Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 28(6): 373 – 398 (2024)
www.ejabf.journals.ekb.eg

Mapping Seagrass Distribution and Cover in Morotai Island District, North Maluku Province

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ARTICLE INFO

Article History:
Received: Oct. 20, 2024
Accepted: Nov. 13, 2024
Online: Nov. 17, 2024

Keywords:
Seagrass,
Seagrass distribution,
Seagrass cover,
Seagrass mapping,
Morotai island

ABSTRACT

Seagrass is a type of marine plant that offers significant ecological and human benefits. It is found in many tropical waters, including those around Morotai Island. However, reliable scientific information about the condition of seagrass beds in Indonesia, particularly in Morotai Island Regency, still needs improvement. This research analyzed the distribution and coverage of seagrass in Morotai Island Regency, conducted from June to September 2024. Seagrass samples were collected from six sub-districts: South Morotai, East Morotai, North Morotai, Morotai Jaya, Southwest Morotai, and Rao Island. Observations were conducted *in situ*, and distribution maps were created using ArcView GIS. Seagrass coverage was assessed using the transect plot method. The results revealed 12 species of seagrass in Morotai Island Regency. Out of 81 observation points, seagrass was found in 64 locations across the six sub-districts. The distribution of specific species is as follows: *Enhalus acoroides* at 37 points (45.68%), *Thalassia hemprichii* at 46 points (56.79%), *Cymodocea serrulata* at 34 points (41.98%), *Cymodocea rotundata* at 43 points (53.09%), *Halodule uninervis* at 25 points (30.86%), *Halodule pinifolia* at 37 points (45.68%), *Thalassodendron ciliatum* at 2 points (2.47%), *Halophila minor* at 16 points (19.75%), *Halophila ovalis* at 18 points (22.22%), *Halophila spinulosa* at 5 points (6.17%), *Halophila decipiens* at 1 point (1.23%), and *Syringodium isoetifolium* at 27 points (33.33%). The seagrass coverage in Morotai Island ranges from sparse to dense. Overall, the water conditions in Morotai Island Regency are still relatively good for supporting seagrass growth.

INTRODUCTION

Seagrass is an angiosperm plant with essential functions and benefits for coastal areas, both ecologically and for human life **(Sjafrie *et al.*, 2018)**. This plant grows in shallow waters, functions as a habitat for various marine species, and contributes to the balance of the ecosystem. The distribution and cover of seagrass are very diverse, influenced by various factors such as environmental conditions, water depth, and human intervention.

Seagrass distribution can be found throughout the world, especially in tropical and subtropical areas. Seagrass grows in calm waters, such as lagoons, bays, and beaches unaffected by large waves or strong currents. Some types of seagrass that are commonly found include *Thalassia testudinum*, *Halodule wrightii*, and *Zostera marina*.

The physical and chemical conditions of water greatly influence the distribution of seagrass. Factors such as salinity, temperature, and nutrition are the main determinants. For example, seagrass tends to thrive in waters with more stable salinity and less pollution. In addition, the depth at which the seagrass grows also plays a role. Typically, seagrass grows at depths of up to 10 meters, depending on water clarity.

Based on initial studies, it is known that in Morotai Island Regency there are eight types of seagrass, namely *Cymodocea rotundata*, *Cymodocea serrulata*, *Syrigodium isoetifolium*, *Halodule uninervis*, *Halodule pinifolia*, *Enhalus acoroides*, *Halophila ovalis*, and *Thalassia hemprichii* **(Nurafni & Nur, 2018a; Muhammad *et al*., 2020; Firmansyah *et al*., 2022; Nur *et al*., 2023)**. These data were obtained from South Morotai and Rao Island sub-districts, while they have yet to be available for the other four sub-districts. Researchers from the LHK Standardization Agency have explained that the extent of seagrass beds in Indonesia is still uncertain. Quantitative studies and studies related to the seagrass area are still limited. In fact, the Indonesian Institute of Sciences has only validated seagrass beds in 29 locations or an area of 25,752 hectares. This number is still below 1% of the estimated area of seagrass beds in Indonesia, reaching 30,000km^2 **(Megarani, 2022)**.

Seagrass cover refers to the area covered by seagrass at a location. The extent of seagrass cover can vary from a few percent to almost the entire seabed, depending on environmental conditions and human factors. Research shows that greater seagrass cover correlates with better ecosystem health, including higher water quality and more extraordinary biodiversity. However, seagrass cover is increasingly threatened by various factors. Land conversion for development activities, unsustainable fishing, and pollution are some of the main causes resulting in a reduction in the area of seagrass cover. A decrease in seagrass cover can cause negative impacts on the ecosystem, such as loss of habitat for fish species and other marine organisms.

Coremap-Lipi (2017) also explained that seagrass ecosystems have high organic productivity in the waters. Seagrass has been used as a primary material for weaving, baskets, doormats, and animal feed. Apart from that, it is reported that seagrass is also used as an ingredient in cosmetics, medicine, and other pharmaceutical fields. It is known that seagrass has antifouling activity **(Nurafni & Nur, 2018b; Nurafni *et al*., 2021; Narayanan *et al*., 2024)**, antibacterial **(Nur *et al*., 2021; Narayanan *et al*., 2023; Narayanan *et al*., 2024)**, anti-larvae and anti-mosquitoes **(Amutha *et al*., 2023)**, as well as antioxidants **(Narayanan *et al*., 2023; Narayanan *et al*., 2024)**. This research analyzed the distribution and cover of seagrass in Morotai Island Regency.

MATERIALS AND METHODS

Time and place

This research was conducted in Morotai Island Regency. Seagrass samples were taken from 6 sub-districts: South Morotai, East Morotai, North Morotai, Morotai Jaya, South West Morotai, and Rao Island Districts. Therefore, the total research points were 81 sampling points, which were all minor islands and coastal areas where seagrass was found. The research location can be seen in Fig. (1).

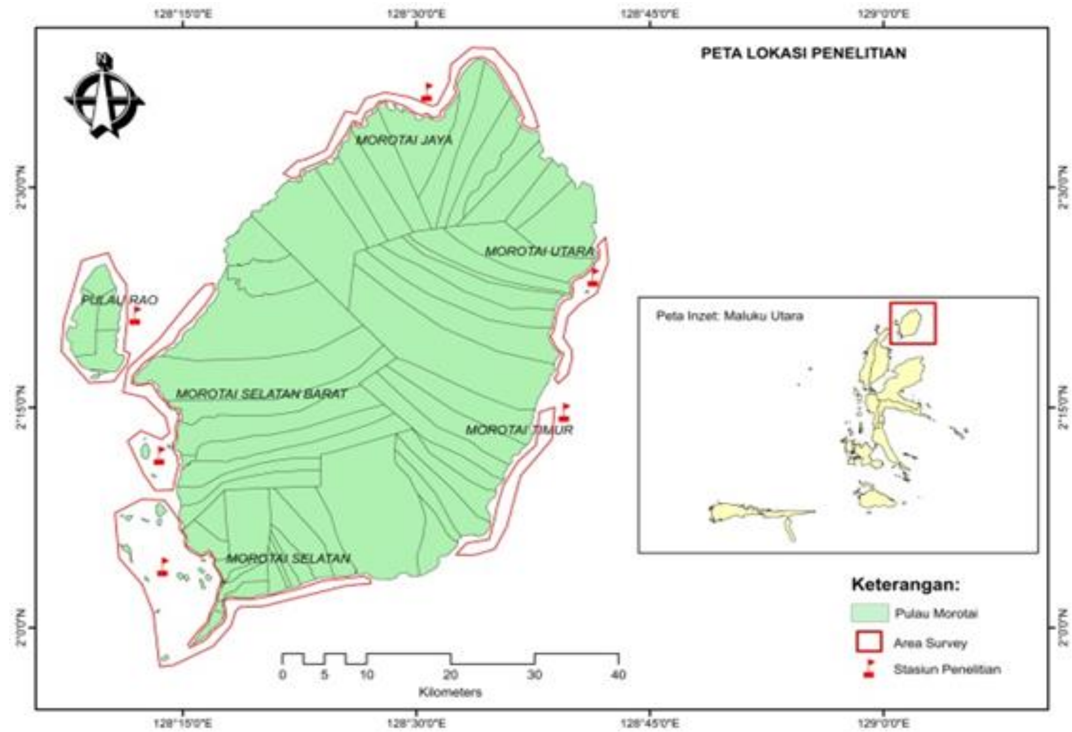

Fig. 1. Seagrass sampling point in the research location

Research procedures

1. Seagrass collection

Seagrass observations were carried out *in situ* in 6 sub-districts. The sampling method used is the census method, which means that all species of seagrass found in the research location were taken for identification.

