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Ecological condition of seagrass meadow in Lembeh Island, Bitung Regency, North Sulawesi, Indonesia

Nuryani Widagti[1,2,*], *Frida* Sidik[1,2], *Agung* Yunanto[1,2], *Eghbert Elvan* Ampou[1,2], and *I Nyoman* Surana[1,2]

[1]Research Center for Oceanography, Jalan Pasir Putih I, East Ancol, Jakarta, Indonesia
[2]Institute for Marine Research and Observation, Jalan Baru Perancak, Jembrana, Bali, Indonesia

Abstract. The condition of seagrass meadows is required information for conducting comprehensive management plans in coastal areas. This study provides information on the ecological condition of the seagrass ecosystem in Lembeh Island, based on seagrass species richness and coverage, macroalgal coverage, epiphyte coverage, and water transparency. We collected the data by performing 24 line transects at eight stations across the island. The seagrass ecosystem condition was determined using the Seagrass Ecological Quality Index (SEQI, range 0-1). We recorded eight seagrass species in the study site, with coverage of 48.88 ± 12.35% (mean ± SE). *Enhalus acoroides* and *Thalassia hemprichii* were the most common species in the sampling stations. The coverage of macroalgal and epiphyte was substantially low, indicated by values of 1.64 ± 0.41% and 12.64 ± 3.57%, respectively. Our analysis showed that most of the seagrass meadows in Lembeh Island are in poor condition (SEQI mean: 0.48 ± 0.03), especially in the locations inside Lembeh Strait. Moderate conditions were only found outside Lembeh Strait, such as in Pancuran, Limangu, and Pasir Panjang (SEQI values: 0.60, 0.58, and 0.56, respectively). We suggest a long-term seagrass monitoring program to evaluate the trend of condition, a restoration program, and improve water environment quality.

1 Introduction

Seagrass beds are keystone ecosystems in coastal areas, providing various ecosystem services for human well-being and marine environments [1]. The primary ecological services are nutrient cycling, coastal protection, food and habitat for marine biotas, maintaining water quality and sediment stabilization [2–6], and regulating and mitigating climate change [7,8]. Nevertheless, seagrass meadows have declined worldwide at 110 km^2 yr^{-1}, mainly caused by dredging activities and declining water quality [5,9]. In Indonesia, seagrass ecosystems are threatened by various factors, such as coastal development, land reclamation, seaweed farming, overfishing, and garbage dumping [10]. Seagrass

[*] Corresponding author: nuryani.widagti@brin.go.id

ecosystems have tremendous ecological services but have the least attention from the public compared with other coastal ecosystems (mangroves and coral reefs) and are often not considered in the management plan of coastal areas [3,11,12].

Lembeh Island waters is an area that has unique water characteristics with a complete coastal ecosystem: mangroves, seagrasses, and coral reefs. Various patterns of spatial uses, such as conservation areas, capture fisheries and mariculture, tourism, industry, transportation, settlement, and other uses, are found in these waters [13–15]. Since 2014, Lembeh Island waters have been proposed to be a Coastal and Small Islands Marine Protected Area, as stated in the Decree of the Mayor of Bitung No. 188.45/HKM/SK/121/2014. As the follow-up to the decree, the local government needs to carry out various stages of activities: compiling a management plan, reviewing the area and boundaries, and conducting socialization before the final stage, which is strengthening the management of the protected area.

Information on the condition of coastal ecosystems is essential for designing a comprehensive MPA management. Coral reef and mangrove ecosystems in Lembeh Island have been widely explored, yet seagrass is rarely studied. Data and information regarding the status of seagrass meadows in Indonesia, including in North Sulawesi waters, still need to be improved [16]. However, it was required as recommendation material in following up the stipulation of the Reserve Decree.

Here, we studied the condition of the seagrass ecosystem in Lembeh Islands, aiming to provide evidence for supporting local government and practitioners in establishing MPA design and baseline data for sustainable coastal ecosystem management. Assessing the status of the seagrass ecosystem in Lembeh Island was conducted in 2014 [17]. The study used a different analytical method and only considered three parameters: the number of seagrass species, seagrass cover, and the number of macroalgae species. Determination of seagrass conditions is done by giving a score on those three parameters [18]. This study assessed the seagrass ecological condition by using a new index (Seagrass Ecological Quality Index, SEQI) that considers five seagrass resilience parameters: seagrass species richness, seagrass coverage, macroalgal coverage, epiphyte coverage, and water transparency [19,20].

