Linking seagrass status to management in North Minahasa's marine protected area

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Abstract. The study was conducted in the recently established local marine conservation area in North Minahasa Regency of North Sulawesi, Indonesia, which was formally established in July 2023. The purpose of this study is to investigate seagrass diversity and coverage and derive management recommendations. Data collection was conducted using the line-quadrat transect method, comprising three transects, each 50 m in length, spaced 25 m apart. The study identified nine seagrass species: *Halodule pinifolia*, *Halodule uninervis*, *Cymodocea rotundata*, *Cymodocea serrulata*, *Syringodium isoetifolium*, *Enhalus acoroides*, *Thalassia hemprichii*, *Halophila ovalis*, and *Halophila minor*. The coverages of the seagrass at eleven observation stations were between 20.83 and 80.49%. The highest cover is at the LM10 station with a cover percentage of 80.49% or is included in the very dense category which is dominated by the species of seagrass *T. hemprichii* at 54.17%, the seagrass cover with the lowest percentage is at the LM07 station with a percentage of cover of 20.83% or included in the rare category which is dominated by the species of seagrass *E. acoroides* at 13.07%. Despite relatively dense conditions at several locations, the overall ecological status falls within the "unhealthy" category based on national standards. These findings indicate an urgent need for adaptive strategies to prevent further degradation of seagrass habitats within the marine conservation area.
Keywords: composition, coverage, density, North Minahasa, seagrasses.

Introduction. Seagrass beds are very important habitats because of their roles in the fisheries sector and their relationship to other coastal ecosystems, such as aquatic biota, coral reefs, and mangroves. Seagrass beds are the foraging place for green turtles, dugongs, and fish (Gulick et al., 2022; Herrera et al., 2022). Seagrass meadows are increasingly recognized as sentinel ecosystems for evaluating the ecological performance of marine protected areas (MPAs) (Nordlund et al., 2018; Unsworth et al., 2019a). These highly productive underwater flowering plants provide essential ecosystem services, including coastal protection, nutrient cycling, carbon sequestration, and serving as nursery grounds for commercially important fisheries (Waycott et al., 2009; Cullen-Unsworth & Unsworth, 2018). However, despite their ecological importance, global seagrass extent is declining at an estimated rate of 7% per year, driven by anthropogenic stressors such as eutrophication, sedimentation, destructive fishing practices, and coastal infrastructure development (Waycott et al., 2009; Duarte et al., 2020). This decline poses a serious threat to the biodiversity and the human communities that depend on these habitats.

Seagrass structure and ecological performance are shaped by key morphological attributes - such as leaf number, length, width, and overall biomass - which in turn are strongly influenced by site-specific environmental conditions (Wakkary et al., 2024). As a foundation habitat, seagrass meadows deliver a suite of ecosystem services central to the goals of marine conservation. They provide critical nursery grounds and foraging areas for numerous commercially valuable fish and invertebrates, thereby underpinning coastal fisheries and local food security (Nagelkerken et al., 2001). In addition, seagrass ecosystems are globally recognized blue-carbon reservoirs, capable of capturing and storing substantial quantities of carbon within both their living tissues and sedimentary deposits, making them important natural assets for climate-change mitigation (Nordlund et al., 2016; Macreadie et al., 2019).

Healthy seagrass meadows are not only indicators of local biodiversity but also proxies for effective marine governance. In well-managed MPAs, seagrass habitats often exhibit higher coverage, species richness, and resilience to disturbance compared to unprotected areas (Cullen-Unsworth et al., 2014; Lefcheck et al., 2018). Conversely, seagrass degradation may signal ineffective management, inadequate enforcement, or insufficient community engagement. Linking ecological metrics, such as seagrass diversity and coverage, to management performance can therefore provide tangible and measurable indicators for assessing MPA success (Gill et al., 2017).

