

Article

A Comparative Study of Community Structure and Plankton Abundance in Seaweed Cultivation Areas in Puntondo, Takalar Regency

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Abstract. Healthy tropical coastal waters ideally have a diverse plankton community, which serves as an indicator of optimal ecological stability. However, seaweed farming activities and fishing boat traffic in the waters off Puntondo, Takalar Regency, have the potential to increase organic nutrient loads and reduce dissolved oxygen levels, thereby gradually disrupting the balance of the plankton community structure. Monitoring based on the analysis of plankton community structure is required as a means of detecting changes in the ecological conditions of the waters. Given the scarcity of ecological data in this region, this study aims to analyse the community structure and abundance of plankton in the waters off Puntondo as a basis for coastal ecosystem management. Sampling was carried out at three stations using *purposive sampling* with a No. 25 plankton net, and the data were analysed using ecological indices and multivariate analyses (nMDS, ANOSIM and SIMPER) via PRIMER version 5. The results showed that the phytoplankton consisted of 12 species dominated by Bacillariophyceae with an abundance of 476–520 ind/L, and the zooplankton consisted of 6 species dominated by Polychaeta with an abundance of 6090–6630 ind/L; there were no significant differences between stations for either group. Moderate diversity, high evenness and low dominance indicate that the plankton community is in a state of equilibrium, reflecting that the waters of Puntondo are still capable of sustaining the plankton ecosystem despite facing anthropogenic pressures that require ongoing monitoring.

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Universitas Hasanuddin, Makassar, IndonesiaEmail : nita.r@unhas.ac.id**1. Introduction**

Plankton are microscopic organisms that live suspended in the water column and play a vital role in aquatic ecosystems. Phytoplankton function as primary producers through photosynthesis, whilst zooplankton transfer energy to higher trophic levels [1]. Plankton abundance is influenced by physico-chemical parameters such as temperature, pH, salinity, dissolved oxygen (DO), nitrate, and phosphate. Consequently, plankton are frequently used as biological indicators of water quality [2].

Assessing the ecological condition of water bodies requires an analysis of community structure, including indices of diversity, evenness, and dominance. A stable ecosystem does not necessarily exhibit high diversity, as environmental pressures can lead to the dominance of certain species [2]. Human activities such as the discharge of industrial and domestic waste directly degrade water quality. Analysis of plankton community structure is a vital tool for comprehensively monitoring changes in the ecological condition of water bodies [3-4].

Seaweed cultivation activities in the Puntondo waters have the potential to increase the load of organic nutrients through the decomposition of unharvested biomass, which directly reduces dissolved oxygen levels and limits phytoplankton primary productivity [5]. The traffic of fishing boats using diesel fuel also contributes to the load of organic pollutants, which synergistically exacerbates the decline in water quality. The combination of these two anthropogenic pressures has the potential to gradually shift the balance of plankton community composition and structure in coastal areas [6].

Tropical coastal areas have high productivity because sufficient sunlight throughout the year supports phytoplankton growth. However, aquaculture, fishing, and boat transport activities have the potential to significantly reduce water quality [7]. Research in the waters of Laikang Bay indicates that aquaculture activities and boat traffic result in water conditions classified as moderately polluted [8]. This suggests that tropical coastal areas facing similar anthropogenic pressures are at risk of plankton community structure degradation.

The waters off Puntondo, Takalar Regency, are subject to anthropogenic pressures from seaweed farming, fishing and tourism, which generate domestic waste and organic pollution from the decomposition of biomass and boat fuel [9]. However, plankton ecological studies integrating community structure analysis with physico-chemical parameters in this area remain very limited compared to other coastal areas in South Sulawesi. It is hypothesised that the homogeneity of physicochemical parameters resulting from evenly distributed anthropogenic pressures does not produce significant ecological gradients capable of creating discernible differences in species composition, abundance, and ecological indices of plankton communities between stations; consequently, this study aims to analyse the community structure and abundance of plankton in the waters off Puntondo as a scientific basis for the sustainable management of coastal ecosystems.

2. Materials and Methods**2.1. Research Location**

This study was conducted in October 2025 in the Puntondo waters (Figure 1). Administratively, the Puntondo waters are situated in the village of Puntondo, Laikang Village, Mangarabombang Sub-district, Takalar Regency, South Sulawesi Province. Sampling was carried out at three stations, each comprising three sub-stations selected via *purposive sampling* to represent the conditions of the study area. These waters are utilized for seaweed cultivation, fishing, and shipping routes, all of which have

the potential to influence water conditions. Consequently, we analyzed the community structure and abundance of plankton.

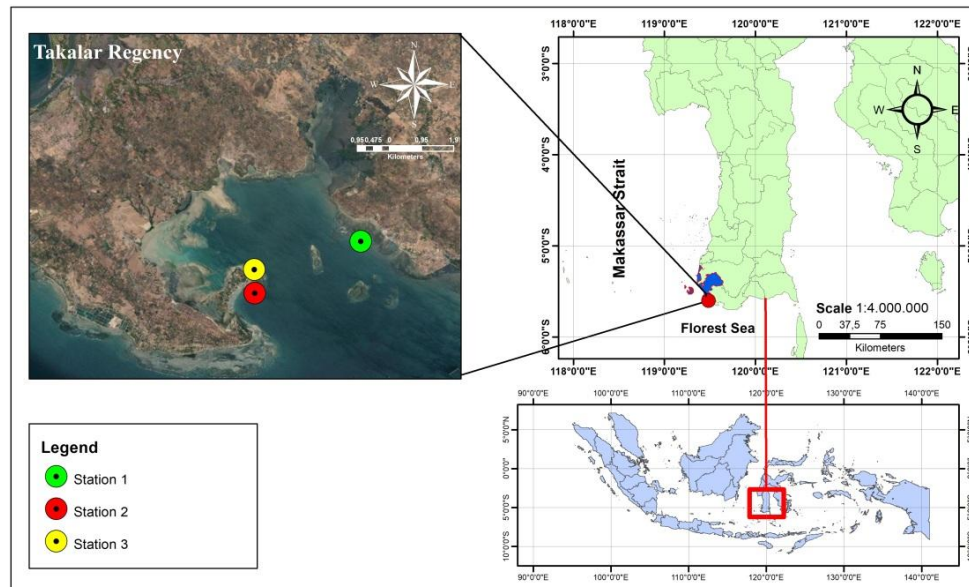


Figure 1. Research location in Puntondo, Takalar Regency, Indonesia.

