ILMU KELAUTAN: Indonesian Journal of Marine Sciences *December 2024 Vol 2(4):503-518* *e-ISSN 2406-7598*

Seagrass Ecosystems in Eastern Indonesia: Status, Diversity, and Management Challenges

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Abstract

Seagrass beds have roles and benefits in shallow water ecosystems, including producers of organic matter, habitats for various marine biota, and providing services that are beneficial for the fishing community. However, increasing development activities in coastal areas, have decreased their valuable roles, which also affects damage in seagrass beds in Indonesian waters. Therefore, information on species diversity and seagrass conditions, especially in East Indonesian waters, is needed. This paper aims to provide information as the initial study of the distribution of species diversity, conditions of seagrass beds, and challenges of seagrass management in eastern Indonesia. This study collected primary and secondary data from several data sources from seagrass monitoring and research activities. The assessment of conditions and categories of seagrass cover refers to the Decree of the state minister for the Environment (KMN-LH) of 2004 No. 200 and the 2017 seagrass monitoring guidelines. As a result of 24 monitoring locations ten species were found indicating that Eastern Indonesia has high species diversity. The results at 24 locations can be categorized as healthy seagrass conditions in six locations (25%) and around 16 locations (67%) as less healthy. Monitoring results after 2015 are predicted to change the diversity and seagrass conditions. The challenges of seagrass management in Eastern Indonesian waters, including the coastal environment changes, need to increase public knowledge and understanding of the role, function, and benefits of seagrass. Also, replanting and enhancement of seagrass-protected areas are essentially needed by the local government.

Keywords: *Species, conditions, environmental, community and government*

Introduction

Globally, seagrass meadows have experienced a decline in areas ranging from meters to hundreds of square kilometers (Dunic *et al.*, 2021), empirically proving that sea level rise and rising sea surface temperatures have harmed seagrass growth (Chefaoui *et al.*, 2018; Keyzer *et al.*, 2020; James *et al.*, 2023). This situation is a consequence of seagrass not being sufficiently resistant/resilient to global climate change (Tang and Hadibarata, 2022) and is one of the most vulnerable ecosystems in shallow water habitats in the world (Unsworth *et al.*, 2019a) compared with coral and mangrove ecosystems. Climate change, which indirectly impacts seagrass distribution, must be addressed to examine its long-term impact and global scope (Duarte *et al.*, 2020).

Besides being under pressure due to climate change, human activities rapidly degrade seagrasses directly and indirectly (Manent *et al.*, 2020). The increasing number of people living in coastal areas (Lukman *et al.*, 2021), and increasing development activities in coastal regions, such as landfilling, land conversion, passing of fishing boats, expansion of mariculture, destructive fishing practices, and surface runoff from agricultural land are the primary triggers for a decline in ecosystem conditions and the development and growth of seagrass (Unsworth *et al.*, 2018; Murphy *et al.*, 2019; Manent *et al.*, 2020; Serrano *et al.*, 2020; UNEP 2020; Bradie, 2020). The results of several studies related to land cover changes in coastal areas can be used as a reference to determine the influence of anthropogenic impacts on water quality. Increasing suspended sediment loads in rivers will be in line with increasing river

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https://ejournal.undip.ac.id/index.php/ijms
DOI: 10.14710/ik.ijms.29.4.503-518
Received : 14-03-2024
Accepted : 07-06-2024

discharge and will have a widespread effect on shallow water ecosystems, such as mangroves, seagrass, and coral, which are vulnerable to environmental change (Yamamoto *et al.*, 2019).

The global decline in seagrass beds is predicted to be approximately 7% per year (Waycott *et al.*, 2009). However, this value is less valid because of the need for quantitative scientific data in the long term, especially in Southeast Asia, where seagrass diversity is known to be the highest in the world (Green and Short, 2003). Several studies have reported that the global spatial distribution of seagrass ranges from 177,000 to 600,000 km^2 (McKenzie *et al.*, 2020). The role of seagrass on a global scale is to maintain the stability of the acidity/pH of seawater and store carbon, having connectivity with the ecosystem of mangroves, corals, and fisheries productivity (Du *et al.*, 2020; Ricart *et al.*, 2021). Wahyudi *et al.* (2020) estimated that the total carbon above ground, carbon below ground, standing stock, and carbon sequestration from seagrass beds in Indonesia are around 80-314ktC, 196-696ktC, 276-1,005ktC respectively, and 1.6-7.4 $MtC.y^{-1}$. On an annual scale, seagrass meadows have accumulated organic carbon (Corg) with an average of 22-25 g $Corg.m^{2\ -1}.y^{-1}$ over the last 80 years (Dahl *et al.*, 2022). Seagrass beds are very effective in absorbing CO_2, with the absorption of 1,867 $ton.km^{2-1}$ (48%), which is relatively higher than the 806 $ton.km^{2-1}$ (21%) and 1,197 $ton.km^{2\ -1}$ (31 %) of corals (Simamora, 2010). Because their role is very complex, seagrass beds are one of the most productive ecosystems in water and are known as critical marine ecosystems (Henderson *et al.*, 2019; Unsworth *et al.*, 2019a). Seagrass beds are also known to function as the main source of primary productivity (producer of organic material), habitat for various biota, the substrate for attached biota, nurturing place for fish larvae and other biota, food sources for rare biotas such as dugongs (*Dugong dugon*), turtles, and seahorses (*Hippocampus* sp.), shelter, and rearing places for several species of commercially important biota and crustaceans (Esteban *et al.*, 2018; Gilby *et al.*, 2018; Irawan *et al.*, 2018; Marsh *et al.*, 2018; Scapin *et al.*, 2018; Whippo *et al.*, 2018) therefore, the existence seagrass ecosystem can be used as a source of life for fishing communities living around coastal areas.

As a tropical and archipelagic country, Indonesia is known as the center of mega biodiversity so it will attract global attention. Indonesia is thought to have a seagrass meadow area of around 30,000 km^2, which results from calculations based on the coastline's length and the beach's width (Unsworth *et al.*, 2018). If this potential is not given attention, it will become a threat. It will impact local food supplies, global fisheries production, the carbon cycle, and biodiversity conservation (Unsworth *et al.*, 2018). Therefore, information related to the condition of seagrass beds in Indonesian waters through regular monitoring is essential for efforts to protect and conserve seagrass, especially in eastern Indonesian waters. This study presents an early stage on the distribution of species diversity, conditions of seagrass beds, and challenges of seagrass management in eastern Indonesian waters. The goal of this study addresses the urgent need for information on seagrass diversity and conditions, particularly in eastern Indonesian waters. This study provides valuable insights and recommendations for local governments to enhance the management and conservation of seagrass habitats. By implementing the suggested measures, local governments can contribute to the preservation of seagrass ecosystems and the sustainable development of their coastal areas.