The North Minahasa Marine Protected Area (MPA) in North Sulawesi, Indonesia, was officially designated in July 2023 as part of Indonesia's national commitment to expand its marine conservation network under the Coral Triangle Initiative. This MPA encompasses critical coastal habitats, including coral reefs, mangroves, and seagrass beds, which together sustain local fisheries and coastal livelihoods. However, the area faces multiple anthropogenic pressures, including fishing activities within or near seagrass zones, unregulated boat anchoring, sediment runoff from agriculture, and potential impacts from coastal development projects. These pressures, if unmanaged, could undermine the MPA's ecological integrity and long-term conservation objectives. The North Minahasa Marine Conservation Area, established in 2023, includes a mosaic of coastal habitats subject to varying degrees of anthropogenic influence. Understanding the current condition of seagrass ecosystems within this area is therefore essential for informing management decisions.

While Indonesia has made substantial progress in expanding its MPA coverage, there is still limited research directly linking ecological indicators - particularly seagrass diversity and coverage - to MPA management performance. Many monitoring programs focus on coral reefs, while seagrass ecosystems often receive less systematic attention despite their functional importance (Fortes et al., 2018). Addressing this gap is critical for ensuring that seagrass conservation becomes an integrated part of marine spatial planning and adaptive management frameworks.

This study aims to (1) quantify seagrass species diversity and coverage, and (2) evaluate ecosystem condition as an indicator of management effectiveness. In doing so, it provides one of the earliest ecological baselines following conservation designation. By explicitly linking ecological indicators with management performance, this study addresses a key gap in applied marine conservation and strengthens the use of seagrass metrics in adaptive management frameworks.

Material and Method

Description of study site. This study was conducted from March to October of 2025 in the North Minahasa marine conservation area of North Sulawesi Province, Indonesia. Data collection was conducted at 11 villages which are located within the marine conservation area (Figure 1), selected based on key criteria for site selection. These villages are characterized by high coastal biodiversity, including seagrass beds and mangrove ecosystems. The names of villages and the codes can be seen in Table 1.

A line-quadrat transect method was applied to obtain field data. Each transect extended 50 m, with a 25 m separation between consecutive transects. Quadrats measuring 0.5 × 0.5 m were positioned at 5 m intervals along each line to document seagrass species composition and estimate percentage cover.