2.2. Equipment and materials

This study utilised the following equipment: a speedboat as a means of transport to the sampling site, a size 25 plankton net for filtering plankton, and sample bottles as containers for storing the filtered samples. A Water Quality Checker (HANNA Instrument 98194) was used to measure water quality parameters *insitu*, such as temperature, dissolved oxygen, and salinity. A dropper pipette was used to collect liquid samples, whilst scissors were used to cut the adhesive tape. A small 5-litre bucket served as a container for water prior to filtration. In addition, a smartphone and GPS (*Avenza Maps*) were used to record the coordinates of each sampling station. Plankton observations were carried out using an Olympus CX43 microscope with the aid of a *Sedgewick Rafter Counting Cell* (SRC) as a counting chamber, as well as a plankton identification guidebook as a reference during the identification process.

The materials used in this study were plankton samples (phytoplankton and zooplankton) as the objects of analysis, Lugol's solution for sample preservation, distilled water and tissues for sterilising and cleaning equipment, permanent markers for labelling sample bottles, and adhesive tape used as labels on each sample bottle.

2.3. Site Selection

The selection of research locations used the *purposive sampling* method, i.e. the determination of locations based on water characteristics considered representative of the research area's conditions. This method was chosen because each station has different conditions and activities, such as seaweed cultivation, fishing, and vessel transport, so it is hoped that this will be able to illustrate the variation in community structure and plankton abundance in the waters of Puntondo. Sampling was conducted at the same time and under the same weather conditions at each station to minimise the influence of temperature and weather variations on the research results. Each station was divided into 3 sub-stations with a distance of 100 m between stations and 5 m between sub-stations. At each sub-station, three replicates were taken to enhance data representativeness.

Table 1. Station characteristics matrix

Station	Station Position	Bottom Substrate	Water Characteristics	Surrounding Activities
I	Near the coast	Sand	Coastal waters that are relatively close to land and are influenced by activities in the surrounding coastal area	Boat traffic, fishing and seaweed farming
II	Transitional waters	Sand	Transitional waters between the coast and more open waters	Boat traffic, seaweed farming and fishing
III	Open waters	Sandy mud	Waters relatively far from the influence of the mainland	Boat traffic and fishing

2.4. Plankton Sampling

Seawater samples were collected using 5-litre buckets, then filtered using a No. 25 plankton net 10 times at each sub-station. The filtered material collected in collection bottles was transferred to labelled sample bottles. Subsequently, the samples were preserved by adding 1 ml of Lugol's solution to each sample bottle prior to laboratory analysis. Following plankton sampling, *in-situ* measurements of water quality parameters (temperature, dissolved oxygen and salinity) were conducted using a Water Quality Checker (HANNA Instrument 98194).

2.5. Plankton Identification

Plankton observation and identification were carried out in the Water Quality Laboratory using an Olympus CX43 microscope. From the preserved samples, 1 ml was placed into a Sedgewick Rafter Counting Cell (SRC) for observation and counting of the number of individuals. Identification was carried out based on the morphological characteristics of the species, referring to the books [7], [10-12]. The classification of the plankton species found was then adapted from [13].

2.6. Data Analysis

Data analysis was performed using PRIMER software version 5 via multivariate statistical analysis, including *Non-metric Multidimensional Scaling* (nMDS), *Analysis of Similarity* (ANOSIM), and *Similarity Percentage* (SIMPER), as well as the calculation of ecological indices such as abundance, diversity, evenness, and dominance, as referenced in [14]. The results of the analysis were subsequently presented in the form of histograms using GraphPad Prism version 8 software to facilitate systematic visualisation and interpretation of the data. nMDS analysis was used to describe the degree of similarity in community structure based on a similarity matrix, with accuracy evaluated via stress values; ANOSIM was applied to statistically test differences in species composition between groups; whilst SIMPER was used to identify the species contributing most to differences between study sites [15]. Plankton abundance (N) was calculated according to [16] using the formula:

$$N = \frac{n}{Ac} \times \frac{At}{Vs} \times \frac{Vt}{As}$$

- N = Plankton abundance (ind/L)
n = Number of individuals observed
Ac = Observation area (mm²)
At = Cross-sectional area of the SRC (mm²)

V_s = Sample volume in SRC (mL)
 V_t = Volume of concentrate in the bottle (mL)
 A_s = Volume of filtered water (L)

Abundance criteria (N) and their interpretation are as follows:

0 – 2000 : Oligotrophic (poorly nourished)
 2000–15.000 : Mesotrophic (moderately fertile)
 >15.000 : Eutrophic (highly fertile)

The diversity index is calculated using the Shannon-Wiener formula [17]:

$$E = \frac{H'}{\ln S}$$

H' = Diversity index
 n_i = Number of individuals of each species
 N = Total number of individuals

The criteria for the diversity index (H') and their interpretation are as follows:

$H' < 1$: low community diversity (unstable)
 $1 < H' < 3$: moderate community diversity (moderate stability)
 $H' > 3$: high community diversity (stable).

