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RESEARCH ARTICLE

The Relationship Between Organic Matter and Phytoplankton Structure in The Aquaculture Zone of Karimunjawa: Non-Metric Multi-Dimensional Scalling (NMDS) and *k*-Dominance Curves Analysis Approach

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Abstract. The marine ecosystem surrounding Menjangan Besar Island in Karimunjawa is a vital site for aquaculture, significantly contributing to the local economy. However, this practice induces organic enrichment that may disrupt ecological balance. This study investigates the relationship between organic matter and phytoplankton community structure in the aquaculture zone, employing non-metric multidimensional scaling (NMDS) and k-dominance curves for analysis. Fieldwork conducted in October 2021 focused on three sites: monoculture cages, Integrated Multi-Trophic Aquaculture (IMTA) polyculture cages, and a reference site. A purposive random sampling method yielded 16 phytoplankton species. NMDS analysis (stress value: 0.03) revealed distinct clustering among sampling stations, indicating variations in phytoplankton community structure. The graphical approach, employing NMDS and k-dominance curves, effectively identifies stations with varying levels of diversity and evenness. The monoculture site (L1S1) exhibited the highest dominance and the lowest diversity. In contrast, the reference site (L3S1) and the polyculture site (L2S2) demonstrated the highest diversity, corresponding to the lowest dominance among all sampling stations. These patterns suggest that polyculture systems exhibit greater ecological stability compared to monoculture systems. Furthermore, the NMDS analysis revealed a clear clustering pattern among sampling stations, reflecting distinct differences in phytoplankton community structure across monoculture, polyculture, and reference locations. These findings highlight the complex interactions between aquaculture practices and phytoplankton dynamics, emphasizing the need for sustainable management strategies in marine ecosystems.

Keywords: Phytoplankton Community Structure, Organic Enrichment, Abundance, Karimunjawa Islands

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Introduction

Indonesia is a maritime nation whose society heavily depends on its marine ecosystems. The country's marine resources have been integral to local communities for a variety of activities, including sea transportation, fishing, biodiversity exploration, and the establishment of aquaculture industries [1]. Supporting the blue economy paradigm is a critical strategy for advancing Indonesia's economic development, particularly through the enhancement of aquaculture production [2]. With a coastline extending over 99,093 km and a sea area covering 6,315,222 km², Indonesia ranks among the countries with the greatest potential in the marine and fisheries sectors. It is also the second-largest producer and the third-largest consumer of seafood globally. Domestic consumption constitutes more than 80% of the country's capture fisheries production and 95% of its aquaculture output, with the majority of seafood consumed locally still came from capture fisheries. However, many fish populations have been overexploited, leaving limited prospects for future growth. Karimunjawa Islands, located to the north of Java Island encompassing 111,625.0 hectares, is a region where mariculture and fisheries play a pivotal role in supporting the livelihoods of local communities [3, 4]. Menjangan Besar Island continues traditional aquaculture activities, which could potentially harms the water quality in the surrounding areas due to intensive farming practices [2].

Nitrate is a byproduct of the nitrification process, which involves the oxidation of nitrogen compounds, first from ammonia to nitrite and subsequently to nitrate. When nutrient concentrations and organic matter levels exceed ecological thresholds, they can trigger eutrophication, a process that promotes algal blooms and disrupts the balance of aquatic ecosystems [5]. Organic matter in aquatic environments typically exists in dissolved forms, rather than as suspended or colloidal particles. The amount of organic matter in water body serves as water quality indicator. When organic matter concentrations surpass normal levels, its accumulation can hinder the natural assimilation processes, potentially leading to the development of suboxic or anoxic conditions within the water column [6].

Phytoplankton is closely correlated with organic matter in aquatic environments, with its primary function on converting inorganic compounds into organic matter through photosynthesis [7, 8]. The quality of the water column significantly influences phytoplankton abundance and diversity, making it an effective bioindicator for assessing environmental conditions [9]. Phytoplankton community structure is highly sensitive to changes in environmental parameters such as temperature, nutrient availability, and light intensity. Variations in these conditions can lead to specific and different biochemical composition of the plankton community [10]. Significant disturbances in water quality can disrupt on the surrounding ecosystem [11] and may hinder the growth and development of fish [12].

