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Ecological Assessment of Seagrass Meadows in Liukang Loe Island, South Sulawesi Using Seagrass Ecological Quality Index (SEQI)

Adelia Almira[1], Rohani Ambo-Rappe[1,2*], Widyastuti Umar[1], Suci Rahmadani Artika[1,2], St. Firjatih Widhah[2,3]

[1] *Department of Marine Science, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, South Sulawesi, Indonesia.*
[2] *Seagrass Restoration and Ecosystem Services Research Group (SESREG), Hasanuddin University, Makassar, South Sulawesi, Indonesia.*
[3] *Doctoral Program of Fisheries Science, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, South Sulawesi, Indonesia.*

[*] *Corresponding author's e-mail: rohani.amborappe@mar-sci.unhas.ac.id*

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ABSTRACT

Seagrass meadows on Liukang Loe Island, Bulukumba Regency, provide essential coastal ecological functions but are increasingly exposed to tourism and local maritime activity. This study aimed to assess the health of seagrass ecosystems using the Seagrass Ecological Quality Index (SEQI). The results showed that the two study stations had SEQI values of 0.84 and 0.85, indicating that the ecological status of the seagrass meadows ranged from Good to Very Good. These high index values were supported by the presence of nine seagrass species, an average seagrass cover of 35.48%, and 100% water clarity, all of which indicate favorable habitat conditions for fish. Therefore, integrated and sustainable coastal management strategies should be implemented to mitigate the impacts of human activities and ensure the long-term conservation of the ecological functions of seagrass meadows.

Keywords:
Blue carbon habitat, coastal management, fisheries, seagrass ecosystem, small islands

1. Introduction

Seagrasses are marine flowering plants that form extensive meadows in intertidal and shallow coastal water areas. Covering approximately 160,387 km² worldwide, seagrass ecosystems are among the most valuable coastal habitats, providing ecosystem services valued at an estimated US$1.9 trillion annually (McKenzie et al., 2020). They deliver a wide range of ecosystem services (Cullen-Unsworth et al., 2013; Nordlund et al., 2016), defined as natural processes and ecosystem components that directly or indirectly support human well-being (Nordlund et al., 2017). These ecosystems provide ecological benefits across four major categories of ecosystem services: provisioning (e.g., food production), regulation (e.g., carbon sequestration), supporting (e.g., primary production), and culture (e.g., recreation and ecotourism) (Do Amaral Camara Lima et al., 2023).

Indonesia's marine ecosystems are vital components of the world's natural heritage, hosting some of the highest levels of marine biodiversity and supporting the second-largest seafood production globally (FAO, 2016). These ecosystems play a crucial role in sustaining global fisheries, with seagrass meadows providing essential ecosystem services, particularly as habitats that support fishery productivity. Indonesia has extensive seagrass meadows, covering an estimated 6,600 km^2 (Ministry of Marine Affairs and Fisheries of the Republic of Indonesia, 2025). These ecosystems are instrumental in maintaining global marine biodiversity (Jones, 2016). Indonesia is among the world's leading producers of marine fishery products. Seagrass meadows are key coastal ecosystems that enhance fishery productivity by serving as spawning grounds, nursery habitats, shelters, and feeding areas for a wide variety of fish and invertebrate species of high economic value (Unsworth et al., 2018).

Indonesia possesses some of the world's most extensive and diverse seagrass meadows, with 17 species recorded in its coastal waters, including *Cymodocea rotundata*, *C. serrulata*, *Enhalus acoroides*, *Halodule pinifolia*, *H. uninervis*, *Halophila minor*, *H. ovalis*, *H. spinulosa*, *H. sulawesi*, *H. major*, *H. decipiens*, *H. beccarii*, *Syringodium isoetifolium*, *Thalassia hemprichii*, *Thalassodendron ciliatum*, *Ruppia maritima*, and *R. brevipedunculata* (Kurniawan et al., 2024; Salim et al., 2025). This high species diversity underscores the ecological importance of Indonesia's coastal waters as a global center of seagrass biodiversity. These seagrass meadows provide a wide range of essential ecosystem services, including enhancing fisheries productivity, improving water quality, stabilizing sediments, attenuating wave energy, and sequestering substantial amounts of blue carbon.