The evenness index (E) is calculated using the formula [18]:

$$E = \frac{H'}{\ln S}$$

E = Evenness index
 H' = Diversity index
 S = Number of species

The criteria for the evenness index (E) and their interpretation are as follows:

0 – 0.4 : Low uniformity
 0.4 – 0.6 : Moderate species uniformity
 0.6 – 1.0 : High species uniformity

The dominance index (C) uses Simpson's formula [17]:

$$C = \sum \left(\frac{n_i}{N} \right)^2$$

C = Dominance index
 n_i = Number of individuals of each species
 N = Total number of individuals

The criteria for the dominance index (C) and their interpretation are as follows:

< 0.5 : Low species dominance
 $0.5 < C < 1$: Moderate species dominance
 > 1 : High-level dominance

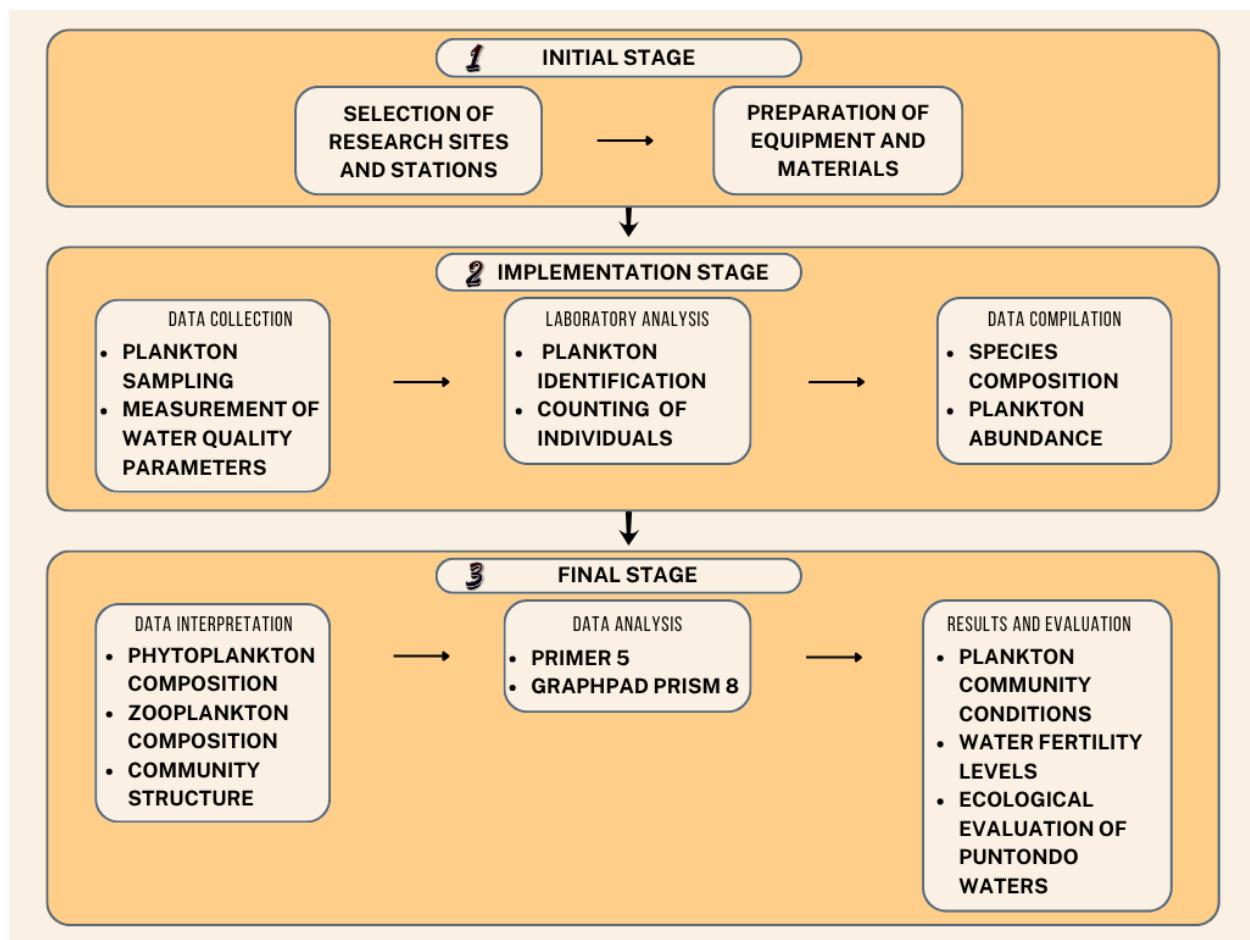


Figure 1. Research flowchart

3. Results and Discussion

3.1. Composition of Phytoplankton and Zooplankton Species in Puntondo, Takalar Regency

3.1.1. Phytoplankton Composition

The identification results from the study site indicate that there were 12 species of phytoplankton, divided into three classes: Bacillariophyceae, Coscinodiscophyceae and Dinophyceae. The Bacillariophyceae class had the highest number of species, namely around 5 species. Coscinodiscophyceae comprised 4 species, whilst Dinophyceae had the fewest, namely 3 species. This composition indicates that Bacillariophyceae dominates the phytoplankton community structure based on the number of species found.

The Bacillariophyceae class in the waters of Puntondo is influenced by favourable environmental conditions, such as temperatures of 28.4–29.8°C, salinity of 27.4–28.4 ppt, and sufficient availability of nitrate and phosphate for phytoplankton growth. These conditions support the development of Bacillariophyceae, making it the most commonly found class. The dominance of this class is also commonly observed in tropical coastal waters with relatively stable environmental conditions. In the coastal waters of South Sulawesi, Bacillariophyceae dominate under environmental conditions that support phytoplankton growth [19]. These conditions are thought to have contributed to the dominance of Bacillariophyceae in the waters of Puntondo.

The low number of Dinophyceae species compared to Bacillariophyceae is thought to be influenced by nutrient levels in the waters of Puntondo, which remain at moderate levels. An increase in nutrient concentration could trigger an increase in Dinophyceae abundance and alter the structure of the phytoplankton community [20]. However, the measured concentrations of nitrate and phosphate during the study are thought to remain more suitable for the growth of Bacillariophyceae, so this class remains the dominant component in the phytoplankton community in the waters of Puntondo.

