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Nitrate, Phosphate, Silica and Phytoplankton Abundance in the Coastal Waters of Maitara Island, North Maluku

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ABSTRACT

Nitrate, phosphate, and silica are nutrients needed for the growth of phytoplankton populations. The primary objective of the present study was to establish the relationship between the nutrient composition (nitrate, phosphate, and silica) and phytoplankton abundance. Sampling was was conducted at three observation stations located in the tidal zone of Maitara Island coast, North Maluku. Collection of plankton samples in coastal waters using a 25 μm plankton net. Phytoplankton cells were identified and counted in the laboratory using a microscope with 100x magnification. Phytoplankton observations were carried out using the field of view method. Testing the concentration of nitrate, phosphate, and silica was using spectrophotometer techniques. The research data were analyzed using a correlation test. The research findings indicated that the coastal waters surrounding Maitara Island were classified as oligotrophic waters, based on the nitrate and phosphate, and silica content. Oligotrophic waters have very low nutrient content such as nitrogen and phosphorus, causing low primary productivity. Simultaneously, nitrate, phosphate, and silica concentrations had a very strong correlation (R=0.823) with phytoplankton abundance. Partially, the correlation between nitrate concentration and phytoplankton abundance was classified as very strong (R=0.729). However, the correlation between phosphate concentration and phytoplankton abundance was moderately significant (R=0.577), and the correlation between silica concentration and phytoplankton abundance was weak (R=0.386). High concentrations of nitrate and phosphate in coastal waters lead to increased abundance of phytoplankton. However, high silica concentrations in waters can only increase the abundance of certain phytoplankton groups, for example diatoms and radiolarians.

Keywords: Phytoplankton abundance, nitrate, phosphate, silica, Maitara Island

ABSTRAK

Nitrat, fosfat, dan silika merupakan unsur hara yang dibutuhkan untuk pertumbuhan populasi fitoplankton. Tujuan penelitian ini adalah untuk mengetahui hubungan antara komposisi hara (nitrat, fosfat, dan silika) dengan kelimpahan fitoplankton. Pengambilan sampel dilakukan di tiga stasiun pengamatan yang terletak di zona pasang surut pesisir Pulau Maitara, Maluku Utara. Pengambilan sampel dilakukan setiap dua minggu, dengan empat periode pengambilan sampel. Pengumpulan sampel plankton menggunakan jaring plankton 25 μm. Sel fitoplankton diidentifikasi dan dihitung di laboratorium menggunakan mikroskop listrik dengan perbesaran 100x. Pengamatan fitoplankton dilakukan dengan metode lapang pandang. Selanjutnya dilakukan pengujian sampel untuk kandungan nitrat, fosfat, dan silika dengan teknik spektrofotometer. Data hasil pengamatan dianalisis dengan menggunakan uji korelasi. Hasil penelitian menunjukkan bahwa perairan pesisir sekitar pulau Maitara tergolong perairan oligotrofik, berdasarkan kandungan nitrat, fosfat, dan silika. Perairan oligotrofik memiliki kandungan hara seperti nitrogen dan fosfor yang sangat rendah, sehingga

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menyebabkan produktivitas primer rendah. Secara simultan, konsentrasi nitrat, fosfat, dan silika memiliki korelasi yang sangat kuat (R=0,823) dengan kelimpahan fitoplankton. Secara parsial, korelasi antara konsentrasi nitrat dengan kelimpahan fitoplankton tergolong sangat kuat (R=0,729). Namun, korelasi antara konsentrasi fosfat dengan kelimpahan fitoplankton tergolong cukup signifikan (R=0,577), dan korelasi antara konsentrasi silika dengan kelimpahan fitoplankton tergolong lemah (R=0,386). Konsentrasi nitrat dan fosfat yang tinggi di perairan pesisir menyebabkan meningkatnya kelimpahan fitoplankton. Namun, konsentrasi silika yang tinggi di perairan hanya dapat meningkatkan kelimpahan kelompok fitoplankton tertentu misalnya kelompok diatom dan radiolaria.

Kata kunci: Kelimpahan fitoplankton, nitrat, fosfat, silika, Pulau Maitara

1. Introduction

Phytoplankton, as primary producers in aquatic environments, provide a crucial function by serving as a vital food supply for other marine organisms (Rahmah et al., 2022). Phytoplankton are also one of the parameters that determines the fertility level of a body of water (Ayu et al., 2019). Phytoplankton abundance and aquatic productivity are positively correlated, meaning that areas with large amounts of phytoplankton tend to have high levels of aquatic productivity (Yuliana et al., 2012). Phytoplankton, sometimes referred to as marine algae, are the main photosynthetic organisms in marine ecosystems, which inhabit or float in water. These objects are so small that they are invisible to human vision without the aid of tools. Phytoplankton are usually between 2 and 200 µm in size. Phytoplankton mostly include unicellular organisms, but certain species can also gather into chains (Rahmatiza et al., 2020).