Materials and Methods

Data on seagrass community structure (species diversity, dominant species, percentage cover, and bottom substrate) and coastal environment characteristics were collected from 2003 to 2015. The method collects primary and secondary data from seagrass monitoring and research activities using nationally recognized assessment guidelines. That location including 2003 (Kotania Bay-Central Maluku), 2005 (Morotai-North Maluku), 2008 (Lembeh Strait-North Sulawesi, Kema-North Sulawesi, Alor-East Nusa Tenggara, Tobelo-North Maluku), 2009 (Rotendao-NTT, Kupang Bay-NTT, Sanger-North Sulawesi), (Toli Toli-West Sulawesi), 2011 Tual-Southeast Maluku, Kei Kecil Island (Ngaf, Ngilngof, Ohoiwa Islands-Southeast Maluku) are some of the locations which was carried out through collaboration between the Research Center for Oceanography (RCO)-National Research and Innovation Agency (BRIN) and the Ministry of Maritime Affairs and Fisheries (KKP) which is now one institution namely the National Research and Innovation Agency (BRIN). Meanwhile, for other locations, this is carried out through the Coral Reef Rehabilitation and Management Program (COREMAP)-Coral Triangle Initiative (CTI) which started in 2015 including in Sikka-East Nusa Tenggara, Batanta and Salawati-West Papua, Marine Nature Reserve Rajaampat-West Papua, Banda Island-Central Maluku, Padaido Island, Wakatobi-Southeast Sulawesi, Selayar-South Sulawesi, Makassar Spermonde-South Sulawesi, Kapoposang-South Sulawesi, Biak Numfor, Ternate-North Maluku and Kendari-Southeast Sulawesi. Details of the location name of the Eastern Indonesian waters are presented in (Figure 1.).

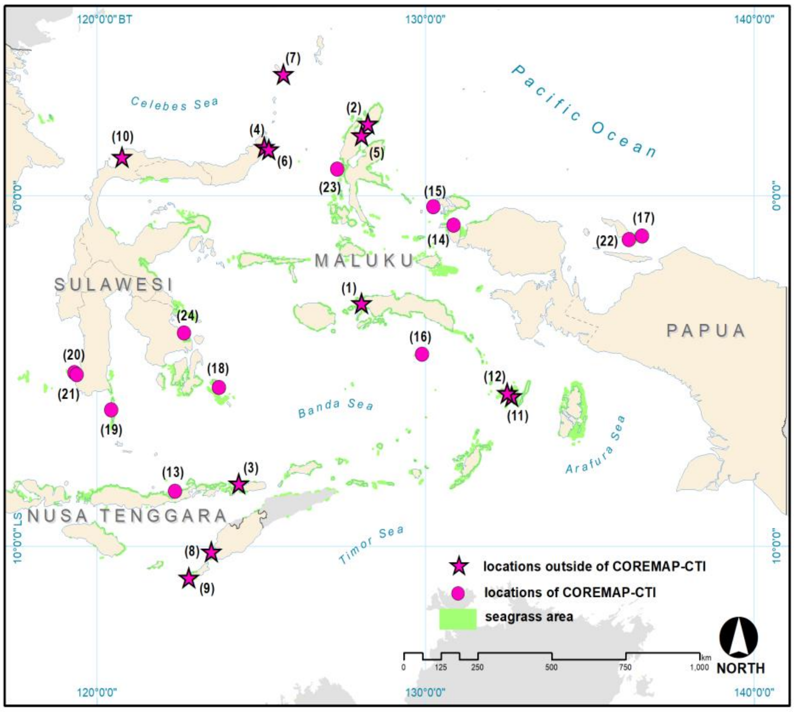

Figure 1. Distribution of seagrass monitoring locations outside COREMAP-CTI: Kotania Bay (1), Morotai (2), Alor (3), Lembeh Strait (4), Tobelo (5), Kema (6), Sanger (7), Kupang Bay (8), Rotendao (9), Toli-Toli (10), Tual (11), Ngaf-Ngilngof-Ohoiwa Island (12); while COREMAP locations: Sikka (13), Batanta (14), Marine Nature Reserve-Rajaampat (15), Banda (16), Padaido (17), Wakatobi (18), Selayar (19), Makasar (20), Kapoposang (21), Biak Numfor (22), Ternate (23), and Kendari (24).

Seagrass species and cover

The diversity of seagrass species was identified by sampling through three transects perpendicular to the shoreline along 100 m or <100 m depending on the width of the seagrass distribution and the distance between transects of 50 m so that the observation area was (100x100) m^2 (Figure 2.). Square frames were placed on the right side of the transect with a distance of 10 meters between one frame and another so that the number of square frames on each transect was 11 frames. The composition of seagrass species within a square frame (50x50) m^2 was identified and the percentage cover was interpreted based on (McKenzie's, 2003; Rahmawati *et al.*, 2017) brief guide to seagrass habitat assessment. The substrate type is determined qualitatively in the field and is divided into gravel, sand, and mud substrates.

Seagrass conditions

Seagrass conditions were determined according to the standard Decree of the Minister of Environment and Forestry (KMN-LH) No. 200 of 2004 concerning the status and damage of seagrass beds which is based on the percentage of seagrass cover namely seagrass healthy (>=60%), less healthy (30%-59.9%), and unhealthy (<29.9%). The use of standards in determining seagrass conditions is based only on the percentage of seagrass cover, considering that KMN-LH standards are easy to apply generally both by the general public, non-governmental organizations, student education environment, and stakeholders in terms of assessing the condition of seagrasses in Indonesian waters both periodically and at different monitoring locations. Seagrass density, which describes the number of seagrass stands per unit area, is grouped into four categories: very dense (76-100)%, dense (51-75)%, medium (26-50)%, and sparse (0-25)% (Rahmawati *et al.*, 2017).

