



Mapping Plankton Community Structure in North Sulawesi Waters Using Ecological Diversity Indices as Indicators of Marine Ecosystem Health

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Abstract: Plankton communities play a crucial role in marine ecosystems and are widely used as bioindicators of environmental quality. This study aimed to map plankton community structure in several coastal waters of North Sulawesi and evaluate their potential as indicators of marine ecosystem health. Plankton samples were collected from Bunaken, Lembah Strait, Amurang, Belang, and Likupang using standard plankton net tows. Community structure was analyzed using species composition, abundance, Shannon–Wiener diversity index (H'), evenness (E), and dominance (D). The results showed clear spatial variation in plankton community structure among study sites. Higher diversity values were recorded in Bunaken ($H' = 2.78$; $E = 0.81$; $D = 0.18$) and Lembah Strait ($H' = 2.65$; $E = 0.79$; $D = 0.21$), indicating relatively stable marine conditions. In contrast, Likupang exhibited lower diversity and higher dominance ($H' = 1.43$; $E = 0.52$; $D = 0.39$), suggesting greater environmental stress. These patterns demonstrate that plankton community indices are sensitive indicators of ecosystem condition in tropical coastal waters. The findings also highlight the potential use of plankton ecological data as contextual learning resources in science education, particularly for teaching marine ecosystem dynamics, biodiversity, and environmental monitoring using real environmental datasets from local coastal ecosystems.

Keywords: Bioindicator; Marine ecosystem health; North Sulawesi; Plankton community; Science education

Introduction

Plankton form the foundation of marine food webs and play a vital role in biogeochemical cycles, particularly carbon and nutrient cycling in coastal and oceanic ecosystems. Changes in plankton community structure often reflect variations in environmental conditions, making plankton effective biological indicators of marine ecosystem health (Falkowski et al., 2008; Halpern et al., 2012). In tropical marine environments, plankton communities are highly

responsive to both natural variability and anthropogenic pressures such as coastal development, land-based pollution, and climate-driven changes.

North Sulawesi waters are among the most ecologically important marine regions in Indonesia, encompassing coral reef systems, mangrove ecosystems, seagrass beds, and heavily utilized coastal zones. Areas such as Bunaken National Park are recognized for their high biodiversity and relatively good environmental conditions, while other coastal regions, including Likupang and Amurang, face

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increasing anthropogenic pressures from tourism development, urbanization, and fisheries activities. These contrasting conditions make North Sulawesi an ideal natural laboratory for evaluating plankton as indicators of marine ecosystem health.

Previous studies in North Sulawesi have reported spatial variability in plankton composition and abundance, particularly in Bunaken, Lembeh Strait, and surrounding coastal waters (Rampengan et al., 2014; Patmawati et al., 2018; Antuke et al., 2020). However, comprehensive mapping of plankton community structure across multiple coastal ecosystems using standardized ecological indices remains limited. Moreover, the integration of plankton ecological data into science education contexts remains underutilized, despite its strong potential to support inquiry-based learning and environmental literacy.

Previous studies conducted in North Sulawesi waters have documented plankton composition, abundance, and distribution in several locations such as Bunaken and Lembeh Strait (Rumengan et al., 2011; Rampengan et al., 2014; Hikmah et al., 2018; Undap et al., 2020). However, most of these studies focused on specific locations or particular plankton groups and did not provide a comparative assessment of plankton community structure across multiple coastal ecosystems using standardized ecological indices. As a result, comprehensive spatial information on plankton community structure as an indicator of marine ecosystem health in North Sulawesi waters remains limited. Addressing this gap is important to provide baseline ecological data that can support environmental monitoring and sustainable coastal management.

In addition to its ecological significance, plankton community analysis also has strong potential for integration into science education. The use of locally generated environmental data can support inquiry-based learning by allowing students to analyze real ecological datasets and understand marine ecosystem processes. Plankton data, including diversity indices and community structure patterns, can be used as contextual learning materials to explain concepts such as biodiversity, food webs, ecosystem health, and environmental monitoring. Integrating regional marine ecological data into science learning can therefore enhance students' environmental literacy and promote place-based science education, particularly in coastal regions such as North Sulawesi.

Therefore, this study aimed to (1) map plankton community structure across selected coastal waters of North Sulawesi, (2) evaluate plankton diversity indices as indicators of marine ecosystem health, and (3) highlight the relevance of plankton-based environmental data for science education and marine resource management.