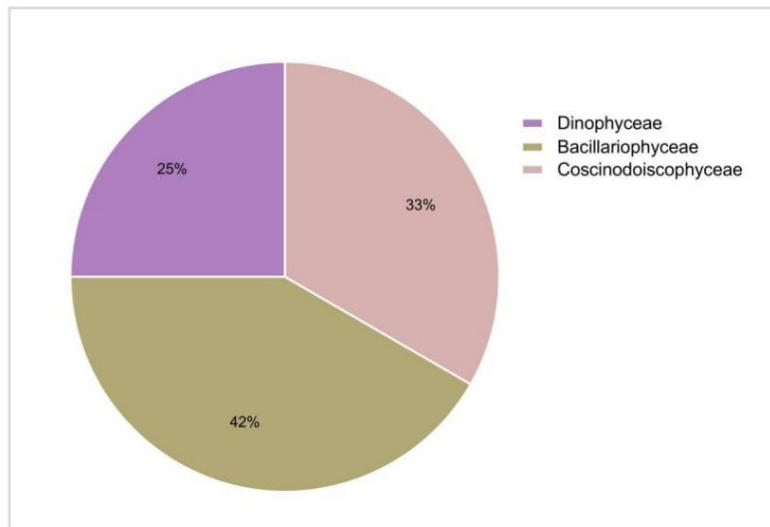


Figure 2. Phytoplankton species composition found in Puntondo

3.1.2. Zooplankton Composition

The zooplankton found in this study were divided into five classes, namely Globigerinidea, Bivalvia, Polychaeta, Maxillopoda and Malacostraca, with a total of 6 species. The class Polychaeta has the highest number of species, totalling 2, whilst the other four classes each comprise 1 species. Generally, the zooplankton composition shows a relatively balanced number of species across the classes, with Polychaeta being the most dominant class based on the number of species found.

The Polychaeta class in the waters off Puntondo is thought to be influenced by environmental conditions that remain conducive to the survival of zooplankton larvae, with dissolved oxygen (DO) levels ranging from 5.66 to 5.83 mg/L. Furthermore, the presence of sandy and silty-sandy substrates at the study site also provides a suitable habitat for this class. Polychaeta are commonly found and tend to dominate coastal waters with soft bottom substrates [21].

The relatively similar zooplankton composition across stations is thought to be influenced by environmental conditions that tend to be uniform, particularly temperature, salinity, and dissolved oxygen. It is known that physico-chemical parameters of the water play a role in shaping the community structure and distribution of zooplankton [22–23]. These similar conditions are thought to limit variations in zooplankton composition, resulting in relatively low community variation between stations in the Puntondo waters.

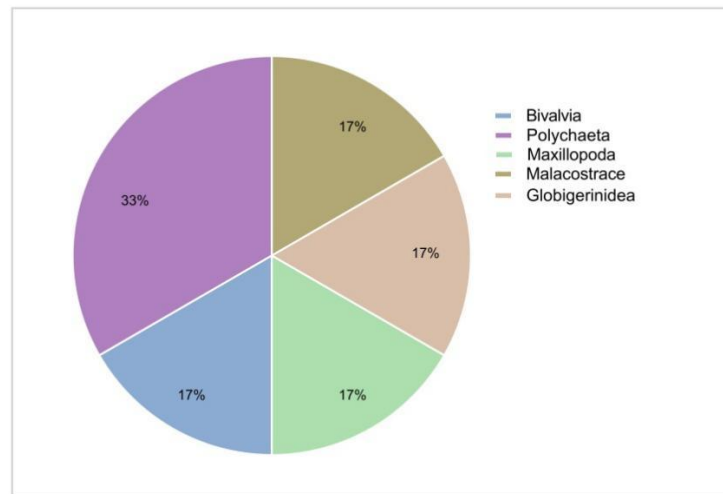


Figure 3. Composition of zooplankton species found in Puntondo

3.2. Plankton Community Structure

3.2.1. Non-Metric Multidimensional Scaling (nMDS)

The nMDS analysis of phytoplankton indicates that species composition between stations does not differ significantly, as shown by the closely clustered plot points forming a single group. A stress value of 0.05 indicates that the nMDS analysis provides an excellent level of data representation with low distortion, allowing the patterns of relationships between stations to be accurately interpreted and to represent actual conditions. In general, Station 2 and Station 3 appear more similar, whilst Station 1 is slightly different; however, these differences remain not significantly different.

The similarity in phytoplankton composition between stations is related to the relatively uniform environmental conditions during the study. Water conditions play a role in shaping the structure of phytoplankton communities, so that the communities formed tend to be similar across stations [24]. Although Station 1 shows a slightly different pattern, seaweed cultivation activities and boat traffic in the coastal area have not yet caused any significant changes in phytoplankton composition [25].

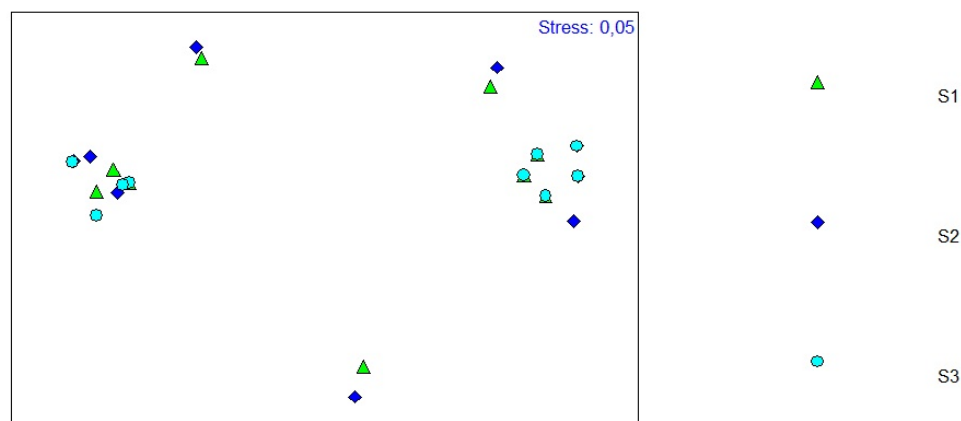


Figure 4. nMDS plot of phytoplankton based on sampling stations in Puntondo

The zooplankton nMDS analysis indicates that species composition between stations does not differ significantly, as shown by Stations 1 and 3, where several plots overlap and form a single cluster,

whilst Station 2 clusters separately with its own group. This suggests a similarity in community structure between Station 1 and Station 3, whilst Station 2 tends to differ. A stress value of 0.11 indicates that the analysis results adequately represent the data and do not reveal any significant differences between stations.

Differences in zooplankton community structure between stations are relatively low, which is thought to be related to the generally homogeneous environmental conditions of the Puntondo waters. The stability of salinity and dissolved oxygen allows zooplankton to live within similar tolerance ranges, thereby reducing environmental selection pressure. This is also supported by stable water quality conditions and the still-limited impact of coastal activities. Overall, physico-chemical factors play a greater role than local anthropogenic disturbances in shaping the uniformity of the zooplankton community [26].