The distribution and quantity of phytoplankton in seas are influenced by physical factors such as water temperature, light intensity, water depth, turbidity level, and nutrient availability (Nurmalitasari & Sudarsono, 2023). The abundance of phytoplankton in aquatic environments is further modulated by the interactions between phytoplankton and other species, such as zooplankton, which has a substantial influence on the makeup of phytoplankton communities. The presence of phytoplankton are determined by seasonal influences, temperature changes, and water flow patterns. Moreover, water pollution has the capacity to alter the quality of water, hence affecting phytoplankton composition and abundance (George et al., 2012). Factors such as the life cycle and reproduction of phytoplankton are also important considerations in explaining their distribution in diverse aquatic environments. Hence, a wide array of phytoplankton species may be observed in different aquatic environments based on their specific environmental requirements (Celekli et al., 2014; Matus-Hernández et al., 2019; Chang et al., 2022; (Muhammad et al., 2023).

Environmental elements influence the abundance, distribution, and structure of phytoplankton communities in marine ecosystems (Rahmah et al., 2022). Fluctuations in plankton populations in aquatic environments serve as a significant bioindicator for assessing the state of the ecosystem in those waters. They also have the capacity to identify specific regions that should be designated as protection zones for marine organisms (Agus et al., 2019). An in-depth comprehension of the intricate interaction between environmental factors and the variety of marine organisms, such as phytoplankton, is crucial for preserving the equilibrium of marine ecosystems. This knowledge is essential for ensuring the sustainability of fisheries resources and the overall marine biota (Adharini & Probosunu, 2021).

The coastal environment of Maitara Island plays a crucial role in sustaining fisheries production. Coastal habitats, such as mangroves, seagrasses, and corals, offer refuge, breeding grounds, and a conducive habitat for several species of fish and other marine animals (Baksir et al., 2018). This shore sustains fisheries resources by serving as an ecological niche for the reproduction of crustaceans, fish, and various other marine organisms. In addition, this ecosystem has the ability to impact the quality of water and the presence of nutrients in aquatic environments, hence enhancing biological production (Widayanti et al., 2023). The productivity of fisheries in an area is heavily influenced by the condition of coastal ecosystems' water quality (Firdaus et al., 2021). Coastal water quality on Maitara Island has deteriorated due to increasing human activities in the coastal tourism industry and increasing household waste production (Sabar et al., 2023). This alteration possesses the capacity to lead to a decline in the quality of water, thus exerting an influence on diminishing the number and dispersion of phytoplankton in the aquatic environment (Mulyadi et al., 2019). In coastal ecosystems, aquatic nutrients can come from the decay of organic matter, so that mangrove density is correlated with the nitrogen and phosphate content in the waters (Sabar et al., 2022).

Nitrate, phosphate, and silica are important nutrients for the proliferation of phytoplankton and can function as constraining factors for population expansion (Patty et al., 2015). An oversupply of nutrients will cause a proliferation of chlorophyll-a and phytoplankton populations in the waterways. An excessive proliferation of phytoplankton might diminish water quality due to its potential toxicity towards organisms in the water (Oktaviana et al., 2023). Water waste containing nutrient elements at concentrations exceeding the threshold can cause eutrophication, namely a condition of nutrient enrichment in waters characterized by blooming. Phytoplankton, such as diatoms and silicoflagellates, rely on silica as an essential ingredient for the construction of their cell walls (Simanjuntak, 2012).

The objective of this study was to establish the relationship between the levels of nitrate, phosphate, silica, and the quantity of phytoplankton in the coastal waters of Maitara Island, located in North Maluku. By understanding the relationship between nutrients and phytoplankton abundance, fisheries management efforts can be more effective. For example, monitoring nutrient levels in coastal waters can be an indicator of the productivity and health of marine ecosystems. If there is a significant increase or decrease in nutrient concentrations, this can be a signal for fisheries managers to anticipate changes in fish populations in the area, both for harvesting and conservation purposes.

2. Materials and methods

2.1. Sampling time and location

Sampling was was conducted at three observation stations located in the tidal zone of Maitara Island coast, from May to August 2023. Determination of the location of the observation station is based on considerations of the representativeness of the research location, with the distance between stations being 250 meters. The location of the research on Maitara Island can be seen in Figure 1.

2.2. Water sampling

The water sampling points at the station are areas that represent the conditions of each observation station. Each observation point is 150 meters from the coastline. Sampling at each station is carried out every two weeks with four sampling periods. Water sampling is carried out by taking water from the surface water layer at a depth ranging from 0 to 1 meter. The volume of water taken per time sampling is 20 litres at each station. Water samples are filtered using a 25 µm plankton net. The filtered water samples are then transferred into a film bottle, and 4% Lugol's solution is added. The measurement of water quality parameters, including temperature,

