007), as a result, when the temperature increases or is extreme, most of the tropical seagrass species will experience lessen in their growth and respiration rate increase and leading to their mortality (IPCC 2013; Collier and Waycott 2014; Frazer et al. 2014; Short et al. 2016). Moreover, as temperature increases over seagrass thermal tolerance, this can decrease population or possible extinction at latitudinal locations (Hyndes et al. 2016; Wilson and Lotze 2019). Changes in mean seawater temperature might be critical to the growth of seagrass by affecting their slender shoots and fewer leaves (Koch et al. 2013; Pansini et al. 2021). Prediction of rising sea surface level up to 1.1m in 2100 could lead to the disappearance of seagrass area to about 17% (Saunders et al. 2013) when seagrass meadows sub-merge below the present level following an increase in water depth that can cause a decrease in light availability on meadows, and seagrass extent decline significantly (Scalpone et al. 2020). Likewise, additional wind and wave energy from hurricane and tropical storm events can cause physical damage to seagrass (Congdon et al. 2019). Extreme hydrodynamic conditions generated from storms can damage tropical marine ecosystems (James et al. 2021). Waves caused by storms affect seagrass meadows by erosion and burial, which lead to uprooting (Oprandi et al. 2020).

Among the treats mentioned, human activities, namely gleaning, anchoring, mooring, and boat propeller, are the factors that potentially affect the most seagrass meadows condition in the study sites. This statement is based on many coastal communities in the study area rely their livelihood on these activities; these activities are their daily activities, and these activities are practiced in all study sites. Climate change could be another factor that should be considered that will affect seagrass meadow's condition in the present day and the future.

In conclusion, the overall status of seagrass meadows in the study sites was *unhealthy*, while coverage was *moderate*. Present study results are crucial and need further action to overcome this finding, or the status regarding the issue could worsen and lead to the loss of the services provided. What is alarming is that all of the sites in this study were predicted to be sites that will be able to rapidly develop with the increase in urban human population, coastal development, fisheries, tourism industries, and climate change shortly. Therefore, we conclude that actions are needed to combat the status of seagrass meadows in the study sites. We recommend that management efforts should therefore be focused on decreasing the effect of decline and damage on seagrass meadows through methods such as providing education campaign programs to the stakeholders to change their attitudes on anchoring and mooring practices, implementing environmentally friendly gleaning fisheries, designing and using long-term monitoring program on health status, and the conservation and restoration. Further studies, though, also are recommended to identify more potential risks that could damage seagrass meadows and their mitigation actions.

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REFERENCES

Andika Y, Kawaroe M, Effendi H, Zamani NP. 2020. The effect of pH conditions on physiological response of seagrass leaves *Cymodocea rotundata*. J Ilmu dan Teknologi Kelautan Tropis 12 (2): 485-493. DOI: 10.29244/jitkt.v12i2.21632. [Indonesian]

Bjork M, Short F, Mcleod E, Beer S. 2008. Managing Seagrasses for Resilience to Climate Change. IUCN, Gland, Switzerland.

Bongga M, Sondak CFA, Kumampung DRH, Roeroe KA, Tilaar SO, Sangari JRR. 2021. Kajian kondisi kesehatan padang lamun di Perairan Mokupa, Kecamatan Tombariri, Kabupaten Minahasa. J Pesisir Laut Tropis 9 (3): 44-54. DOI: 10.35800/jplt.9.3.2021.36519. [Indonesian]

Boudouresque CF, Bernard G, Bonhomme P, Charbonnel E, Diviacco G. 2012. Protection and Conservation of *Posidonia oceanica* Meadows. RAMOGE and RAC/SPA Publisher, Tunis.

Boudouresque CF, Pergent G, Pergent-Martini C, Ruitton S, Thibaut T, Verlaque M. 2016. The necromass of the *Posidonia oceanica* seagrass meadow: Fate, role, ecosystem services and vulnerability. Hydrobiologia 781: 25-42. DOI: 10.1007/s10750-015-2333-y.