2. Water quality

Water quality measurements were carried out *in situ* at each observation point to determine the environmental conditions during sampling. This measurement was carried out as supporting data for the presence of seagrass at each research point. The physicochemical parameters of the waters measured were temperature, salinity, dissolved oxygen DO, and pH. In addition to water quality, the substrate where seagrass was found was also identified.

3. Identify seagrass

Seagrass was identified directly by examining specific characteristics. If there was any uncertainty about the identification, samples were taken to the Laboratory of the Faculty of Fisheries and Marine Sciences at Pacific Morotai University for further analysis. This identification was supported by a seagrass identification guidebook **(Lanyon, 1986; Kuo & den Hartog, 2001; El Shaffai, 2016; Sjafrie *et al.*, 2018; Putra, 2019)**.

4. Seagrass distribution

The distribution of seagrass data found in the field was directly analyzed. Next, a map of the distribution of seagrass types in Morotai Island Regency was created using Arcview GIS 10.8.

5. Seagrass cover

The percentage of seagrass cover was carried out using the transect plot method measuring $1×1m^2$.

RESULTS AND DISCUSSION

Water quality

Marine water parameters were measured *in situ,* including temperature, dissolved oxygen (DO), salinity, pH, and substrate type. The results of measuring water parameters can be seen in Table (1).

Table 1. Average physical and chemical parameters of Morotai Island Regency waters

Districts	Physical and Chemical Parameters				
	Substrate	DO (mg/L)	Temperature (°C)	pH	Salinity (‰)
South Morotai	sand, stone, muddy sand, rocky sand, coral faults	40.6±2.9	30.3±1.0	8.3±0.7	29.7±2.0
Morotai South West	Muddy sand, rocky sand, coral faults	44.2±2.4	30.4±2.2	7.5±1.0	24.1±2.9
Morotai Jaya	sand, muddy sand, coral, sand with coral faults, rocky sand, coral faults	42.1±3.0	29.8±1.0	7.3±0.4	25.1±1.4
North Morotai	sand, stony sand, sandy mud, muddy sand, muddy sand with coral faults	41.6±2.0	29.2±1.4	6.9±0.2	26.0±8.9
East Morotai	Stony sand, mud, muddy sand	42.7±4.3	32.3±1.6	7.2±0.3	24.4±1.4
Rao Island	sand, sand and coral faults, coral faults	42.1±0.1	29.5±0.3	8.9±0.6	29.5±1.6
Standards		>5	28-30	7-8.5	33–34

1. Dissolved oxygen (DO)

The results of *in situ* dissolved oxygen measurements (Table 1) are of utmost importance since they indicate that the levels were highest in South West Morotai District with an average of 44.2±2.4mg/ L and the lowest in South Morotai with an average of

40.6± 2.9mg/ L. These high values of dissolved oxygen at all observation points are crucial for the optimal running of the photosynthesis process, leading to a high production of oxygen. As per the Decree of the Minister of the Environment No. 51 (2004), the DO quality standard value for aquatic biota is >5mg/ L, and the minimum dissolved oxygen (DO) content is 2ppm under normal conditions and is not contaminated by toxic compounds. This minimum dissolved oxygen content is more than sufficient to support the life of organisms **(Salmin, 2005)**.

2. Water temperature

The results of *in situ* temperature measurements (Table 1) show that the highest temperatures were recorded in East Morotai District with an average of 32.3± 1.6℃ and the lowest in North Morotai District with an average of 29.2± 1.4℃. The high-water temperature is due to the measurements being carried out during the day when the sun is at its peak. Most seagrasses live or are found in open areas, allowing direct sunlight to penetrate the seagrass without any obstacles. The temperature range obtained in East Morotai District is higher than the temperature range for seagrass growth according to Minister of Environment Decree No. 51 of 2004, influenced by the hot weather at the time of sampling. Temperature can significantly affect the photosynthesis process of seagrass. If the temperature is outside the threshold range, the ability of the photosynthesis process will decrease sharply **(Poedjirahajoe, 2013)**. Temperatures exceeding 30ºC are due to the shallow water topography so that sunlight reaches the bottom. The water conditions then become warmer as the sun shines longer **(Handayani *et al*., 2016)**. The higher the temperature, the more it affects the content of secondary metabolite compounds, especially tannin **(Mossi *et al*., 2009)**. This underscores the crucial role of environmental parameter conditions such as temperature, nutrients, and CO2 levels in influencing the presence of compounds in plants **(Rahakbauw & Wataguly, 2016)**.

Changes in water temperature can affect biochemical processes, photosynthesis, and seagrass growth and determine nutrient availability, absorption, respiration, leaf length, and other physiological and ecological factors. At temperatures above 45°C, seagrass will experience stress and can die. Seagrass that grows in conditions approaching compensation levels or lack of light will achieve optimal growth at low temperatures. However, at high temperatures, it will require quite a lot of light to overcome the effects of respiration and maintain carbon balance. **Mohamed and Geneid (2007)** also explained that water temperature and depth are the main factors affecting the iodine concentration of water and its subsequent absorption by seagrasses.

3. pH (Degree of acidity)

The results of *in situ* pH measurements (Table 1) were highest in Pulau Rao District with an average of 8.9± 0.6, followed by South Morotai District with an average of 8.3± 0.7, South West Morotai with an average of 7.5± 1, 0, Morotai Jaya with an average of 7.3± 0.4, East Morotai with an average of 7.2± 0.3, and the lowest in North Morotai with an average of 6.9± 0.2. The pH standard value for marine biota is 7–8.5. Thus, the pH value obtained was determined by the values set for South Morotai, West South Morotai, East Morotai, and Morotai Jaya Districts. Meanwhile, the average pH of the waters in North Morotai is lower than the quality standard, and the average pH on Rao Island is higher than the established quality standards. The pH value is smaller or more acidic due to increased carbon dioxide (CO_2) absorbed by seawater. As **Andika *et al*. (2020)** explained, seawater's pH value is closely related to dissolved carbon; the more carbon dioxide, the lower the pH value. However, **Effendi (2003)** explains that pH greatly influences the biochemical processes of water; in the pH range < 4.00, marine plants will die. The pH measured from the research location was more significant than four, so seagrass plants could tolerate it.