Despite their ecological and socio-economic importance, Indonesia's seagrass ecosystems are increasingly threatened by human activities, including coastal development, land-based pollution, destructive fishing practices, and climate change. These pressures can lead to habitat degradation, disrupt ecosystem functions, and reduce seagrass meadows' capacity to provide essential ecosystem services (Supriyadi et al., 2024). Therefore, continuous assessment and monitoring are essential for evaluating ecosystem condition, identifying vulnerable areas, and informing effective management and conservation strategies. Such efforts are critical for enhancing coastal resilience and supporting the sustainable blue economy.

The Seagrass Ecological Quality Index (SEQI) is an assessment tool used to evaluate the ecological condition of seagrass meadows at specific locations and points in time. It has been widely applied in tropical regions, including Indonesia and other parts of Southeast Asia, by integrating multiple ecological parameters to assess seagrass ecosystem health (Ambo-Rappe et al., 2026). The SEQI was developed as a cost-effective and straightforward assessment method, making it suitable for routine monitoring and management of seagrass ecosystems (Hernawan et al., 2021).

Liukang Loe Island is located in Bulukumba Regency, South Sulawesi, Indonesia. The island is characterized by a karst landscape dominated by carbonate and limestone formations, which make it an attractive tourist destination. As tourism continues to develop, the island attracts visitors for beach recreation, snorkeling, and diving (Uysal & Modica, 2016). However, if not properly managed, tourism activities can threaten coastal habitats, particularly seagrass meadows, by increasing anthropogenic pressure

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(Giglio et al., 2019). These activities may disturb seagrass habitats, degrade ecosystem condition, and adversely affect seagrass ecological health. The seagrass meadows surrounding Liukang Loe Island play a vital role in maintaining coastal ecosystem functions by providing breeding and nursery habitats for marine organisms, supporting biodiversity, and contributing to marine conservation (Arhan Rajab et al., 2013).

Although the seagrass meadows of Liukang Loe Island are ecologically important, information on their ecological condition remains limited. To the best of our knowledge, no previous study has comprehensively assessed the ecological quality of seagrass meadows in Bulukumba Regency, including Liukang Loe Island, using the Seagrass Ecological Quality Index (SEQI). Consequently, baseline information on the overall ecological condition of these ecosystems is still lacking.

The Seagrass Ecological Quality Index (SEQI) provides an integrated assessment by combining multiple ecological indicators that reflect ecosystem structure, function, and resilience. Therefore, this study aims to assess the ecological quality of seagrass meadows on Liukang Loe Island using the SEQI framework, determine their overall ecological condition, and provide a scientific basis for ecosystem-based coastal management and long-term monitoring. The findings are expected to support the sustainable management of seagrass ecosystems, thereby ensuring the long-term provision of ecosystem services and the well-being of coastal communities that depend on them.

2. Materials and Methods

2.1 Sampling Location

This study was conducted on Liukang Loe Island, Bonto Bahari Subdistrict, Bulukumba Regency, South Sulawesi (Figure 1).

