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Seagrass Meadows as Critical Ecosystems: An Integrated Approach to Conservation Area in Saleh Bay, West Nusa Tenggara

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Abstract

Seagrass beds are crucial for marine ecosystems, providing habitats and food sources for diverse species while naturally protecting coastlines from erosion. These ecosystems play a pivotal role in stabilizing sediments, filtering pollutants, and acting as carbon sinks, which helps mitigate the effects of climate change. Their significance extends to supporting ecotourism and providing essential services to coastal communities, thereby promoting environmental conservation awareness. Saleh Bay, designated as a marine nature reserve, exhibits rich marine biodiversity across its five distinct zones: core, utilization, sustainable fisheries, non-conservation, and other zones. This study aimed a comprehensive understanding of the pivotal role played by seagrass beds in Saleh Bay's integrated ecosystem in West Nusa Tenggara. The density and percentage cover were count from three linear transects and placed perpendicularly to the coastline. Correspondence Analysis (CA) was applied to represents which species most strongly associated with specific zones. Meanwhile, Cluster Analysis was used to grouping specific zones based on the ecological characteristics. A total of eight seagrass species were identified, which dominated by Enhalus acoroides (42.15%) and closely related to Sustainable Fisheries and Utilization zones. Furthermore, the Cluster Analysis indicates that the Utilization and Sustainable Fisheries zones exhibit the highest degree of similarity (90%) based on their density characteristics. This research underscores the broader understanding of seagrass ecosystems. The high similarity between the Utilization and Sustainable Fisheries zones suggests that these areas play complementary roles in supporting the health of seagrass ecosystems. Management plans should integrate these findings to optimize resource use while ensuring ecological sustainability.

Keywords: Coastal, Conservation, Environment, Island, Similarity

Introduction

Indonesia's seagrass meadows are an important blue carbon habitat on a global scale. Located at the heart of the Coral Triangle, Indonesia is a biodiversity hotspot for seagrass, boasting a record of up to 16 species (Fortes *et al.,* 2018). Seagrasses offer a variety of essential ecosystem services, such as serving as a nursery habitat for fish (Bertelli and Unsworth, 2014; Irawan *et al.*, 2019), nutrient cycling (Human *et al.,* 2015), and carbon storage (Fourqurean *et al.,* 2012; Hernawan *et al.,* 2021; Choesin *et al.,* 2024), all of which contribute to human well-being (Cullen-Unsworth *et al.,* 2014). Moreover, seagrass leaves offer a suitable surface for the colonization and development of microorganisms, potentially serving as a food source for many fish species (Atmaja *et al.*, 2021).

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Seagrass meadows, recognized for their significant ecological potential and essential role in supporting aquatic life, require effective management (Simanjuntak *et al*., 2022). Coastal management is crucial as these ecosystems act as transition areas between land and sea, which exposes them to substantial risks of ecosystem degradation that can threaten various species (Prasetya *et al.,* 2017; Jordan and Frohle, 2022). Proactive and strategic area management planning is necessary to ensure the sustainability of these ecosystems and their natural resources. According to Di Franco (2016), Marine Protected Areas (MPAs) have been shown to effectively meet conservation objectives by facilitating the restoration of marine ecosystems. According to Presidential Regulation No. 60 of 2007, MPAs are defined as protected marine regions managed through zoning systems to achieve sustainable fisheries and environmental resource management. These zones encompass core zones, sustainable fisheries zones, utilization zones, and other zones designated for specific purposes. Implementing such structured management approaches ensures the preservation and resilience of marine biodiversity and ecosystem health.

The implementation of zoning in seagrass ecosystems through sustainable management is aimed at preserving the ecosystem services provided by seagrass (Pramudianto *et al*., 2023), which include provisioning services, regulatory services, cultural services, and supporting services in coastal areas and small islands. As a provisioning service, seagrass serves as a food source and contributes to bioprospecting, influencing capture fisheries activities (Supriyadi *et al*., 2024). The benefits of seagrass for humans include providing livelihoods by serving as a site for harvesting economically important marine biota and as a location for marine aquaculture (Nordlund *et al*., 2016). In terms of regulatory services, seagrass meadows function as storage for carbon reserves and heavy metals in aquatic environments. The ecological benefits of seagrass include sediment stabilization, water productivity, serving as a bioindicator of water quality, and acting as a carbon stock (McKenzie *et al*., 2021). Seagrasses have the ability to absorb CO_2 through the process of photosynthesis (Khairunnisa *et al*., 2018). As a supporting service, seagrass provides essential habitats for marine biota, facilitating breeding and foraging activities (Riniatsih *et al*., 2021). Finally, as a cultural service, seagrass is considered a cultural heritage, valuable for research, education, and recreational purposes (Zulkifli, 2021; Rahmawati and Hernawan, 2022). Improper management of seagrass meadows, valued as a cultural service, can lead to significant negative impacts (Nadiarti *et al*., 2012). Heightened anthropogenic activities in and around seagrass ecosystems exert ecological pressure, resulting in the degradation of these vital habitats. The rise in recreational activities and fisheries utilization within seagrass areas contributes to increased coastal development. Anthropogenic activities cause a reduction in the area of seagrass ecosystems by approximately 5% per year (Waycott *et al*., 2009; Supratman *et al*., 2024). This, in turn, leads to further recreational and fishing activities, which degrade water quality and harm the ecosystem (Zulkifli, 2021; Rahmawati and Hernawan, 2022).