BPS (Badan Pusat Statistik). 2020. Statistics of Marine and Coastal Resources: Climate Change on Coastal Area. [Indonesian]

Brodie G, N'Yeurt ADR. 2018. Effect of Climate Change on Seagrasses and Seagrass Habitats Relevant to Pacific Islands. Pacific Marine Climate Change Report Card: Science Revie.

Browne NK, Yaakub SM, Tay JKL, Todd P. 2017. Recreating the shading effects of ship wake induced turbidity to test acclimation responses in the seagrass *Thalassia hemprichii*. Estuar Coast Shelf Sci 199: 87-95. DOI: 10.1016/j.ecss.2017.09.034.

Collier CJ, Waycott M. 2014. Temperature extremes reduce seagrass growth and induce mortality. Mar Poll Bull 83 (2): 483-490. DOI: 10.1016/j.marpolbul.2014.03.050.

Congdon VM, Bonsell C, Cuddy MR, Dunton KH. 2019. In the wake of a major hurricane: Differential effects on early vs ate successional seagrass species. Limnol Oceanogr Lett 4: 155-163. DOI: 10.1002/lot2.10112.

Congdon VM, Dunton KH, Brenner J, Goodin KL, Ames KW. 2018. Ecological resilience indicators for seagrass ecosystems. In: Goodin, KL et al. (eds.). Ecological Resilience Indicators for Five Northern Gulf of Mexico Ecosystems. Nature Serve, Arlington, VA.

Costanza R, de Groot R, Sutton P, vander Ploeg S, Anderson SJ, Kubiszewski I, Farber S, Turner RK. 2014. Changes in the global value of ecosystem services. Glob Environ Change Human Policy Dimensions 26: 152-158. DOI: 10.1016/j.gloenvcha.2014.04.002.

Cullen-Unsworth L, Unsworth R. 2018. A call for seagrass protection. Science 361 (6401): 446-448. DOI: 10.1126/science.aat7318.

Demers MA, Davis AR, Knott NA. 2013. A comparison of the impact of seagrass-friendly boat mooring systems on *Posidonia australis*. Mar Environ Res 83: 54-62. DOI: 10.1016/j.marenvers.2012.10.010.

Devault DA, Pascaline H. 2013. Herbicide impact on seagrass communities. In: Price AJ, Kelton JA (eds.). Herbicides - Current Research and Case Studies in Use. IntechOpen, London. DOI: 10.5772/55973.

Duarte B, Martins I, Rosa R, Matos AR, Roleda MY, Reusch TBH, Engelen AH, Serrào EH, Pearson GA, Marques JC, Caćador I, Duarte CM, Jueterbock A. 2018. Climate change impacts on seagrass meadow and macroalgal forests: An integrative perspective on acclimation and adaptation potential. Front Mar Sci 5: 190 DOI: 10.3389/fmars.2018.00190.

Duarte CM, Borum J, Short FT, Walker DI. 2008. Seagrass ecosystems: their status and prospects. In Aquatic Ecosystems: Trends and Global Prospects. Cambridge University Press, Cambridge, UK. DOI: 10.1017/CBO9780511751790.025.3.

Duarte CM, Kennedy H, Marba N, Hendriks I. 2013. Assessing the capacity of seagrass meadows for carbon burial: Current limitations and futures strategies. Ocean Coast Manag 83: 32-38. DOI: 10.1016/j.ocecoaman.2011.09.001.

El Shaffai A. 2015. Field Guide to Seagrasses of the Red Sea. Second Edition. Gland Switzerland: IUCN and Courbevoie, Total Foundation, France.

Fales RJ, Boardman FC, Ruesink JL. 2020. Reciprocal interaction between bivalve molluscs and seagrass: A review and meta-analysis. J Shellfish Res 39 (3): 547-562. DOI:10.2983/035.039.0305.

Fortes MD, Lean J, Ooi S, Tan M, 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: 269-288. DOI: 10.1515/bot-2018-0008.

Frazer MW, Kendrick GA, Statton J, Hovey RK, Zavala-Perez A, Walker DI. 2014. Extreme climate events lower resilience of foundation seagrass at edge of biogeographical range. J Ecol 102: 1528-1536 DOI: 10.1111/1365-2745.12300 .