Method

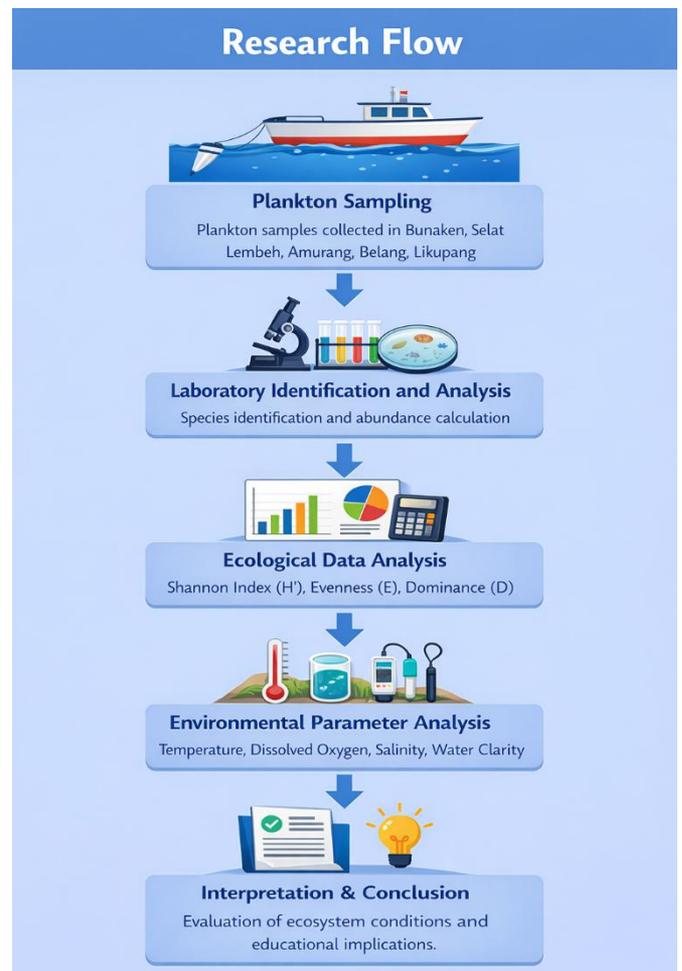


Figure 1. Research Flow

Study Area

This study was conducted in five coastal locations, which was determined purposively (Sugiyono, 2018; Mukhlis et al., 2019; Mukhlis et al., 2024; Asgaf et al., 2025) in North Sulawesi waters: Bunaken, Lembeh Strait, Amurang, Belang, and Likupang. These sites represent a gradient of environmental conditions ranging from relatively pristine marine protected areas to coastal zones influenced by human activities.

Plankton Sampling

Plankton samples were collected using a plankton net with a mesh size of 25 μm for phytoplankton and 100 μm for zooplankton. Horizontal tows were conducted at the surface for a standardized duration at each site. Samples were preserved in 4% buffered formalin solution for laboratory analysis.

Laboratory Analysis

Plankton identification and counting were performed using a compound microscope following

standard taxonomic references. Abundance was expressed as individuals per cubic meter (ind/m³). Community structure was assessed using Shannon–Wiener diversity index (H'), evenness index (E), and Simpson dominance index (D).

Data Analysis

Spatial differences in plankton diversity indices among sites were analyzed descriptively and visualized using tables and graphs. The results were interpreted in the context of environmental conditions and previous

Result and Discussion

Results

Table 1. Plankton diversity indices across study sites

Site	H'	E	D
Bunaken	2.78	0.81	0.18
Lembeh	2.65	0.79	0.21
Amurang	2.12	0.68	0.27
Belang	2.05	0.66	0.29
Likupang	1.43	0.52	0.39

Table 2. Dominant plankton taxa recorded in North Sulawesi waters

Major group	Dominant taxa	Site occurrence
Diatoms	<i>Chaetoceros, Thalassiosira</i>	Bunaken, Lembeh, Amurang, Belang
Dinoflagellates	<i>Ceratium, Peridinium</i>	Bunaken, Lembeh
Copepods	<i>Acartia, Calanus</i>	Bunaken, Lembeh, Belang
Protozoa	<i>Tintinnopsis</i>	Likupang

Table 3. Environmental parameters of North Sulawesi waters (mean ± SD)

Site	Temperature (°C)	Salinity (ppt)	pH	DO (mg L ⁻¹)	Water transparency (m)
Bunaken	29.1 ± 0.4	33.5 ± 0.3	8.1 ± 0.1	6.4 ± 0.3	18.2 ± 1.5
Lembeh	29.3 ± 0.5	33.2 ± 0.4	8.0 ± 0.1	6.1 ± 0.4	15.6 ± 1.2
Amurang	29.8 ± 0.6	32.6 ± 0.5	7.9 ± 0.1	5.6 ± 0.5	10.4 ± 1.0
Belang	29.7 ± 0.6	32.4 ± 0.6	7.8 ± 0.2	5.4 ± 0.6	9.8 ± 0.9
Likupang	30.2 ± 0.7	31.8 ± 0.7	7.7 ± 0.2	4.9 ± 0.7	7.6 ± 0.8