Saleh Bay, designated as a marine nature reserve, is located in Fisheries Management Area (WPP-NRI) 713, between Sumbawa Regency and Dompu Regency in West Nusa Tenggara Province (NTB). This area serves as a hub for small-scale fisheries activities. Effective management of conservation areas in line with sustainable development principles is essential to maintaining the sustainability of the seagrass conservation area. This not only protects the biodiversity within but also has a significant positive impact on the associated populations in the area. Through sustainable approaches, such as case studies on seagrass in the conservation area of Saleh Bay, recommendations can be made regarding the management of conservation areas to achieve the set conservation goals. This also ensures that the seagrass ecosystem continues to function well and supports the life of various species that depend on this ecosystem. Thus, this research aims to investigate the species distribution, density, coverage, and environmental features of the seagrass ecosystem in Saleh Bay, illustrating the vital role that seagrass beds play in sustaining the conservation area.

Materials and Methods

The study area in Saleh Bay specifically focuses on two regions: the conservation area of Liang-Ngali Island and the proposed conservation area of Lipan-Rakit. Liang Ngali was officially designated as a conservation area through the Ministerial Decree of the Ministry of Maritime Affairs and Fisheries No. 105/2023. Previously, the Rakit Lipan area was established under the Governor of West Nusa Tenggara Decree No. 523-222 of 2019. According to these decrees, both regions are divided into several zones for conservation purposes: the core zone (Red Line), utilization zone (Green Line), sustainable fisheries zone (Light Blue Line), rehabilitation zone, and other zones (Gray Line).

The research conducted on July, 2021, involved data collection from 13 sampling points across the two marine conservation areas in Saleh Bay, as shown in Figure 1. The data collection method employed in this research was using the seagrass watch method (McKenzie and Mellors, 2003), where three transect lines were established perpendicular to the coastline at each data collection point. The distance between transect lines was 100 m, and each transect comprises ten quadrants measuring 1x1 m, spaced 5 meters apart (Ihwani *et al.,* 2023). Chlorophyll-a and Sea Surface Temperature (SST) were observed using satellite, subjected to geometric and radiometric corrections and field data verification obtained from E.U. Copernicus Marine Service Information. The chlorophyll data has daily temporal resolution and 0.25°×0.25° spatial resolution. SST data has daily temporal resolution and 0.05°×0.05° spatial resolution.

The values of chlorophyll-a and SST were analyzed by averaging spatially in Saleh Bay and sampling area. Seagrass density was analyzed using calculations by Snedecor and Cochran (1980), Seagrass density was obtained from the total number of shoots of a seagrass species per unit area (ind.m^{-2}) (Short and Coles, 2001). Then, the percentage of seagrass cover (%) is calculated based on Minister of Environment Decree No. 200 of 2004 (Table 1).

Similarity analysis was conducted using cluster analysis, and the results are presented in a dendrogram to visualize the similarities between research sampling points based on seagrass species density (Bengen, 2000). Correspondence analysis was used to demonstrate that the spatial distribution of sampling points is influenced by habitat characteristics (Sugianti *et al.*, 2021). Statistical analysis was performed using PRIMER software and Microsoft Excel.

Result and Discussion

Seagrass density and percentage cover

The results of this study show variations in the density and cover of seagrass in different zones within Saleh Bay (Figure 2 and 3). The analysis of seagrass density and cover data provides important insights into the condition of seagrass ecosystems and the effectiveness of existing conservation areas. Seagrass density is a crucial indicator of the health of seagrass ecosystems. *Cymodocea rotundata* has the highest density value, at 447.39 ind.m^{-2}, located in the non-conservation zone. This species is more commonly found in shallow waters and in conditions where the substrate supports seagrass growth.

High density signifies favorable environmental conditions and optimal ecosystem functions, such as providing habitat for various marine species (Rosalina *et al*., 2023). This study has shown differences in seagrass density across various zones in Saleh Bay. High-density areas indicate healthy seagrass ecosystems, while low-density areas highlight the need for enhanced conservation and rehabilitation efforts.