2 Methods

2.1 Study area

This study was undertaken on Lembeh Island waters, a small island in the Bitung Regency area, North Sulawesi Province, Indonesia (1º25'08" N, 125º13'49"E; Fig. 1). Lembeh Strait separates this island from the mainland of Sulawesi (Bitung City) and connects the Sulawesi and Moluccas Seas. This island is close to Bitung Port, the largest and busiest port in North Sulawesi, with extensive shipping, fisheries, and industrial activities [21]. This port is a hub for local sea transportation connecting major cities in Indonesia, especially in the Eastern Region of Indonesia.

Lembeh Island and the adjacent waters at the heart of the Coral Triangle (CT) region have the world's highest marine biodiversity. This island has amazing marine life [22,23], productive coral reefs [24], mangrove forests [25,26], and seagrass meadows [17]. Coastal habitats co-exist, creating the coast as an attractive tourism site. The site is characterized by the mixed semidiurnal tide, where seagrass meadow is exposed during low tide (0.36 to 1.11 m) and fully inundated during high tide (1.18 to 2.15 m). In 2013, Lembeh Strait was declared a Marine Park under the Decree of the Mayor of Bitung with an area of 9,647 ha and has been proposed as MPA.

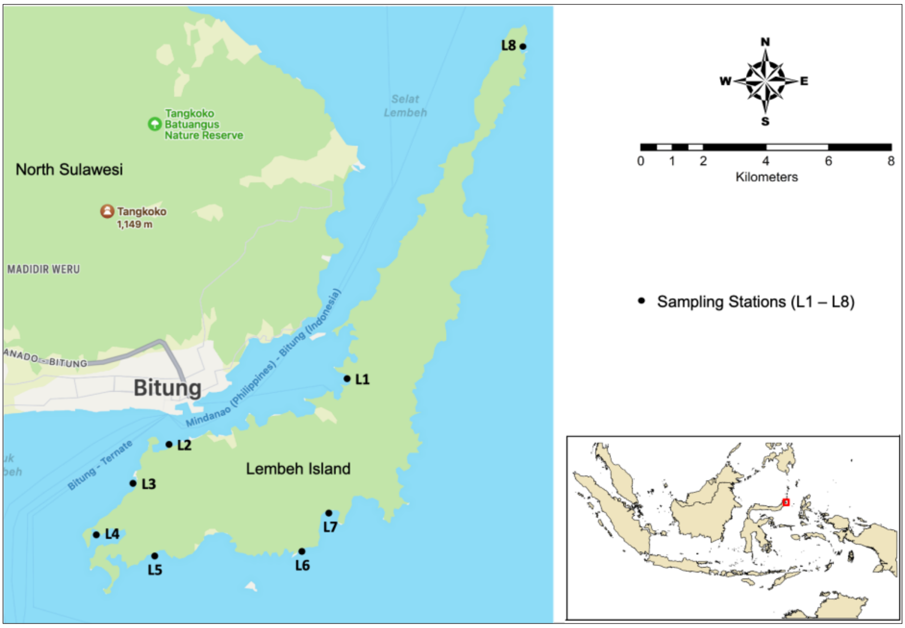

Fig. 1. Study areas with eight sampling stations: **inside Lembeh Strait** (**L1** – Pintu Kota; **L2** – Batu Lubang; **L3** – Paudean; **L4** – Lembeh Lodge) and **outside Lembeh Strait** (**L5** – Pasir Panjang; **L6** – Limangu; **L7** – Pancuran; and **L8** – Lirang)

2.2 Data collection

The field campaign was undertaken in July 2019 around Lembeh Island. Eight stations were selected for data collection based on the previous study in 2014 [17], considering ecological features and anthropogenic factors (Fig. 1). Four stations were placed inside the Lembeh Straits facing the city of Bitung, representing high anthropogenic stress (L1– L4). Another four stations were laid outside the Lembeh Strait, facing the Moluccas Sea (L5 – L8). In each station, we collected five seagrass ecological-related parameters: seagrass species richness, seagrass cover, macroalgal cover, epiphyte cover, and water transparency. Those parameters are simple, cost-effective, and indicate seagrass resilience [19].