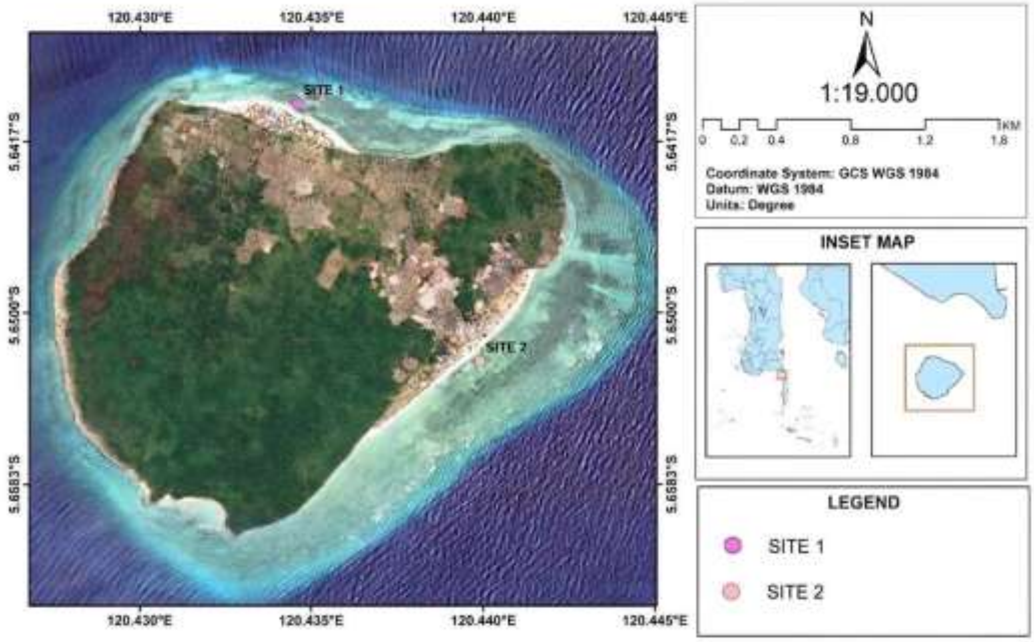

Figure 1. Sampling location on Liukang Loe Island, Bulukumba Regency, South Sulawesi

Located off the southeastern coast of Sulawesi, Liukang Loe Island supports extensive coastal ecosystems, including seagrass meadows that provide important habitats for a wide variety of marine organisms. Two sampling stations were purposively selected to represent different coastal environmental conditions and varying levels of anthropogenic disturbance. Station 1 (120.431837° E, 5.639893° S) was located closer to the shoreline and areas of local boat activity, representing a site with greater anthropogenic influence. In contrast, Station 2 (120.441660° E, 5.651614° S) was situated in relatively open, shallow waters with limited direct human disturbance.

2.2 Data Collection

Data collection was conducted in July 2025 during the dry season under low-tide conditions, following the seagrass monitoring guidelines of the COREMAP-CTI program (Rahmawati et al., 2014). At each sampling station, transects ranging from 40 to 100 m in length were established perpendicular to the shoreline. Along each transect, 50 cm × 50 cm quadrats were placed at intervals corresponding to 10% of the width of the intertidal zone, resulting in 11 quadrats per transect. Within each quadrat, the dominant seagrass species, seagrass cover, epiphyte cover, and macroalgal cover were visually recorded. Species richness was determined by counting the total number of seagrass species identified across all quadrats, following the standard taxonomic classification of Short et al. (2007). Seagrass cover (%) was calculated as the proportion of the substrate surface occupied by seagrass within each quadrat using the method described by Short and Coles (2001).

$$\%\,Seagrass\ Cover = \frac{Total\ percentage\ of\ segrass\ cover}{Total\ observed\ quadrat\ transect}$$

2.3 Seagrass Ecological Quality Index (SEQI) Calculation

The ecological health of seagrass meadows was assessed using the Seagrass Ecological Quality Index (SEQI), a composite index that integrates several key indicators of seagrass ecosystem condition. This index was developed to evaluate habitat quality by considering both community structure characteristics and environmental factors that influence ecosystem sustainability. The parameters used in the SEQI calculation include seagrass species richness (St), seagrass cover (Ct), epiphyte load (Et), macroalgal cover (Mt), and water clarity (Wt). These parameters were selected because they represent important biological and environmental conditions that influence the overall ecological quality of seagrass ecosystems (Hernawan et al., 2021).