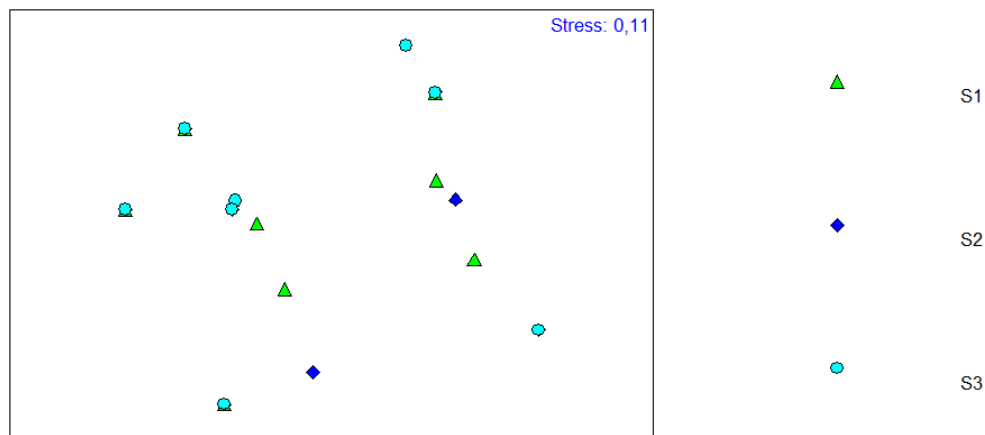


Figure 5. Zooplankton nMDS plot based on sample research stations at Puntondo

3.2.2. Analysis of Similarity (ANOSIM)

The ANOSIM results indicate that the Global R values for phytoplankton and zooplankton are close to zero ($P > 0.05$). This suggests that there are no differences in community composition between stations. Phytoplankton and zooplankton show similarities, meaning that the community structure of both is relatively uniform across all study stations. The ANOSIM results are presented in Table 2.

Table 2. Analysis of similarity (ANOSIM)

Pair Wise	ANOSIM Results	
	Global R	Significance Level (%)
Fitoplankton		
Station 1 vs Station 2	-0.065	79.2
Station 1 vs Station 3	-0.094	98.2
Station 2 vs Station 3	-0.075	84.2
Zooplankton		
Station 1 vs Station 2	-0.09	91.9
Station 1 vs Station 3	-0.112	98.3
Station 2 vs Station 3	-0.091	89.8

The structure of the plankton community in the waters of Puntondo exhibits a uniform pattern across stations, which is thought to be due to the low variation in physico-chemical parameters, meaning that habitat conditions at each location tend to share similar characteristics. Consequently, the distribution and composition of plankton do not show any significant differences. The waters of Laikang Bay demonstrate that the uniformity of environmental parameters is associated with a high degree of similarity in plankton community structure across the study sites [8].

3.3.3. Similarity of Percentage (SIMPER)

Table 3 presents the results of the SIMPER analysis used to identify the species with the greatest contribution to compositional differences between each pair of observation stations. SIMPER analysis indicates that the difference in contribution between stations is greater for zooplankton (53.24%) than for phytoplankton (33.91%). The species contributing most to the differences in phytoplankton was *C. trichoceros* with a contribution of 15.91%, whilst in zooplankton it was *Temora* sp. with the highest contribution of 26.66%. These results indicate that these two species are the primary differentiators in plankton community structure.

Table 3. Similarity of percentage (SIMPER)

Pair Wise	Difference (%)	3 Distinguishing species (%)
Fitoplankton		
Station 1 vs Station 2	33.19	<i>C. trichoceros</i> (15.43)
		<i>Chaetoceros decipiens</i> (14.45)
		<i>C. extensum</i> (10.43)
Station 1 vs Station 3	30.62	<i>C. trichoceros</i> (15.91)
		<i>Chaetoceros decipiens</i> (13.28)
		<i>C. extensum</i> (11.96)
Station 2 vs Station 3	33.91	<i>Chaetoceros decipiens</i> (16.00)
		<i>C. trichoceros</i> (14.40)
		<i>C. extensum</i> (10.73)
Zooplankton		
Station 1 vs Station 2	50.29	<i>Temora</i> sp (26.65)
		Larva Pagurus sp (23.15)
		Unidentified Larva Annelida (14.10)
Station 1 vs Station 3	49.43	<i>Temora</i> sp (25.29)
		Larva Pagurus sp (21.13)
		Unidentified Larva Annelida (14.22)
Station 2 vs Station 3	53.24	<i>Temora</i> sp (26.66)
		Larva Pagurus sp (21.64)
		Unidentified Larva Annelida (13.71)

The dominance of variation in zooplankton indicates that this class is more responsive to variations in environmental conditions than phytoplankton. *C. trichoceros* is the primary differentiator in phytoplankton, linked to its ability to adapt to changes in nutrient levels and salinity, whilst *Temora* sp. in zooplankton reflects a response to changes in habitat and food availability. These differences

illustrate the existence of distinct adaptation strategies among plankton classes in response to aquatic conditions [27].

3.4. Plankton Abundance

3.4.1. Phytoplankton Abundance

The phytoplankton abundance results obtained at Puntondo ranged from 476–520 ind/L. Based on the results of the t-test, no significant differences were found in phytoplankton abundance among the three stations ($P > 0.05$) (Figure 6).

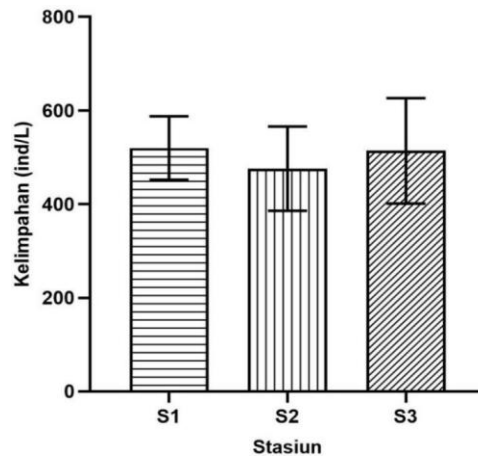


Figure 6. Histogram of differences in phytoplankton abundance between stations at Puntondo ($\bar{X} \pm SE$, $N = 9$)

The relatively consistent phytoplankton abundance across stations indicates that environmental conditions in the Puntondo waters tend to be uniform across the study area. Similarities in physico-chemical factors such as temperature, salinity, and nutrient availability mean that phytoplankton growth occurs under comparable ecological conditions at each location, so that no significant differences in abundance are formed between stations. This indicates that community dynamics are influenced more by the uniformity of hydrological conditions than by local microhabitat variations [28].