4. Water salinity

The results of *in situ* salinity measurements (Table 1) were highest in South Morotai District with an average of 29.7±2.0‰, followed by Rao Island with an average of 29.5±1.6‰, North Morotai with an average of 26.0±8.9‰, Morotai Jaya with an average of 25.1±1.4‰, East Morotai with an average of 24.4±1.4‰, and the lowest in South West Morotai with an average of 24.1±2.9‰. The salinity quality standard for seagrass waters, according to the Decree of the Minister of Environment No. 51 of 2004, ranged from 33–34‰. However, most seagrasses are tolerant to a wide range of salinity, namely 10–40‰ **(Rugebregt, 2015)**. Hence, the results of this study show that the salinity value is still within the specified range. However, a decrease in salinity can affect the process of photosynthesis **(Santos, 2004)**. The photosynthesis process produces compounds that play a role in growth and other compounds that do not play a role in growth **(Aho & Beck, 2011)**.

5. Substrate

The substrates found at the research location were sand, mud, rocks, coral, coral fragments, and mixtures. Seagrasses that live on substrates with large sediment grain sizes tend to have stronger roots than those that live on substrates with finer sediment grain sizes. The substrate has a large porosity, requiring longer roots to grip it tightly and withstand currents and waves **(Bavaria, 2007)**. The substrate dramatically influences the growth of seagrass leaves because it contains high levels of N and P nutrients. The presence of sediment is significant for seagrass as a place to live and as a supplier of nutrients.

The substrate is essential for seagrass as a supplier of nutrients and a place to live. The substrate on which seagrass lives is mud, sand, dead coral (rubble), a mixture of these two substrate types, or all three **(Kiswara, 2004)**. The growth rate of seagrass varies from one location to another because the speed or growth rate of seagrass is influenced by several factors, including the level of substrate fertility, grain size, and nutrient content in the water column **(De Silva & Amarasinghe, 2007; Yunitha *et al*., 2014; Amale *et al*., 2016; Sahertian & Wakano, 2017)**.

Seagrass species

Based on the identification results, 12 species of seagrass from 7 genera were found, and they are members of the Cymodoceaceae and Hydrocharitaceae families. The species of seagrass found in the waters of Morotai Island Regency are *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea serulata*, *Cymodocea rotundata*, *Halodule uninervis*, *Halodule pinifolia*, *Thalassodendron ciliatum*, *Halophila minor*, *Halophila ovalis*, *Halophila spinulosa*, *Halophila decipiens*, and *Syringodium isoetifolium*. It was also reported that eight species of seagrass were found on Morotai Island, namely *Cymodocea rotundata*, *Cymodocea serrulata*, Syrigodium isoetifolium, *Halodule uninervis*, *Halodule pinifolia*, *Enhalus acoroides*, *Halophila ovalis*, and *Thalassia hemprichii* **(Purwandani *et al*., 2014)**. On Dodola Island, Morotai Island Regency, six types of seagrass were found, namely *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, *Halodule pinifolia*, *Halodule uninervis* and *Halophila ovalis* **(Nurafni & Nur, 2018a)**. The types of seagrass found on Zum-Zum Island, Morotai Island are *Halodule pinifolia*, Syrigodium isoetifolium, *Halophila ovalis*, *Enhalus acoroides*, *Cymodocea rotundata*, Cymodecea sululata, and *Thalassia hemprichii* **(Nur *et al*., 2023)**. The morphology of seagrass in the Morotai Island Regency is explained in detail below.

1. *Enhalus acoroides*

Enhalus acoroides, a member of the Hydrocharitaceae family, stands out with its long, ribbon-like leaves and rounded leaf tips. The leaves, which are thick and robust, boast a striking dark green hue. The large, thick rhizoma is a unique feature, distinguished by its black fibers. The unbranched, brownish-white roots add to the distinctiveness of this seagrass. The fruit, measuring 4-6cm in diameter, is another characteristic feature. The unique morphology of *E. acoroides* is depicted in Fig. (2).

Fig. 2. *Enhalus acoroides* showinh: **A)** Morphology and **B)** Leaf tip shape

The leaf length of *Enhalus acoroides* ranges from 2.0 to 54.3cm, with a leaf width of 0.6 to 1.5cm. The rhizome measures between 1 and 8.3cm, while the roots can reach lengths of 1 to 27.7cm **(Wagey & Sake, 2013)**. The rhizome has segments that are 1cm long and is covered with stiff, blackish fibers. Leaves can grow up to 100cm in length and have a width of 1.5cm. The roots are numerous, unbranched, and typically reach lengths of 12cm, thriving in sandy and muddy substrate areas **(Ernaningsih *et al.*, 2019)**. Additionally, it has been reported that the rhizome of *E. acoroides* is thick, with a diameter of 1cm, and lacks a stem; the leaves grow directly from the rhizome **(Pranata *et al.*, 2018)**. The leaves are ribbon-shaped, measuring 30 to 150cm in length and 1.25 to 1.75cm in width. Female flowers feature spiral-shaped supporting stalks, while male flowers have slender, straight stalks.

2. *Thalassia hemprchii*

Thalassia hemprichii has thick, slightly curved leaves with brown lines or spots on the leaf blades. This type has short stems. The rhizomes are thick and covered in leaf scars but slightly rounded. Female flowers have shorter supporting stalks than male flowers and are found in muddy sand areas. The morphology of *T. hemprichii* can be seen in Fig. (3).

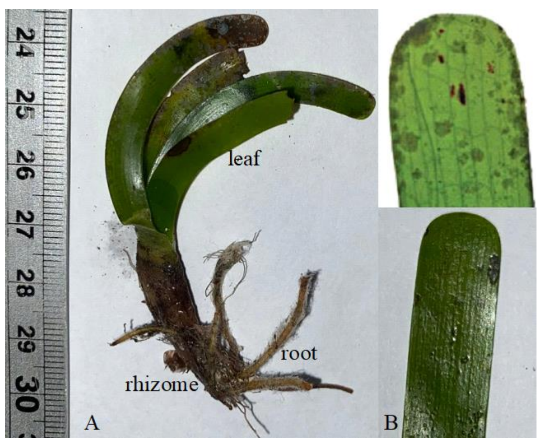

Fig. 3. *Thalassia hemprichii* showing: **A)** Morphology and **B)** Leaf tip shape

Thalassia hemprichii has a characteristic curved strap-like leaf shape, round apex, and dark green color, with the number of leaves in one stand being 2-5. On the horizontal rhizoma, there are brownish-white scales or sheets. Rhizoma has a length between 3.0–8.6cm. Leaf length ranges from 0.5-15.5cm and width 0.3–1.1cm **(Wagey & Sake, 2013)**. The results of measurements of *T. hemprichii* seagrass at Tanjung Tiram Beach, Ambon Bay, showed that the leaf length was 9.1–104.2mm, leaf width 0.3–9.6mm, rhizome length 7.8–133mm, number of leaves 2–5, and root length 3.8–141.9mm **(Sermatang *et al*., 2021)**. The same thing was also found in the root length of the *T. hemprichii* seagrass, which lives on Pasir Panjang Beach, North Minahasa, on a coral rubble substrate which had the highest root length of 45.78mm, the highest leaf length of the *T. hemprichii* seagrass was on a mud sand substrate of 65.96mm **(Zachawerus *et al*., 2019)**.

3. *Cymodocea serrulata*

Cymodocea serrulata, a member of the Cymodoceaceae family, is characterized by its unique leaf sheath. The relatively narrow leaf sheath at the base, which forms a triangle and does not close completely, is a distinctive feature. The purple color of the leaf sheath adds to its uniqueness. Each stem typically bears about 2–5 leaves. The tips of the leaves, which are clearly rounded and serrated, are another unique feature. The green rhizome, with its upright stems and fibrous roots at each segment, is another characteristic of *C. serrulata*. The unique morphology of *C. serrulata* is depicted in Fig. (4).