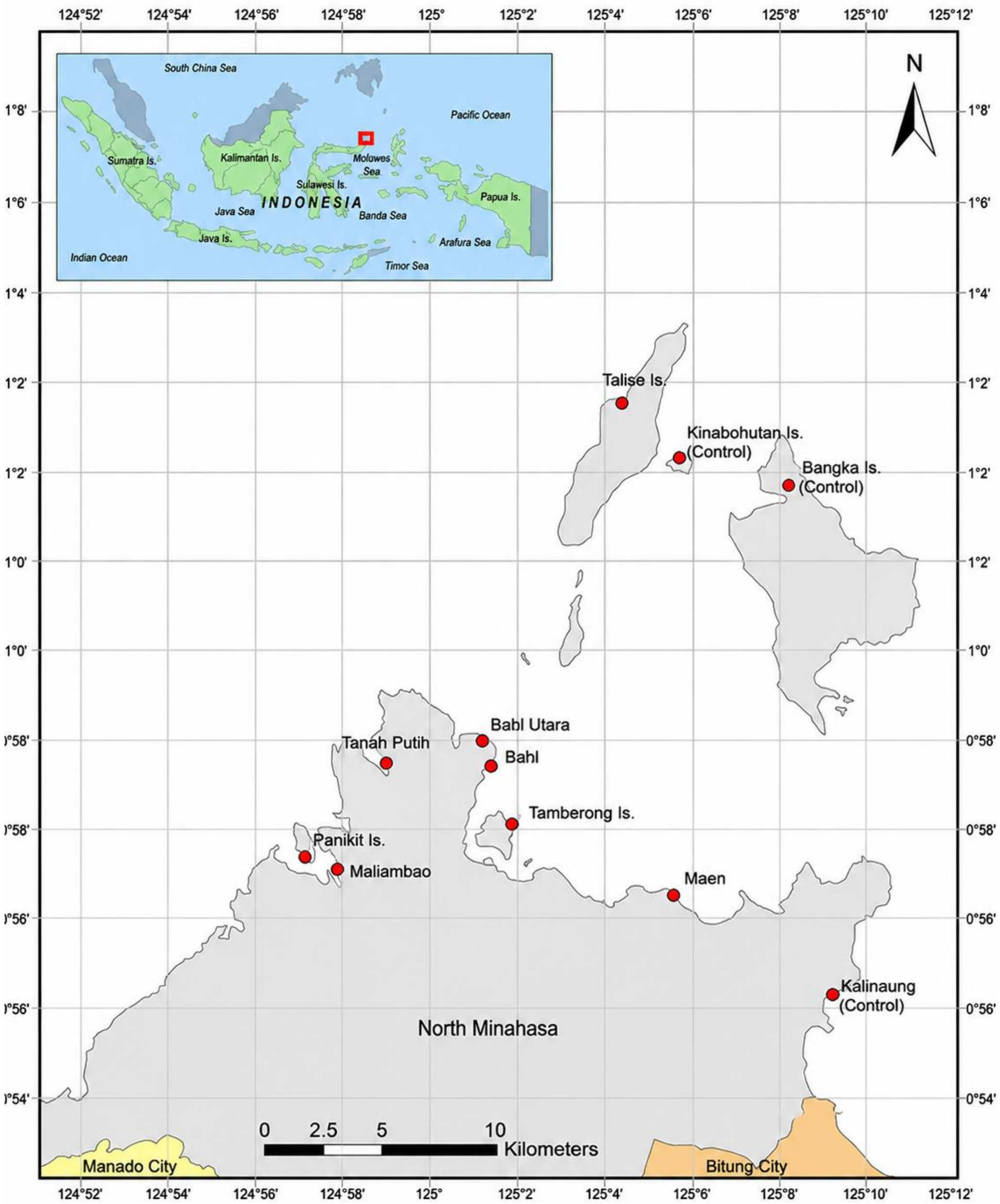

Figure 1. Study site.

Table 1

The codes, names of locations, and site coordinates

Site code	*Locations*	
	Name	*District*
LM01	Paniki Island	West Likupang
LM02	Tamberong Island	West Likupang
LM03	Maen Village	Likupang East
LM04	Kalinaung Village	Likupang East
LM05	Tanah Putih Village	West Likupang
LM06	Bangka Island	Likupang East
LM07	Pulau Kinabuhutan	West Likupang
LM08	Talise Island	West Likupang
LM09	North Bahoi Village	West Likupang
LM10	Bahoi Village	West Likupang
LM11	Maliambao Village	West Likupang

Data analysis

Seagrass coverage. The percentage of coverage was calculated referring to the COREMAP CTI LIPI 2014 (Rahmawati et al., 2017). The formula is as follows:

$$\text{Total coverage (\%)} = \frac{\text{Total seagrass coverage}}{\text{Total transects}}$$

The mean seagrass coverage for each transect was calculated by summing the quadrat-level cover values derived from Equation 1 and dividing this total by the number of quadrats within that transect. The following is the formula:

$$\text{Average coverage (\%)} = \frac{\text{The sum of the coverages of all transects}}{\text{The total quadrat area within the transect}}$$

Species coverage at each site was estimated to assess species dominance. The dominance of each species at a station was determined by summing its percentage cover across all line quadrats within the transect and dividing this value by the total number of quadrats at that station. The following is the formula:

$$\text{Average seagrass dominance (\%)} = \frac{\text{The sum of the coverage of each species in the entire square}}{\text{The square of the entire transect}}$$

Furthermore, the status of the seagrass ecosystem in the study area was assessed using the national classification criteria, based on the Decree of the Indonesian Ministry of Environment and Forestry No. 200 of 2004, which classifies seagrass beds based on their percentage cover (Table 2).