We adopted Seagrass-Watch and COREMAP-CTI guidelines for collecting the data [27,28]. We performed three line transects in each station perpendicular to the coastline as a repetition. The lengths of each transect was 100 m, and the distance between transects was 50 m. Data recording was conducted in a 100 cm x 100 cm quadrat, placed along a line transect with a 10 m distance between quadrats, towards the sea.

Seagrass species richness was determined by counting the number of species found in each sampling station. Seagrass cover and macroalgal cover were assessed using the percent cover standard in the Seagrass-Watch guideline [27]. The coverage was categorized as rare (0-25%), moderate (26-50%), dense (51-75%), and very dense (76-100%) [29,30]. Estimation of the epiphytes cover was using a matrix considering two parameters: % of leaves in quadrat covered by epiphytes and the average epiphyte cover on each leaf or blade (https://www.seagrasswatch.org/wp-content/uploads/monitoring/pdf/Epiphyte_matrix.pdf).

This study obtained water transparency by measuring the turbidity parameter (NTU) at the starting, middle, and end points of each line transect using the Multiparameter Water Quality Checker TOA DKK-24. If the observation was performed during the lowest tides, the measurement was done in the lower intertidal area [30]. The water transparency value is classified into three categories: 2 for clear, 1 for turbid, and 0 for very turbid water [19,20]. Referring to the Ministry of Environment 51/2004, the turbidity threshold for seagrass life was < 5 NTU, so the location with turbidity less than 5 NTU categorized clear water (value: 2), and for the location with turbidity of more than 5 NTU, it was considered as turbid water (value: 1).

2.3 Data analysis

The ecological condition of the seagrass ecosystem in the study site was defined using the SEQI value. The value was calculated at each sampling station by entering the average value per seagrass resilience parameter observed in the following equation [19]:

$$SEQI = \left(\frac{St}{Sref}\right) * 0.2 + \left(\frac{Ct}{Cref}\right) * 0.2 + \left(\frac{Wt}{Wref}\right) * 0.2 + \left(1 - \left(\frac{Mt}{Mmax}\right)\right) * 0.2 + \left(1 - \left(\frac{Et}{Emax}\right)\right) * 0.2 \quad (1)$$

Where

St	:	is seagrass species richness observed.
Sref	:	is the maximum value of seagrass species richness (9).
Ct	:	is seagrass percent cover observed.
Cref	:	is the maximum value of seagrass percent cover (100%).
Wt	:	is water transparency observed.
Wref	:	is the maximum value of water transparency (2).
Mt	:	is macroalgal percent cover observed.
Mmax	:	is the maximum value of macroalgal percent cover (100%).
Et	:	is epiphyte percent cover observed.
Emax	:	is the maximum value of epiphyte percent cover (100%).

The value of SEQI ranges between 0 (worst condition for resilience) and 1 (optimum condition for resilience). The seagrass ecological condition was classified into five categories based on the SEQI value: bad (0 – 0.36); poor (0.37 – 0.52); moderate (0.53 – 0.68); good (0.69 – 0.84); and excellent (0.85 – 1) [19,20]. The SEQI value for all stations was averaged to specify the ecological condition of the seagrass meadow in the study site.

3 Results and Discussion

The ecological condition of the seagrass ecosystem can be determined through various proxies, including seagrass species richness, seagrass coverage, macroalgal coverage, epiphyte coverage, and water transparency. These parameters are considered simple and low-cost or cost-effective measures; however, they can adequately describe seagrass ecosystem resilience and are suitable for implementation in tropical seagrass ecosystems, especially in Indonesia [19,20]. These parameters are commonly integrated into seagrass monitoring programs [5,31,32]. Here, we used the proxies to provide baseline information on the condition of seagrass meadows in Lembeh Island waters for supporting the management strategies.