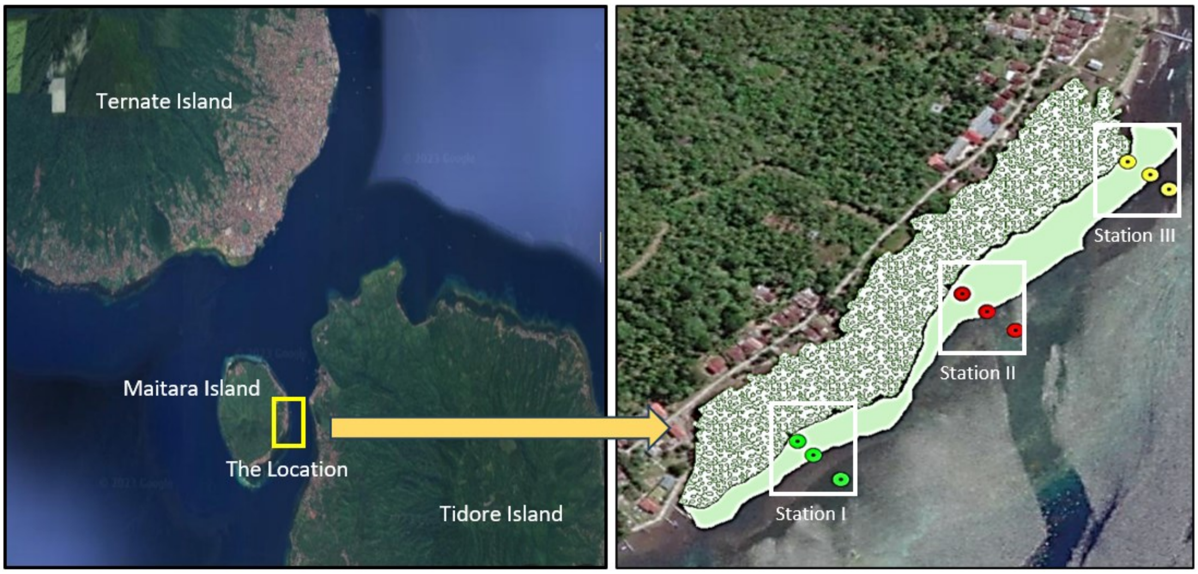

Figure 1. Research Locations in Maitara Island

light penetration, salinity, pH, and dissolved oxygen (DO) levels, was carried out directly in the waters at the sampling point before water sampling. Measurement of water quality parameters, including temperature, light penetration, salinity, pH, and dissolved oxygen (DO) levels, was carried out directly in the waters at the sampling point before water sampling. Measurement of water quality parameters, including temperature, light penetration, salinity, pH, and dissolved oxygen (DO) levels, which are measured directly at the water sampling point. Measurement of quality parameters using pH meters (Hanna HI83141-1), DO meters (Lutron DO-5110), refractometers (Atago MASTER-53M), thermometers, and secchi discs.

2.3. Phytoplankton assessment

The bottles containing the samples were sent to the laboratory to be identified and counted using binocular microscope ZEISS Primostar with 100x magnification and a Sedgwick Rafter Cell. Phytoplankton assesmen were carried out using the fields of view method. Phytoplankton identification was carried out using an identification book written by Davis (1955) and Tomas (1997). The calculation of phytoplankton abundance was obtained from the APHA equation in Baird et al. (2017). The correlation between nitrate, phosphate, and silica concentrations and phytoplankton abundance was calculated using the Pearson formula (Roflin & Zulvia, 2021). Identification, observation, and quantification of phytoplankton cells were carried out at the Aquatic Resources Management Bioecology Laboratory, Faculty of Fisheries and Marine Sciences, Universitas Khairun.

2.4. Assessment of nitrate, phosphate, and silica

Sample testing for nitrate, phosphate, and silica was carried out using a spectrophotometer UV Vis 150 at the Water Quality Laboratory, Universitas Hasanuddin.

2.5 Data analysis

The measurement and testing data were analyzed using Pearson correlation analysis with SPSS for Windows. The relationship between nitrate, phosphate, and silica concentration variables with phytoplankton abundance was analyzed partially and simultaneously.

3. Results and Discussion

3.1. Water Quality Parameters

The measured parameters of water quality in the coastal waters of Maitara Island included temperature, light penetration, salinity, pH, and dissolved oxygen (DO) levels. Water quality assessments were conducted throughout four distinct time intervals. Table 1 presents the mean and range of values for the measurement findings of these parameters.

The water temperature at the three observation stations varied from 28-30°C. The temperature range mentioned is optimal for the proliferation and procreation of phytoplankton. Heightened and more consistent temperatures might expedite the proliferation and procreation of various aquatic creatures, such as several species of plankton, thus leading to a rise in populations (Armiani & Harisanti, 2021). Elevated water temperatures impact the accessibility of food in aquatic environments. Certain species of phytoplankton exhibit temperature-dependent responses that can have cascading effects on the food chain, ultimately affecting the survival and well-being of creatures reliant on these food sources. Fluctuations in water temperature can influence the equilibrium of the entire aquatic environment. These factors can induce alterations in the dynamics of predator-prey relationships, competition, and species distribution in coastal ecosystems (Safitri et al., 2023).