This study evaluated environmental parameters to assess the quality of water conditions of the aquaculture cages area. The research aimed to ensure the sustainability of resources and assess the compatibility of hydro-oceanographic conditions for aquaculture operations.

Materials and Methods

This study used a qualitative descriptive analysis method, consisted of primary and secondary data. Bathymetry, current speed, significant wave height, temperature, salinity, wind, and tide data were collected as primary data, while secondary data included Indonesian Rupa Bumi (RBI) maps of Karimunjawa Islands, bathymetry from Hydro-Oceanographic Center, Indonesian Navy Maps, current speed and wave height from modelling, wind from CDS Copernicus, and temperature-salinity from Marine Copernicus. Sampling location shown in Figure 1.

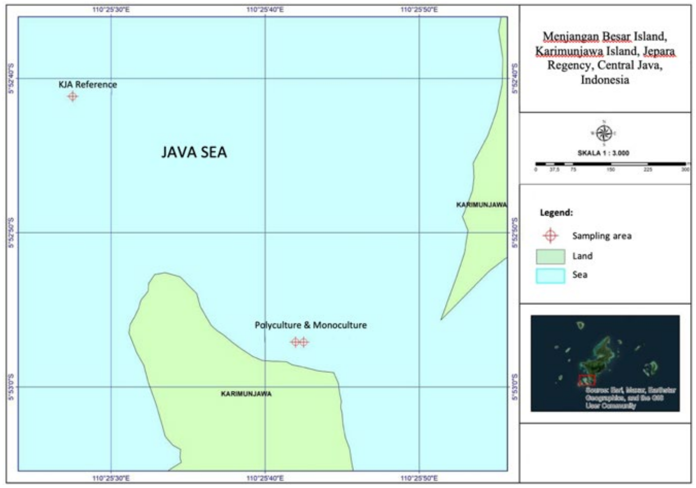

Figure 1. Map of sampling stations at Menjangan Besar Island, Jepara Region, collected from three sites: monoculture cages, polyculture cages, and reference site

Data Sampling & Preparation

The sampling was conducted at Menjangan Besar Island, Karimunjawa Island, Jepara, Central Java, Indonesia. This research used purposive random sampling method, Monoculture and IMTA polyculture are active aquaculture site, meanwhile reference site is an open sea area without anthropogenic activities nearby. Sampling period for sedimentation and water sample collection was in 2-3th October 2021, which were analyzed further at Ce-MEBSA (Center for Marine Ecology and Biomonitoring for Sustainable Aquaculture) Integrated Laboratory Unit, Diponegoro University. Phytoplankton samples were collected by filtering water with a plankton net of size 25 and sifting it vertically. The water sample was collected 10 cm below the water surface. At each site, 30 L of water were collected with 3 replicates. The water parameter includes temperature, pH, salinity, dissolved oxygen (DO), turbidity, total dissolved solid (TDS), ORPmV, conductivity, pHmV, SSG, nitrate, phosphate, and depth.

Data Analysis

Both biotic and abiotic data were analyzed using PRIMER v.6 software. The structure of the phytoplankton community was examined through Non-Metric Multidimensional Scaling (NMDS) ordination and cumulative k-dominance curves. The NMDS analysis, employing the Bray-Curtis similarity matrix, visualized species composition based on spatial location, with the distance between points in the NMDS plot representing the degree of species variation or grouping across locations [13]. The stress value in the NMDS plot was used to assess the accuracy of the ordination in representing the original community structure. A stress value of < 0.05 indicates a highly accurate plot with minimal error, a stress value of < 0.15 suggests a reasonably accurate plot with low interpretation error, a stress value of < 0.2 indicates a poor plot, and a stress value of > 0.2 suggests a high likelihood of misinterpretation [14]. Cumulative k-dominance curves were used to illustrate the cumulative dominance of phytoplankton at each site. Additionally, the relationship between phytoplankton structure and abiotic factors was further analyzed through Biota-Environment Stepwise Analysis (BIOENV). This analysis determined the correlation between environmental quality and phytoplankton abundance, identifying the specific abiotic factors most strongly influencing the plankton distribution [15].