A total of eight seagrass species were observed across the study site: C*ymodocea rotundata* (*Cr*), *Cymodocea serrulata* (*Cs*), *Enhalus acoroides* (*Ea*), *Halophila ovalis* (*Ho*), *Halodule uninervis* (*Hu*), *Thalassodendron ciliatum* (*Tc*), *Thalassia hemprichii* (*Th*), and

Syringodium isoetifolium (*Si*) (Fig. 1). Seagrass meadows in Lembeh Island showed high species richness since 88.9% of the maximum seagrass species in Indonesia's intertidal zone can be found in the waters. The maximum number of species richness that represents the best resilience for the seagrass ecosystem was 9 [19]. The most common species was *Ea* since they were found in all sampling stations. *Th* is found in almost all locations except Pintu Kota (L1) and Lembeh Lodge (L4). *Tc* was the uncommon species, only found in L7 (Limangu), the most diverse location. The seagrass species found on the sampling locations outside Lembeh Strait were more diverse, resulting in a higher seagrass diversity (6-8 species) compared to those on the inside of Lembeh Strait (only 1-3 species) (Fig. 2). Seagrass meadows inside the Lembeh Strait tended to be monospecies of *Ea*, as shown in Pintu Kota (L1) and Lembeh Lodge (L4). *Ea* occupied two other locations inside Lembeh Strait with patchy *Ho* and *Th*: Batu Lubang (L2) and Paudean (L3).

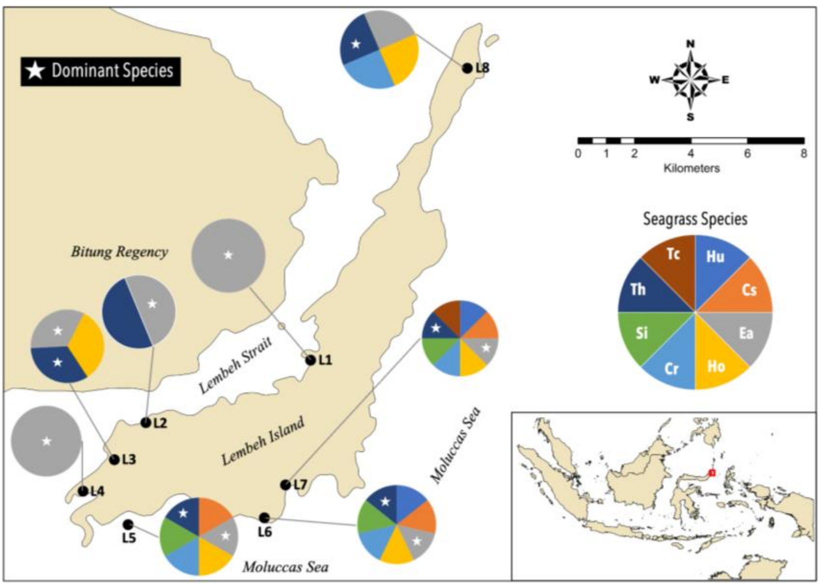

Fig. 2. Distribution of seagrass species richness at sampling stations: **Persistent Species** (*Ea*, *Th*, *Tc*); **Opportunistic Species** (*Cr*, *Cs*, *Hu*, *Si*); and **Colonising Species** (*Ho*)

According to the seagrass life-history traits, we encountered three categories of seagrass species in the study site: persistent, opportunistic, and colonizing [33]. There are three persistent species, four opportunistic species, and only one colonizing species (Fig. 2). The existence of persistent species in all locations was higher than opportunistic and colonizing species and became the most common species. The persistent *Ea* were dominant at 7 locations, and *Th* was at five locations (Fig. 2). In contrast, the opportunistic species *Cs*, *Cr*, and *Si* were only found in certain locations outside Lembeh Strait, such as in L5, L6, and L7. Meanwhile, another opportunistic species, *Hu*, was found in only two locations (L6 ang L7). The colonizing species *Ho* was mainly found outside Lembeh Strait (L5, L6, L7, L8) and only one location inside Lembeh Strait (L3). Colonizing and opportunistic species, except for *Cr*, were greatly common.