Furkon, Nessa N, Ambo-Rappe R, Cullen-Unsworth LC, Unsworth RKF. 2019. Social-ecological drivers and dynamics of seagrass gleaning fisheries. Ambio 49: 1271-1281. DOI:10.1007/s13280-019-01267-x.

Giyanto, Utama RS, Budiyanto A, La Pay, Aji LP, Widyastuti A, La Tanda, Lorwens J, Dharmawan IWE, Usman B, Pelleng HSB, Ismial, Tanarto Y, Farwas E. 2016. Monitoring Kesehatan Terumbu Karang dan Ekosistem Terkait di Kabupaten Biak Numfor. Coremap-CTI dan Puslit. Oseanografi-LIPI, Jakarta. [Indonesian]

Hernawan UE, Sjafrie NDM, Supriyadi IH, Suyarso, Iswari MY, Angraini K, Rahmat. 2017. Status Padang Lamun Indonesia 2017. Puslit Oseanografi-LIPI, Jakarta. [Indonesian]

Hyndes GA, Heck KL, Verges A, Harvey ES, Kendrick GA, Lavery PS, McMahon K, Orth RJ, Pearce A, Vanderklift M, Wernberg T, Whiting S, Wilson S. 2016. Accelerating tropicalization and the transformation of temperate seagrass meadows. Bioscience 66 (11): 938-948. DOI: 10.1093/biosci/biw111.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate change 2007: Change, adaptation and vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds.). Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge.

James RK, Lynch A, Herman PMJ, van Katwijk MM, van Tussenbroek BI, Dijkstra HA, van Westen RM, van der Boog CG, Klees R, Pietrzak JD, Slobbe C, Bouma TJ. 2021. Tropical biogeomorphic seagrass landscapes for coastal protection: Persistence and wave attenuation during major storms events. Ecosystems 24: 301-318. DOI: 10.1007/s10021-020-00519-2.

Kamaruddin ZS, Rondonuwu SB, Maabuat PV. 2016. Keragaman lamun (seagrass) di pesisir Desa Lihunu, Pulau Bangka, Kecamatan Likupang, Kabupaten Minahasa Utara, Sulawesi Utara. J MIPA 5 (1): 20-24. DOI: 10.35799/jm.5.1.2016.11194. [Indonesian]

Kambey CSB, Campbell I, Cottier-Cook EJ., Nor ARM, Kassim A, Sade A, Lim PE. 2021. Seaweed aquaculture: A preliminary assessment of biosecurity measures for controlling the ice-ice syndrome and pest outbreaks of *Kappaphycus* farm. J Appl Phycol 33: 3179-3197. DOI: 10.1007/s10811-021-02530-z.

Kendrick GA, Nowicki RJ, Olsen YS, Strydom S, Fraser MW, Sinclair EA, Statton J, Hovey RK, Thomson JA, Burkholder DA, McMahon KM, Kilminster K, Hetzel Y, Fourqueran JW, Heithaus MR, Orth RJ. 2019. A systematic review of how multiple stressors from an extreme event drove ecosystem-wide loss of resilience in an iconic seagrass community. Front Mar Sci 6: 455. DOI: 10.3389/fmars.2019.00455.

Kirkman N. 2014. Near-coastal seagrass ecosystem. In: Monson RK (eds.). Ecology and the Environment, The Plant Sciences 8. Springer Science+Business Media, New York. DOI 10.1007/978-1-4614-7501-9_20.

Koch M, Bowes G, Ross C, Zhang XH. 2013. Climate change and ocean acidification effects on seagrasses and marine macroalgae. Glob Change Biol 19: 103-132. DOI: 10.1111/j.1365-2486.2012.02791.x.

Kusumaningtyas MA, Rustam A, Kepel TL, Ati RNA, Daulat A, Mangindaan P, Hutahaean AA. 2016. Ekologi dan struktur komunitas lamun di Teluk Ratatotok, Minahasa Tenggara, Sulawesi Utara. J Segara 12 (1): 1-9. DOI: 10.15578/segara.v12i1.146. [Indonesian]

La Manna G, Donno Y, Sarà G, Ceccherelli G. 2015. The detrimental consequences for seagrass of ineffective marine park management related to boat anchoring. Mar Poll Bull 90 (1-2): 160-166. DOI: 10.1016/j.marpolbul.2 014.11.001.