Results and Discussion

This study found phytoplankton with a total abundance of 697 individuals.m^{-2}, consist of 20 genus from 16 families, i.e. Bacillariophyceae class consist of 14 genus from 11 families, Dinophyceae class consist of 3 genus from 3 families, and Cyanophyceae class consist of 3 genus from 2 families. The composition of phytoplankton species is presented in Table 1.

Table 1. Phytoplankton composition in Monoculture Site, IMTA polyculture Site, and Reference Site

Class	Family	Genus/Species	Site		
			Monoculture	IMTA Polyculture	Reference
Bacillariophyceae	Stephanodiceae	*Cylotella sp.*	0	34	10
	Licmophoraceae	*Licmophora sp.*	20	4	174
	Naviculaceae	*Navicula sp.*	17	0	17
		Amphiprora sp.	0	134	237
	Rhizosoleniaceae	*Guinardia sp.*	18	14	8
		Rhizosolenia sp.	464	0	67
		Proboscia sp.	0	20	10
	Melosiraceae	*Melosira sp.*	8	174	0
	Fragilariaceae	*Synedra sp.*	0	18	10
	Hamiaulaceae	*Eucampia sp.*	0	0	7
	Bacillariaceae	*Pseudo-nitzschia*	58	0	0
	Leptocylindraceae	*Leptocylindrus sp.*	4	0	0
	Skeletonemaceae	*Skeletonema sp.*	7	0	0
	Chetoceroaceae	*Chaetoceros sp.*	0	0	4
Dinophyceae	Dinophysiaceae	*Dinophysis sp.*	7	44	30
	Brachinidiniaceae	*Karenia sp.*	37	4	161
	Ceratiaceae	*Ceratium longipes*	8	0	0
Cyanophyceae	Aphanizomenonaceae	*Cylindrospermopsis sp.*	0	118	114
		Aphanizomenon flos-aquae	0	11	0
	Oscillatoriaceae	*Oscillatoria sp.*	14	4	0
		Total number of individuals (N)	662	579	849
		Number of species (ni)	12	12	12
		Diversity index (H')	1.04	1.65	1.33
		Abundance index (N)	736	644	944
		Relative abundance index (KR %)	10.56	9.23	13.54
		Evenness index (e)	0.42	0.64	0.62
		Dominance index (D)	0.53	0.26	0.34

From the three sampling sites, total individual phytoplankton reached 2,090 ind/L from the classes Bacillariophyceae, Dinophyceae, and Cyanophyceae, with each individual total, namely: 1,538 ind/L, 291 ind/L, 251 ind/L. The Bacillariophyceae class dominated the total phytoplankton in all three sites (Figure 2), the abundance of Bacillariphyceae in Monoculture Site reached 90% of the total species, 69% in IMTA Polyculture locations, and 64% in reference locations.

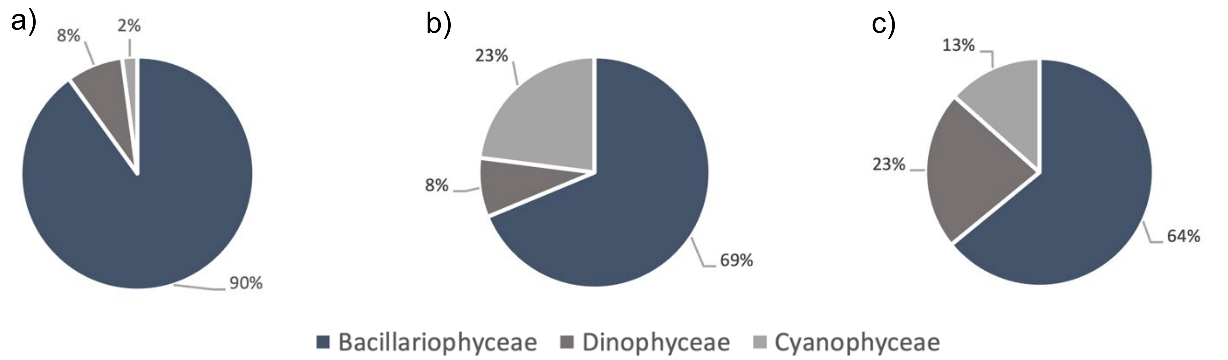

Figure 2. Classes of Phytoplankton diagram at three sites: (a) Monoculture Site, (b) Polyculture Site, and (c) Reference Site.