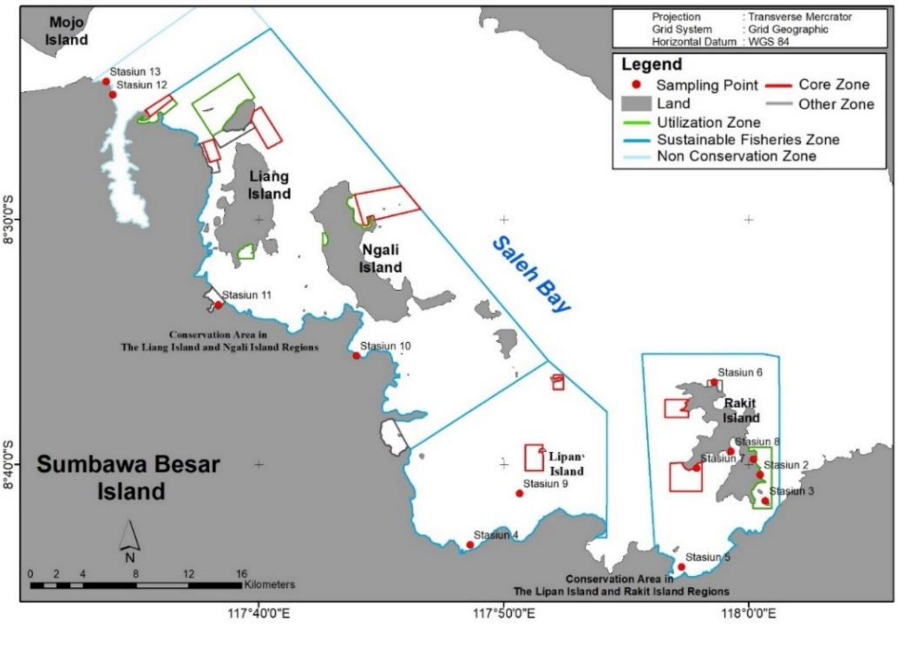


Figure 1. Map of study sites for research at Saleh Bay West Nusa Tenggara (A): Conservation Area in The Liang Island and Ngali Island Regions (B) Conservation Area in The Lipan Island and Rakit Island Regions.

Table 1. Seagrass status based on Percentage cover

Status	Condition	Cover (%)
Good	Rich/Healthy	>60
Medium	Less Rich/Not Healthy	30-59.9
Damage	Poor	<29

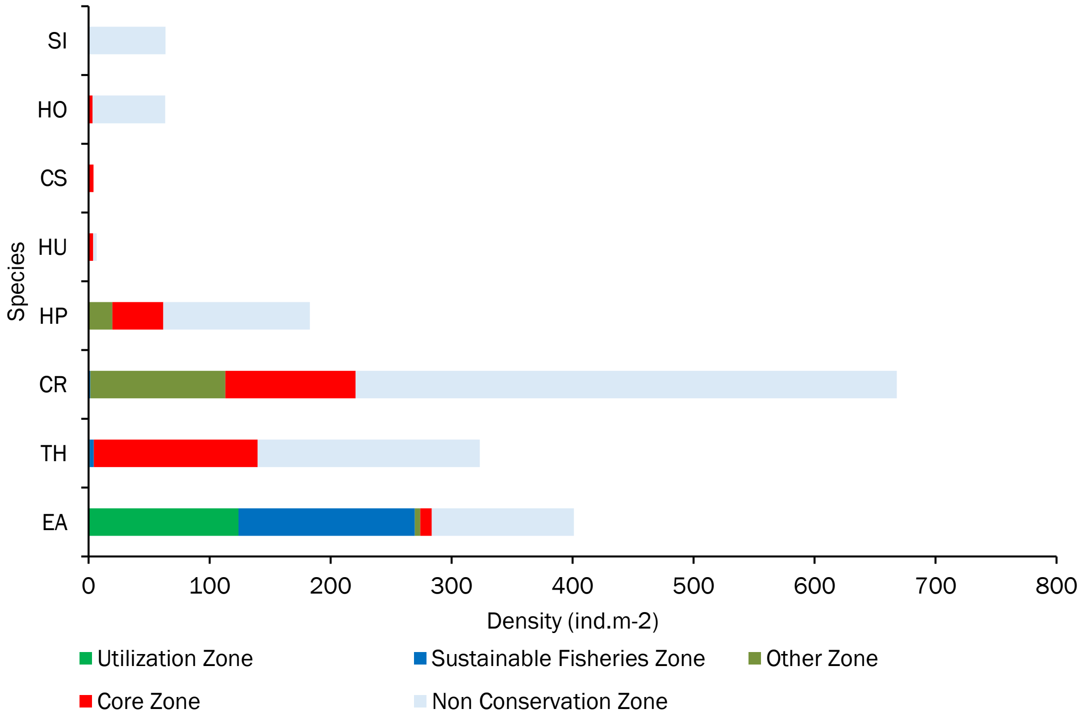


Figure 2. Seagrass density (ind m^{-2}) per species in each zone (SI= *Syringodium isoetifolium; HO= Halophila ovalis; CS= Cymodocea serulatta; HU= Halodule uninervis; HP= Halodule pinifolia; CR= Cymodocea rotundata; TH= Thalassia hemprichii; EA= Enhalus acoroides*

According Juma *et al*. (2020), the differences between species can also play a significant role. For example, large-leaved species like *E. acoroides* can support higher shoot densities and more stable beds compared to smaller, shorter species. This information highlights the importance of understanding how species-specific traits and local environmental factors impact the structure and function of seagrass meadows, especially when comparing meadows from different regions or under varying human impacts. Therefore, ongoing monitoring and effective management are crucial to maintaining the sustainability of seagrass ecosystems in Saleh Bay.