Phytoplankton are microscopic organisms that carry out photosynthesis. Light penetration at station I was 89.58 cm, station I was 90.00 cm, and station III was 96.67 cm. The depth of light penetration is sufficient for the growth of phytoplankton population. Phytoplankton require light to perform photosynthesis. The proliferation of phytoplankton on a significant magnitude is contingent upon the prevailing light conditions, coastal upwelling, and the infusion of nutrients from the incursion of marine

Table 1. Mean/Range of Water Quality Parameters in the Coastal Waters of Maitara Island

Parameter	Station I	Station II	Station III
Temperature (°C)	29-30	29-30	28-29
Light Penetration (cm)	89.58	90.00	96.67
Salinity (ppt)	28.0	28.0	27.7
pH	7.0	7.0	7.13
DO (mg/L)	5.27	4.18	3.37

waters (Zhang et al., 2020). The number of phytoplankton is also influenced by the penetration of sunlight into the water, since phytoplankton exhibit positive phototaxis towards sunshine (Fitriyah et al., 2021). The growth features of phytoplankton are influenced by several variables, including the combined effects of temperature and light. These parameters play a vital role in determining the development and reproductive properties of phytoplankton (Flynn et al., 2021).

The salinity of seawater affects the development and reproduction of phytoplankton (Antoni et al., 2020). The salinity levels recorded at three observation stations, ranging from 27.7 to 28.0 ppt, are already conducive to the growth of phytoplankton communities. The reduction in salinity at station III (27.7 ppt) may impact the composition and development of phytoplankton species. The mean pH of the three observation sites was within the neutral to mildly alkaline spectrum, ranging from 7 to 7.13. This condition indicates that the water at the three places exhibited a very consistent and comparable pH level. Various species of phytoplankton exhibit specific pH requirements to achieve optimal development. The research location is in shallow waters near mangrove forests and receives organic material runoff (such as domestic waste, animal waste, or leaves) from the mainland, causing an increased rate of decomposition by bacteria that require oxygen and produce CO_2. This process increases acidity and lowers the pH in the water. The interplay of pH, temperature, salinity, and the accessibility of aquatic nutrients has more significance in defining the overall state of the aquatic environment (Palit et al., 2022).

Observation data showed that the average DO concentration at station I was 5.27 mg/L, station II was 4.18 mg/L, and station III was 3.37 mg/L. Organic waste pollutants from residential areas are suspected to be the cause of the relatively lower DO concentration in the waters at the research location. The ideal DO concentration for phytoplankton reproduction was over 3.5 mg/L (Liqoarobby et al., 2021). In addition, the low density of plankton as photosynthetic organisms that produce oxygen as a by-product causes DO concentration to be lower (Chowdhury et al., 2024). Insufficient dissolved oxygen levels may have an adverse effect on the development of phytoplankton. Phytoplankton will face challenges in conducting photosynthesis and may undergo a decrease in population in situations of reduced dissolved oxygen (DO). In the region of ST I, a high dissolved oxygen (DO) level could promote the proliferation of phytoplankton. Phytoplankton thrive more effectively in regions with elevated dissolved oxygen levels. Insufficient dissolved oxygen levels suggest environmental issues and changes in the composition of the phytoplankton population in coastal waters.

3.2. Nitrate, Phosphate and Silica Concentrations

The measurement results indicated fluctuations in nitrate concentrations throughout each measurement period at the three research sites. Nevertheless, the detected nitrate content was less than 0.02 mg/L. Figure 2 illustrates the mean levels of nitrate, phosphate, and silica at the observation sites.

Nitrate (NO3) is the primary nitrogen compound. It readily dissolves in water and exhibits stability. In natural waters, nitrate serves as the main nutrient for aquatic plants and algae. The nitrate content in natural waters seldom exceeds 0.1 mg/L. Nitrate concentrations over 5 mg/L signify anthropogenic contamination derived from human activities and animal excrement. Exceeding nitrogen concentrations of 0.2 mg/L can lead to eutrophication, which is the enrichment of water bodies. This enrichment can cause the excessive growth of algae and aquatic plants, but only if there are enough other nutrients present (Effendi, 2007). Nitrate can be employed for the categorization of water fertility levels. According to Effendi (2007), oligotrophic waters include nitrate concentrations ranging from 0 to 1 mg/L, mesotrophic waters contain nitrate concentrations ranging from 1 to 5 mg/L, and eutrophic waters contain nitrate concentrations ranging from 5 to 50 mg/L.

The observation site of station I had the greatest nitrate content (0.0161 Mg/L), followed by station II (0.0159 mg/L), and station III (0.0153 mg/L). The range of nitrate concentrations at the research location is relatively low, allegedly due to weak upwelling activity. In addition, denitrification activity is a biological process carried out by anaerobic microorganisms through chemical reactions that cause gradual nitrate reduction.