Result and Discussion

Species diversity

In Indonesian waters, 16 seagrass species have been recorded and only 15 species have been found (Rahmawati *et al.*, 2022). The diversity of seagrass species includes *Enhalus acoroides (Ea), Thalassia hemprichii (Th), Cymodocea rotundata (Cr), Oceana serrulata (Cs), Halophila decipiens (Hd), Halophila ovalis (Ho), Halophila minor (Hm), Halophila spinulosa (Hs), Halodule pinifolia (Hp),*

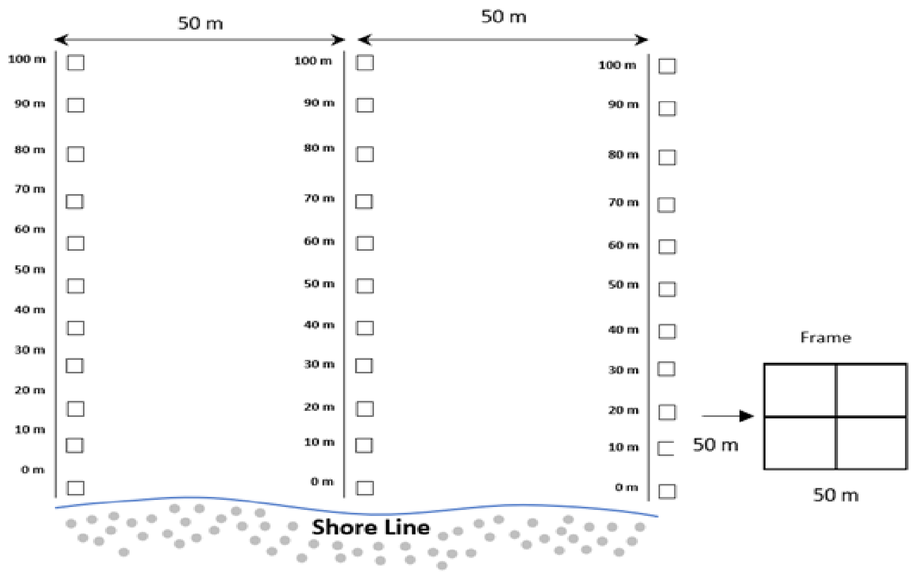

Figure 2. Line transects data collection for seagrass monitoring in each station.

Halodule uninervis (Hu), Syringodium isoetifolium (Si), Thalassodendron ciliatum (Tc) (Green and Short, 2003) and *Halophila sulawesii Kuo (Hsl)* which are endemic species of seagrass in the Spermonde Archipelago-South Sulawesi (Kuo, 2007). Two species of *Halophila becarii (Hb)* and *Ruppia maritima (Rm)* have also been found and are presently stored in Bogoriense herbarium-Bogor City, West Java (Kuriandewa *et al.*, 2003). The *Hb* and *Rm* species data on the date, location name, and discoverer were not recorded properly.

The outcomes of monitoring the distribution of diversity of seagrass species at 24 locations representing eastern Indonesian waters have found 10 species, namely *Enhalus acoroides (Ea), Thalassia hemprichii (Th), Halodule uninervis (Hu), Cymodocea rotundata (Cr), Cymodocea/Oseana serrulata (Cs), Halophila ovalis (Ho), Syringodium isoetifolium (Si), Halodule pinifolia (Hp), Thalassodendron ciliatum (Tc)* and Species *Halophila decipiens* (*Hd*). Species *Hd* is the only species in Kotania Bay, Central Maluku (Kuriandewa *et al.*, 2003). The distribution of the diversity of 9 species can only be found in five locations, namely the Central Maluku region (Kotania Bay) and Southeast Maluku such as the Kei Kecil Islands (Ngaf, Ngilngof, and Ohoiwa islands), West Papua (Batanta and Salawati), East Nusa Tenggara (Alor) and North Sulawesi region (Kema-Minahasa). The diversity of 5 species is only found in Teluk Kupang-East Nusa Tenggara Table 1. Based on Figure 3, the distribution of the number of species diversity in each region in eastern Indonesian waters can be identified and illustrated, the total diversity of which is eight species dominated in the Maluku region (Ternate, Banda, Tual), and Sulawesi (Sanger, Toli-Toli, Selayar, Wakatobi, and Kendari), compared to the regions of West Papua and East Nusa Tenggara, which have only one location.

When compared with the diversity of seagrass species that have ever been found in Indonesian waters, four species namely *Halophila spinulosa (Hs), Halophila decipiences (Hd),* and *Halophila minor (Hm)* are still rare. Other species have also been found in Indonesian waters, such as *Halophila sulawesii (Hsl*), but this species is endemic to South Sulawesi (Kuo, 2007). Of the 24 monitoring locations both at the Coremap location and outside the Coremap in eastern Indonesian waters, it has been observed that the most popular species found include species *Ea, Th, Cr, Si, Ho, Hu, Cs, Hp, Tc*, and only the *Tc* species, which are a species that is rarely found because this species grows and develops with the properties of the waters that have currents and waves. However, *Thalassodendron ciliatum* species, which have unique environmental characteristics, can still be found in several locations such as Alor, Sanger, Rotendao, Small Islands (Ngaf-Ngilngof-Ohoiwa), Kema, Batanta, Wakatobi, and Selayar or some are more commonly found in the waters of Sulawesi. According to Rahmawati *et al.* (2022), based on the life scheme of each seagrass species facing increasing pressure from environmental change, seagrass species in Indonesia can be grouped into three groups: persistent (persistent species), opportunistic (opportunistic species), and pioneer (colonizing species). The persistent seagrass types include *Ea*, *Th*, and *Tc*, which have large leaf widths, grow relatively slowly, and resist environmental changes in coastal areas. *Enhalus acoroides*, a seagrass species more tolerant to