Generally, the locations outside Lembeh Strait have a more complex composition of seagrass life-history traits than those inside Lembeh Strait (Fig. 2). Persistant species, such as *Ea* and *Th*, incorporated with colonizing species (*Ho*) and opportunistic species (*Cr*, *Cs*, *Hu*, and *Si*), particularly in the location L5 – L8. Colonizing species can produce seed banks with low resistance to disturbance but can recover rapidly. The opportunistic species can also build seed banks and quickly recover even from seed [33]. This combination of species with three life-history traits describes that seagrass meadows outside Lembeh Strait have higher resilience to disturbance and harmful environmental conditions than the meadows inside the Lembeh Strait. Nevertheless, seagrass meadows in Lembeh Strait can generally be more persistent in disturbance since the dominant species has persistent life-history traits. The species would probably decline when the colonizing species dominated the Lembeh's seagrass [34].

The seagrass coverage in Lembeh Island was generally in moderate condition, indicated by the average cover of 48.88 ± 12.35% (Fig. 3a). Dense and even very dense seagrass beds were found in almost all stations outside Lembeh Strait (L5 – L8), with a high average cover above 50%, ranging from 65% to 92.22%. Station L6, located in Limangu, had the highest percentage cover (92.22 ± 0.28%), stretching up to ±100 m to the sea to the well-growing coral reef flats (Fig. 3a). Stations inside Lembeh Strait (L1 – L4) are categorized as rare, indicating that the average cover is less than 25% (range: 11.50% to 19.44%). Station L4 (Lembeh Lodge) was recorded as the lowest average seagrass cover (11.50 ± 1.11%) across the locations.

Generally, the coverage of macroalgae in Lembeh Island was considerably low, ranging from 0% to 3.28% (mean: 1.64 ± 0.41%) (Fig. 3b), and was categorized as rare since it was under 26% [29,30]. Lirang (L8) was the most dense location, with an average cover of 3.28 ± 0.65% (mean ± SE). There were two locations without macroalgal, L1 in Pintu Kota and L4 in Lembeh Lodge. Stations located outside Lembeh Strait (L5 – L8) have higher macroalgal coverage (more than 1.64%), whereas those inside the strait (L1 – L4) were extremely low. We recorded several species of macroalgal in the study site, including *Halimeda sp., Gracillaria sp., Sargassum* sp., *Dyctiota* sp., *Padina* sp., *Galaxaura* sp., *Laurencia* sp., *Codium* sp., and *Caulerpa* sp.

Macroalgal coverage was higher in the outside Lembeh Strait compare to those location inside the strait. Macroalgal coverage indicates the risk of competition between seagrass and macroalgal. In addition, it can also be an indicator that the regime is being altered [19]. Macroalgal coverage in Lembeh Island was considerably low (mean: 1.64 ± 0.41%), implying that the competition between seagrass and macroalgae in the study area is still under control. The super-abundance of macroalgae on seagrass meadows will interfere with the light penetration required for photosynthesis and other biogeochemical processes, triggering the anoxic and eutrophic situation [35–39].

The average epiphyte cover contradicted with macroalgal cover (Fig. 3a and 3b). The average epiphyte cover has a wide-ranging value across the sampling station, from 3.11% to 23.72% (mean: 12.64 ± 3.57%) (Fig. 3c). Some locations have high epiphyte coverage, particularly inside Lembeh Strait (L1 – L4), and some other locations have rare epiphyte cover (L5 – L8). The station with the highest epiphyte cover was located in Batu Lubang (L2), and the lowest was in Limangu (L6) and Pancuran (L7) (Fig. 3). High epiphyte cover inside the Lembeh Strait can indicate environmental change and water quality, suggesting the potential for water body contamination by organic or inorganic matter, mostly from land-based sources [40]. High epiphyte cover in the seagrass bed is harmless in clear waters but acute in turbid waters [41]. The seagrass average epiphyte cover in Lembeh's was generally higher than the Indonesian seagrass's average epiphyte cover (mean: 10 ± 2%) [19]. However, the epiphyte cover was not overgrowth in Lembeh Island waters as the average was less than 25% or categorized as rare [29,30].