Table 2

Seagrass coverage categories

Coverage (%)	*Category*
0-25	Infrequently
26-50	Moderate
51-75	Dense
76-100	Very dense

Results. In terms of seagrass diversity, a total of nine seagrass species were recorded across the eleven sampling sites (LM01-LM11), representing two families: Hydrocharitaceae and Cymodoceaceae. The species identified included *Halodule uninervis*, *Halodule pinifolia*, *Cymodocea rotundata*, *Cymodocea serrulata*, *Syringodium isoetifolium*, *Enhalus acoroides*, *Thalassia hemprichii*, *Halophila ovalis*, and *Halophila minor* (Table 3). The results indicate relatively high species diversity within the study area. Species richness varied among sites, ranging from two to seven species per site.

The highest species diversity was observed at LM11, where seven species were present. This site supported a mixture of large climax species (*E. acoroides* and *T. hemprichii*) as well as smaller pioneer species such as *H. minor*, *H. ovalis*, *H. uninervis*, and *C. serrulata*. In contrast, LM06 exhibited the lowest diversity, with only two species (*E. acoroides* and *T. hemprichii*) recorded. Intermediate levels of diversity were found at LM02, LM03, LM04, LM08, and LM10, each containing five species, while LM01, LM05, and LM09 supported four species each. LM07 contained three species. This variation in species richness suggests differences in environmental conditions, habitat characteristics, and ecological niches among sampling sites.

Among the recorded species, *T. hemprichii* was the most widely distributed, occurring at all sites, followed by *E. acoroides*, which was present at nearly all locations. Conversely, *H. minor* was the least common species, occurring only at LM11. The coexistence of both pioneer species (*Halophila* spp. and *Halodule* spp.) and climax species (*E. acoroides* and *T. hemprichii*) indicates a heterogeneous seagrass ecosystem with varying habitat conditions and stages of community development.

Table 3

Seagrass species found in North Minahasa's Marine Conservation Area

Species of seagrass	*Sites*										
	LM 01	*LM 02*	*LM 03*	*LM 04*	*LM 05*	*LM 06*	*LM 07*	*LM 08*	*LM 09*	*LM 10*	*LM 11*
Cymodoceaceae											
Halodule uninervis	-	√	-	-	-	-	-	-	-	-	√
Halodule pinifolia	-	-	√	-	-	-	-	-	-	√	-
Cymodocea rotundata	√	-	√	√	√	-	√	√	√	-	-
Cymodocea serulata	-	√	√	√	-	-	-	-	-	-	√
Syringodium isoetifolium	-	-	-	-	√	-	-	√	√	√	√
Hydrocharitaceae											
Enhalus acoroides	√	√	-	√	√	√	√	√	√	√	√
Thalassia hemprichii	√	√	√	√	√	√	√	√	√	√	√
Halophila ovalis	√	√	√	√	-	-	-	√	-	√	√
Halophila minor	-	-	-	-	-	-	-	-	-	-	√
Total of species	4	5	5	5	4	2	3	5	4	5	7

Note: (√) seagrasses found; (-) no seagrasses.

The dominance of *T. hemprichii* and *E. acoroides* across most sampling stations provides important insight into ecosystem condition. These species are characterized by relatively large morphology, slow growth rates, and high structural complexity, making them more resilient to moderate levels of disturbance compared to smaller, fast-growing species (Short et al., 2007). Their widespread occurrence in the study area suggests that some level of ecological stability is maintained. In addition, *T. hemprichii* seagrass is a cosmopolitan species of seagrass that has high adaptability to aquatic environmental conditions, so it is widely found in Indo-Pacific waters (Short et al., 2007). *T. hemprichii* seagrass is also reported to be found easily in seagrass ecosystems in four regions of Indonesian waters (Kawaroe et al., 2016). Seagrass in the waters of North Minahasa exhibits a broad and relatively uniform distribution, with beds recorded at nearly all sampling sites, albeit with varying densities.