Based on these cover values, the seagrass meadows in the monitored area are considered to be in poor condition, with an average cover of 28.06%. This poor condition may result from significant anthropogenic activities (Nugraha *et al*., 2024), such as environmentally harmful fishing practices and coastal activities like construction, logging, and the expansion of aquaculture ponds, which have led to the degradation of coastal ecosystems. This is evidenced by ecosystem changes in the highlands of Teluk Saleh, where the original forest ecosystem has been replaced by maize cultivation, leading to sedimentation caused by rainwater runoff. Sedimentation can reduce water clarity, limiting the light available for seagrass photosynthesis, which is essential for their growth and survival. Additionally, according Cabaco *et al*. (2008), excessive sediment deposition can smother seagrass beds, alter substrate composition, and disrupt the ecological balance of the seagrass ecosystem, affecting associated marine biodiversity and ecosystem services. The cover ranges from 3.25% to 43.8%. The highest seagrass cover was recorded in non-conservation zones at 43.8%, followed by sustainable fisheries

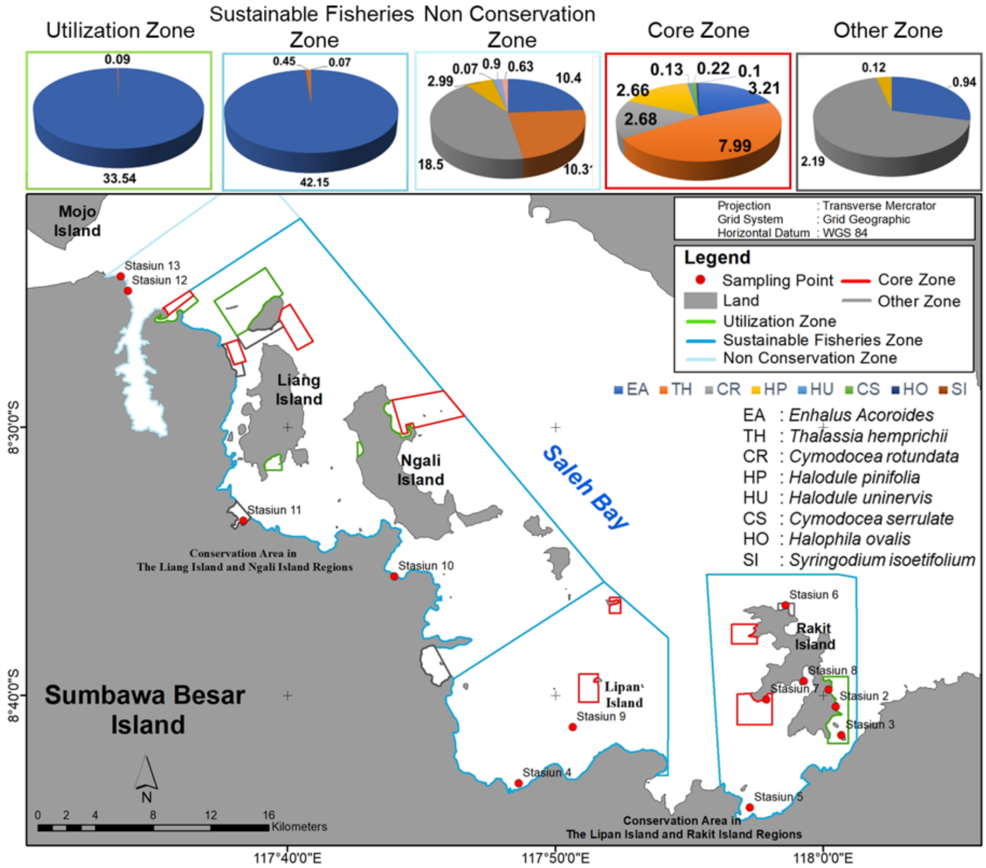


Figure 3. Seagrass percentage cover (%) per species in each zone

zones at 42.67%, utilization zones at 33.63%, core zones at 16.99%, and the lowest in other zones at 3.25%.

Seagrass cover serves as a key indicator of seagrass ecosystem resilience. Higher cover indicates greater ability to withstand and recover from disturbances (Unsworth *et al*., 2015). In areas with low or poor seagrass cover like Saleh Bay (Figure 4), additional management is needed to protect the seagrass beds from worsening conditions. Good management practices can also prevent the formation of fragmented seagrass bed communities, which increase vulnerability and the risk of damage. Establishing conservation areas is one potential management approach.

The variation in the percentage of seagrass cover found can serve as a criterion for selecting future conservation areas (Habibah *et al*., 2023). Areas with high seagrass cover have the potential to become conservation zones that need to be preserved and protected. This is because seagrasses with high coverage can create extensive habitat niches for various types of biota dependent on seagrasses, thereby potentially increasing the abundance and diversity of biota within them. These biotas utilize seagrasses as habitats, spawning grounds, nurseries, feeding areas, and shelters (Rahmawati *et al*., 2017). The criteria for determining conservation areas vary depending on the type of zoning. For instance, the designation of core zones should consider functional aspects of the area, including serving as a refuge for genetic resources, protecting critical natural habitats for fishery resources, and facilitating the recovery of biota and habitats (PermenKP, 2020). Seagrass species diversity and the percentage of seagrass cover are worthy parameters to consider in determining conservation zone areas. Yonvitner *et al*. (2019) mentioned that species diversity and seagrass cover can be parameters for identifying conservation areas, as seagrass ecosystems provide essential services for the fishery resources inhabiting them. Seagrass species diversity is generally supported by factors such as water quality, suitable substrates, habitat variation, and minimal human disturbance (Sugianti and Mujiyanto, 2020). Additionally, minimal human disturbance can allow seagrasses to grow optimally, which, in turn, enhances the density and coverage of seagrasses in the area (Rahman *et al*., 2024).