Class Bacillariophyceae is commonly known as diatoms. Malviya *et al.*, (2016) stated diatoms are one of the most crucial climate modulators for their contribution to carbon dioxide absorption and the biological pump of carbon making them the most abundant and diverse siliceous marine microorganisms [17], nutrient-rich coastal ecosystems [18] and known to be higher abundance in the middle of the ocean in the subtropical zone, this causes diatoms has been estimated to account for 40% of marine primary production [19]. Diatoms itself also adaptable to different environmental conditions, thus their abundance is higher compared to other phytoplankton classes [20].

Phytoplankton with most abundance in Monoculture Site, IMTA Polyculture Site, and Reference Site are from Bacillariophyceae class, namely *Rhizosolenia* sp, *Melosira* sp, and *Amphiprora* sp. Phytoplankton species with the highest abundance in three sites is *Rhizosolenia* sp. *Rhizosolenia* sp is diatom species which highly related to temperature and nitrogen fixation. *Rhizosolenia* sp were found in multiple cases of algae-bloom, such as in monoculture sites. The residue of fish pellets caused organic enrichment in water body, causing rapid growth of algae leading to algae-blooming [3, 21, 22]. According to Amin *et al.*, (2022), *Rhizosolenia* sp is one of the most abundant phytoplankton in floating cages, consisting of 33.04% in 0-0.3m depth and 7.07% in 2.5m depth of the collected phytoplankton community. Monoculture site and IMTA Polyculture site have a similar amount of abundance, whereas the abundance in the reference site is higher. The characteristics of the reference site in this research are open sea, which far from anthropogenic activities, thus has a preferable environmental condition for phytoplankton to grow. Lamy *et al.*, (2020) stated that species richness will promote a stable community and eventually a stable ecosystem, later increase species diversity and abundance.

Multivariate assessment: NMDS and k-Dominance Curves

Phytoplankton abundance in each location was analyzed using PRIMER v.6 using Numeric Multi-Dimensional Scaling (NMDS) tool. According to the results of the graphical ordination as shown in Figure 3, a similarity index of 40% was obtained with a stress value of 0.03. The similarity index itself is a biological index that represents the degree of similarity of one community structure to another. The stress value of 0.03 indicates that the plot is a perfect plot. According to Trombetta *et al.*, (2003), <0.05 is a perfect plot, with the possibility of no error in interpreting it. The locations of each sampling site form three groups, marked with green circle. The three groups content is following: Group I) L1S1, L1S2; Group II) L2S1, L2S2, L2S3, L3S1; and Group III) L3S2, L3S3, L1S3. Based on the clustering, Group I consist of two locations from monoculture site (L1S1 and L1S2) has similar community structure. Group II consist of four locations, three locations from IMTA Polyculture site (L2S1, L2S2, and L2S3) and one location from reference site (L3S1), indicates similarity of community structure in IMTA Polyculture site and L3S1 from reference site. Group III consist of 2 locations from reference site (L3S2 and L3S3) and one location from monoculture site (L1S3).