Table 1. Diversity of seagrass in Eastern Indonesia Waters

No.	Regions/Locations	Species										Number of species
		Ea	*Th*	*Tc*	*Cr*	*Cs*	*Si*	*Hu*	*Ho*	*Hp*	*Hd*	
MALUKU												
	North Maluku											
1	Morotai	+	+	-	+	-	+	+	+	+	-	7
2	Tobelo	+	+	-	+	+	+		+			6
3	Ternate	+	+	-	+	+	+	+	+	+	-	8
	Central Maluku											
4	Kotania	+	+	-	+	+	+	+	+	+	+	9
5	Banda	+	+	-	+	+	+	+	+	+	-	8
	Southeast Maluku											
6	Tual	+	+	-	+	+	+	+	+	+	-	8
7	Kei Kecil (Ngaf, Ngilngof, Ohoiwa)	+	+	+	+	+	+	+	+	+	-	9
WEST PAPUA												
8	Marine Nature Reserve Rajaampat	+	+	-	+	-	+	+	+	-	-	6
9	Batanta and Salawati	+	+	+	+	+	+	+	+	+	-	9
10	Biak Numfor	+	+	-	+	-	+	+	+	-	-	6
11	Padaido Archipelago	+	+	-	+	+	+	+	+	+	-	8
EAST NUSA TENGGARA												
12	Alor	+	+	+	+	+	+	+	+	+	-	9
13	Sikka	+	+	-	+	+	+	+	+	+	-	8
14	Kupang Bay	+	+	-	+	-	+	+	-			5
15	Rotendao	+	+	-	+	+	+	+	+	-	-	7
SULAWESI												
	North Sulawesi											
16	Lembeh Strait	+	+	-	+	-	+	+	+	+	-	7
17	Sanger	+	+	+	+	-	+	+	+	+	-	8
18	Kema-Minahasa	+	+	+	+	+	+	+	+	+	-	9
	West Sulawesi											
19	Toli-Toli	+	+	-	+	+	+	+	+	+	-	8
	South Sulawesi											
20	Selayar	+	+	+	+	-	+	+	+	+	-	8
21	Makasar-Spermonde	+	+	-	+	-	+	+	+	-	-	6
22	Kapoposang	+	+	-	+	-	+	+	+	-	-	6
	Southeast Sulawesi											
23	Wakatobi	+	+	+	+	-	+	+	+	+	-	8
24	Kendari	+	+	-	+	+	+	+	+	+	-	8

siltation, can thrive in declining physical conditions (Mascarinas and Otadoy, 2023). However, when there is a disturbance or environmental change, these three species require a long time to recover and grow. The pioneer group has the properties of being small, growing fast but short-lived, and vulnerable to environmental changes found on the Indonesian scale in the genus *Halophila* and part of the genus *Halodule*. After the disturbance, this pioneer group will recover more quickly under environmental conditions suitable for their growth. The opportunistic species group has characteristics between persistent and pioneer species, such as *Cr*, Cs (*Cymodocea/ Oceana serrulate*), *Si,* and *Hu* (Kilminster *et al.*, 2015).

The diversity of seagrass species in all monitoring locations in eastern Indonesia, the species that are often observed are as follows: *Thalassia hemprichii (Th)* and *Enhalus acoroides (Ea)*, whereas *Thalassodendron ciliatum (Tc)* is rarely found. Those are similar to the monitoring findings at the Coremap-CTI location of the nine dominant seagrass species found, namely *Ea, Th*, and *Cr* (Hernawan *et al.*, 2021).

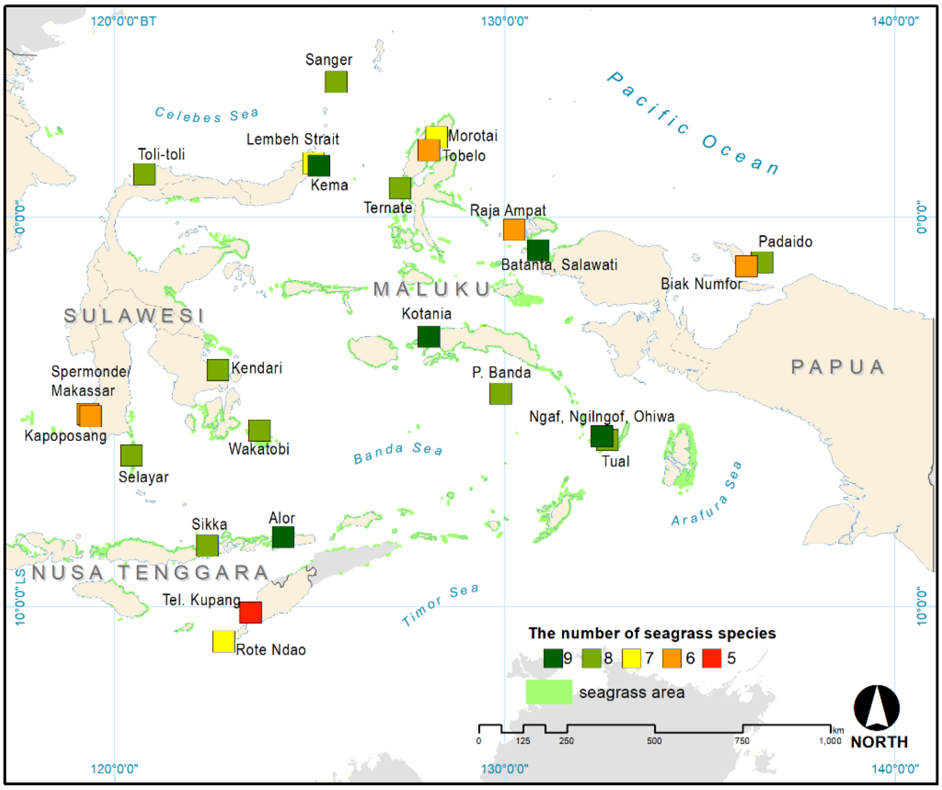

Figure 3. Distribution of the number of seagrass species diversity in eastern Indonesian waters

Seagrass conditions

Based on data, the percentage of seagrass cover at 24 monitoring locations (Figure 4.) representing the Maluku, West Papua, East Nusa Tenggara, and Sulawesi regions in Eastern Indonesian waters it is known that overall seagrass conditions of approximately 67% can be categorized as 'unhealthy' seagrass conditions with an average range of cover (41-54) % and only 25 % categorized as 'healthy' with as average range of cover (60-73)% (KMN-LH, 2004). The condition of 'unhealthy' seagrasses throughout Eastern Indonesia can be found in the North Maluku region in Morotai location with 45% and Ternate 42% seagrass cover, the Southeast Maluku region in the Tual 31% and the Kei Kecil Islands 48%, West Papua region located in the Marine Nature Reserve Rajaampat 42% and Batanta and Salawati Island which are 32% and 36% respectively, while for the East Nusa Tenggara (NTT) region it can be found in the Kupang Bay 53% and Rotendao 44%. Sulawesi region is found almost throughout Northern Sulawesi such as Lembeh, Sanger, and Kema namely 42%, 49%, and 51%, for the South Sulawesi region it is found in the Selayar, Makasar-spermonde, and Kapoposang locations 59%, 45% and 51% and found in the Southeast Sulawesi region namely in the Wakatobi and Kendari locations 51% and 41% respectively.