Water transparency varied among the sampling stations (Fig. 3e). The water inside Lembeh Strait seems to be more turbid (Index Value: 2) than outside the Lembeh Strait. Based on the turbidity value, the most turbid water across the location was L1 in Pintu Kota, demonstrated by a mean of 13.10 ± 0.05 NTU (Fig. 3e.). The Limangu station (L6) had the clearest water with turbidity only of 0.10 ± 0.05 NTU (Fig. 3e).

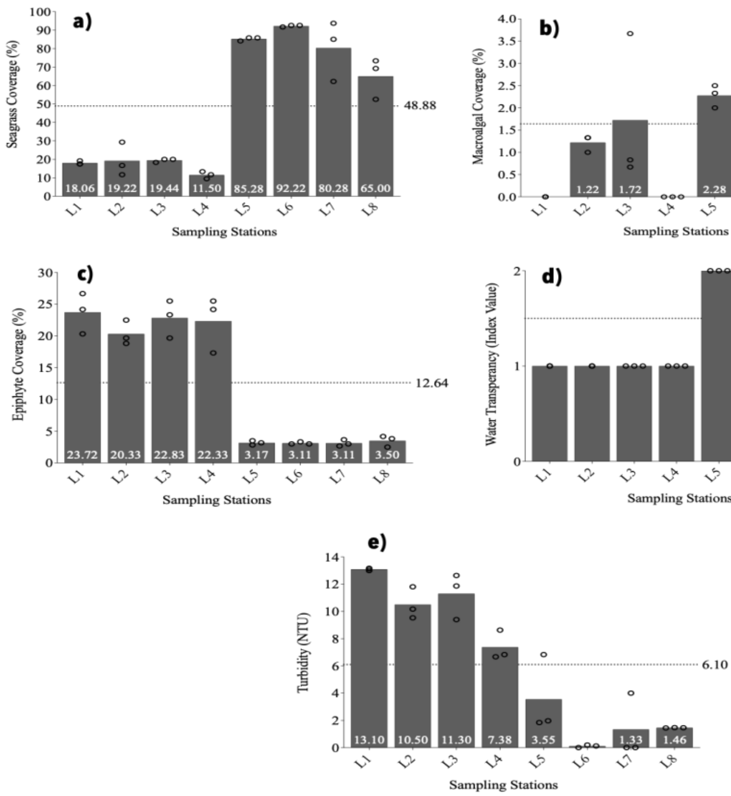

Fig. 3. Seagrass resilience parameters: seagrass coverage, macroalgal coverage, epiphyte coverage, and water transparency (with turbidity value)

Based on the SEQI value, the condition of the seagrass ecosystem in Lembeh Island varied from bad to moderate (SEQI: 0.36 – 0.40). The average condition was categorized as a poor condition, illustrated by a mean SEQI value of 0.48 ± 0.03. Some locations have moderate ecological conditions, as shown in Pancuran, Limangu, and Pasir Panjang, with SEQI values of 0.60, 0.58, and 0.56, respectively (Fig. 4.). All the stations were located outside Lembeh Island. Lirang (L8) was the only location outside Lembeh Island that was categorized as a poor condition; however, the SEQI values were almost in the upper limit of poor condition (Fig. 4). The bad and poor ecological condition of seagrass mostly appeared in locations inside Lembeh Strait (L1 – L4), with SEQI values ranging from 0.36 to 0.40. Pintu Kota (L1) and Lembeh Lodge (L4) were the locations with bad conditions (SEQI: 0.36). Meanwhile, Batu Lubang and Paudean had poor conditions (SEQI: 0.38 and 0.40, respectively). The best seagrass ecological condition was documented in Pancuran or L7 (SEQI: 0.60), and the worst were in Pintu Kota (L1) and Lembeh Lodge (L4) (SEQI: 0.36) (Fig. 4).