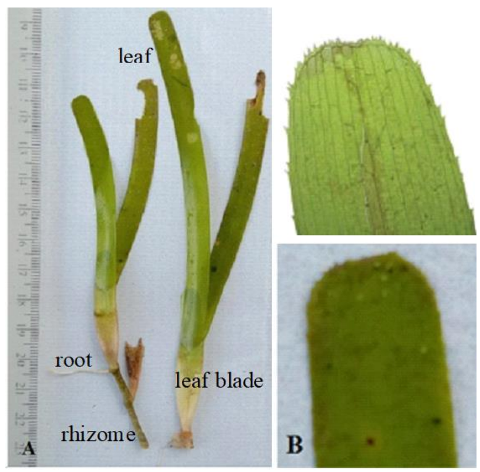

Fig. 4. *Cymodocea cerallata* showing: **A)** Morphology and B) Leaf tip shape

Cymodocea cerrullata is very similar to *Cymodocea rotundata*. It differs in its relatively larger size, and the tip of the leaf feels rough when touched because it has serrations. The color of the rhizomes can be yellow, green, or brown, depending on their health and light exposure. The length of the leaves is up to 15cm, and the width of the leaves is 0.4–0.9cm **(Pranata *et al*., 2018)**. The node segments on the rhizoma are 1.5cm long, and the leaf sheath is 3cm long. Each node consists of 2 roots and a shoot; the leaf blade is 9cm long with a width of 1cm and lives on muddy substrates **(Ernaningsih *et al*., 2019)**. It has also been reported that this type of leaf is 6–15cm long with a width of 0.4–0.9cm **(Putra, 2019)**.

4. *Cymodocea rotundata*

This seagrass belongs to the Cymodoceaceae family. The leaf sheaths develop well and close completely. It forms upright stems at each node with 2–7 leaves per stem. The number of veins (leaf veins) is around 7-15 in a longitudinal position. The leaves are slightly curved with rounded leaf tips (rotundus) or form a heart curve and are not serrated. The rhizomes are smooth, and the roots branch irregularly at each node (nodes). This species also has short erect lateral stems at each node. The morphology of *C. rotundata* is shown in Fig. (5).

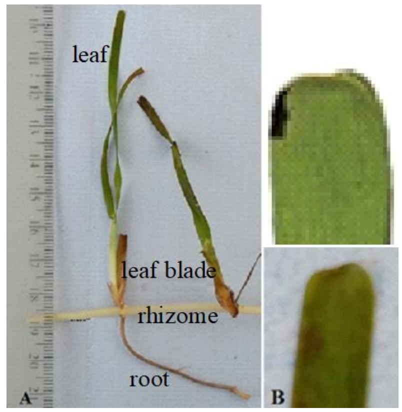

Fig. 5. *Cymodocea rotundata* showing: **A)** Morphology and **B)** Leaf tip shape

The leaves of *C. rotundata* are 7–15cm long with a width of 0.2–0.4cm, and the rhizome is segmented at a distance of 1.0–4.5cm **(Pranata *et al*., 2018)**. The rhizome of *C. rotundata* is segmented 2cm long, and the leaf midrib is 4cm long; each node consists of 3 roots with long shoots, the leaf blade is 12cm long and 1cm wide, lives on muddy and sandy substrates **(Ernaningsih *et al*., 2019)**. It is also stated that the leaf sheath of *C. rotundata* is 1.5–5.5cm long, the leaf length is around 7-15cm, and the leaf width is 0.2–0.4cm **(Putra, 2019)**.

5. *Halodule uninervis*

This seagrass belongs to the Cymodoceaceae family. The leaf size is more significant than *H. pinifolia*. The leaf structure is almost the same as that of *H. pinifolia*, but the leaf tip is different because the leaf tip always ends with three points (trident-shaped), and the central vein does not divide into two like that of *H. pinifolia*. One central vein of the leaf is precise. The rhizome is smooth with clearly blackened leaf scars. In each node (node), there are three roots and shoots. The morphology of the *uninervis* handle is shown in Fig. (6).

Halodule uninervis has fine rhizomes with segments 0.5–4cm long; each segment has 1 to 6 roots, consists of 2 to 3 leaves, and has short stems. The leaves are 6–15cm long, with a 0.05–0.5cm width. It can be found on sandy substrates and grows in tidal areas **(Pranata *et al*., 2018)**. The rhizome of this species has nodes with segments that are 3 cm long, leaf sheaths measuring 2cm, and leaf blades that are 17cm long and 1mm wide **(Ernaningsih *et al*., 2019)**.

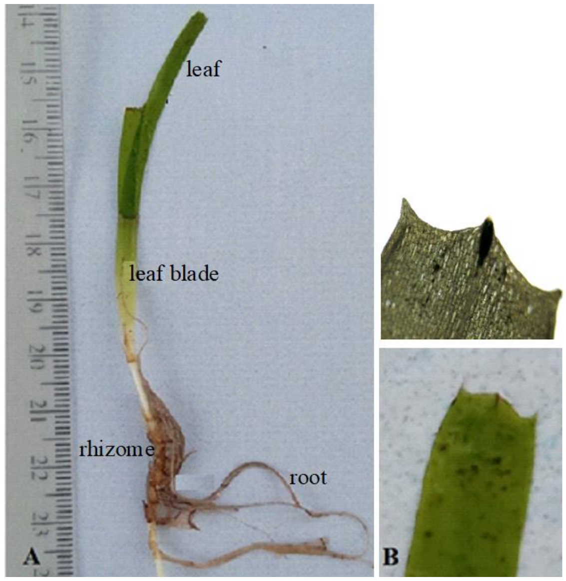

Fig. 6. *Halodule uninervis* showing: **A)** Morphology and **B)** Leaf tip shape

6. *Halodule pinifolia*

This seagrass belongs to the Cymodoceaceae family. *Halodule pinifolia* has the smallest size in the Halodule genus. The tip of the leaf is slightly rounded, serrated, and divided into three points. The leaf's central vein is precise with a slightly dark color and splits at the tip of the leaf into two (forming the letter "V"). The rhizome is smooth with clearly blackened leaf scars. The morphology of *Haludule pinifolia* is shown in Fig. (7).

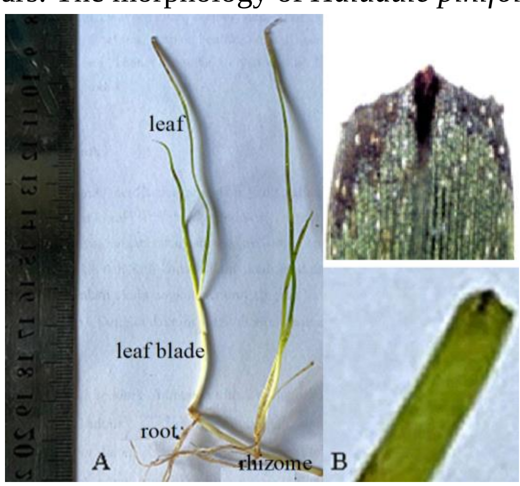

Fig. 7. *Halodule pinifolia* showing: **A)** Morphology and **B)** Leaf tip shape

The rhizome segments of *H. pinifolia* are about 1–3cm long. The stems of this species are short and erect, often covered with dense leaflets, and look like leaves growing directly from the rhizome. The leaves are 5-20cm long with a width of 0.6–1.2cm and live in muddy sand substrates **(Pranata *et al*., 2018)**. The length of the leaves of *H. pinifolia* is less than 20cm, and the width of the leaves is approximately 0.25mm **(Putra, 2019)**.