Water quality parameters

The analysis of environmental parameters and water conditions are crucial in determining the growth processes and activities of seagrass, both physiologically and morphologically. These parameters can even influence the presence of seagrass ecosystems in a body of water (Roca *et al*., 2016; Orth *et al*., 2017; Congdon *et al*., 2023). The water condition parameters in this study include temperature and chlorophyll which were obtained through satellite data observations. Figure 5 depicts the Sea Surface Temperature (SST) and Chlorophyll values in Saleh Bay. It can be observed that the water parameters, specifically SST and CHL, vary across several zones.

The study findings suggest that lower sea surface temperatures are associated with higher chlorophyll levels, possibly indicating a physiological disruption that reduces photosynthetic activity due to rising temperatures (Collier and Waycott, 2014). Furthermore, the presence of low temperatures and high chlorophyll levels in the sustainable utilization and core zones is likely due to the minimal or lack of anthropogenic activities. According Bolan *et al*. (2024), While reduced human impact can support water quality and ecosystem health, there is insufficient evidence to directly link human activities to changes in local SST in this context. As a result, the environmental conditions are directly linked to the increased primary productivity of the seagrass ecosystem. However, further research is needed to determine the specific factors driving these environmental conditions.

The variations in sea surface temperature (SST) and chlorophyll (CHL) levels observed across different zones highlight the interconnectedness of water parameters and seagrass ecosystem health. Zones with low anthropogenic disturbances, such as the sustainable utilization and core zones, exhibit low SST and high chlorophyll levels, which create favorable conditions for seagrass growth and productivity. These areas likely benefit from reduced thermal stress and stable nutrient availability, promoting photosynthesis and ecosystem resilience (Hernawan *et al*., 2021).

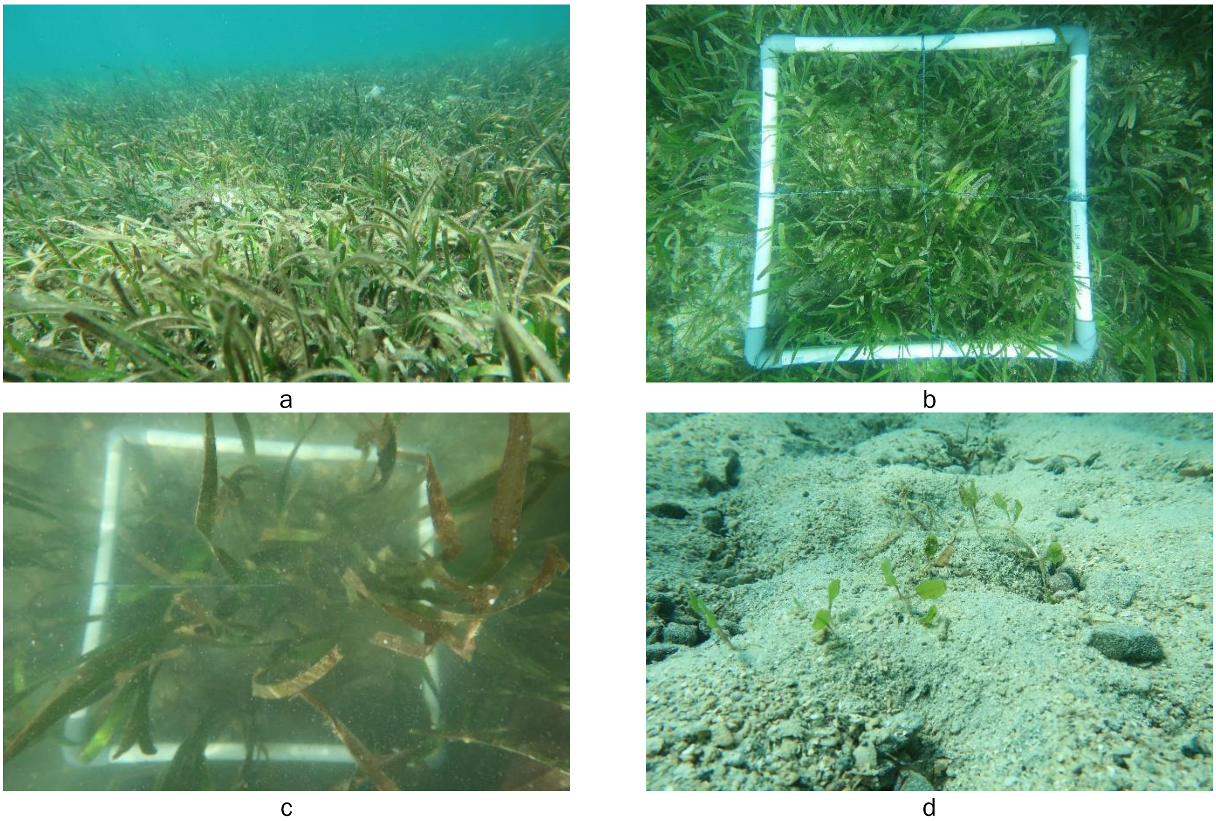


Figure 4. The seagrass condition at the study area: (a) *Cymodocea rotundata* in non-conservation zone; (b) *Thalassia hemprichii* in core zone; (c) *Enhalus acoroides* in Sustainable Fisheries zone; (d) *Halophila ovalis* in other zones