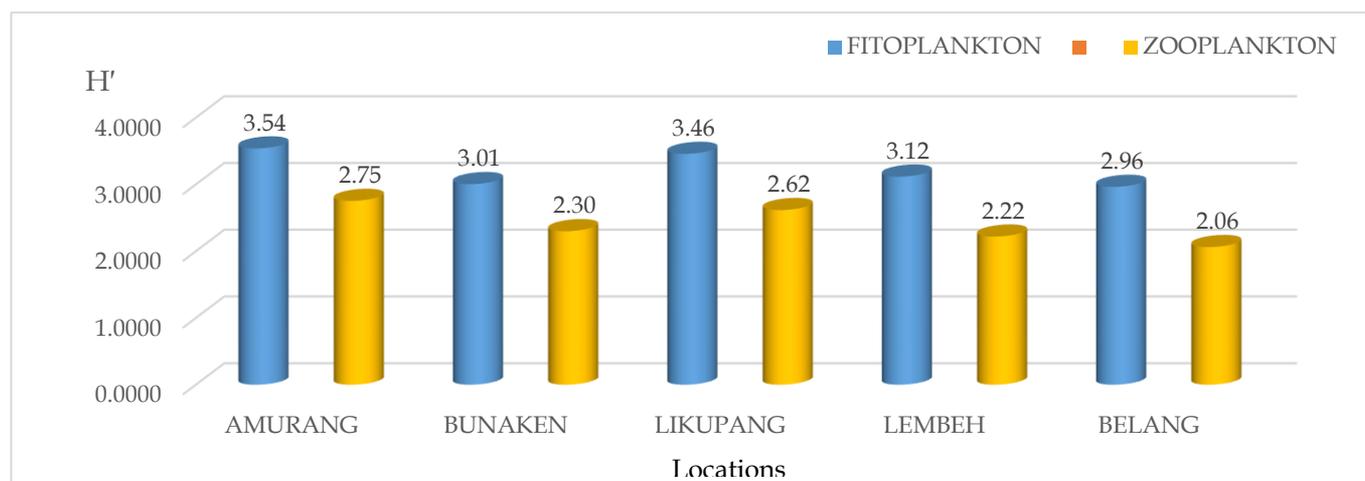


Figure 2. Spatial variation of Shannon–Wiener diversity index (H') of phytoplankton and zooplankton across study sites in North Sulawesi waters.

Discussion

The spatial variability of plankton community structure observed across North Sulawesi waters

reflects differences in environmental quality, habitat complexity, and anthropogenic pressure among sites. Higher Shannon–Wiener diversity (H') and evenness

values recorded in Bunaken and Lembah Strait indicate relatively stable and productive marine ecosystems. Such conditions are typically associated with well-developed coral reef systems, good water circulation, and lower nutrient and pollutant inputs, which support diverse phytoplankton and zooplankton assemblages (Falkowski et al., 2008; Nybakken & Bertness, 2020).

In contrast, lower diversity and higher dominance values observed in Likupang suggest environmental stress and reduced ecological stability. Previous studies have demonstrated that coastal development, land-based runoff, and tourism-related activities can alter nutrient regimes and increase suspended solids, leading to shifts in plankton composition toward fewer, more tolerant taxa (Caroni et al., 2013; Cloern et al., 2014; Borja et al., 2020). The dominance of protozoa and opportunistic plankton groups at stressed sites is a common ecological response to fluctuating environmental conditions and has been widely reported in tropical coastal ecosystems (Paerl et al., 2011; Carstensen et al., 2015).

Comparative studies in North Sulawesi waters support the patterns observed in this study. Rumengan et al (2011); Rampengan et al (2014) reported higher plankton diversity in Bunaken waters than in more urbanized coastal areas, underscoring the role of marine protected areas in maintaining plankton biodiversity. Similarly, research conducted in Lembah Strait has shown that despite intensive maritime activities, localized water circulation and habitat heterogeneity can sustain relatively diverse plankton communities (Hikmah et al., 2018; Yanguo et al., 2018; Undap et al., 2020). These findings suggest that physical oceanographic processes, such as tidal mixing and current dynamics, may partially mitigate anthropogenic impacts on plankton communities.

From an ecological indicator perspective, plankton community metrics provide early warning signals of environmental change. Diversity indices, dominance patterns, and shifts in major plankton groups have been widely used to assess eutrophication, pollution, and ecosystem degradation in coastal waters (Carstensen et al., 2011; Tett et al., 2013). These approaches have been successfully applied across a wide range of coastal systems, reinforcing the robustness of plankton-based indicators. The clear spatial gradients observed in this study confirm the sensitivity of plankton-based indicators for assessing marine ecosystem health in tropical regions.