The waters at the three observation locations are classified as oligotrophic based on the average nitrate content. Nitrates present in agricultural and residential waste can be introduced into coastal waters via river flows or runoff. Utilizing nitrogen fertilizer might also elevate nitrate levels in coastal waterways. Rivers transporting water from agricultural or residential regions might introduce higher levels

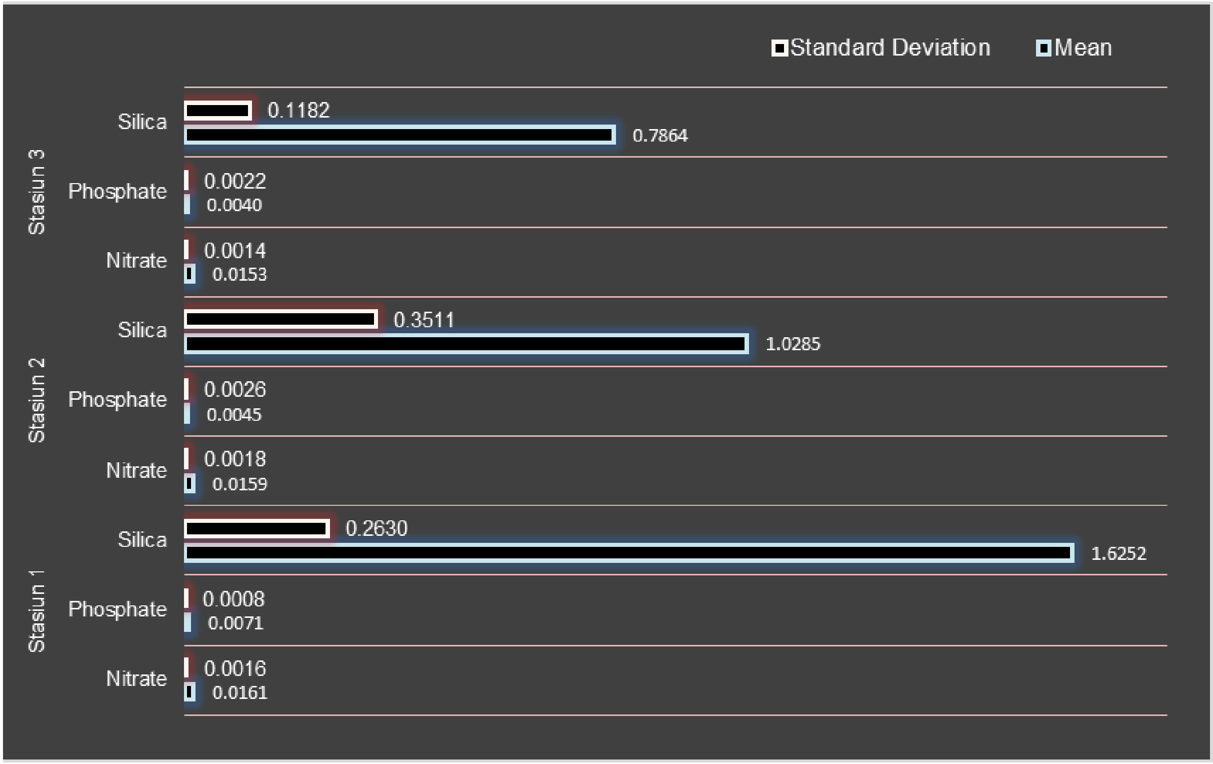

Figure 2. Mean and Standard Deviation of Nitrate, Phosphate and Silica Concentrations at Three Research Sites/Stations

of nitrates into coastal waterways. The water can also be exposed to nitrates through natural processes like organic breakdown. The quantity of nitrates in coastal waters has a strong dependence on the season (Meirinawati & Muchtar, 2017). Elevated precipitation can enhance the transport of nutrients from terrestrial areas to marine environments, encompassing nitrate. Rivers transporting water from agricultural and residential regions can transport substantial quantities of nitrates into coastal waterways.

Phosphate (PO4-P) is an essential element for metabolic processes and the synthesis of proteins. Phosphate is a crucial nutritional component in marine environments (Wohlgemuth, 2023). Phosphate is a critical determinant of water productivity, influencing whether the water is productive or unproductive Phosphate is a crucial factor in influencing the quantity and composition of phytoplankton in aquatic environments (Jiashun et al., 2023). Phosphate is not present in its free state in water. Instead, it exists in the form of dissolved inorganic compounds (orthophosphate and polyphosphate) and organic molecules as particulates. High concentrations of phosphate (over the threshold level) pose a significant risk to marine organisms, perhaps leading to eutrophication and a proliferation of algal populations.

The phosphate concentration at station I was 0.0071 mg/L, station II was 0.0045 mg/L, and station III was 0.0040 mg/L. The findings indicated that the phosphate content at the three observation sites was less than 0.1 mg/L. The coastal waters of Maitara Island are classified as oligotrophic based on their phosphate concentration. The ideal phosphate concentration for phytoplankton growth is 0.27 – 5.51 mg/L (Paiki & Kalor, 2017). Phosphate concentrations in this range are considered sufficient to support phytoplankton growth and maintain ecosystem balance without causing excessive eutrophication. Waterways containing a phosphate content over 0.1 mg/L are considered eutrophicated. Waters with high phosphate concentrations often experience phytoplankton blooms (Tilahun et al., 2024).

The silica concentration at station I was 1.6252 mg/L. Station II was 1.0285 mg/L, and station III was 0.7864 mg/L. The presence of dissolved silica in water is crucial for the development of cell walls in diatoms (Muhammad et al., 2023). Silica has a crucial function in facilitating the development of phytoplankton. Silica is a chemical substance consisting of silicon dioxide (SiO_2) and serves as the primary constituent of diatoms' skeletal structures. Diatoms are a form of tiny phytoplankton that are typically seen in both fresh and marine environments. Diatoms require silica to construct rigid and robust cell walls. Diatom phytoplankton utilize silica from their surroundings to construct their cell walls, ensuring optimum reproduction and growth. The availability of silica in the aquatic environment is essential for the growth of diatom populations, thereby impacting the entire marine ecosystem (Saxena et al., 2021).