Lamit N, Tanaka Y. 2021. Effect of river water inflow on the growth, photosynthesis, and respiration of the tropical seagrass *Halophyla ovalis*. Bot Mar 64: 93-100. DOI:10.1515/bot-2020-0079.

Lee KS, Park SL, Kim YK. 2007. Effects of irradiance, temperature and nutrients on growth dynamics of seagrasses: A review. J Exp Mar Biol Ecol 350 (1): 144-175. DOI: 10.1016/j.jembe.2007.06.016.

Luff AL, Sheehan EV, Parry M, Higgs ND. 2019. A simple mooring modification reduces impacts on seagrass meadows. Sci Rep 9: 20062. DOI: 10.1038/s41598-019-55425-y.

Makatipu PC, Hukum F, Giyanto, Souhoka J, Budiyanto A, Azkab MH, Arbi UY, Dharmawan IWE, Hermanto B, Nurdiansah D, Patty SI, Akbar N, Djabbar M. 2015. Survei Baseline Coremap CTI Kondisi Terumbu Karang dan Ekosistem Terkait di Ternate, Tidore, dan Sekitarnya, Maluku Utara. Pusat Penelitian Oseanografi-LIPI, Jakarta. [Indonesian]

McKenzie LJ, Nordlund LM, Jones BL, Cullen-Unsworth LC, Roelfsema C, Unsworth RKF. 2020. The global distribution of seagrass meadows. Environ Res Lett 15: 1-13. DOI:10.1088/1748-9326/ab7d06.

McKenzie LJ. 2008. Seagrass Educator Handbook. Seagrass Watch HQ/DPI&F, Australia.

McKenzie LJ. Campbell SJ. Roder CA. 2001. Seagrass-Watch Manual for mapping ad Monitoring Seagrass Resources by Community (citizen) Volunteers. Department of Primary Industries, Queensland.

Mvungi EF, Lyimo TJ, Bjork M. 2012. When *Zostera marina* is intermixed with *Ulva*, its photosynthesis is reduced by increase pH and lower light, but not by changes in light quality Aquat Bot 102: 44-49. DOI: 10.1016/J.AQUABOT.2012.04007.

Neckles HA, Kopp BS, Peterson BJ, Pooler PS. 2012. Integrating scales of seagrass monitoring to meet conservation needs. Est Coast 35: 23-46. DOI: 10.1007/s12237-011-9410-x.

Nordlund LM, Jackson EL, Nakaoka M, Samper-Villareal J, Beca-Carretero P, Creed JC. 2018. Seagrass ecosystem services-what's next? Mar Poll Bull 134: 145-151. DOI: 10.1016/j.marpolbul.2017.09.014.

Nordlund LM, Koch EW, Barbier EB, Creed JC. 2016. Seagrass ecosystem services and their variability across genera and geographical regions. PLoS ONE 11 (10): e0163091. DOI: 10.1371/journal.pone.0163091.

Nugraha AH, Tasabaramo IA, Hernawan UE, Rahmawati S, Putra RD, Darus RF. 2021. Diversity, coverage, distribution and ecosystem services of seagrass in three small islands of Northern Papua, Indonesia: Liki Island, Meossu Island and Befondi Island. Biodiversitas 22: 5544-5549. DOI: 10.13057/biodiv/d221238.

Oprandi A, Mucerino L, De Leo F, Bianchi CN, Morri C, Azzola A, Benelli F, Besio G, Ferrari M, Montefalcone M. 2020. Effects of severe storm on seagrass meadow. Sci Tot Env 748: 141373. DOI: 10.1016/j:sctotenv.2020.141373.