Coverage. Seagrass coverage exhibited substantial spatial variation across the study area. Among all species, *T. hemprichii* was the dominant species at most sites and reached its highest dominance at LM09 (54.17%), followed by LM10 (39.20%) and LM05 (37.69%), with the lowest coverage values of 1.52% at LM01. *C. rotundata* occurred at several sites, particularly LM07 (14.02%), LM04 (12.50%), LM09 (11.17%), LM03 (10.98%), LM08 (8.90%), and LM01 (0.19%), but was absent from several other locations. *S. isoetifolium* was found at five sites and attained its highest dominance at LM08 (19.32%), followed by LM11 (10.23%) and LM10 (8.33%), while low cover values occurred at LM 05 (1.89%) and LM 09 (3.14%). The genus *Halophila* was represented by *H. minor* and *H. ovalis*, both of which occurred at relatively low dominance levels. *H. ovalis* was most abundant at LM11 (14.39%), followed by LM03 (9.09%) and LM10 (8.14%), while *H. minor* was recorded only at LM11 (0.76%). *H. pinifolia* was found mainly at LM10 (13.26%) and occurred in low abundance at LM03 (0.95%), whereas *H. uninervis* was recorded only at LM02 and LM11 with dominance values of 1.33% and 0.76%, respectively. *E. acoroides* occurred throughout the study area, except at LM03, with the highest cover recorded at LM01 (29.17%) and the lowest at LM10 (9.85%), while intermediate cover values were observed at LM02 (22.73%), LM07 (20.45%), LM11 (18.75%), LM05 (15.72%), and LM04 (15.53%).

Overall, the seagrass meadows were characterized by mixed-species assemblages dominated primarily by *C. rotundata* and *T. hemprichii*, with site-specific contributions from *C. serrulata*, *S. isoetifolium*, and several species of *Halophila* and *Halodule*. The highest diversity of species occurred at LM11, where seven species were recorded, while LM06 supported only two species, suggesting considerable spatial variation in community composition across the study area (Table 4).

Table 4

Site	Cover (%)	(%)								
		Ea	*Th*	*Cr*	*Cs*	*Hm*	*Ho*	*Si*	*Hp*	*Hu*
LM01	31.06	29.17	1.52	0.19	0.00	0.00	0.19	0.00	0.00	0.00
LM02	57.01	22.73	31.44	0.00	0.76	0.00	0.38	0.00	0.00	1.33
LM03	39.96	0.00	10.80	10.98	7.95	0.00	9.09	0.00	0.95	0.00
LM04	58.52	15.53	26.14	12.50	1.89	0.00	2.46	0.00	0.00	0.00
LM05	60.42	15.72	37.69	4.73	0.00	0.00	0.00	1.89	0.00	0.00
LM06	20.83	13.07	7.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LM07	58.71	20.45	24.24	14.02	0.00	0.00	0.00	0.00	0.00	0.00
LM08	61.74	11.17	21.40	8.90	0.00	0.00	0.95	19.32	0.00	0.00
LM09	80.49	11.74	54.17	11.17	0.00	0.00	0.00	3.41	0.00	0.00
LM10	78.79	9.85	39.20	0.00	0.00	0.00	8.14	8.33	13.26	0.00
LM11	69.32	18.75	24.62	0.00	0.38	0.76	14.39	10.23	0.00	0.76

Note: Ea: *Enhalus acoroides*; Th: *Thalassia hemprichii*; Cr: *Cymodocea rotundata*; Cs: *Cymodocea serulata*; Hm: *Halophila minor*; Ho: *Halophila ovalis*; Si: *Syringodium isoetifolium*; Hp: *Halodule pinifolia*; Hu: *Halodule uninervis*.

Based on national classification criteria, most stations fell within the "Dense" category (51-75%), including LM02 (57.01%), LM04 (58.52%), LM05 (60.42%), LM07 (58.71%), LM08 (61.74%), LM09 (80.49%), LM10 (78.79%), and LM11 (69.32%). In contrast, LM06 (20.83%) was categorized as "Infrequently", while LM01 (31.06%) and LM03 (39.96%) were classified as "Moderate" (Table 5).