7. *Thalassodendron ciliatum*

This seagrass belongs to the Cymodoceaceae family. It is often found attached to rocky or coral substrates. Rhizome thickness is 0.5cm, and it has erected shoots with a length of between 10 and 65cm. Its leaves are 10–15cm long and 0.5–1.4cm wide. On the leaves, there are 17–27 longitudinal veins. The leaf tips are round and serrated **(Lanyon, 1986)**. The morphology of *Thalassodendron ciliatum* is depicted in Fig. (8).

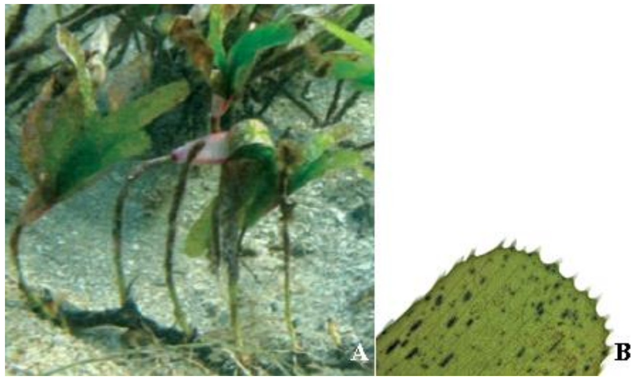

Fig. 8. *Thalassodendron ciliatum* showing: **A)** Morphology and **B)** Leaf tip shape

8. *Halophila minor*

This seagrass belongs to the Hydrocharitaceae family. The leaves have shorter petioles compared to *H. ovalis* and are oval-shaped, smaller in size, and arranged in pairs along each segment of the rhizome. They have fewer than ten pairs of cross veins. The rhizome is thin and smooth. The morphology of *Halophila minor* is illustrated in Fig. (9). *Halophila minor* features small, oval-shaped leaves with stalks, and its leaf veins are fewer than eight **(Sjafrie *et al*., 2018)**. The leaves range from 0.5 to 1.5cm in length and are less than 0.5cm in width **(Putra, 2019)**.

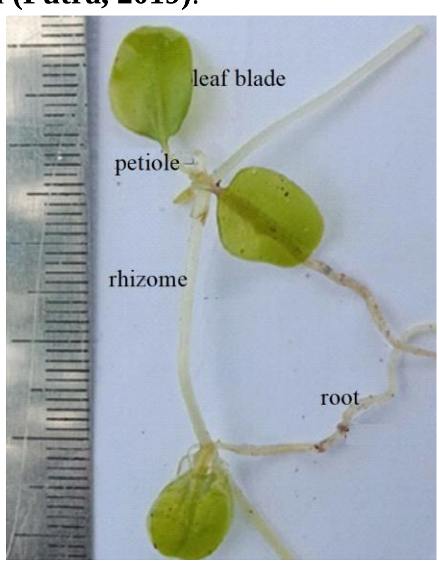

Fig. 9. Morphology of *Halophila minor*

9. *Halophila ovalis*

This seagrass belongs to the Hydrocharitaceae family. The leaves are oval with rounded leaf tips, paired with petioles on each rhizome segment, and the surface is hairless. It has 5-25 pairs of leaf veins that cross each other (cross-veins). Cross veins form a 45–60-degree angle. Apart from cross veins, *H. ovalis* also has intramarginal veins. Rhizoma is thin, smooth, and light-colored. Luminary shoots are found at each stand's base (node) between the stem and the rhizome. The morphology of *Halophila ovalis* is depicted in Fig. (10).

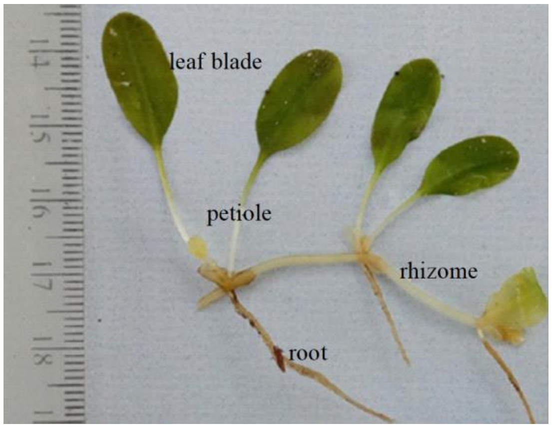

Fig. 10. Morphology of *Halophila ovalis*

The rhizome length of *Halophila ovalis* ranges from 0.2 to 3.2cm, with a luminary length of 0.2 to 0.6cm, leaf length of 0.3 to 2.7cm, leaf width of 0.5 to 1.6cm, petiole length of 0.1 to 4.1cm, and root length of 0.2 to 5.3cm **(Wagey & Sake, 2013)**. It has also been reported that *H. ovalis* has rhizomes up to 2mm wide, with leaf stalks measuring 0.4 to 8.0cm that arise directly from the rhizome. The leaves are 1 to 4cm long and approximately 0.6cm wide. This type of seagrass can be found in various substrates, ranging from muddy sand to gravel, and is distributed from tidal areas to depths of 10 to 12m **(Pranata *et al.*, 2018)**. Additionally, the length of *H. ovalis* leaves is noted to be between 1 and 4cm, with a width of 0.5 to 2cm **(Putra, 2019)**.

10. *Halophila spinulosa*

This seagrass belongs to the Hydrocharitaceae family. It has erected lateral shoots reaching 15cm in length. Each lateral shoot contains 10–20 pairs of leaves. The leaves are oval with a length of 1.5–2.5cm and a width of 0.3 - 0.5cm. The edges of the leaves are serrated. *H. spinulosa* has a shape that resembles a fern plant **(Lanyon, 1986)**. The morphology of *Halophila spinulosa* is shown in Fig. (11).

Fig. 11. Morphology of *Halophila spinulosa*

11. *Halophila decipiens*

This seagrass belongs to the Hydrocharitaceae family. The leaves are elliptical with a 1-2.5cm length and a width of 0.05cm. The leaves emerge from the node in pairs with serrated leaf edges. The middle leaf veins are visible, with 6–9 pairs of cross veins. It is found throughout tropical and subtropical areas **(Lanyon, 1986)**. The morphology of *Halophila decipiens* is shown in Fig. (12).

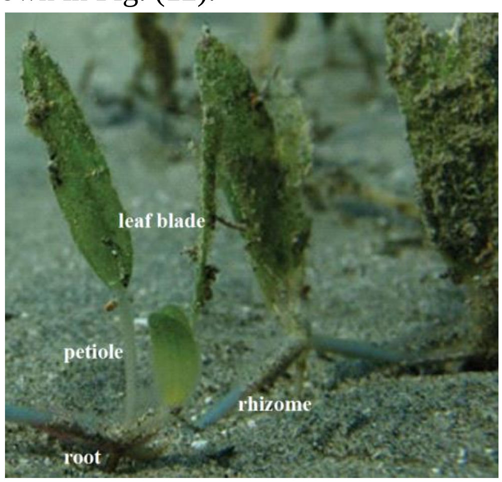

Fig. 12. Morphology of *Halophila decipiens*

12. *Syrigodium isoetifolium*

This seagrass belongs to the Cymodoceaceae family. The leaves are cylindrical with a pointed tip. Between the leaves, rhizomes are connected by a rather hard stem. From the base of the leaf to the stem, it is covered by a brownish-white leaf sheath. Roots grow at the bottom of the base, namely between the stem and the rhizome (node). The morphology of *Syringodium isoetifolium* is shown in Fig. (13).