As for healthy seagrass conditions, only about 25% is in Eastern Indonesian waters which can be found in the Central Maluku region namely in Kotania Bay (64%) and Banda Island (73%), the West Papua region in Biak-Numfor (60%) and the Padaido Islands (64%), NTT area is in the Sikka location (64%) and West Sulawesi region in the Toli-Toli waters and the surrounding small islands namely (61%) detailed distribution of the seagrass conditions is presented in Figure 4. According to Hernawan *et al.* (2021), the monitoring location for the Coral Reef and Management Program (COREMAP)-Coral Triangle Initiative (CTI) for seagrass conditions in Eastern Indonesian waters, the average abundance of seagrass cover is higher (45.4%) than that in the western part of Indonesian waters (31.4%). It was further stated that locations with an average high percentage of cover were found in the West Papua region which is located in Biak and the East Nusa Tenggara region in Sika (65,5%) and (65,3%), respectively.

The distribution of seagrasses in Indonesian waters is known to have a wide distribution namely 150,693 hectares, consisting of 4,409 hectares (3%) in western waters and 146,283 hectares (97%) in eastern waters (Hernawan *et al.*, 2017). Based on the abundance of seagrass cover from 24 locations in eastern Indonesian waters, only 12 locations (50 %)

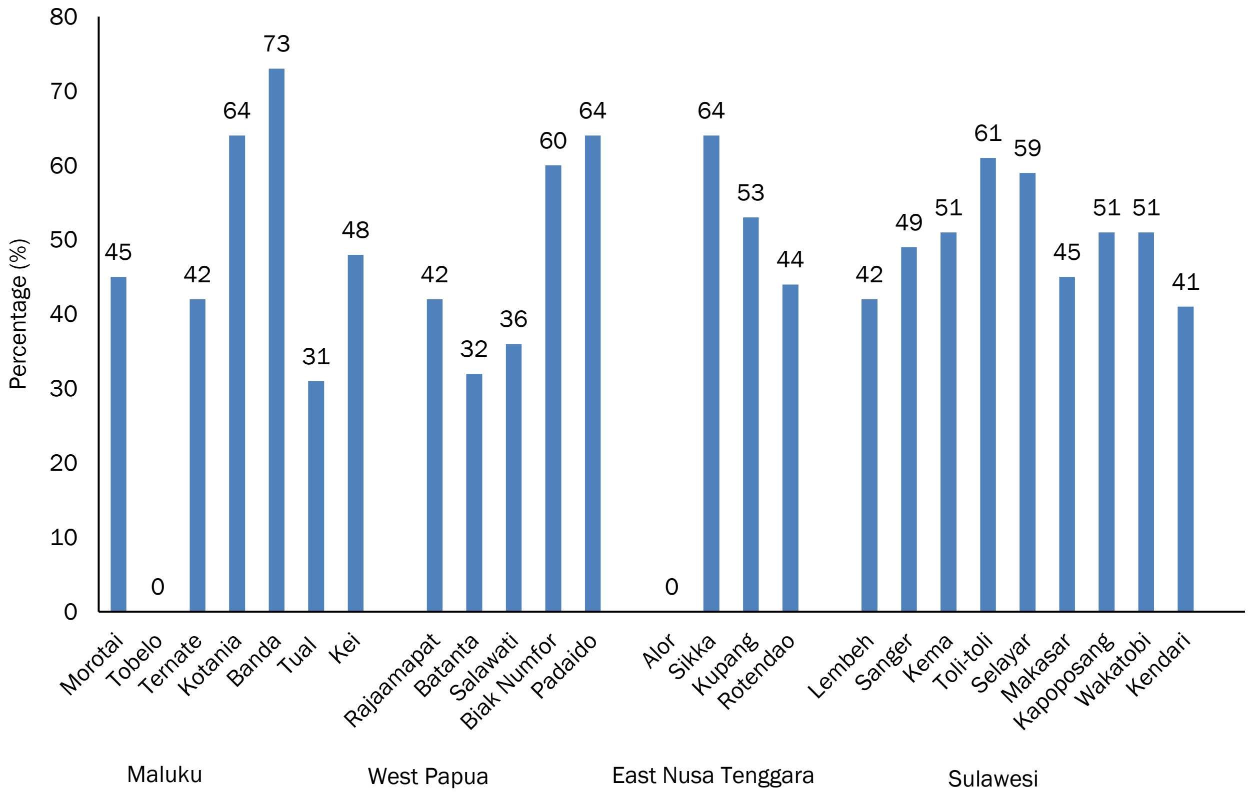

Figure 4. Seagrass conditions at several locations in Eastern Indonesian waters, >= 60 % (healthy), 30-59,9 % (less healthy) and <=29,9 % (not healthy) (KMNLH, 2004 No. 200).

can be categorized as the seagrass 'dense' and 10 locations (41 %) are 'less dense' (Rahmawati *et al.*, 2017).

Challenge in seagrass management

This study identifies the main challenges in managing seagrass in the eastern waters of Indonesia such as involving the wisdom of local communities in conservation, coastal environmental changes, understanding seagrass, seagrass damage, and replanting efforts. These challenges can lead to a decline in seagrass populations, negatively impacting marine biodiversity and ecosystem services. By identifying these challenges this study enables local governments to effectively develop strategies and policies to manage the seagrass ecosystem.

Local community wisdom in conservation

Indonesia succeeded in establishing a marine conservation area of 28.9 million hectares in 2022 from the target set by the Indonesian government in 2030 of 32.5 million hectares (Ambari, 2023), this is expected to encourage local governments to increase efforts to protect shallow water habitats and utilize them. resources in a sustainable manner. Some examples of activities for the protection and utilization of aquatic resources in Indonesia involving local communities or local wisdom have been developed in Regional Water Conservation Areas such as "Panglima Laot" in Aceh-Sumatra, "Sasi" in Ambon-Maluku and "Awiq-awiq" in Bali and Lombok. These activities are expected to be more effective in improving Marine Protected Areas. Even in the western waters of Indonesia namely Panggang Island in the Seribu Islands Administrative Regency-DKI Jakarta with the result of community agreement regarding the reduced availability of fish, Panggang Island has also divided its waters into fishing areas, cultivation areas, and Environmental Conservation Areas (Bahri *et al*., 2017). An approach that involves local communities is part of local knowledge or wisdom in maintaining the sustainability of coastal resources and the environment.

Several locations with "healthy" or "less healthy" seagrass conditions are known to have conservation area status as Marine Tourism Parks, Marine Conservation Areas, and Sea National Parks based on Ministerial Decrees, Governor's Decrees, and Regent's Decrees as presented in Table 2. From Table 2 it is known that 9 locations have been managed by the Regional Government and 9 locations by the Ministry of Forestry and Maritime Affairs however several locations were also found that not yet have a legal basis for being designated as Conservation Areas. Most (67%) of the seagrass conditions classified as "unhealthy" in eastern waters are within conservation areas and only a portion is outside marine conservation areas such as Tobelo and Ternate-North Maluku, Lembeh and Sanger-North Sulawesi, Spermonde and Kendari-Sulawesi (Figure 5).