Table 5

Overall seagrass coverage

Stations	*Total coverage (%)*	*Category*
LM01	31.06	Moderate
LM02	57.01	Dense
LM03	39.96	Moderate
LM04	58.52	Dense
LM05	60.42	Dense
LM06	20.83	Infrequently
LM07	58.71	Dense
LM08	61.74	Dense
LM09	80.49	Dense
LM10	78.79	Dense
LM11	69.32	Dense

Discussion. The seagrass diversity and coverage in the marine protected area of North Minahasa can be better understood in the context of other marine conservation areas in Indonesia and the broader Southeast Asian region. For example, surveys in the Wakatobi National Park and Raja Ampat marine conservation area reported species richness of up to 12 species and percentage cover often exceeding 60%, attributed to effective zoning enforcement and strong community co-management (Unsworth et al., 2015; Rahmawati et al., 2017). Conversely, marine conservation areas in more densely populated areas, such as certain coastal zones in the Philippines and Thailand, have experienced declines in seagrass coverage to below 30% due to coastal development, unregulated tourism, and weak enforcement (Fortes et al., 2018).

With average cover in North Minahasa currently falling within the lower range of these benchmarks, the results suggest that the marine conservation area's recent designation in July 2023 has yet to produce measurable ecological recovery, possibly due to both historical degradation and ongoing local pressures. Several factors may explain the observed diversity and coverage levels in North Minahasa. Fishing practices involving bottom-contact gear can physically damage seagrass beds, uprooting shoots and disturbing sediment layers (Fonseca et al., 1998). Unregulated boat anchoring in shallow areas can cause long-lasting scarring and fragmentation of meadows (Milazzo et al., 2004). Sedimentation from nearby gold mining operated by PT Soputan Mires is potentially the main cause. Additionally, agricultural runoff and coastal construction can reduce light penetration, limiting photosynthesis and growth (Unsworth et al., 2019b). Nutrient enrichment from domestic wastewater can further worsen declines through algal overgrowth and increased turbidity (Dai et al., 2023). In contrast, MPAs with well-enforced no-take zones, effective tourism regulations, and active local stewardship often maintain higher seagrass coverage and resilience (McKenzie et al., 2020).

Like other shallow tropical coastal ecosystems, seagrass meadows in the North Minahasa marine conservation area are increasingly vulnerable to climate change. Elevated sea surface temperatures can induce physiological stress, reduce growth, and increase disease susceptibility (Short & Neckles, 1999; Waycott et al., 2009). More frequent and intense storm events, projected for the Coral Triangle region, can physically damage meadows through uprooting and sediment displacement (Dahl et al., 2021). Altered rainfall patterns may also change sediment and nutrient loads in coastal waters, compounding local stressors. Integrating climate resilience measures - such as reducing anthropogenic pressures, protecting habitat diversity, and identifying potential refugia - into marine conservation area management plans will be crucial for sustaining seagrass ecosystems over the long term. Therefore, the management of the marine conservation area in North Minahasa should put more effort into restoring the seagrass beds' co-benefits for biodiversity protection, fisheries productivity, and Indonesia’s commitments to its Nationally Determined Contributions under the Paris Agreement.

Conclusions. The seagrass ecosystem at the observation location of the marine protected area of North Minahasa, is classified as less in "Unhealthy", but overall, all stations are in the "Densely Populated" category. Of the 11 species of seagrass in Indonesia at the observation location, 9 species of seagrass were recorded. *Thalassia hemprichii* and *Enhalus acoroides* dominate almost every observed station. This means the area is stable, because both species are seagrasses with a large shape that takes a long time to grow. Overall, the current status of seagrass diversity and coverage in the North Minahasa marine conservation area reflects both the legacy of past degradation and the influence of ongoing local pressures. Establishing this ecological baseline after marine conservation area designation offers a critical reference point for adaptive management, enabling measurable progress toward long-term conservation goals.

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Conflicts of Interest. The authors declare that there is no conflict of interest.

Data Availability. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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