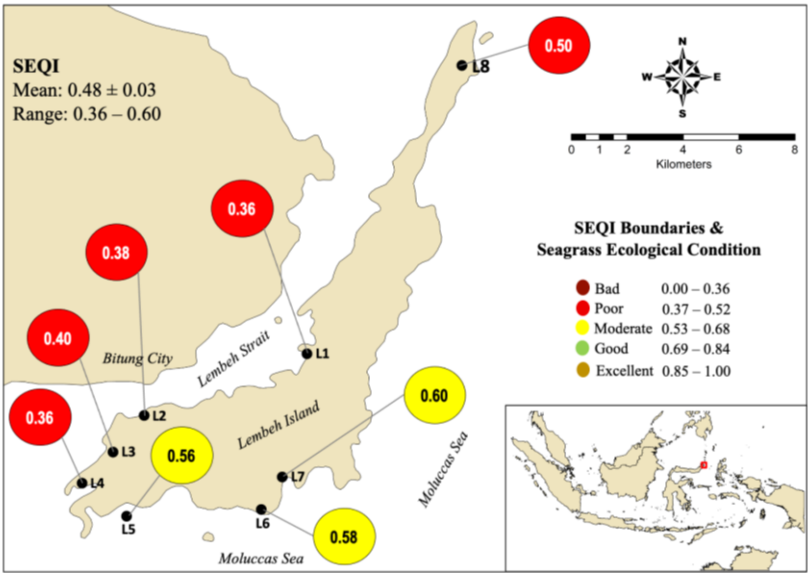

Fig. 4. SEQI boundaries and seagrass ecological condition categories at eight sampling stations over Lembeh Island

The worst condition in the location inside Lembeh Strait compared to outside the strait was driven by the lower seagrass cover, higher epiphyte cover, and more turbid water (Fig. 3). This condition might be led by the greater anthropogenic factors in the Lembeh Strait, such as activities in the port of Bitung, the largest and busiest port in North Sulawesi [42]. Oil or fuel spills, ballast waters, and wastewater from the ships might be some of the threats to the seagrass ecosystem inside Lembeh Strait. Another input from the land activities was plastic waste that accumulated in the coastal area along Lembeh Strait [14,17].

The government declared Lembeh Island and the adjacent waters was a proposed Marine Protected Area in 2014. When designing MPA for fisheries and biodiversity, our results suggest prioritizing the location outside Lembeh Strait, primarily where most of the sites comprise seagrass life history complexity. The locations outside Lembeh Strait are characterized by clear water, have less epiphyte cover, and occupied by dense and complex seagrass meadows (Fig. 3a, 3b). In contrast, the seagrass meadows outside Lembeh Strait, where the water is more turbid, have high epiphyte cover and appear to be monospecific and rare coverage. Seagrass ecosystems with high structural complexity in low turbidity areas are the prioritized zones with a high level of protection [43].

Seagrass management strategies require time-series data on habitat extent and condition, ecosystem services, and threats [44]. The information allows the MPA managers to encounter early changes in seagrass habitats and notice long-term trends to select appropriate management. SEQI can be used to develop ecological time-series data through a monitoring program. The index has wider ranged value boundaries than the analytical method applied in the previous study. It is resulting in a precautionary approach for seagrass ecosystem management in Lembeh Island and the adjacent waters. Fixed line transects or stations within representative meadows should be established for the monitoring programs, which can be set in the sampling station of this study. Furthermore, restoration programs and improving the water environment quality are other management actions for the sustainability of seagrass and coastal ecosystems in Lembeh Island in moderate ecological conditions [20].

4 Conclusion

The seagrass ecosystems in Lembeh Island ranged from bad to moderate conditions across all stations. The seagrass ecosystem outside Lembeh Strait has better conditions than inside Lembeh Strait in terms of species richness, seagrass coverage, macroalgal coverage, epiphyte coverage, and water transparency. We assume that the area inside Lembeh Strait has been more affected by anthropogenic factors than the outside. We suggest seagrass monitoring program by setting fixed line transects or stations within representative meadows to detect early changes and evaluate the trend condition. The SEQI has wider value boundaries, resulting in a precautionary approach for seagrass ecosystem management in Lembeh Island and the adjacent waters. We also recommend a seagrass restoration program in locations with moderate conditions and improving the water environment quality.

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