Field data were collected at each sampling station using the transect–quadrat method. Species richness was determined by recording the total number of seagrass species observed at each station. Seagrass cover (%) was estimated as the proportion of the quadrat area occupied by seagrass. Epiphyte cover was visually assessed following the Seagrass-Watch monitoring protocol (McKenzie et al., 2003). To estimate epiphyte cover, the observer first determined the proportion of each seagrass leaf surface covered by epiphytes and then estimated the proportion of seagrass leaves within each quadrat that were colonized by epiphytes. The total epiphyte cover (%) was subsequently calculated as the estimated percentage of seagrass leaf area covered by epiphytes within each quadrat.

Water clarity was measured using a Secchi disk during low tide. The Secchi disk was lowered vertically into the water until it was no longer visible, and the Secchi depth (cm) was recorded as an indicator of water clarity. The measured values were then classified into predefined water quality categories. Each ecological parameter was subsequently assigned a score based on predefined value ranges representing ecological conditions from poor to excellent.

Hernawan et al. (2021) explained that this normalization method enables the Seagrass Ecological Quality Index (SEQI) to represent the condition of seagrass ecosystems relative to optimal ecological standards, thereby facilitating consistent comparisons among different monitoring sites. The ecological classification of Seagrass Ecological Quality Index (SEQI) values used in this study is presented in Table 1. The SEQI value was subsequently calculated by averaging the normalized scores of all parameters using the following equation:

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

Where:

- St represents the observed seagrass species richness, while Sref indicates the maximum species richness (which is 9).
- Ct is the observed seagrass coverage percentage. Cref is the maximum value at 100%.
- Wt denotes the observed water clarity, and Wref represents the highest water clarity value of 2.
- Mt is the observed macroalgal coverage percentage, and Mmax is the maximum macroalgal coverage at 100%.
- Et refers to the observed epiphytic coverage percentage, and Emax indicates its maximum at 100%.

Table 1. SEQI Value Ecological Status

No	SEQI Value	Ecological Status
1	0.00 - 0.36	Very Poor
2	0.37 - 0.52	Poor
3	0.53 - 0.68	Moderate
4	0.69 - 0.84	Good
5	0.85 - 1.00	Very good

3. Results and Discussion

3.1 Seagrass Ecosystem Quality Index (SEQI) Assessment in Liukang Loe Island, Bulukumba

The ecological condition of the seagrass meadows on Liukang Loe Island was assessed using the Seagrass Ecological Quality Index (SEQI), which integrates multiple ecological indicators representing ecosystem structure and environmental quality. The evaluated parameters included seagrass species richness (St), seagrass cover (Ct), water clarity

(Wt), macroalgal cover (Mt), and epiphyte cover (Et). The values of these ecological variables and the resulting SEQI scores for each sampling station are presented in Table 2.

Table 2. Ecological variables of SEQI evaluated on Liukang Loe Island. The table summarizes seagrass species richness (St), seagrass cover (Ct), water clarity (Wt), macroalgal cover (Mt), epiphyte cover (Et), and overall SEQI

Location	St	Ct	Wt	Mt	Et	SEQI
Site 1	9	31.71	2	0.00	9.42	0.84
Site 2	9	39.25	2	0.00	12.94	0.85

The high SEQI value observed on Liukang Loe Island is also reflected in the relatively high diversity of its seagrass community. Nine seagrass species were identified: *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, *C. serrulata*, *Halodule uninervis*, *H. pinifolia*, *Syringodium isoetifolium*, *Thalassodendron ciliatum*, and *Halophila ovalis*. This high species diversity indicates that the seagrass meadow supports a wide range of ecological strategies and contributes to ecosystem resilience. According to Kilminster et al. (2015), seagrass species can be classified into three ecological groups: persistent, opportunistic, and colonizing. Persistent species, such as *T. hemprichii* and *E. acoroides*, play a crucial role in maintaining habitat stability because of their extensive belowground biomass, ability to stabilize sediments, and long lifespan. In contrast, opportunistic species such as *C. rotundata* respond rapidly to environmental changes, while colonizing species, including *H. uninervis*, *H. pinifolia*, and *H. ovalis*, facilitate habitat recovery and recolonization following disturbance.