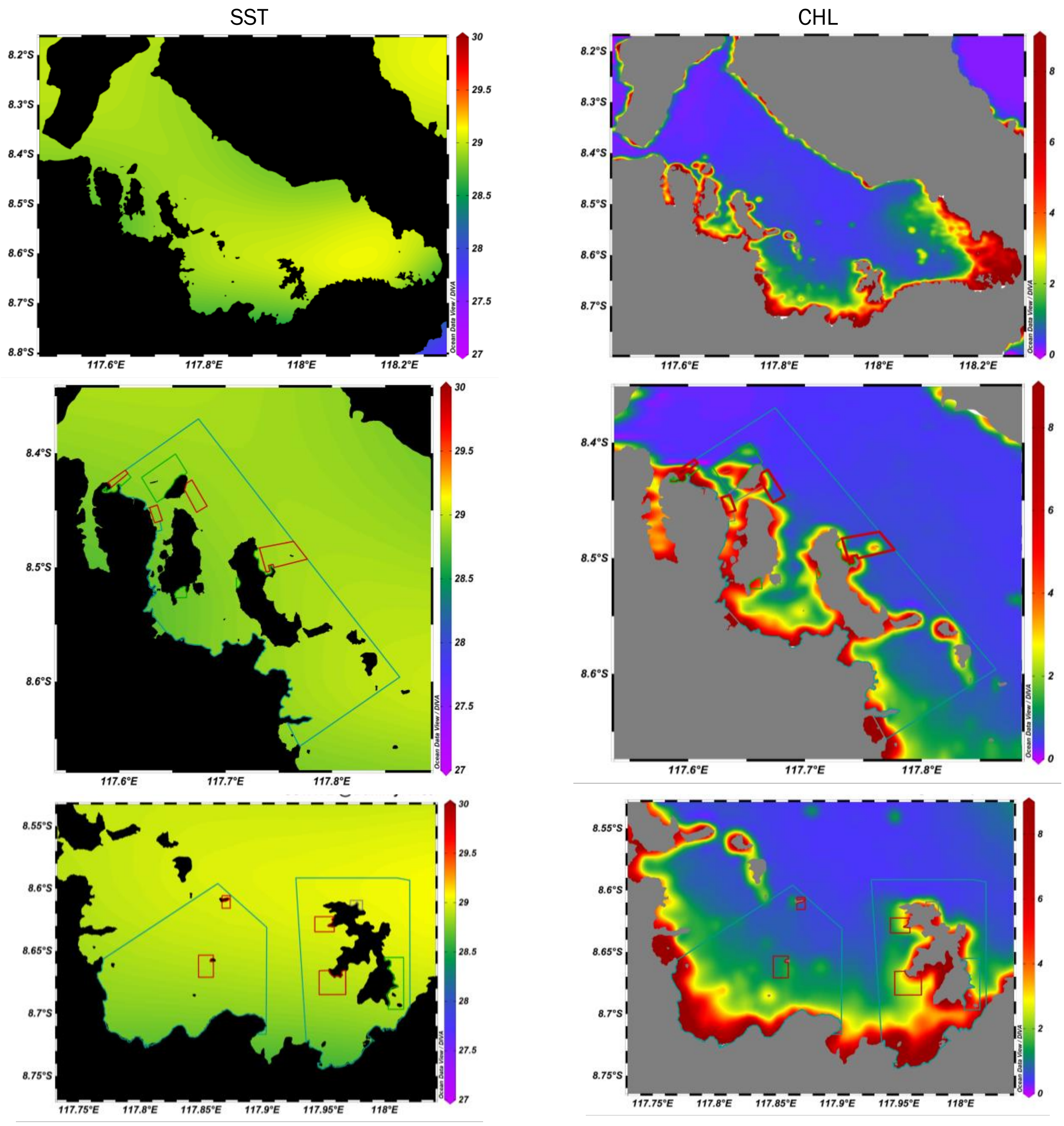
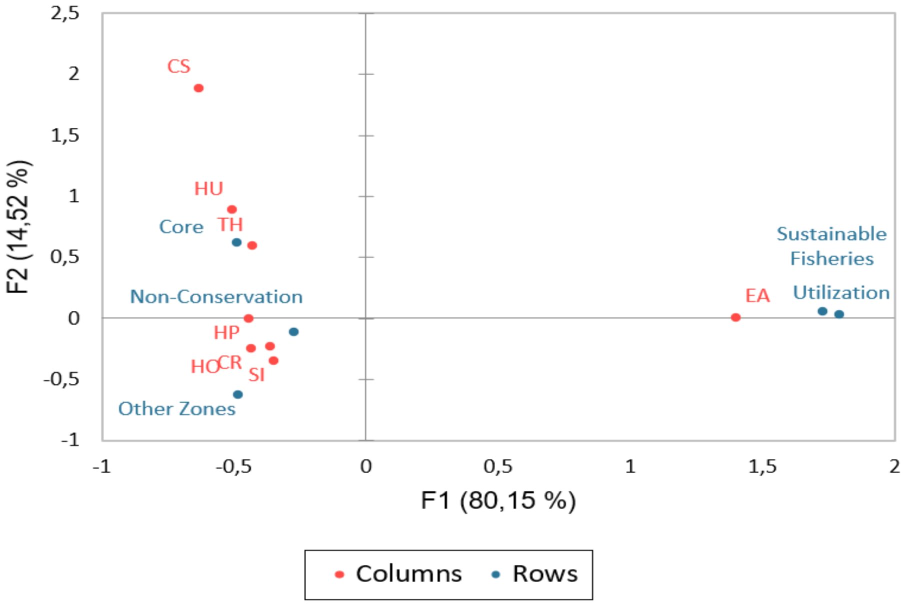