As primary producers, phytoplankton are highly responsive to changes in the balance of environmental factors that regulate the rate of photosynthesis and cell growth. When environmental gradients are not clearly established, the ecological response of phytoplankton becomes relatively uniform across all stations, so that abundance structures tend to be stable without significant spatial differentiation [29].

3.4.2. Zooplankton Abundance

Zooplankton abundance results obtained at Puntondo ranged from 6,090 to 6,630 ind/L. Based on the results of the t-test, no significant differences were found in zooplankton abundance between the three stations ($P > 0.05$) (Figure 7).

Zooplankton abundance in the waters of Puntondo indicates that the primary consumer community is able to be maintained stably across all observation stations. Zooplankton possess the ability to utilise various food sources within the water column, meaning the sustainability of their populations does not depend solely on a single energy source component. This ability allows the zooplankton community to continue to thrive without showing marked variations in abundance between locations [30].

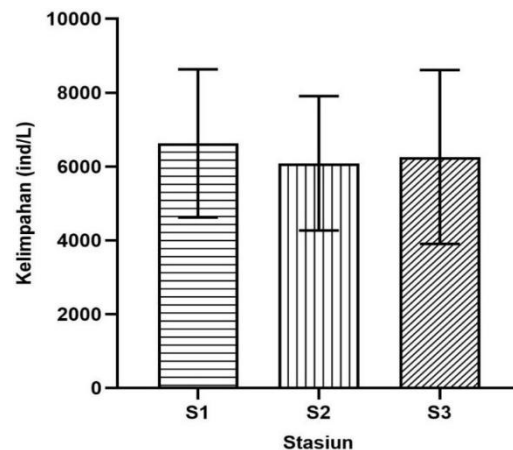


Figure 7. Histogram of zooplankton abundance differences between stations at Puntondo ($\bar{X} \pm SE$, N = 9)

Compared to phytoplankton, the high ratio of zooplankton to phytoplankton suggests that energy flow in the Puntondo waters likely does not occur solely through phytoplankton-based grazing pathways. The presence of organic matter and detritus has the potential to provide additional energy support for zooplankton, enabling this group to maintain relatively high abundance. These conditions highlight the importance of the detrital pathway in supporting zooplankton community dynamics within coastal ecosystems [31].

3.3. Plankton Biological Index

3.3.1. Diversity Index

The phytoplankton diversity index at Puntondo ranged from 1.8572 to 1.9147 ind/L. The results of the t-test indicate that there is no significant difference in phytoplankton diversity between the three stations ($P > 0.05$) (Figure 8a), whilst the zooplankton diversity index at Puntondo ranges from 1.0945 to 1.2283 ind/L. The results of the t-test indicate that there is no significant difference in zooplankton diversity between the three stations ($P > 0.05$) (Figure 8b). The results of the diversity index calculations are presented in the form of a histogram in Figure 8.

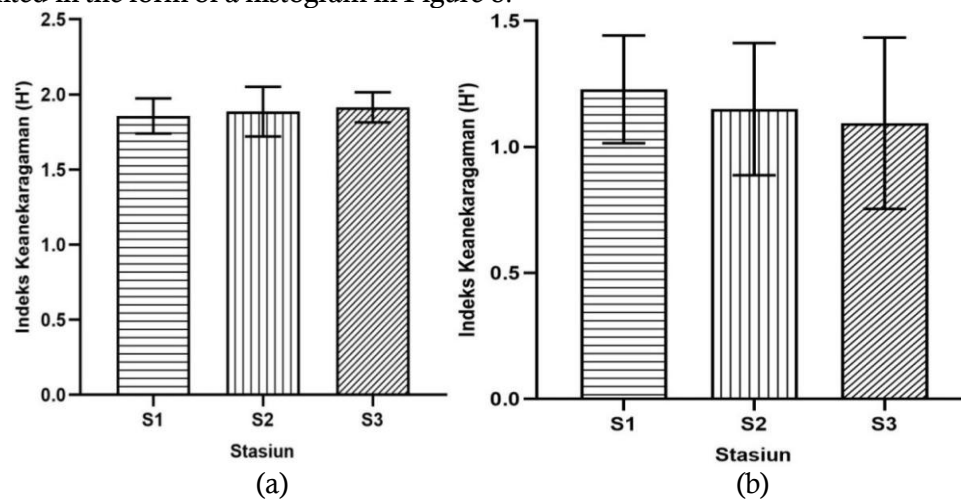


Figure 8. Histogram of the plankton diversity index between Stations in Puntondo (a) phytoplankton (b) zooplankton ($\bar{X} \pm SE$, N = 9)

Phytoplankton diversity in the waters of Puntondo falls into the moderate category, indicating a community that is not yet stable and remains under environmental pressure. Bacillariophyceae were recorded as the dominant class, consistent with distribution patterns in the tropical coastal waters of South Sulawesi [32], driven by their broad osmotic tolerance to fluctuations in temperature and salinity, thereby outcompeting taxa with narrower tolerance ranges [33]. Nitrate and phosphate limitations in Puntondo act as limiting factors suppressing phytoplankton diversity, in contrast to nutrient-rich tropical waters which generally exhibit higher diversity.

The lower diversity of zooplankton compared to phytoplankton reflects a common trophic pattern, whereby the consumer level is structurally less diverse than its primary producers. Fluctuations in salinity and limited dissolved oxygen levels favour Polychaeta as the most adaptive taxon, whilst less tolerant classes are gradually eliminated from the community [34]. This contrasts with a number of other tropical estuaries that record higher zooplankton diversity under similar environmental conditions, which is likely due to differences in habitat complexity and the availability of ecological refuge zones.