The environmental parameters measured in this study further support the observed patterns in plankton community structure. Higher dissolved oxygen levels, stable salinity, and greater water transparency in Bunaken and Lembah Strait indicate well-oxygenated, less disturbed marine environments

that favor diverse plankton assemblages. In contrast, lower dissolved oxygen levels, reduced salinity, and decreased water transparency recorded in Likupang suggest increased terrestrial input and environmental stress, conditions commonly associated with reduced plankton diversity and greater dominance of tolerant taxa (Cloern et al., 2014; Paerl et al., 2011). These results highlight the close linkage between physicochemical conditions and biological responses, reinforcing the suitability of plankton communities as integrative indicators of marine ecosystem health.

The variation in plankton community structure observed among study sites is closely associated with differences in physicochemical parameters of the water. Higher diversity values recorded in Bunaken and Lembah Strait correspond with relatively stable environmental conditions, including higher dissolved oxygen, stable salinity, and greater water transparency. These conditions favor the growth of diverse phytoplankton communities and support more complex zooplankton assemblages. In contrast, the lower diversity and higher dominance observed in Likupang may be related to higher temperature, reduced salinity, lower dissolved oxygen, and decreased water transparency recorded at this site. Such environmental conditions can limit plankton diversity and favor opportunistic or tolerant taxa. Similar relationships between environmental variability and plankton community structure have been widely reported in tropical coastal ecosystems, where physicochemical factors play a key role in shaping plankton distribution and diversity.

Beyond ecological assessment, the results of this study have important implications for science education. Locally generated plankton data can be effectively integrated into inquiry-based learning, enabling students to explore real-world environmental problems using authentic datasets. The use of plankton as a teaching tool can enhance students' understanding of marine food webs, ecosystem dynamics, and the impacts of human activities on coastal environments (Bybee, 2014; OECD, 2019). Incorporating regional marine data into science curricula also strengthens environmental literacy and fosters place-based learning, which is particularly relevant for coastal communities such as those in North Sulawesi.

From a science education perspective, the ecological information generated in this study can be utilized as contextual learning material in environmental and marine science education. Plankton diversity data and environmental parameters can be incorporated into inquiry-based learning activities where students analyze real datasets to understand relationships between environmental conditions and biological communities. For example, students can

explore how variations in temperature, salinity, and dissolved oxygen influence plankton diversity and ecosystem stability. Such learning activities help students develop scientific reasoning, data interpretation skills, and environmental awareness. Using locally generated marine ecological data also supports place-based education, enabling students in coastal regions to connect scientific concepts with environmental conditions in their surrounding ecosystems.

Study Limitations

This study was limited to a single sampling period and surface plankton collection, which may not fully capture temporal variability and vertical distribution patterns of plankton communities. Seasonal changes in monsoon-driven circulation and nutrient availability are known to influence plankton dynamics in Indonesian waters (Susanto et al., 2016). Future studies should incorporate multi-seasonal sampling, depth-stratified collections, and additional environmental parameters, such as nutrients, chlorophyll a, and turbidity, to improve ecosystem health assessments.

Conclusion

Plankton community structure in North Sulawesi waters shows clear spatial variation related to ecosystem conditions. Higher diversity and evenness values recorded in Bunaken and Lembeh Strait indicate relatively stable marine environments, whereas lower diversity and higher dominance observed in Likupang suggest greater environmental stress. These findings confirm that plankton community indices can serve as effective bioindicators for assessing marine ecosystem health in tropical coastal waters.

Beyond their ecological significance, the results of this study also provide practical implications for coastal environmental monitoring and management by offering baseline ecological information on plankton community structure in North Sulawesi waters. In addition, the ecological data generated in this study can be utilized as contextual learning resources for science education, particularly for teaching biodiversity, marine ecosystem dynamics, and environmental monitoring using real environmental datasets from local coastal ecosystems.

However, this study was limited to a single sampling period and surface plankton collection. Future research is therefore recommended to conduct multi-seasonal sampling and include additional environmental parameters, such as nutrient concentrations and chlorophyll-a, in order to obtain a more comprehensive understanding of plankton

dynamics and ecosystem health in North Sulawesi waters.

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Author Contributions

R.O.S.E.M.: Developing ideas, analyzing, writing, reviewing, responding to reviewers' comments; D.A.S., S.L.U., R.B., H.R., T.S.K.: analyzing data, overseeing data collection, reviewing scripts, and writing.

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Conflicts of Interest

The authors declare no conflict of interest.

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