Meanwhile, the unhealthy condition of the seagrass despite being in a conservation area requires further evaluation to identify the factors contributing to this condition. An example of this can be seen at a monitoring site in Raja Ampat. The seagrass condition represented a “less healthy” status although it's located in the Marine Wildlife Reserve of Raja Ampat. Based on a report which was conducted by (Sahavacharin *et al.,* 2022), the losing of seagrass beds as the result of land-based activity such as mining, forestry, and coastal development that release sediment into coastal waters. The occurrence of this condition is not limited to Raja Ampat but is prevalent in various parts of Indonesia, highlighting the need for community-supported management strategies to safeguard seagrasses. Enhancing local autonomy in marine resource oversight is crucial to implementing conservation programs that incentivize sustainable practices (Unsworth *et al.*, 2018). Policymakers, despite having authority, often lack specialized knowledge about specific environmental issues. Therefore, scientists and policymakers need to collaborate to integrate expertise and authority, ensuring that well-informed decisions are effectively implemented to catalyze societal transformation (Fortes, 2018).

Coastal environmental changes.

It is known that the distribution and growth of seagrasses in water depend on the properties of the environmental conditions of the waters including the level of brightness, bottom substrate, salinity, and temperature (McKenzie, 2008), as well as the morphology of the coastal waters such as the area of the reef flat and tides. The outcomes of identifying the properties of the coastal environment at several seagrass monitoring and research locations generally have environmental characteristics namely being in protected bay waters, open bays, straits, and small islands with shallow or deep reef flat waters. Approximately 80% of the seagrass beds in eastern Indonesian waters grow and develop in the coastal waters of small islands and flat coral reefs in shallow to relatively deep waters. Seagrasses are also vulnerable to environmental changes, especially human activities on the coast. Environmental changes can affect the growth and distribution of seagrass. These changes are like the effect of fish farming activities on seagrass beds through the accumulation of 'organic matter' deposits and nutrients, which continue to increase (Jiang *et al.*, 2018; Kletou *et al.*, 2018). It is still found that the application of the snail trawl fishing gear in the snail fishing community is suspected to be one of the reasons for damage to seagrass beds. Other environmental changes that require attention have severe impacts, such as sedimentation, suspended materials, and increased nutrients, which can accelerate the loss of seagrass (Rodemann *et al.*, 2021). One example of the cases of variations in the coastal environment that occurred in the Bintan Island-Riau Archipelago, the impact of land clearing continued to increase for ten years (2006-2016) decreasing the percentage of seagrass cover namely 46% (Kuriandewa and Supriyadi, 2006), and 41% (Supriyadi *et al*., 2016). The problems of rapid variations in the coastal environment include development activities in coastal areas, such as forming coastal embankments, ports, and embankments extending towards the sea, which must be controlled and better planned. It is assumed that development activities in Eastern Indonesia will continue to increase.

Changes in land application in the upper area (upland) can change the structure of the soil surface, increase surface runoff, and reduce downstream water quality, thus affecting the distribution and conditions of seagrass (Bujang, *et al*., 2018; Supriyadi *et al*., 2018). According to Rakasiwi *et al.* (2020), the growth of land change on the coast to form ports, ponds, and settlements can directly change the distribution of seagrass. Likewise, community activities such as mining and opening palm oil plantations will cause soil surface erosion (Buelow *et al.*, 2022; Wibowo *et al*. 2020). The sedimentation of suspended inorganic solids, sediment traps (burials), and water pollution affect seagrass conditions (Barcelona *et al.*, 2021). The degradation of seagrasses can also be caused directly by human activities (dredging, anchoring), household eutrophication, agricultural waste, cultivation, various developments on the coast, and indirect effects of climate change (Moreno *et al.*, 2021). This case has also occurred on the coast of Indonesia (Kendari-Southeast Sulawesi), where mangrove forests have been converted into residential areas, ports, aquaculture, offices, fuelwood, and house buildings (Amelia *et al.*, 2019). This condition is a concern for land clearing activities to do so with integrated planning in handling coastal and marine areas (Griffiths *et al.*, 2020), especially the eastern Indonesian waters. Deterioration of water