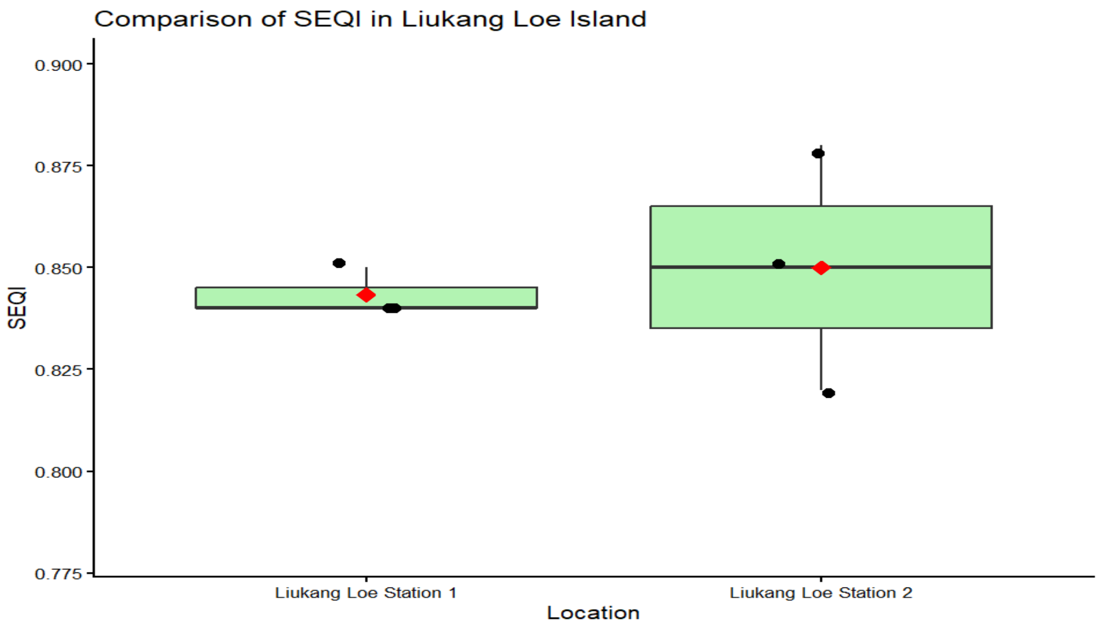

Figure 2. SEQI values on Liukang Loe Island

The SEQI scores at both sampling stations (Figure 2) indicate that the seagrass meadows on Liukang Loe Island are in Good to Very Good ecological condition. Station 1 recorded a SEQI value of 0.84, while Station 2 had a slightly higher value of 0.85. The minimal difference between the two stations indicates relatively uniform ecological quality across the study area, suggesting that both sites are subject to similar environmental conditions and relatively low levels of disturbance. The high SEQI values reflect favorable habitat conditions, a well-maintained seagrass community structure, and limited ecological disturbance, all of which contribute to ecosystem stability and resilience. These findings indicate that the seagrass meadows of Liukang Loe Island continue to perform essential ecological functions, including providing habitat for marine organisms, stabilizing sediments, sequestering blue carbon, and protecting coastlines from wave action. These results are consistent with the findings of Unsworth et al. (2015), who reported that well-conserved seagrass meadows generally exhibit high ecological integrity and maintain their capacity to provide essential ecosystem services.

The presence of these three ecological strategy groups suggests that the seagrass meadows on Liukang Loe Island possess a high level of ecological resilience. Persistent species indicate long-term habitat stability, whereas opportunistic and colonizing species demonstrate the ecosystem's capacity to adapt to environmental changes and recover from disturbances. This community structure is characteristic of healthy seagrass ecosystems that can maintain ecological functions while recovering from natural or anthropogenic disturbances. This may explain why Station 2 maintained a high SEQI value despite its proximity to coastal activities. The high SEQI value reflects not only the habitat's current ecological condition but also its capacity for adaptation and recovery, thereby supporting the long-term sustainability of its ecosystem services. Nevertheless, future coastal development, maritime transportation, and land-use change should be managed sustainably to preserve the stability of the seagrass community and maintain its ecological functions over the long term.