Orth RJ, Carruthers TJB, Dennison WC, Duarte CM, Fourqurean JW, Kenneth L, Heck A, Hughes R, Kendrick GA, Kenworthy JD, Olyarnik S, Short FT, Waycott M, Williams SL. 2006. A global crisis for seagrass ecosystems. BioScience 56 (12): 987-996. DOI: 10.1641/0006-3568)56[987:AGCFSE]2.0.CO,2.

Pansini A, La Manna G, Pinna F, Stipcich P, Ceccherelli G. 2021. Trait gradients inform predictions of seagrass meadows changes to future warming. Sci Rep 11: 18107. DOI: 10.1038/s41598-021-97611-x.

Patti SI, Rifai H. 2013. Struktur komunitas padang lamun di perairan Pulau Mantehage, Sulawesi Utara. J Ilmiah Platax 1 (4): 177-186. DOI: 10.35800/jip.1.4.2013.3699. [Indonesian]

Pergent G, Bazairi H, Bianchi C, Boudouresque C, Buia M, Calvo S, Clabaut P, Harmelinvivien M, Mateo M, Montefalcone M, Morri C, Orfanidis S, Pergent-Martini C, Semroud R, Serrano O, Thibaut T, Tomasello A, Verlaque M. 2014. Climate change and Mediterranean seagrass meadows: A synopsis for environmental managers. Mediterr Mar Sci 15 (2): 462-473. DOI: 10.12681/mms.621.

Peterson BJ, Heck KL. 2001. Positive interactions between suspension feeding bivalves and seagrass - a facultative mutualism. Mar Ecol Prog Ser 213: 143-155. DOI: 10.3354/meps213143.

Poedjirahajoe E, Mahayani NPD, Sidharta BR, Salamuddin M. 2013. Tutupan lamundan kondisi ekosistemnya di Kawasan pesisir Madasanger, Jelenga dan Maluk, Kabupaten Sumbawa Barat. J Ilmu dan Teknologi Kelautan Tropis 5 (1): 36-36. DOI: 10.29244/JITKTV511.7744. [Indonesian]

Potoroglou M, Bull JC, Krauss KW, Keneddy HA, Fusi M, Daffonchio D, Mangora MM, Githaiga MN, Diele K, Huxham M. 2017. Measuring the role of seagrasses in regulating sediment surface elevation. Nat Sci Rep 7: 11917. DOI: 10.1038/s41598-017-12354-y.

Quiros TEAL, Croll D, Tershy B, Fortes MD, Raimondi P. 2016. Land use is a better predictor of tropical seagrass condition than marine protection. Biol Conserv 209: 454-463. DOI: 10.1016/j.biocon.2017.03.011.

Rahman AA, Nur AI, Ramli M. 2016. Studi laju pertumbuhan lamun (*Enhalus acoroides*) di perairan pantai Desa Tanjung Tiram, Kabupaten Konawe Selatan. J Sapa Laut 1 (1): 10-16. DOI: 10.33772/jsl.v1i1.925. [Indonesian]

Rahmawati S, Irawan A, Supriyadi IH, Azkab MH. 2014. Panduan Monitoring Padang Lamun. CRITC COREMAP CTI LIPI, Jakarta. [Indonesian]

Reed BJ, Hovel KA. 2006. Seagrass habitat disturbance: How loss and fragmentation of eelgrass *Zostera marina* influences epifaunal abundance and diversity. Mar Ecol Prog 324: 133-143. DOI: 10.3354/meps326133.

Rifai H, Hernawan UE, Zulpikar F, Sondak CFA, Ambo-Rappe R, Sjafrie NDM, Irawan A, Dewanto HY, Rahayu YP, Reenyan J, Safaat M, Alifatri LO, Rahmawati S, Hakim A, Rusandi A, Wawo M. 2022. Strategies to improve management of Indonesia's blue carbon seagrass habitats in marine protected areas. Coast Manag. DOI: 10.1080/08920753.2022.2022948.