Table 2. Identification of Marine Protected Areas in Eastern Indonesia Waters

Region	Location	Seagrass condition	Existing Conservation Zone (2019)	Legal Foundation	Manage
North Maluku	Morotai	Less Healthy	Marine Tourism Park Rao Island- Tanjung Dehegila	Decree of the Governor of North Maluku Number 361/KPTS/MU/2018	Local Government
	Tobelo	No Data	Outside	No data	No data
	Ternate	Less Healthy	Outside	No data	No data
Central Maluku	Kotania	Healthy	Marine Recreation Park-Marsegu Island	Minister of Forestry Decree No.144/Kpts-II/1999. (March 5, 1999)	The Ministry of Environment and Forestry
	Pulau Banda	Healthy	Marine Tourism Park Banda Sea 2014-2034	Decree of the Minister of Maritime Affairs and Fisheries No.58/KEPMEN-KP/2014	The Ministry of Marine Affairs and Fisheries
Southeast Maluku	Tual	Less Healthy	Coastal and Small Island Conservation Area	Decree of the Minister of Maritime Affairs and Fisheries No. 6/KEPMEN-KP/2016	Local Government
	Kei Kecil	Less Healthy	Coastal and Small Island Conservation Area	Decree of the Minister of Maritime Affairs and Fisheries No. 6/KEPMEN-KP/2016	Local Government
West Papua	Raja Ampat	Less Healthy	Marine Wildlife Reserve	Decree of the Minister of Maritime Affairs and Fisheries No. 63/KEPMEN-KP/2014	The Ministry of Marine Affairs and Fisheries
	Batanta Salawati	Less Healthy	Coastal and Small Island Conservation Area-Raja Ampat Archipelago	Decree of the Minister of Maritime Affairs and Fisheries No. 36/KEPMEN-KP/2014	Local Government
	Biak Numfor	Healthy	Lokal Marine Protected Area-Biak Numfor	Regent's Decree No. 231 of 2015	Local Government
	Padaido	Healthy	Marine Tourism Park-Padaido Archipelago	Decree of the Minister of Maritime Affairs and Fisheries No. 62/KEPMEN-KP/2014	The Ministry of Marine Affairs and Fisheries
East Nusa Tenggara	Alor	No Data	Marine Wildlife Reserve-Pantar Strait and Sea	Decree of the Minister of Maritime Affairs and Fisheries No. 35/KEPMEN-KP/2015	Local Government
	Sikka	Healthy	Marine Recreational Park-Maumere Bay	Minister of Forestry Decree No.126/Kpts-II/1987. April 21, 1987	The Ministry of Environment and Forestry
	Kupang Bay	Less Healthy	Marine Recreational Park -Kupang Bay	Minister of Forestry Decree No.18/Kpts-II/1993	The Ministry of Environment and Forestry
	Rotendao	Less Healthy	Sea National Park-Sawu Sea	Decree of the Minister of Maritime Affairs and Fisheries No. 6/KEPMEN-KP/2014	The Ministry of Marine Affairs and Fisheries
North Sulawesi	Lembeh	Less Healthy	Outside	No data	No data
	Sanger	Less Healthy	Outside	No data	No data
	Kema-Minahasa	Less Healthy	Local Marine Preotected Area-Bitung	Number 188, 45/HKM/SK/121/2014	Local Government
West Sulawesi	Toli-toli	Healthy	Coastal and Small Island Conservation Area-Doboto	Central Sulawesi Governor Decree No. 523/635A/DIS.KANLUT-GST/2017	Local Government
	Selayar	Less Healthy	Local Marine Protected Area-Pasi Gusung Island	Selayar Islands Regent Decree 466/IX/2011	Local Government
	Spermonde	Less Healthy	Outside	No data	No data
	Kapoposang	Less Healthy	Marine Tourism Park - Kapoposang Archipelago	Decree of the Minister of Maritime Affairs and Fisheries No. 59/KEPMEN-KP/2014	The Ministry of Marine Affairs and Fisheries
Southeast Sulawesi	Wakatobi	Less Healthy	Sea National Park-Wakatobi Archipelago	Minister of Forestry Decree No. 7661/Kpts-VI/1996 Dated 19 August 2002	The Ministry of Environment and Forestry
	Kendari	Less Healthy	Outside	No data	No data

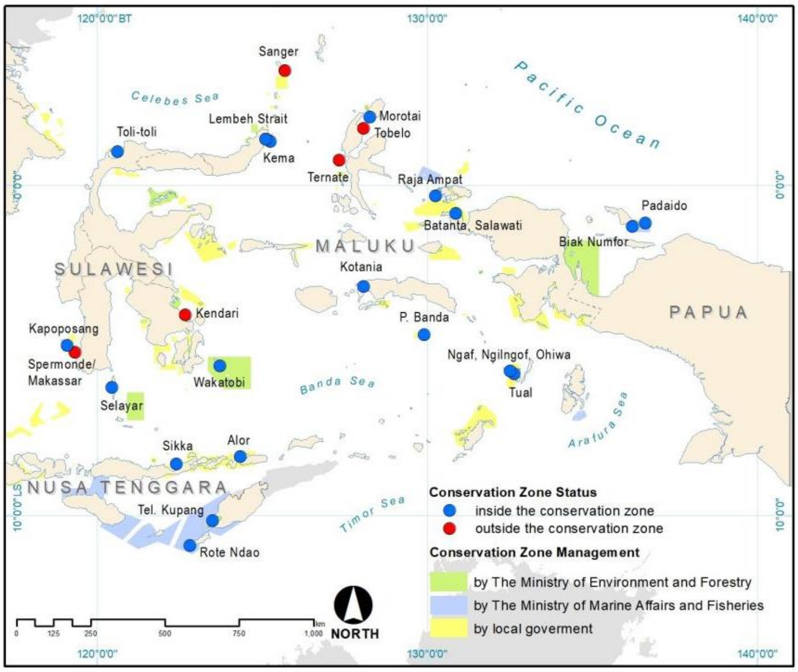

Figure 5. Marine Protected Areas in Eastern Indonesian Waters

quality and brightness levels in the coastal zone is believed to be one of the decreases in seagrass abundance. Changes in land application in an uncontrolled watershed (DAS) can reduce water quality, so it is necessary to manage the health of seagrass beds at the local level and to provide instructions for maintaining water quality to meet the requirements for habitat availability for seagrass growth (Turschwell *et al.*, 2021). According to Shumway *et al.* (2018), most are terrestrial-based and are the main threat to seagrasses' "health" integrated coordination is also required in planning coastal areas. The effect of variations in the coastal environment (municipal waste, industry, mangrove cutting, beach reclamation) will undoubtedly decrease the fishing yields of local fishermen (Nordlund *et al.*, 2018; Unsworth *et al.*, 2019b).

Understanding of seagrass

People's attention and information about seagrass ecosystems are relatively far behind compared to the aquatic ecosystems surrounding mangroves and coral reefs. This condition is more or less since there is no visible significant utilization of seagrass resources. Therefore, attention to the seagrass ecosystem has been lower, and the basic knowledge of seagrass resources is lower also. However, this basic knowledge is essential to the underlying management efforts. The research outcomes of Rifai *et al.* (2023) noted that the participation of local stakeholders in seagrass restoration activities could have been improved by their lack of awareness and appreciation of the functions and services of seagrass habitats. Lack of awareness and appreciation can threaten seagrass recovery efforts (Unsworth *et al.*, 2019a). Many problems occur due to the absence of public understanding of the behavior still found in fishing with explosives, consuming coral for burning, and felling mangroves in coastal waters. Community behavior related to the damage to seagrass beds is also caused by the ignorance of coastal communities about the functions and services of the presence of seagrass beds because there are still several ways to use destructive permanent fishing nets and fishing gear for marine cultivation in seagrass habitats (Joseph *et al.*, 2019). In one of the social studies of the coastal communities of Kendari, Southeast Sulawesi, out of 200 respondents related to knowledge of the functions and advantages of a seagrass ecosystem many still do not understand 69.8%, understand 28%, and others 2.2% (Vibriyanti and Nagib, 2015). The understanding of fishermen in using services for seagrass ecosystems is still low compared with mangrove and coral ecosystem services, which are more attractive because they are service providers and tourists (Lukman *et al.*, 2021).