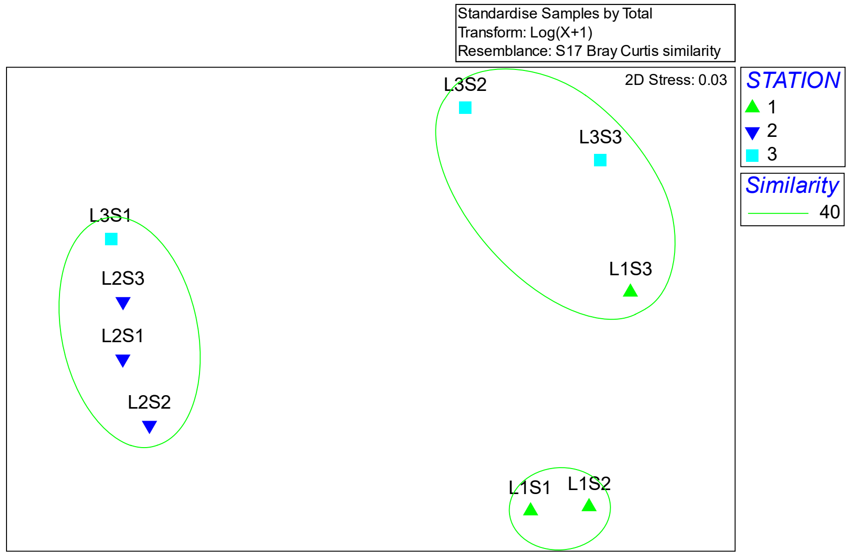

Figure 3. Graph of ordination based on abundance of phytoplankton taken from the three main locations

The k-dominance curve depicts the cumulative dominance of the species rank. Based on the k-dominance curve, will project plankton abundance in the same graph. Khalaf *et al*., (2021) stated that the highest graph shows the highest dominance in the community. The pink line shows L2S2 is at the bottom, meaning that the dominance is the lowest and the diversity is the highest. Meanwhile, the highest dominance is in L1S1 which is indicated by a green line which also has low diversity, as shown in Figure 4. Based on these results it indicates that L2S2 has the highest diversity, and thus the lowest dominance among other sampling stations. Nuraina *et al.* (2018) stated that the value of the species dominance index indicates the level or dominant species in the community. Odum (1993) stated that a dominance index value greater than zero but less than 0.5 indicates that no species dominates, whereas if the value is more than 0.5 but less than 1 indicates a dominant species. Dominance index at station 1 monoculture sites showed 0.74, which means that there was dominance at that station, while no dominance was found at stations 2 and 3 in monoculture site. This can be seen from the number of *Rhizosolenia* sp. from the class Bacillariophyceae whose numbers are quite significant compared to other genera or species. This dominance is most likely due to *Rhizosolenia* sp. have high adaptability. In accordance with Ariana *et al.* (2014) which stated that fluctuations in Bacillariophyceae are caused by nutrient inputs originating from anthropogenic activities. The response of Bacillariophyceae to the presence of this nutrient adapts quickly. While the other two classes may have a slow response to environmental changes and reproductive abilities are not as fast as Bacillariophyceae.