Rustam A, Kepel TL Kusumaningtyas MA, Afiati RN, Daulat A, Suryono DD, Sudirman N, Rahayu YP, Mangindaan P, Heriati A, Hutahaean A. 2015. Ekosistem lamun sebagai bioindikator lingkungan di P. Lembeh, Bitung, Sulawesi Utara. J Biologi Indones (11) 2: 233-241. DOI: 10.14203/jbi.v11i2.2197. [Indonesian]

Rustam A, Kepel TL, Afiati RN, Salim HL, Astrid M, Daulat A, Mangindaan P, Sudirman N, Puspitaningsih Y, Dwiyanti D, Hutahaean A. 2014. Peran ekosistem lamun sebagai *blue carbon* dalam mitigasi perubahan iklim, Studi kasus Tanjung Lesung, Banten. J Segara 10 (2): 107-117. DOI: 10.15578/segara.v10i2.20. [Indonesian]

Rustam A. 2019. Pemantauan ekosistem lamun Pulau Pari dan Pulau Tikus. J Riset Jakarta 12 (1): 7-15. DOI: 10.37439/jurnaldrd.v12i1.3. [Indonesian]

Salimi PA, Creed JC, Esch MM, Fenner D, Jaafar Z, Levesque JC, Montgomery AD, Salimi MA, Edward JKP, Raj KD, Sweet M. 2021. A review of the diversity and impact of invasive non-native species in tropical marine ecosystems. Mar Biodivers Rec 14 (11): 1-19. DOI: 10.1186/s41200-021-00206-8.

Salo T, Pedersen MF, Boström C. 2014. Population specific salinity tolerance in eelgrass (*Zostera marina*). J Exp Mar Biol Ecol 461: 425-429. DOI: 10.1016/j.jembe.2014.09.010.

Saunders MI, Leon JX, Phinn SR, Callaghan DP, O'Brien KR, Roelfsema CM, Lovelock CE, Lyons MB, Mumby PJ. 2013. Coastal retreat and improved water quality mitigate losses of seagrass from sea level rise. Glob Change Biol 19 (8): 2569-2583. DOI: 10.1111/gcb.12218.

Saunders ML, Bode M, Atkinson S, Klein CJ, Metaxas A, Beher J, Beger M, Mills M, Giakoumi S, Tulloch V, Possingham HP. 2017. Simple rules can guide whether land - or ocean-based conservation will best benefit marine ecosystems. Plos Biol 15 (9): e2001886. DOI: 10.1371/journal pbio.2001886.

Scalpone CR, Jarvis JC, Vasslides JM, Testa JM, Ganju NK. 2020. Seagrass (*Zostera marina*) to future scenarios of temperature and sea level. Front Mar Sci 7: 539946. DOI: 10.3389/fmars.2020.539946.

Short FT, Carruthers T, Dennison W, Waycott M. 2007. Global seagrass distribution and diversity: A bioregional model. J Exp Mar Biol Ecol 350: 3-20. DOI: 10.1016/j.jembe.2007.06.012 .

Short FT, Koch EW, Creed JC, Magalhaes KM, Fernandez E, Gaeckle JL. 2006. Seagrass net monitoring across the Americas: case studies of seagrass decline. Mar Ecol Evol Perspect 27: 277-289. DOI: 10.1111/j.1439-0485.2006.00095.x.

Short FT, Kosten S, Morgan PA, Malone S, Moore GE. 2016. Impacts of climate change on submerged and emergent wetland plants. Aquat Bot 135: 3-17. DOI:10.1016/j.aquabot.2016.06.006.

Short FT, Polidoro B, Livingstone SR, Carpenter KE, Bandeira S, Bujang JS, Calumpong HP, Carruthers TJB, Coles RG, Dennison WC, Erftemeijer PLA, Fortes MD, Freeman AS, Jagtap TG, Kamal AHM, Kendrick GA, Kenworthy WJ, La Nafie YA, Zieman JC. 2011.

Extinction Risk assessment of the world's seagrass species. Biol Conserv 144 (7): 9161-1971. DOI:10.1016/j.biocon.2011.04.010.