In general, the physico-chemical characteristics of the water body have been shown to play a crucial role in determining the composition and structure of the plankton community in the waters of Puntondo, as reflected by a temperature range of 28.4–29.8°C, salinity of 27.4–28.4 ppt, dissolved oxygen of 5.66–5.83 mg/L, and relatively low nitrate and phosphate levels. The limited availability of nutrients in this area poses a significant constraint on maximising the development of plankton community diversity [35–36], making comprehensive management and monitoring of the coastal ecosystem throughout the Puntondo waters a top priority.

3.3.2. Evenness Index

The phytoplankton evenness index at Puntondo ranged from 0.9350 to 0.9423 ind/L. The results of the t-test showed that there was no significant difference in phytoplankton evenness among the three stations ($P > 0.05$) (Figure 9a), whilst the zooplankton evenness index at Puntondo ranged from 0.9291 to 0.9462 ind/L. The results of the t-test showed that there was no significant difference in zooplankton evenness between the three stations ($P > 0.05$) (Figure 9b). The results of the evenness index calculations are presented in the form of histograms in Figure 9.

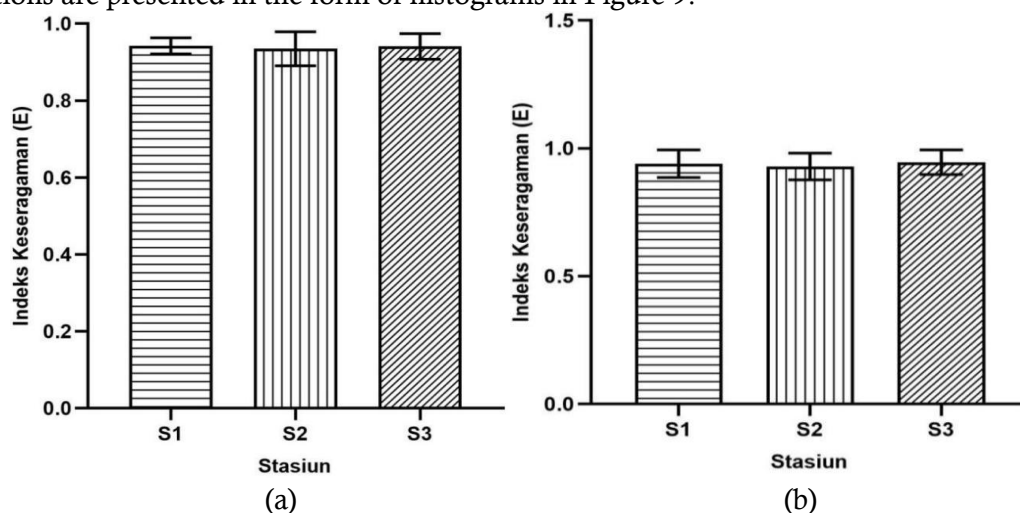


Figure 9. Histogram of the plankton evenness index between stations in Puntondo (a) phytoplankton (b) zooplankton ($\bar{X} \pm SE$, $N = 9$)

The phytoplankton evenness index in the waters of Puntondo is classified as high, reflecting a proportional distribution of abundance among species without excessive dominance [37]. The

homogeneous temperature conditions of 28.4–29.8°C and salinity of 27.4–28.4 ppt across the stations are thought to play a role in maintaining the balance of distribution among species, as there is no sufficiently strong environmental gradient to provide a competitive advantage to any particular species. In contrast to nutrient-rich waters, which tend to have lower uniformity due to the proliferation of species capable of utilising nutrients more efficiently, the low levels of nitrate and phosphate in Puntondo actually help to maintain a proportional distribution of species.

The zooplankton evenness index in the waters of Puntondo is also relatively high, indicating a balanced distribution of individuals across taxa without significant disparities in abundance. Stable environmental conditions and sufficient food availability have been shown to play a role in maintaining the uniformity of zooplankton community distribution in coastal waters [38]. This contrasts with nutrient-rich waters, where the disproportionate development of certain taxa creates distribution imbalances that reduce community uniformity [39].

Overall, the high evenness indices in both plankton communities reflect relatively stable ecological conditions in the waters of Puntondo [40]. Increased nutrient levels have the potential to trigger the disproportionate proliferation of certain species, which ultimately reduces the community's evenness index; consequently, the low levels of nitrate and phosphate in Puntondo actually act as a balancing factor for the distribution of abundance among species [41]. The high zooplankton evenness is further supported by the abundance of phytoplankton as a food source that is evenly distributed, making the entire Puntondo water area an ecosystem with a proportional distribution despite limited productivity.

3.3.3. Dominance Index

The phytoplankton dominance index at Puntondo ranged from 0.1649 to 0.1731 ind/L. The results of the t-test showed that there was no significant difference in phytoplankton dominance between the three stations ($P > 0.05$) (Figure 10a), whilst the zooplankton dominance index at Puntondo ranged from 0.032 to 0.3721 ind/L. The results of the t-test indicate that there is no significant difference in zooplankton dominance between the three stations ($P > 0.05$) (Figure 10b). The results of the dominance index calculations are presented in the form of a histogram in Figure 10.