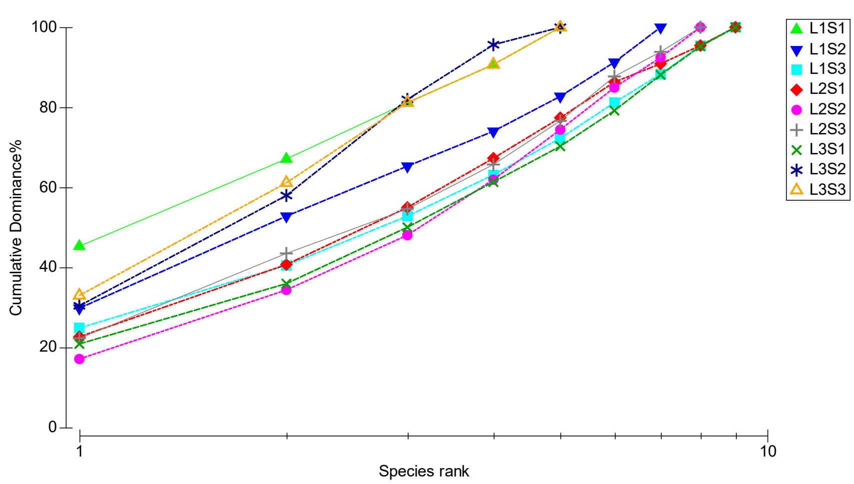

Figure 4. Graph of cumulative from 3 sampling locations

Physical and Chemical Water Characteristics

Based on the results of nitrate and phosphate amount in floating net cages and the open sea, it can be seen in the Figure 5 that the content of phosphate and nitrate in the cages exceeds the water quality standards for marine biota cultivation areas based on the Decree of the Minister of State for the Environment No. 51 of 2004, concerning Sea Water Quality Standards. According to Andriani *et al.*, (2018), nitrate and phosphate come from the decomposition, weathering and decomposition of aquatic biota. Based on Wetzel (1983), which classifies into 3 types of water fertility, namely nitrate content of 0-1 mg/L categorized as oligotrophic, 1-5 mg/L categorized as mesotrophic and 5-50 mg/L categorized as eutrophic. The waters in floating net cages with the IMTA and open sea systems are classified as oligotrophic because they are between 0-1, while the location of monoculture cages is between 1-5 which indicates mesotrophic waters. Oligotrophic itself is waters with low nutrients and productivity, while mesotrophic is waters with moderate nutrients and productivity. Based on Ortiz *et al.*, (2022) in their publication, oligotrophic water has low nutrients and low chlorophyll (LNLC) due to low primary production (PP) and low ChlA and ChlB from phytoplanktons. It indicates that oligotrophic water body has low abundance of phytoplanktons. According to Kämpf *et al.*, (2023), mesotrophic water in Lincoln Shelf has sufficient nutrition persistently, thus able maintaining high diversity of picophytoplankton in the area.

Phosphate content is higher than nitrate because phosphate generally comes from human activities around these waters, which in this case are aquaculture activities with floating net cages. This activity produces waste such as leftover feed and also metabolic waste from cultured fish. In addition, according to Patricia *et al.* (2019) stated that nitrate is a natural form of nitrogen and its levels can decrease due to the activity of microorganisms in the waters. Microorganisms oxidize ammonium to nitrite which is then oxidized again by bacteria to nitrate. Nitrates themselves dissolve easily in water and are more stable than phosphates. The low concentration of nitrate is due to denitrification events, nitrate through nitrite produces free nitrogen and then returns to ammonia.

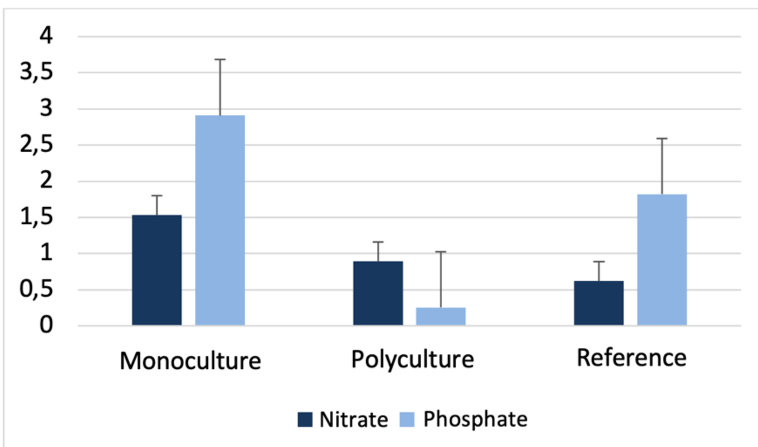

Figure 5. Nitrate and Phosphate amount in three sampling locations

Hasibuan *et al.* (2021) stated that organic content reflects water quality, organic content whose amount exceeds from the water quality standards is considered as pollution. Furthermore, he stated that the richness of organic matter content in waters is an indicator of water quality because naturally the richness of organic matter comes from weathering and decomposition processes of the biota that inhabit these waters. Organic materials become a supporting factor for the life of phytoplankton. Therefore, the community structure of phytoplankton with organic enrichment in a water has a positive relationship. The content of nitrate and phosphate in the open seas exceeds the water quality standard, but in terms of the nitrate content, the waters in the open seas are categorized as oligotrophic waters. Oligotrophic waters have low nutrient content so that the abundance of phytoplankton in these waters is low. Anshari and Irawan (2019) stated that the classification of waters with trophic status serves to monitor water quality which further can help on assessing nutrient cycles and food webs. In addition, low nutrient conditions lead to low biomass. However, high nutrient content in water body can trigger algae bloom. Tobing *et al.* (2020), stated that phytoplankton has a very strong linear relationship with nitrate and phosphate content in the waters.