Figure 5. Sea Surface Temperature (SST) and Chlorophyll in Saleh Bay

In contrast, zones with elevated SST levels may experience physiological stress on seagrass, such as reduced photosynthetic efficiency and increased susceptibility to mortality. Rising SSTs are known to impose thermal stress on seagrass ecosystems, especially in shallow and poorly circulated waters, where the temperature variations can be more pronounced (Carlson *et al*., 2018). The findings underscore the importance of monitoring water quality and temperature fluctuations, as these factors are critical for the management and conservation of seagrass ecosystems under the growing impact of climate change and anthropogenic activities.

The relationship between seagrass species and zonation

Correspondence analysis (CA) clearly illustrates the relationships between various seagrass species and their respective usage zones. The first group in the CA results, which includes the Sustainable Fisheries and Utilization zones, is characterized by the species *Enhalus acoroides*. This indicates a strong connection between *E. acoroides* and sustainable fishing practices. As it provides critical nursery habitats and food resources for fish and invertebrates, enhancing juvenile survival and



EA: *Enhalus acoroides*	CS: *Cymodocea serrulata*
SI: *Syringodium isoetifolium*	CR: *Cymodocea rotundata*
TH: *Thalassia hemprichii*	HP: *Halodule pinifolia*
HU: *Halodule uninervis*	HO: *Halophila ovalis*

Figure 6. Correspondence Analysis (CA) Results in Saleh Bay per Zones

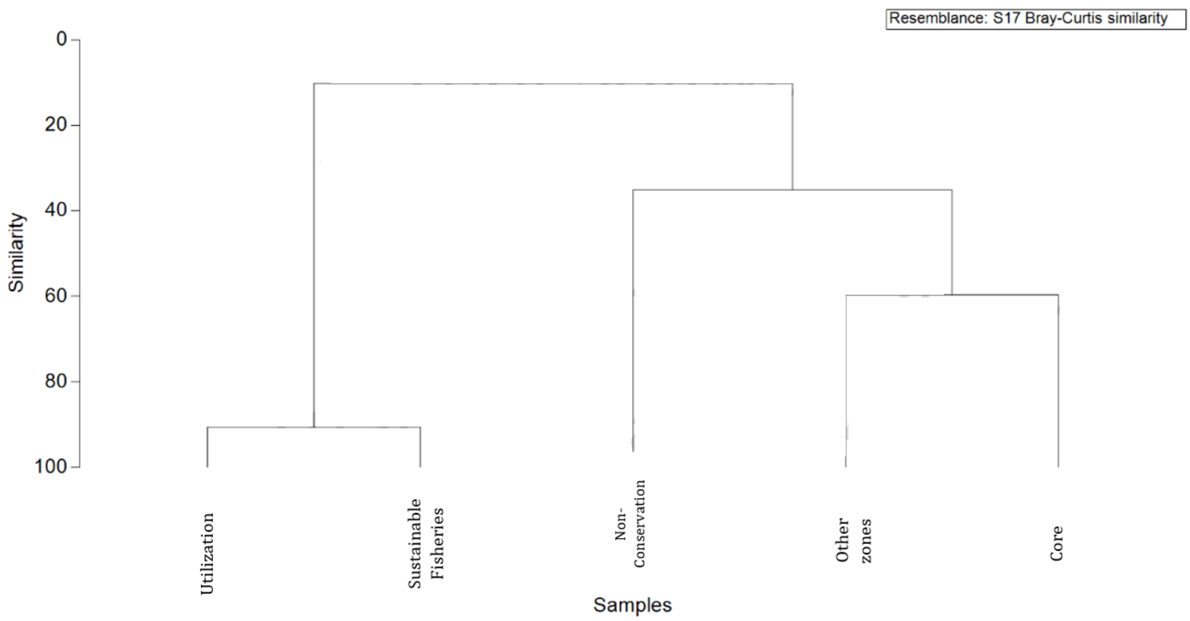


Figure 7. Similarity Analysis Based on Seagrass Species in Each Zone of Saleh Bay