3.2 Connection between SEQI variables in Liukang Loe Island

The results of the Spearman rank correlation analysis among the selected SEQI component variables are presented in Table 3. The analysis showed that seagrass species richness (St) and macroalgal cover (Mt) exhibited a strong and statistically significant positive correlation (r = 0.845, p = 0.034), indicating that higher seagrass species richness tended to be associated with higher macroalgal cover. This relationship may reflect the influence of shared environmental factors, such as nutrient availability, substrate stability, and water quality, which affect both seagrass and macroalgal communities. In a balanced ecosystem, a moderate level of macroalgal cover is a natural component of the benthic community and can contribute to overall ecosystem productivity (Gibbons & Quijon, 2023).

Table 3. Spearman rank correlations among selected SEQI component variables

Relationship	Coefficient (rs)	p-Value	Interpretation
St-Mt	0.845	0.034	Strong, significant
St-Et	0.657	0.156	Strong, non-significant
Mt-Et	0.778	0.069	Strong, non-significant

However, excessive nutrient enrichment, particularly nitrogen input, can stimulate macroalgal growth, increasing competition with seagrass for light and space. Macroalgal dominance may reduce light penetration through the seagrass canopy, decrease photosynthetic efficiency, and ultimately increase the risk of seagrass habitat degradation (Alexandre et al., 2017). Therefore, the positive correlation observed on Liukang Loe Island suggests that the interaction between seagrass and macroalgae remains within a balanced ecological state that supports ecosystem functioning. Nevertheless, future increases in nutrient inputs could alter this balance and negatively affect the overall ecological quality of the seagrass ecosystem.

The correlation between macroalgal cover (Mt) and epiphyte cover (Et) yielded a correlation coefficient of 0.788 with a significance value of 0.069 ($p > 0.05$). Although this indicates a strong positive relationship, the correlation was not statistically significant. The observed trend suggests that higher macroalgal cover tends to be associated with greater epiphyte cover. This relationship may be explained by the fact that both macroalgae and epiphytes respond positively to increased nutrient availability in the water, which promotes macroalgal biomass production while simultaneously enhancing epiphyte growth on seagrass leaves. However, the lack of statistical significance indicates that other environmental factors also influence the relationship between these two components.

Excessive macroalgal growth can increase competition with seagrass by reducing light availability and limiting space for growth, while the accumulation of epiphytes on seagrass leaves further decreases photosynthetic efficiency (Brodersen & Kühl, 2022). Although the relationship between macroalgal cover and epiphyte cover was not statistically significant, both components are known to respond similarly to nutrient enrichment. Elevated nutrient concentrations often stimulate the growth of macroalgae and epiphytes simultaneously, potentially increasing competition with seagrass for light and space. Therefore, continuous monitoring of these biological indicators is essential for detecting early signs of ecosystem degradation before substantial declines in seagrass condition occur.

From a management perspective, the ecological conditions observed on Liukang Loe Island provide an important baseline for future seagrass monitoring and conservation efforts. Although the current ecological quality of the seagrass ecosystem remains high, increasing tourism activities, coastal development, and maritime transportation may pose significant threats if not properly managed. Therefore, implementing ecosystem-based coastal management, combined with periodic ecological assessments using the Seagrass Ecological Quality Index (SEQI), is recommended to maintain ecosystem resilience and ensure the long-term sustainability of the ecosystem services provided by seagrass meadows.

4. Conclusion

Ecological assessment using the Seagrass Ecological Quality Index (SEQI) showed that the seagrass meadows on Liukang Loe Island were generally in Good to Very Good ecological condition, with SEQI values ranging from 0.84 to 0.85. This high ecological quality was supported by excellent water clarity, suitable sandy–coral substrates, and a diverse seagrass community representing different ecological strategy groups.

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