Syringodium isoetifolium has 2–3 leaves at each node and is 1–2mm in diameter **(Kuo & den Hartog, 2001)**. The leaves of *S. isoetifolium* are 14–15cm long with a diameter of 0.08–0.1cm. Meanwhile, other research found that the leaf length of *S. isoetifolium* is 0.5–18.0cm with a diameter of 0.1–0.2cm, the stem length is 1.0–5.0cm, the rhizoma length is 0.4–9.0cm, and roots are 0.8–6.4cm **(Wagey & Sake, 2013)**. It was further reported that this type has fine rhizomes with 1–3 small branching roots; the rhizomes have segments that are 1.5-3.5cm apart **(Pranata *et al*., 2018)**. The leaf blade is up to 30cm long and 0.1 to 0.2cm wide. The leaves are smooth, and the leaf tips are slanted. Lives on muddy substrates and cannot tolerate long periods of drought.

Fig. 13. Morphology of *Syrigodium isoetifolium*

Seagrass distribution

Distribution mapping, a vital activity process, provides crucial information on the surface of the earth. It aims to paint a comprehensive picture of the earth's surface and the natural resources found in a place, including the distribution of seagrass species in the waters of Morotai Island Regency. The data collection on the distribution of seagrass species was meticulously carried out at 81 observation points distributed in 6 sub-districts. South Morotai District has 24 points, South West Morotai has 10 points, Morotai Jaya has 14 points, North Morotai has 15 points, East Morotai has 15 points, and Rao Island has 3 points. Overall, the research revealed 64 observation points where seagrass was found, while 17 observation points showed no seagrass presence. The potential impact of this research on conservation efforts is significant, underlining the urgency and importance of our work in preserving these vital ecosystems.

The distribution mapping process, a vital activity in environmental research, provides a detailed picture of the earth's surface and the natural resources it harbors. This includes the distribution of seagrass species in the waters of Morotai Island Regency. The data collection on seagrass distribution was carried out *in situ* using the census method. Observations were made at 81 points, which were strategically distributed across the study area, including coastal villages and small islands. South Morotai District had 24 points, South West Morotai had 10 points, Morotai Jaya had 14 points, North Morotai had 15 points, East Morotai had 15 points, and Rao Island had 3 points. In total, 64 observation points revealed the presence of seagrass, while 17 points did not.

The distribution of seagrass species *Enhalus acoroides* in the waters of Morotai Island was found at 37 observation points (45.68%); the *Thalassia hemprichii* type was found at 46 points (56.79%); the *Cymodocea serulata* type was found at 34 points (41.98%); the species *Cymodocea rotundata* was found at 43 points (53.09%); the *Halodule uninervis* type was found at 25 points (30.86%); the *Halodule pinifolia* type was found at 37 points (45.68%); the *Thalassodendron ciliatum* type was found at 2 points (2 .47%), *Halophila minor* type was found in 16 points (19.75%); *Halophila ovalis* type was found in 18 points (22.22%); *Halophila spinulosa* type was found in 5 points (6.17%); *Halophila decipiens* type found in 1 point (1.23%), and the *Syringodium isoetifolium* type was found in 27 points (33.33%) (Fig. 14). No seagrass was found at several observation points due to the different forms of adaptation of seagrass. It follows the results of Coremap-CTI research on the status of seagrasses in 2021. Certain types of seagrasses, such as *E. acoroides*, were not found at several points due to certain forms of adaptation and habitat ranges, such as substrate types and the influence of high waves. From the observations, it can also be seen that Morotai Jaya has waters with high waves because it faces the open sea. It is also caused by the morphological condition of seagrass (such as *E. acoroides*) which has the most significant and extended leaves compared to other types of seagrass, thus affecting its adaptation to waters with high waves.

Environmental factors play a significant role in the distribution of seagrass species. The substrate composition, such as black sand or iron sand, which does not support seagrass growth, and the decrease in nutrient content in the substrate underscore the intricate relationship between environmental conditions and seagrass distribution. The organic matter content in the substrate and calm water conditions also influence seagrass distribution **(Dahlan & Nofrizal, 2007)**. **Rahman *et al*. (2022)** explained that *Cymodocea* sp. can grow on various substrates ranging from muddy clay to rough coral fragments. This seagrass forms large and dense monospecific meadows in calm environments and sandy substrates. *Halodule* sp. is generally found on fine calcareous mud or sand substrates. The seagrass *Thalassia hemprichii* is found abundantly on sand substrates and coral fragments **(Arifin, 2001)**. **Rani *et al*. (2020)** also reported that differences in the substrate can influence the morphometrics of *Thalassodendron ciliatum* on the East Coast of Bulukumba Regency.

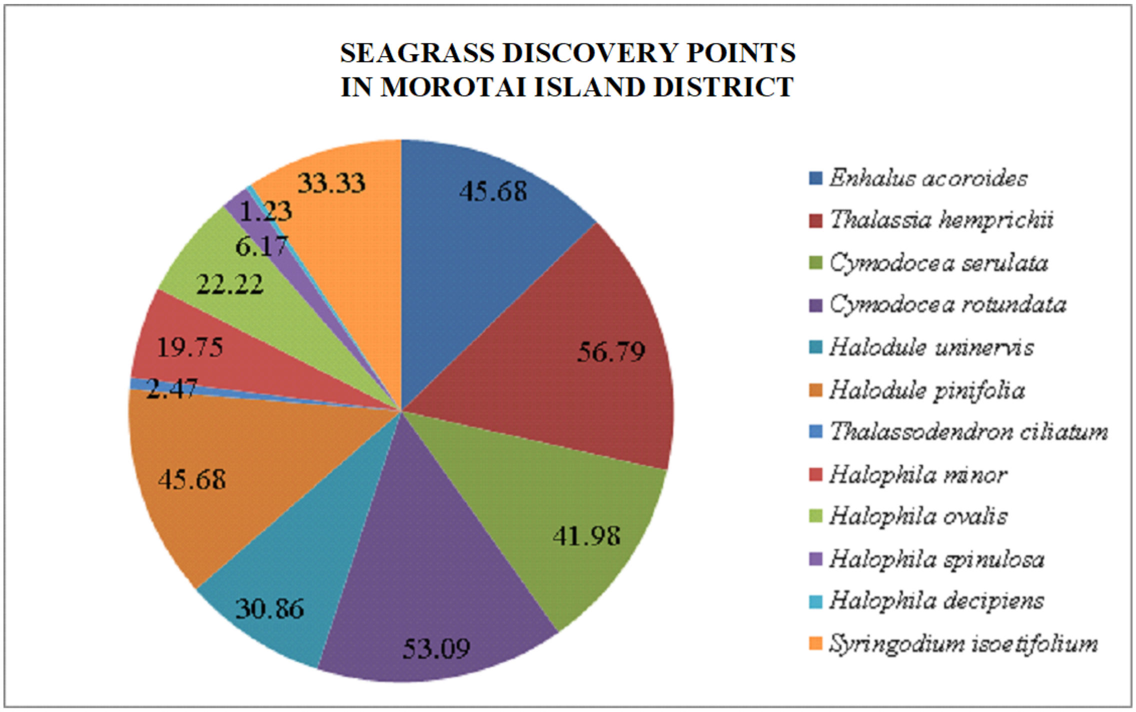

Fig. 14. Percentage distribution of seagrass species in Morotai Island Regency

Apart from that, seawater's low acidity (pH) has a positive effect on seagrass. Namely, it can increase photosynthesis and seagrass productivity. Overall, the seawater pH measured at the research location ranged from 6.9 to 8.9, indicating a range that supports seagrass growth. These findings have potential implications for the management and conservation of seagrass ecosystems. Several studies have reported pH ranges for the growth of *E. acoroides*. **Ananda *et al*. (2024)** found that the pH range in Badak Island, East Kalimantan, was around 8.1-8.2, while **Zainuri *et al*. (2011)** reported that the pH in the coastal seagrass beds of Bontang City was around 8.03–8.06. In contrast, **Irawan *et al*. (2021)** found that the pH range on the coast of Bontang City was around 6.32-7.6. Similarly, **Widyawati *et al*. (2022)** reported that the average pH in the seagrass beds of Kedindingan Island was 7.53. These diverse data suggest that *E. acoroides* can thrive in a wide pH range of 6.32-8.2. **Sermatang *et al*. (2021)** reported that the pH at the Tanjung Tiram beach in Ambon Dalam Bay ranges from 5.85-6.95, supporting the growth of *T. hemprichii*.