Based on the abundance of phytoplankton and nitrate content at the three locations, it can be concluded that the three locations have oligotrophic water status. However, in a monoculture site, the phosphate content is quite high due to cultivation activities using the traditional monoculture system, which is less friendly to the environment and causes a lot of organic matter to enter the waters. The results of measurements of the physical condition of the waters are shown in Table 2.

Table 2. The Result of Water Parameter Measurement Keputusan MENLH No. 51 tahun 2004 Baku Mutu Kualitas Air Laut Bagi Biota Laut

Location	Monoculture			Polyculture			Reference Area			Quality Standard (unit)
	L1S1	L1S2	L1S3	L2S1	L2S2	L2S3	L3S1	L3S2	L3S3	
Temperature (ºC)	25.7	24.81	25.17	25.8	25.8	25.44	24.58	24.55	24.53	25-30
pH	5.8	5.65	8.4	7.41	7.41	8.77	5.75	6.44	9.01	7-8.5
Turbidity (NTU)	0	0.37	0.47	0.48	0.48	0	0	0	0	<5
DO (mg/L)	1.68	14.35	13.4	9.74	9.74	8.9	2.16	1	1.32	>5
Salinity (ppt)	14.87	3.25	14.27	5.05	5.05	12.54	9.01	11.15	12.78	30-33
Phosphate (%)	2.909	2.809	3.009	0.357	0.157	0.257	1.821	1.921	1.721	0.008
Nitrate (%)	1.429	1.529	1.629	0.991	0.891	0.791	0.623	0.723	0.523	0.015

In all sampling sites (monoculture site, IMTA Polyculture site, and reference site), the water temperature ranged between 24.5ºC to 25.8ºC. Indrayana *et al.* (2014) stated that the suitable temperature for aquatic biota is around 28-32ºC. Temperature affects many aspects of aquatic life such as the rate of photosynthesis in phytoplankton. According to Dewanti *et al.* (2018), the suitable temperature for phytoplankton growth ranged between 25-30ºC. This shows that the temperature at the three locations is the optimal temperature for the growth of phytoplankton.

Based on the Regulation of the Indonesia National Minister of Environment No. 1 of 2010 concerning Procedures for Control of Water Pollution, the ideal pH range of waters is at 6-9 so it can be concluded that the pH at the three locations is categorized as ideal but at location 3 station 3 the threshold is 9.01.

At Monoculture site Station 1 (L1S1), the DO content was 1.68mg/L, Reference Site Station 2 (L3S2) was 1mg/L, and Reference Site Station 3 (L3S3) was 1.32mg/L which showed dissolved oxygen which was not ideal because it was less than 2mg/L. According to Putri *et al.*(2012) good range of dissolved oxygen in marine environment is not less than 2 mg/L. The low dissolved oxygen content found in Monoculture Site Station 1 (L1S1) along with the dominance of *Rhizosolenia* sp. and low diversity of phytoplankton at the station. In addition, the phosphate content in Monoculture cages was higher than in the IMTA Polyculture Site and the Reference areas. This indicates ecosystem in Monoculture Site was unstable. Zhang *et al.* (2022) stated that phosphorous content in water increased with feeding process in aquaculture practice, thus increasing the amount of nutrient concentration surrounding the aquaculture water body.

According to Rahmah *et al.* (2022), phytoplankton have a higher growth rate in water with low salinity. According to PP RI No. 22 of 2021, the ideal salinity for marine biota is 33-34 ppt. The salinity in all sampling sites ranged between 3. 25 – 14.87 ppt, which below the water quality standard. Sari *et al.* (2016), stated that salinity is an important indicator that determines circulation and mixing in waters. The salinity in coastal areas determined by dynamic input between freshwater and seawater.

Turbidity influences the penetration of light below the sea surface. This then affects the phytoplankton structure, due to their need of light for photosynthesis. Turbidity at the three locations ranged between 0 – 0.48 NTU, which were ideal for phytoplankton. The ideal turbidity for phytoplankton photosynthesis is below 5 NTU. According to Hariyati and Putro (2018), turbidity affects the penetration of light entering the waters, then affects the photosynthetic activity of phytoplankton. The level of turbidity is composed of units of organic or inorganic content.