The waters of station I exhibited elevated levels of nitrate, phosphate, and silica due to its proximity to the mangrove forest region. Mangrove forests generate organic matter that is broken down by decomposers, resulting in the release of nutrients into the water. The primary mechanisms that regulate the storage and recycling of carbon and other nutrients in mangroves are litter formation and the process of litter breakdown (Kamruzzaman et al., 2019). During the initial phases, macrofauna typically contributes to the decomposition process by assisting in the breakdown and burial of organic waste. This, in turn, facilitates the pace of decomposition through microbial activity in the water (Friesen et al., 2018).

3.3. Phytoplankton Abundance

The identification results revealed the presence of 5 distinct classes of phytoplankton in the waters of Maitara Island. These classes include *Bacillariophyceae*, which encompasses 8 genera and 8 species, *Chlorophyceae* with 2 genera and 2 species, *Cyanophyceae* with 1 genus and 1 species, *Dinophyceae* with 2 genera and 2 species, and *Thalassiosiraceae*, which consists of 1 genus and 1 species. The class *Bacillariophyceae* had the maximum abundance with a count of 6961 cells/L, followed by the class *Dinophyceae* with 2590 cells/L. The class *Chlorophyceae* had a count of 1209 cells/L, while the class *Cyanophyceae* had 963 cells/L. The lowest abundance was seen in the class *Thalassiosiraceae*, with a count of 865 cells/L. The abundance of phytoplankton in the coastal waters of Maitara Island based on class can be seen in Figure 3.

The class *Bacillariophyceae* was highly prevalent in the marine waters of Maitara Island because of its exceptional adaptation to the marine ecosystem. These organisms are known as diatoms. Diatoms possess traits that facilitate their capacity to adapt to aquatic environments. The first trait is cellular composition. Diatoms possess robust cellular membranes composed of silica, a mineral compound including silicon and oxygen. The structure offers defense against predators and confers resilience to the challenges of the marine ecosystem. Diatoms usually have optimal photosynthesis. They possess chlorophyll and other pigments that allow them to perform photosynthesis with high efficiency even in environments with little light, such as the deep oceans. Additionally, they possess the ability to utilize light of diverse wavelengths, enabling their growth at varied depths. These organisms also have a rapid life cycle. Diatoms exhibit a brief life cycle, often lasting only a few days, enabling them to reproduce expeditiously. In addition, diatoms possess a cellular structure that enables them to assimilate essential nutrients such as iron, nitrate, phosphate, and silica from their immediate surroundings (nutritional adaptation). This capability enables them to flourish in oceanic environments abundant in nutrient (Jewson, 1992).

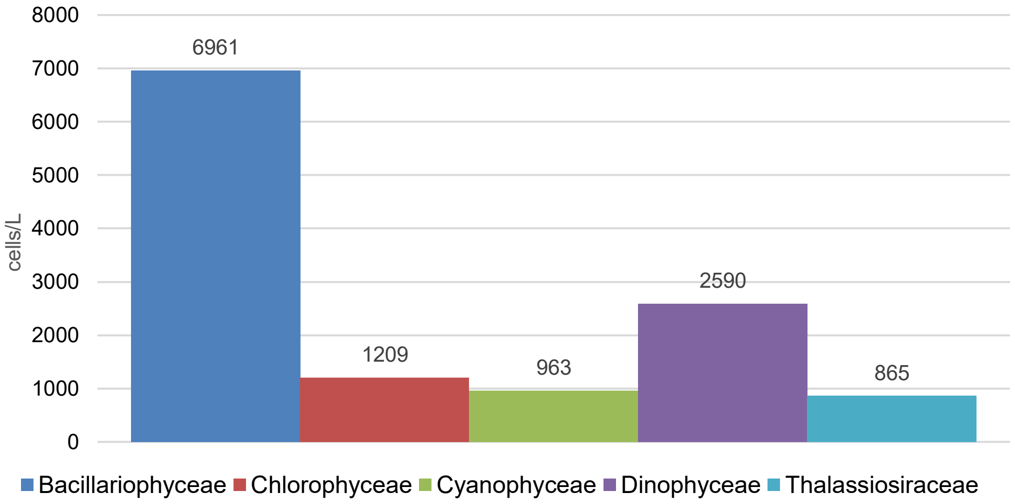

Figure 3. The Abundance of Phytoplankton in the Coastal Waters of Maitara Island Based on Class

The research findings indicated that the abundance of phytoplankton at station I was 4881 cells/liter, at station II was 4423 cells/L, and at station III was 2796 cells/L. Phytoplankton abundance (cells/L) at the three observation stations can be seen in Table 2. The concentration of nutrients such as nitrate, phosphate, and silica can affect the development of phytoplankton. The increasing levels of nutrients (nitrate, phosphate, and silica) at station I resulted in a greater number of phytoplankton compared to stations II and III. Adequate availability of nitrate, phosphate, and silica will promote enhanced phytoplankton proliferation. The scarcity of phytoplankton at station III was believed to be a result of reduced nitrogen availability. Insufficient nutrient availability in water impedes the development of phytoplankton (Martiny et al., 2022). Insufficient nutrients can arise due to a range of circumstances, including pollution, climate change, or alterations in the dynamics of aquatic ecosystems.