Enhalus acoroides has a broader distribution and is most often found in Indonesian waters. It aligns with what was reported in Coremap-CTI (2017 to 2018), which shows that *Enhalus acoroides* and *Thalassia hemprichii* are cosmopolitan types spread throughout Southeast Asia and the Indo-West Pacific region. Types of seagrass found in South Morotai waters include *Cymodocea rotundata*, *Enhalus acoroides*, *Halodule uninervis*, *Halodule pinifolia*, *Halophila ovalis*, *Sryngodium isoetifolium*, and *Thalassia hemprichii* **(Julianinda *et al*., 2022)**.

Further research is crucial to fully understand the distribution of seagrass species. For instance, of the 8 types of seagrass in the intertidal area of Pulau Dua, Enggano District, the *E. acoroides* type was found unevenly and was not found at all observation stations. Only the types *Thalassia hemprichii*, *Cymodocea serrulata*, and *Halodule uninervis* were found evenly in the intertidal area **(Suniati, 2018)**. Similarly, in Kapoposang Island, the distribution of seagrass species is low and only found in certain spots, namely *Enhalus acoroides* **(Rosalina *et al*., 2022)**. These findings underscore the need for further research to comprehensively map the distribution of seagrass species and the importance of ongoing studies in understanding seagrass distribution.

Several studies have shown that *E. acoroides* can flourish within a specific temperature range of 28–32℃ and a salinity range of 15–36‰. **Ananda *et al*. (2024)** found that the average water temperature of Badak Island, East Kalimantan, was 30.2℃ with a salinity of 31‰, while **Zainuri *et al*. (2011)** reported that the average temperature on the coast of Bontang City was 28℃ with a salinity of 34-36‰. The temperature range at Tulehu State Beach, Central Maluku Regency's seagrass beds, falls within 28-32℃, with a salinity of 15-33‰ **(Payung & Irawati, 2020)**. **Irawan *et al*. (2021)** reported that the salinity range in Bontang City waters is approximately 27.85–32.15‰. The water temperature in our research location (Table 1) ranges from 29.2–32.3℃ with a salinity of 24.1–29.7‰. These findings not only confirm the ideal temperature and salinity conditions for *E. acoroides* but also highlight the crucial role of small islands in protecting the growth area. As a result, this species is scarce in East Morotai and Morotai Jaya, while it is abundant in South Morotai and West South Morotai, thanks to the protective influence of small islands.

Thalassodendron ciliatum is one of the dominant types of seagrass but has a limited distribution. Of the 366 research locations in Indonesia, the *T. ciliatum* type was only found in 33 locations, or around 9% **(Sjafrie *et al*., 2018)**. In South Sulawesi, it has only been found around the Flores Sea, namely in the districts of Selayar and Bulukumba **(Kiswara, 2009)**. Seagrass usually grows to form dominant monospecific communities on sand, rubble (dead coral fragments), and rigid substrates. Overall, the distribution of seagrass species in Morotai Island waters can be seen in Fig. (15). Seagrass species' distribution data are taken directly in the field now. These data are not compared with data from the previous year because the data do not exist for other sub-districts. Meanwhile, image data cannot distinguish the point of presence of seagrass, algae, and coral.

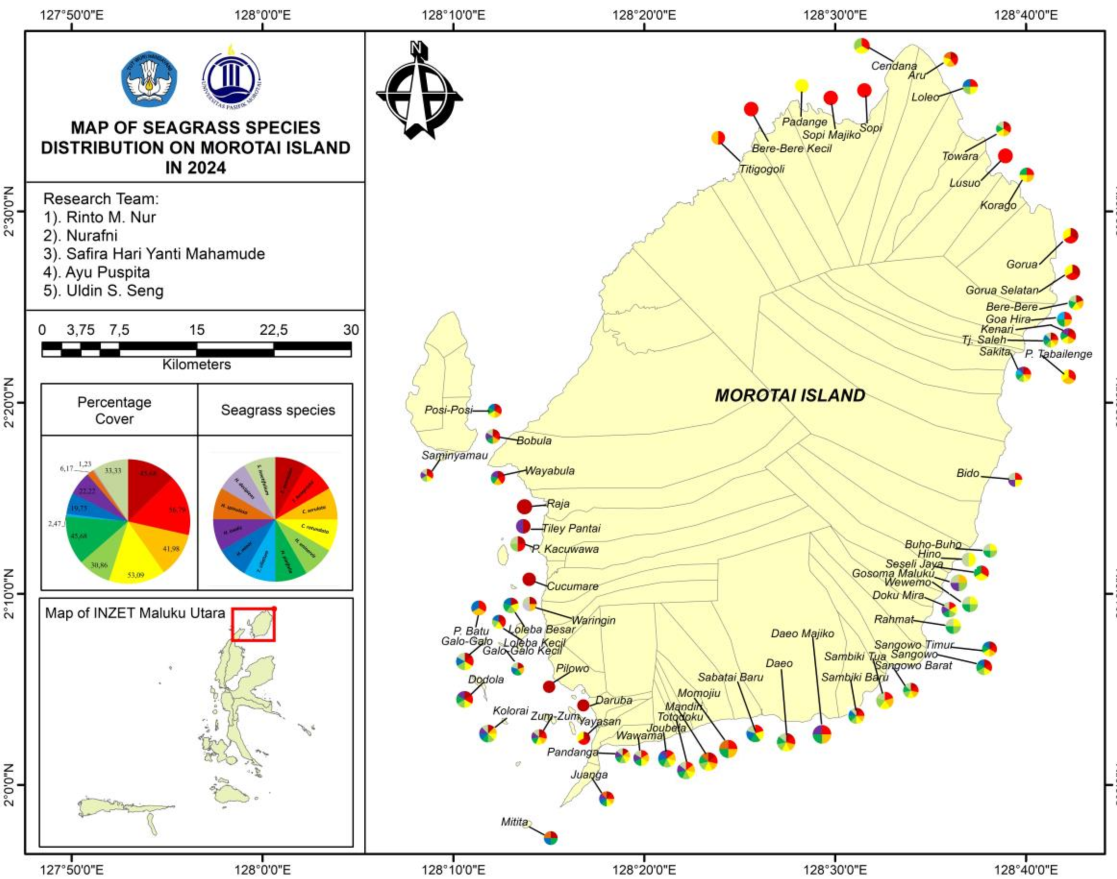

Fig. 15. Map of seagrass distribution covering Morotai Island Regency

Rahman *et al*. (2022) reported that water temperature also affects the growth and existence of *Thalassia*. Photosynthesis in *Thalassia* decreases if the water temperature is below or above 28-30℃. High temperatures showed that *Thalassia* could flower but could not bear fruit. In addition, high temperatures will result in the loss of many leaves and will increase the sediment temperature. An increased sediment temperature will cause plants to die. For tropical seagrasses, photosynthesis becomes impaired at temperatures of 40–45℃. **Nugraha *et al*. (2020)** also reported that *Halophila ovalis* seagrass grows best in Dompak Bintan Island with a water temperature of 32℃, salinity 35‰, pH 8.3, and DO 6.3mg/ L.