Sjafrie NDM, Hernawan UE, Prayudha B, Supriyadi IH, Iswari MY, Rahmat, Anggraini K, Rahmawati S, Suyarso. 2018. Indonesia's Seagrass Meadow Status 2018 [Status Padang Lamun Indonesia 2018]. Pusat Penelitian Oseanografi-Lembaga Ilmu Pengetahuan Indonesia, Jakarta. [Indonesian]

Sudo K, Quiros TEAL, Prathep A, Luong CV, Lin HJ, Bujang JS, Ool JLS, Fortes MD, Zakaria MH, Yaakub SM, Tan YM, Huang X, Nakaoka M. 2021. Distribution, temporal change, and conservation status of tropical seagrass beds in Southeast Asia: 2000-2020. Front Maret Sci 8: 1-11. DOI:10.3389/fmars.2021.637722.

Supriadi, Kaswadji RF, Bengen DG, Hutomo M. 2012. Komunitas lamun di Pulau Barranglompo Makassar: Kondisi dan karakteristk habitat. Maspari J 4 (2): 148-158 [Indonesian]

Supriyadi IH, Iswari MY, Suyarso. 2018b. Preliminary study of the condition of seagrass meadow in the waters of eastern Indonesia. J Segara 14 (3): 169-177. DOI: 10.15578/segara.v14i3.6887. [Indonesian]

Supriyadi IH, Rositasari R, Iswari MY. 2018a. Dampak perubahan lahan terhadap kondisi padang lamun di Perairan Timur Pulau Bintan, Kepulauan Riau. J Segara 14 (1): 1-10. 10.15578/segara.v14i1.6630. [Indonesian]

Suraji, Rasyid N, Kenyo AS, Jannah AR, Wulandari DR, Saefudin M, Ashari M, Widiastutik R, Kuhaja T, Juliyanto E, Afandi YA, Wiyono B, Syafrie H, Handayani SN. 2015. Profil Kawasan Konservasi Propinsi Sulawesi Utara. Direktorat Konservasi Kawasan dan Jenis Ikan, Kementerian Kelautan dan Perikanan, Sulawesi Utara. [Indonesian]

Unsworth RKF, Ambo-Rappe R, Jones BL, La Nafie YA, Irawan A, Hernawan UE, Moore AM, Cullen-Unsworth LC. 2018. Indonesia's globally significant seagrass meadows are under widespread threat. Sci Total Environ 643: 279-286. DOI: 10.1016/j.scitotenv.2018.03.315.

Unsworth RKF, McKenzie LJ, Collier CJ. et al. 2019. Global challenges for seagrass conservation. Ambio 48: 801-815. DOI:10.1007/s13280-018-1115-y.

Unsworth RKF, Williams B, Jones BL, Cullen-Unsworth LC. 2017. Rocking the boat: Damage to eelgrass by swinging boat moorings. Front Plant Sci 8: 1309. DOI: 10.3389/fpls.2017.01309.

Vermaat JE, Rollon R, Lacap CDA, Billot C, Alberto F, Nacorda HM, Wiegman F, Terrados J. 2006. Meadow fragmentation and reproductive output of the SE Asian seagrass *Enhalus acoroides*. J Sea Res 52 (4): 321-328. DOI: 10.1016/j.seares.2004.04.002.

Waycott M, Duarte CM, Carruthers TJB, Orth RJ, Dennison WC, Olyarnik S. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proc Natl Acad Sci USA 106 (30): 12377-12381. DOI: 10.1073/pnas.0905620106.

Wilson KL, Lotze HK. 2019. Climate change projections reveal range shifts of the eelgrass *Zostera marina* in the Northwest Atlantic. Mar Ecol Prog Ser 620: 47-62. DOI:10.3354/meps12973.

Xu S, Zhou Y, Wang P, Wang F, Zhang X, Gu R. 2016. Salinity and temperature significantly influence seed germination, seedling establishment, and seedling growth of eelgrass *Zostera marina* L. PeerJ 6 (4): e2697. DOI: 10.7717/peerj.2697 .

Zabarte-Maeztu I, Matheson FE, Manley-Harris M, Davies-Colley RJ, Oliver M, Hawes I. 2020. Effects of fine sediment on seagrass meadows: A case study of *Zostera muelleri* in Pàuatahanui Inlet, New Zealand. J Mar Sci Eng 8 (9): 645. DOI:10.3390/jmse8090645.