fishery yields. This connection aligns with research by Nakamura and Sano (2004), which found that seagrass meadows with *E. acoroides* had significantly higher numbers of fish species and individuals. Fish tend to occupy seagrass meadows dominated by *E. acoroides* because its broad and tall leaves provide mple foraging and habitat space (Syukur *et al.,* 2014). Other zones are characterized by the species *Syringodium isoetifolium*, suggesting that *S. isoetifolium* prefers different habitats, specifically zones with special purposes (Satriani *et al.,* 2024). According to Rawung *et al*. (2018), *S. isoetifolium* typically grows on coral rubble and muddy sand substrates. The core zone is characterized by the species *Thalassia hemprichii*, *Halodule uninervis*, and *Cymodocea serrulata*. According to Kusnadi *et al*. (2024), these species are important in the core zone and these species in the CA plot (Figure 6) highighs its strong association with core zones that indicates they are frequently found in areas essential for maintaining biodiversity and marine ecosystem health.

Persistent species are large, grow slowly, and have high resistance to environmental stress. However, according Darus *et al*. (2023) and Marba *et al*. (2004) that they take a long time to recover when disturbed. In Indonesia, persistent seagrass species include *E. acoroides*, *T. hemprichii*, and *T. ciliatum*. Pioneer species, on the other hand, are smaller, grow quickly, have short lifespans, and are vulnerable to environmental disturbances. They recover quickly after disturbances in conditions suitable for seagrass growth. Examples of pioneer seagrasses in Indonesia include species from the genera Halophila and some Halodule. Opportunistic seagrasses, which have characteristics between persistent and pioneer species, include *Cymodocea rotundata*, *Cymodocea serrulata*, *Syringodium isoetifolium*, and *Halodule uninervis* (medium-sized) (Rahmawati and Hermawan 2022).

The non-conservation zone is characterized by species such as *Cymodocea rotundata*, *Halodule pinifolia*, and *Halophila ovalis*. These species, which are separate from the core zone group in the CA plot (Figure 6) where those species are found on sandy substrates. This aligns with the opinion expressed by Lokollo *et al*. (2022); De Silva and Amarasinghe (2007); Newmaster *et al*. (2011), which is the characteristics of the substrate influence the composition and abundance of seagrass. Seagrasses can grow on a range of substrates, from muddy areas to sediments containing up to 40% silt and fine sand, with each species showing a preference for specific substrate types. According to Nugraha *et al*. (2021); Unsworth *et al*. (2015); Hemminga and Duarte (2000), the seagrass cover resembles the resilience of seagrass to environmental conditions. Despite being vulnerable and sensitive to anthropogenic activities, *Halodule pinifolia* and *Halophila ovalis* have high growth rates and play crucial roles in ecosystem recovery (Nugraha *et al.,* 2023; Rahmawati and Hermawan, 2022).

The Utilization and Sustainable Fisheries zones exhibit the highest degree of similarity (90 %) (Figure 7), suggesting a strong resemblance in species communities between these two zones. This is evidenced by the fact that the species found in both zones are almost identical such as *E. acoroides* and *T. hemprichii*. According Mirdayanti *et al*. (2024), the similarity can be attributed to comparable environmental conditions or significant ecological connections between them. For instance, if these locations are in close proximity or share similar habitat types, the exchange of species between them is likely to be more fluid.

According to Febriani and Hafsar (2020), in the utilization zone, human activities are permitted provided they adhere to environmentally friendly practices that do not harm the ecosystem, akin to the principles of sustainable fisheries that stress the importance of fishing methods that maintain stable fish populations and biodiversity. Both approaches prioritize ecosystem preservation, ensuring that resource utilization takes into account ecological boundaries to prevent long-term damage and maintain the health of marine habitats such as coral reefs and seagrass beds.

Additionally, education and public awareness play pivotal roles in both approaches, enhancing understanding and concern for environmental conservation (Ahmad and Wahidin, 2022). Active engagement of local communities in the management of utilization zones and sustainable fisheries ensures that policies are tailored to local needs and knowledge, fostering a sense of ownership and responsibility towards the environment. By focusing on prudent and sustainable natural resource management, both strategies aim to secure ecosystem sustainability and the welfare of communities reliant on these resources.

Conclusion

This study underscores the ecological importance of seagrass ecosystems in Saleh Bay, where eight distinct seagrass species were identified, with *Enhalus acoroides* dominating the sustainable fisheries and utilization zones. The high similarity (90%) in species composition between these zones highlights their shared environmental conditions and ecological connections, which are pivotal for sustaining marine biodiversity. The findings demonstrate that the conservation and management of seagrass ecosystems in Saleh Bay are critical for maintaining their ecological functions, such as providing habitats, supporting biodiversity, and enhancing carbon sequestration. However, the variability in seagrass density and cover across zones, with some areas showing signs of degradation due to anthropogenic activities, emphasizes the need for targeted conservation efforts. Regular monitoring, the implementation of environmentally friendly practices, and enhanced public awareness are vital strategies to ensure the resilience and sustainability of these ecosystems. Future management should prioritize preserving species like *E. acoroides*, which play a central role in ecosystem stability, while addressing the pressures posed by human activities. By integrating scientific research with sustainable practices, Saleh Bay can continue to serve as a model for balancing conservation and utilization in marine protected areas.

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