The level of understanding of coastal communities with relatively low educational backgrounds is a problem in attempts to increase public understanding of the role and advantages of seagrasses in marine ecosystems, particularly concerning the decrease in the functions and advantages of seagrasses. Environmental changes can occur due to decreased functions and advantages of seagrass beds; therefore, it is essential to increase our understanding of the reasons for seagrass decline (Dunic *et al.*, 2021). Some coastal communities still consider seagrass as trash or plants that pollute the beach. Seagrass ecosystems provide substantial benefits for community welfare, namely in the form of ecosystem services, both ecologically, socially, and economically (de los Santos *et al.*, 2020). Based on the results of economic valuation studies, show that seagrass ecosystems have high value for community welfare and can be used as a comprehensive consideration in managing seagrass beds.

The understanding in question is that there still needs to be more community ability regarding the meaning of seagrass, its benefits, and its role in the sustainability of fisheries catches and their use in a sustainable manner. Public understanding can also be found in the attitude toward preventing damage to the coastal water environment, which is still low. The pace and increase in development in coastal and coastal waters have not been well controlled, so a Coastal Spatial Plan is needed, and attempts to add Regional Seagrass Protected Areas are needed to minimize the damage and shrinkage of seagrass areas. According to Grimm *et al.* (2023) applying the precautionary principle of conservation actions through community participation and stakeholder involvement is still necessary.

Seagrass damage and replanting efforts

Indications of some damage to seagrass beds can be observed from the reduction in the percentage of seagrass cover or the shrinking area of seagrass beds owing to the effect of human activities, sedimentation, and increased turbidity due to land clearing. The distribution area of seagrass in Indonesia is 150,693 ha, consisting of 4,409 ha (3%) in western waters and 146,283 ha (97%) in eastern waters (Hernawan *et al.*, 2017). After updating the data on variations in seagrass areas in Indonesia, approximately 293,464 ha (Sjafie *et al.*, 2018). Seagrass beds in eastern Indonesian waters are expected to change owing to environmental changes, which have increased annually. In general, Indonesia's area of seagrass reduction is 0.4 $ha.y^{-1}$ (Rahmawati *et al.*, 2022). According to Nordlund *et al.* (2018) and McKenzie *et al.* (2020), with high traffic activity, fishing boats can also harm the presence of seagrass beds. The loss of seagrass beds can also be caused by anchoring or increasing boat lanes (Egardt, 2018). The condition of seagrasses in Indonesia, especially in western Indonesian waters, tends to decrease owing to intensive human activity in coastal waters. This lesson is learned from attempts to restore seagrass beds lost or damaged in eastern Indonesian waters. One is replanting seagrasses to repair damaged seagrasses or adding new seagrass beds. Efforts to restore seagrass beds will be a natural-based solution that needs to be promoted, especially when dealing with climate change (Rifai *et al.*, 2023). According to the findings of a paper by Fonseca *et al.* (1998) attempts to restore seagrass (restoration), conservation, and attempts to replant seagrass have a success rate of only 30%. Therefore, in addition to replanting seagrass, it is necessary to add seagrass-protected areas. Efforts to plant seagrass were borne out by the Research Center for Oceanographic-Indonesia Institute of Science-Jakarta in 1988 namely the restoration of seagrass beds on Pari Island (Jakarta), Ambon Island (Maluku), Bintan Island (Riau Islands), and Halmahera (North Maluku). In 2000, it was also carried out in Banten (West Java) and Pari Island (Jakarta) in 2009 and successfully planted the species *Enhalus acoroides* and *Thalassia hemprichii*. Therefore, attempts to manage seagrass beds need attention from all stakeholders: the general public, academics, government, NGOs, and the private sector. The success in seagrass management that the Research Centre for Oceanography-Indonesian Institute of Science achieved on the Bintan Island-Riau Archipelago in the western waters of Indonesia from 2007 to 2009 was based on community empowerment through the formation of a Seagrass Conservation Area, which the Teluk Bakau Village Regulation, Gunung Kijang District strengthened. Bintan District No. 21 in 2009 was also strengthened by the Decree of the Head of the Bintan Regent No. 267/VI/2010, which can be used as an example in attempts to manage seagrass beds in Indonesia.

Seagrass beds have deteriorated in several coastal areas due to various activities including beach reclamation for the formation of wharves, industrial areas, settlements, trade, and the growth of marine aquaculture activities. Conditions such as this will have a severe impact owing to a lack of data regarding the effect of developmental activities that will damage the habitat for seagrass growth. Likewise, there needs to be more understanding regarding the functions and advantages of seagrass beds for people who depend on marine products for their livelihood. Therefore, taking steps towards optimal and sustainable management of seagrass beds is necessary. It is important to note that seagrass beds must be protected and used rationally to maintain their functions sustainably.

In other words, the utilization of seagrass resources and their ecosystems needs to be regulated and given signs to maintain their existence and condition. Seagrass beds are a renewable natural resource therefore, these resources can be utilized sustainably as long as they are carried out rationally according to their carrying capacity while their habitat is protected from disturbing factors. This fundamental principle must be adhered to if sustainable management efforts are to be realized.

Conclusion

In eastern Indonesia, ten species of seagrass were found, including *Thalassia hemprichii, Cymodocea rotundata, Enhalus acoroides, Syringodium isoetifolium, Halodule pinifolia, Halophila ovalis, Halodule uninervis, Cymodocea/Oceana 514errulate, Halopila decipiens* and *Thalassosendron ciliatum*. The number of 10 species out of 15 that have ever been found in Indonesian waters, the eastern Indonesian waters have 'high' species diversity. Nine species were found in Central Maluku, Southeast Maluku, West Papua, East Nusa Tenggara, and West Sulawesi. The condition of seagrass 'healthy' can be found in the waters of Central Maluku, West Papua, East Nusa Tenggara, and West Sulawesi. Based on monitoring locations and research results from 2003 to 2015 predicted that there would be variations in both the diversity and condition of seagrasses, owing to the effect of environmental variations in coastal areas. The issues that will be faced in the handling of seagrasses in eastern Indonesian waters include challenges to variations in coastal environmental conditions, how attempts to increase knowledge and understanding of the role and advantages of seagrasses in coastal communities, as well as attempts to replant, increase the area of seagrass protection that is urgently needed and inculcate patterns think with the concept of sustainable utilization of marine resources.

Acknowledgment

The author would like to thank the Director of COREMAP-CTI III for the 2015-2019 period, Prof. Suharsono. Thank you also for the collaboration that has been carried out between the Research Center for Oceanography-Indonesian Institute of Sciences-Jakarta and the Ministry of Maritime Affairs and Fisheries of the Republic of Indonesia-Jakarta, sharing data especially seagrass monitoring and research data in several locations in eastern Indonesian waters. Many thanks to colleagues in several eastern Indonesian waters locations who have helped collect data outside the monitoring location of COREMAP.

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