Abiotic and Biotic Correlation

Analysis with BIOENV (Biota-Environment Stepwise Analysis) to determine the relationship between the abundance of phytoplankton and the physicochemical parameters of the waters. Based on the BIOENV analysis results, the most influential parameters towards the phytoplankton structure were pH, nitrate

(NO_3^-), and phosphate **(PO_4^{3-})**, with the highest correlation value (r) as much as 0.409, as shown in Table 3. The physiological function and competitiveness of various phytoplankton taxa are influenced by the pH level, which is crucial in regulating nutrient bioavailability and enzymatic processes [44]. Diatoms and other microalgae typically thrive in somewhat alkaline environments, whereas more acidic settings may inhibit overall diversity. Variations in nitrate concentrations frequently result in changes in species composition, favouring chlorophytes and specific cyanobacteria that can rapidly absorb and grow in eutrophic conditions. This is because nitrate, a significant source of inorganic nitrogen, directly supports protein synthesis and cellular proliferation [45]. In primary production, phosphate, a crucial macronutrient, is often the limiting factor. Its availability governs not only phytoplankton biomass accumulation but also the dominance of opportunistic species such as cyanobacteria during nutrient enrichment events [46]. The differential responses of phytoplankton taxa to these three parameters underscore their critical roles as key ecological drivers in shaping community structure and succession. Aligned with Pratiwi *et al.* (2016), which stated that the abundance of phytoplankton has a positive relationship with organic content. In this case, higher content of nitrate and phosphate correlates with higher abundance of phytoplankton.

Table 3. Results of BIOENV Analysis determine the relationship between the abundance of phytoplankton and the physicochemical parameters

Number of Variant	Correlation Value	Variable
3	0.409	2, 11, 12
3	0.408	2, 12, 13
4	0.408	1, 2, 11, 12
4	0.389	2, 11-13
3	0.387	1, 2, 12
5	0.384	1, 2, 11-13
2	0.383	2, 12
2	0.371	12, 13
3	0.371	1, 12, 13

Notes: 1) temperature, 2) pH, 3) ORPmV, 4) Conductivity, 5) Turbidity, 6) DO, 7) TDS, 8) Salinity, 9) pHmV, 10) SSG, 11) Nitrate, 12) Phosphate, 13) Depth

The pH level is used to express the level of acidity or alkalinity of a solution. Dewanti *et al* (2018), stated that the pH of water is influenced by the surrounding conditions, which can be affected by the activities of phytoplankton. Marsela *et al.* (2021) stated that nitrate and phosphate show positive regression to the phytoplankton abundance in the Upstream Citarum River, with a correlation coefficient (r) as much as 0.662. Phytoplankton carry out respiration, and the higher the photosynthetic process, the higher the pH in the water. According to Arofah *et al.* (2021), phytoplankton need nitrogen and phosphate in order to photosynthesize, which later produce fats and proteins.

Conclusions

In conclusion, we recorded 697 individuals.m^{-2} consisting of 20 genus from 16 families of phytoplankton. The graphical approach, employing NMDS and k-dominance curves, effectively identifies stations with varying levels of diversity and evenness. The monoculture site (L1S1) exhibited the highest dominance and the lowest diversity, whereas the reference site (L3S1) and the polyculture site (L2S2) demonstrated the highest diversity, corresponding to the lowest dominance among all sampling stations. These patterns suggest that polyculture systems exhibit greater ecological stability compared to monoculture systems. Furthermore, the NMDS analysis revealed a clear clustering pattern among sampling stations, reflecting distinct differences in phytoplankton community structure across monoculture, polyculture, and reference locations. The organic content in the aquaculture area affects the phytoplankton community structure. The higher the content of nitrate and phosphate, the higher the abundance of phytoplankton in these waters. In addition to the content of nitrate phosphate, pH level also correlates with the structure of the phytoplankton community. The pH in a water is influenced by the surrounding conditions, and its fluctuations are influenced by the activities of phytoplankton. The higher the respiration of phytoplankton and the photosynthesis process, the higher the pH in these waters. Based on the organic content and abundance of phytoplankton, the aquaculture cages in Karimunjawa has the status of oligotrophic waters with low nutrients and low water productivity.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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