In Fig. (15) it can also be seen that *Cymodocea* seagrasses are distributed at almost all observation points. This indicates that environmental conditions favor the growth of *Cymodocea*. The water temperature at the research location ranges from 29.2—32.3℃, salinity 24.1—29.7‰, pH 6.9—8.9, and DO 40.6—44.2mg/ L. **Hidayat *et al*. (2018)** explained that *Cymodocea rotundata* and *Cymodocea serrulata* are types of seagrass that can be found in the Celukanbawang Harbor area. *Cymodocea rotundata* is the species that dominates and has the highest frequency of occurrence in the area. Meanwhile, *Halophila decipiens* is the type of seagrass with the lowest frequency of occurrence. This is because the biophysical characteristics of the waters in the Celukanbawang Harbor area in terms of temperature, salinity (29-30‰), turbidity, DO (4.04-4.05 mg/l), and substrate are classified as having a normal range for the growth and development of seagrass. **Senduk *et al*. (2021)** also reported that *Cymodocea rotundata* was most often found at Station 1, East Likupang, with a water temperature of 32℃, salinity 30‰, and pH 7. **Elenin *et al*. (2020)** also reported that at the Hurghada Beach location, the Red Sea with a water temperature of 29.5-32.49℃ and a pH of 7.45-8.9 found seagrass species *Halodule uninervis*, *Thalassodendron ciliatum*, *Halophila stiplacea*, and *Thalassia hemprichii*.

Seagrass cover

Seagrass cover, the area covered by seagrass plants, was determined through rigorous field observations. We used quadrat transects and transect plots at each observation station to ensure comprehensive data collection. Several factors can influence seagrass growth, including temperature, salinity, depth, current, pH, and substrate. The percentage of seagrass cover can vary depending on location and environmental conditions. In this study, the seagrass cover observed was the cover of all types of seagrass found at each point or location observed (Fig. 16). From the research results, it was found that the highest seagrass cover was in South Morotai District with a cover percentage of 61.25%, followed by East Morotai at 52.61%, North Morotai at 49.21%, Rao Island at 42.66%, South West Morotai at 21.01%, and the most minor percentage covered was in Morotai Jaya at 7.84%.

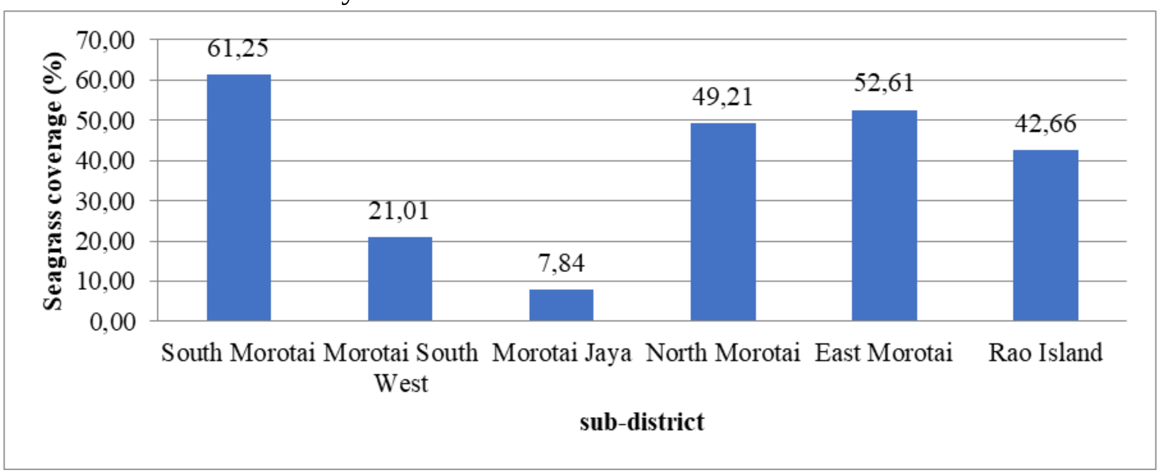

Fig. 16. Data on seagrass cover in Morotai Island Regency

These results show that the waters of South Morotai District have a high percentage of closure. It can be seen from the existing potential that almost all types of substrate surfaces in the area have living spaces occupied by seagrass. The beach conditions are calm, and there are many small islands without much ecosystem disturbance, causing the seagrass cover in this area to still appear suitable. According to the Decree of the Minister of Environment No. 200 of 2004, seagrass beds with a cover percentage above 60% are categorized as sound, rich, and healthy. Therefore, only the percentage of seagrass coverage in the South Morotai District falls within these categories. Furthermore, according to the 2014 COREMAP-LIPI guidelines for seagrass cover categories, seagrass beds are classified into four categories: sparse (0–25% cover), moderate (26–50%), dense (51–75%), and excellent (76–100%). In South Morotai, the seagrass cover is 61.25%, placing it in the dense category, while East Morotai has a cover of 52.61%, also in the dense category. North Morotai and Rao Island fall into the moderate category, while South West Morotai (21.01%) and Morotai Jaya (7.84%) are classified as sparse. Additionally, seagrass cover in Pulau Rao District, Morotai Island Regency, ranges from 31% to 36%, indicating a moderate category **(Sandra *et al.*, 2020)**. In contrast, seagrass cover on Manado Tua Island is classified as good/dense, with an average cover percentage of 71.40% **(Bulele *et al.*, 2020)**.

CONCLUSION

The research results indicate that water parameters in Morotai Island Regency, such as dissolved oxygen (DO), temperature, pH, salinity, and substrate type, are relatively favorable for supporting seagrass growth. The DO ranges from 40.6 to 44.2 mg/L, the temperature is between 29.2 and 32.2°C, pH levels range from 6.9 to 8.9, and salinity varies from 24.1 to 29.7‰. The substrates consist of sand, muddy sand, rocky sand, sand with coral fragments, and coral fragments.

Identification efforts revealed 12 types of seagrass: *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea serrulata*, *Cymodocea rotundata*, *Halodule uninervis*, *Halodule pinifolia*, *Thalassodendron ciliatum*, *Halophila minor*, *Halophila ovalis*, *Halophila spinulosa*, *Halophila decipiens*, and *Syringodium isoetifolium*. Out of 81 observation points, seagrass was found at 64 locations across six sub-districts. The distribution of specific species is as follows: *Enhalus acoroides* was found at 37 points (45.68%), *Thalassia hemprichii* at 46 points (56.79%), *Cymodocea serrulata* at 34 points (41.98%), *Cymodocea rotundata* at 43 points (53.09%), *Halodule uninervis* at 25 points (30.86%), *Halodule pinifolia* at 37 points (45.68%), *Thalassodendron ciliatum* at 2 points (2.47%), *Halophila minor* at 16 points (19.75%), *Halophila ovalis* at 18 points (22.22%), *Halophila spinulosa* at 5 points (6.17%), *Halophila decipiens* at 1 point (1.23%), and *Syringodium isoetifolium* at 27 points (33.33%).

In terms of seagrass cover, South Morotai (61.25%) and East Morotai (52.61%) are classified as dense; North Morotai (49.21%) and Rao Island (42.66%) fall into the moderate category, while South West Morotai (21.01%) and Morotai Jaya (7.84%) are categorized as sparse.

ACKNOWLEDGEMENTS

The authors would like to thank the Directorate of Research, Technology, and Community Service at the Ministry of Education, Culture, Research, and Technology for funding this research, as well as Pacific Morotai University for providing support and facilities.

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