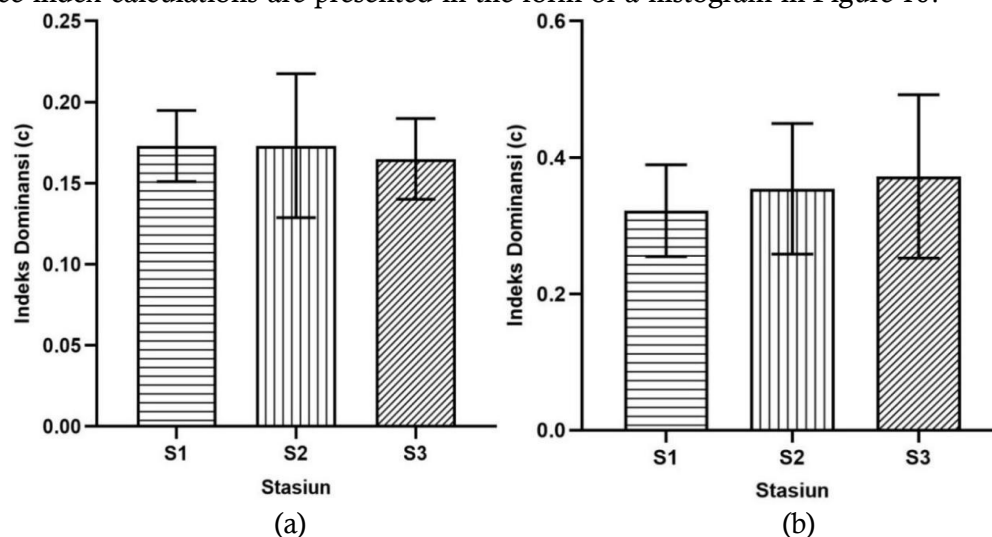


Figure 12. Histogram of the plankton dominance index between Stations in Puntondo (a) phytoplankton (b) zooplankton ($\bar{X} \pm SE$, $N = 9$)

The phytoplankton dominance values in the waters off Puntondo fall into the low category, indicating that no single species significantly dominates the community structure [42]. This condition reflects that each species has a proportional opportunity to utilise the available aquatic resources. The

uniformity of the water's physicochemical conditions is thought to be a factor inhibiting the development of dominance by a particular species [43]. This contrasts with coastal waters under high anthropogenic pressure, which tend to experience species blooms due to excessive nutrient enrichment, thereby drastically increasing dominance values.

The zooplankton dominance index in the waters of Puntondo is also in the low category, indicating an abundance of individuals distributed evenly across taxa without excessive dominance by any particular taxon. Zooplankton communities with low dominance tend to be more resilient and less vulnerable to sudden ecological disturbances [44]. This pattern differs from that in eutrophic waters, where environmental instability tends to weaken the resilience of zooplankton communities, allowing certain taxa that are more physiologically tolerant to dominate the community structure.

The structural stability of plankton communities in the waters off Puntondo is reflected in the low dominance values for both communities, indicating the absence of any taxon significantly dominating the aquatic ecosystem [45]. This condition is vulnerable to change as the intensity of anthropogenic activities in coastal areas increases, which has been shown to trigger a drastic rise in dominance in various coastal waters experiencing similar ecological disturbances [44].

3.3.4. Water Quality Parameters

The results of observations of water quality parameters at the Puntondo waters study site are shown in Table 4.

Table 4. Water quality parameters at the study site

Location	Station	Physical Parameters		Chemical Parameters		
		Temperature (°C)	Salinity (ppt)	DO (mg/L)	Nitrate (NO ₃) (mg/L)	Phosphate (PO ₄) (mg/L)
Puntondo Waters	1	28.4	27.4	5.66	0.101	0.039
	2	28.6	28.4	5.70	0.114	0.043
	3	29.8	27.9	5.83	0.114	0.042

The measurements of water quality parameters in Table 4 show that the water conditions at the time of sampling in the Puntondo waters were as follows: temperature ranging from 28.4 to 29.8°C, salinity ranging from 27.4 to 28.4 ppt, dissolved oxygen (DO) ranging from 5.66 to 5.83 mg/L, nitrate (NO₃) ranging from 0.101 to 0.114 mg/L and orthophosphate (PO₄) levels ranging from 0.039 to 0.043 mg/L.

Temperatures of 28.4–29.8°C and salinity of 27.4–28.4 ppt across stations reflect the minimal horizontal environmental gradients in the waters off Puntondo, consistent with the uniform phytoplankton abundance ranging from 476 to 520 ind/L. These two parameters have been shown to act as the primary environmental filters determining the distribution of plankton communities in coastal waters [46], in contrast to highly heterogeneous waters where fluctuations in hydrological conditions have been shown to significantly reshape the composition and spatial distribution of phytoplankton communities [47].

Dissolved oxygen (DO) levels of 5.66–5.83 mg/L, which lie at the lower limit of the optimal range, are suspected to contribute to limited primary productivity, reflected in the low phytoplankton abundance of 476–520 ind/L compared to zooplankton abundance of 6090–6630 ind/L. This imbalance in the ratio indicates that zooplankton also utilise the detrital pathway from aquaculture residues as an alternative energy source [48], unlike waters with higher DO levels where primary productivity is sufficient to support zooplankton abundance without reliance on the detrital pathway.

Low nitrate and phosphate concentrations place the waters of Puntondo in the oligotrophic category, acting as a natural mechanism that maintains the structural balance of the plankton community [40]. Nevertheless, even a high increase in nutrients does not always stimulate a proportional increase in phytoplankton biomass [49], indicating that plankton community dynamics are determined by the complex interactions of all the water's physicochemical parameters. This oligotrophic status must be maintained through the controlled management of aquaculture activities to ensure the coastal ecosystem's carrying capacity remains intact.

4. Conclusion

The plankton community in the waters of Puntondo is dominated by Bacillariophyceae, comprising 5 species in the phytoplankton, and Polychaeta, comprising 2 species in the zooplankton, with phytoplankton abundance of 476–520 ind/L and zooplankton abundance of 6090–6630 ind/L, showing no significant differences between stations. The uniformity of physicochemical parameters, including temperature of 28.4–29.8°C, salinity of 27.4–28.4 ppt, dissolved oxygen 5.66–5.83 mg/L, and low nitrate and phosphate levels, proved to be the primary determinants of the homogeneity of the plankton community structure across the entire area, as confirmed by Global R ANOSIM values approaching zero.

Moderate diversity, high uniformity, and low dominance reflect a plankton community in a state of proportional ecological balance without significant structural distortion. However, the oligotrophic status of the waters, reflected in the limited abundance of phytoplankton, indicates that the ecosystem's carrying capacity is not yet optimal; consequently, an increase in the intensity of aquaculture activities and boat traffic has the potential to degrade the currently maintained balance of the plankton community, making continuous ecosystem monitoring a top priority for the management of the Puntondo water area.

Further research is recommended during different seasons, such as the wet and dry seasons. This aims to investigate plankton communities during different periods. Seasonal variations can influence aquatic environmental conditions. Consequently, changes in plankton communities and abundance can be better understood.

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