Blooming instances are mostly comprised of a single species, with diatoms accounting for 58% of blooms and dinoflagellates making up 19% (Carstensen et al., 2015). *Bacillariophyceae*, sometimes known as diatoms, is a family of phytoplankton mostly found in coastal waters (Aryawati et al., 2017). Diatoms possess strong adaptability to the specific environmental conditions found in coastal waters, characterized by their shallowness and ample exposure to sunshine. Furthermore, diatoms possess photosynthetic pigments that exhibit high efficiency in capturing sunlight for the purpose of conducting photosynthesis. As a result, they thrive in environments with abundant light. Moreover, diatom cells possess a robust and protective structure called the frustule, composed of silica, which imparts excellent durability and safeguarding to the cells. Diatoms possess this cellular architecture to enhance their ability to flourish in diverse aquatic habitats, such as coastal waters that may experience variations in salinity and temperature. Diatoms have the capacity for rapid reproduction by cell division, enabling their populations to proliferate swiftly in nutrient-abundant coastal waters (Inomura et al., 2023). Diatoms have a set of physiological adaptations and reproductive capabilities that contribute to their prevalence as phytoplankton in coastal environments (Adhiambo et al., 2023).

3.4. The Correlation between Nitrate, Phosphate, Silicate and Phytoplankton Abundance in Maitara Island Coastal Waters

The correlation between nitrate, phosphate, silicate, and phytoplankton abundance simultaneously reached a level of around 82.3%. This finding indicated that higher levels of nitrate, phosphate, and silicate could lead to a rise in the number of phytoplankton, but lower levels of these substances could cause a decline in phytoplankton population.

Simultaneously, nitrate, phosphate and silica had a very strong correlation (R=0.823) with phytoplankton abundance. The Simultaneous Correlation between the Concentrations of Nitrate, Phosphate, Silicate, and Phytoplankton Abundance can be seen in Table 3. Besides, nitrate, phosphate and silica concentrations contributed 67% to phytoplankton abundance. These data suggested that 33% of phytoplankton abundance was affected by other variables that

Table 2. Nitrate, Phosphate and Silica Concentrations at Three Stations in the Coastal Waters of Maitara Island

Station	Period	Concentration		
		Nitrate (mg/L)	Phosphate (mg/L)	Silica (mg/L)
Station I	Period 1	0.0179	0.0083	1.9399
	Period 2	0.0156	0.0064	1.6395
	Period 3	0.0141	0.0069	1.2961
	Period 4	0.0169	0.0069	1.6252
Station II	Period 1	0.0133	0.0078	1.5408
	Period 2	0.0169	0.0054	0.9528
	Period 3	0.0172	0.0027	0.8670
	Period 4	0.0165	0.0021	0.7535
Station III	Period 1	0.0164	0.0072	0.9399
	Period 2	0.0156	0.0029	0.6524
	Period 3	0.0133	0.0038	0.7670
	Period 4	0.0161	0.0022	0.7864

Table 3. The Abundance of Phytoplankton (cells/liter) at the Three Observation Stations

Class	Genus	Species	ST I	ST II	ST III
Bacillariophyceae	Asterionellopsis	*Asterionellopsis glacialis*	321	-	344
	Chaetoceros	*Chaetoceros capense*	298	367	-
	Leptocylindricus	*Leptocylindricus danicus*	550	550	183
	Nitzschia	*Nitzschia closterium*	275	229	92
	Pseudo nitzschia	*Pseudo nitzschia delicatissima*	115	458	435
	Rhizosolenia	*R. hebetata*	481	252	481
	Synedra	*Synedra sp*	206	-	-
	Thalassionema	*T. nitzschioides*	688	413	-
Chlorophyceae	Mougetia	*Mougeotia sp*	-	275	69
	Ulothrix	*Ulothrix sp*	69	252	413
Cyanophyceae	Oscillatoria	*Oscillatoria sp*	344	275	275
Dinophyceae	Doniphysis	*Doniphysis fortii*	733	619	206
	Gyrodinium	*Gyrodinium sp*	458	390	138
Thalassiosiraceae	Thalassiosira	*Thalassiosira eccentrica*	344	344	160
		Jumlah	4881	4423	2796

Notes: ST refers to the Observation Station

Table 4. The Simultaneous Correlation between the Concentrations of Nitrate, Phosphate, Silicate, and Phytoplankton Abundance

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.823[a]	0.677	0.555	893.571

were not included in this investigation. The availability of nitrate, phosphate, and silicate in water has a crucial role in regulating the number, composition, and productivity of phytoplankton in aquatic habitats. Fluctuations in the accessibility of these essential nutrients may exert substantial effects on entire ecosystems, including food chains, fishery resources, and water quality. Hence, the surveillance and control of these nutrients are crucial components in the endeavor to effectively preserve and regulate the aquatic environment.

The correlation between nitrate content and phytoplankton abundance was quite significant (R=0.729). This value showed a notable and robust correlation between the quantity of nitrates in water and phytoplankton abundance. A correlation value of 72% in this situation is considered strong, suggesting that variations in nitrate content have a substantial impact on the quantity of phytoplankton (Muhammad et al., 2023), where a higher correlation value indicates a more robust association. A determination coefficient (R^2) of 53% indicated that around 53% of the changes in phytoplankton abundance might be accounted for or anticipated by changes in nitrate concentration. The Partial Correlation between the Concentrations of Nitrate, Phosphate, Silicate, and Phytoplankton Abundance can be seen in Table 4-5.

Phytoplankton, which are photosynthetic microorganisms, play a crucial role in the aquatic food chain. The primary determinant of phytoplankton abundance and productivity in coastal waters seems to be the influx of nitrates into the euphotic zone. The rate at which carbon is assimilated by photosynthesis is directly proportional to the rate at which nitrate is assimilated and the nitrate ratio. Additionally, there is a simultaneous and parallel rise in the production of phytoplankton that receive additional inputs of nitrate into the euphotic zone (Eppley et al., 1979). Phytoplankton drive biogeochemical cycles and nutrient recycling, not only in aquatic ecosystems but also in terrestrial ecosystems (Naselli-Flores & Padisák, 2023).

The average nitrate concentration at observation station I (0.0161 mg/L) was relatively higher than at station II (0.0159 mg/L) and station III (0.0153 mg/L) causing the average density of phytoplanktok cells at station I to be higher (4881 cells/L) than station II (4423 cells/L) and station III (2796 cells/L). Adequate nitrate availability can enhance the development of phytoplankton, therefore leading to an increase in the quantity and biomass of phytoplankton in aquatic environments (Glibert et al., 2016). Nitrate exerts a substantial impact on the quantity of

Table 5. The Partial Correlation between the Concentrations of Nitrate, Phosphate, Silicate, and Phytoplankton Abundance

		Coefficient (R)	Correlation Level
Pearson Correlation	Nitrate	0.729	Very strong
	Phosphate	0.577	Moderately strong
	Silicate	0.386	Weak

phytoplankton. Phytoplankton utilize nitrate as a nutrient to synthesize proteins, amino acids, and other cell parts needed for their growth process. Diatoms are nitrate (NO3-N) opportunists but can also use ammonium (NH4-N) for their growth. Diatoms are perhaps being more sensitive to nitrogen reduction than other algae (Liu et al., 2022).

Nitrogen is an important nutrient in aquatic ecosystems. Nevertheless, in the event of an increase in nutrient availability, eutrophication can develop. Changes in chemicals are accompanied by corresponding modifications in the biological production, composition, and variety of organisms, as well as changes in the physical characteristics of water bodies. The primary problems pertaining to eutrophication are the constraints on water utilization and the hazards linked to the proliferation of algae beyond acceptable levels. Nitrogen is a nutrient that restricts or limits the growth of organisms in estuarine and marine environments. The introduction of N pollutants leads to acidification of aquatic ecosystems in places that are sensitive to acidity, resulting in alterations to the general structure of the biota and a decrease in biodiversity (Hornung, 1999).

The correlation between the concentration of phosphate in water and phytoplankton abundance in this study fell within the medium range, with a correlation coefficient (R) of 0.577 and a coefficient of determination of 33%. While there is a connection between phosphate and the number of phytoplankton, most of the fluctuations in phytoplankton abundance cannot be solely attributable to changes in phosphate concentration. Additional variables, such as the levels of other nutrients, temperature, light, and other environmental conditions, might have an impact on the quantity of phytoplankton at the research site.

Apart from nitrate, phosphate is also one of the main nutrients needed by phytoplankton. Higher availability of phosphate in coastal waters can increase the abundance and diversity of phytoplankton. Compared to station II (0.0045 mg/L) and station III (0.0040 mg/L), a higher phosphate concentration (0.0071 mg/L) at station I would have a better effect on increasing the composition and abundance of phytoplankton in the area because sufficient phosphate is able to support phytoplankton growth at a moderate level. Phytoplankton growth is restricted by low phosphate concentrations, as shown at station III. Phytoplankton cells experience hindered development and reproduction due to the challenges they face in conducting photosynthesis under low phosphate concentration circumstances. The varying supply of phosphate at the three observation locations resulted in varying quantity of phytoplankton.

The growth and reproduction of phytoplankton at the study location was also determined by the phosphate concentration. Phosphate is a vital nutrient for marine phytoplankton and other living organisms, and the availability of phosphate limits growth in marine living systems (Lin et al., 2016). Phosphate is essential for the manufacture of ATP (adenosine triphosphate), the main source of energy in the process of photosynthesis. High phosphate concentrations result in increased availability of nutrients for phytoplankton, leading to population growth. Phosphate is a crucial ingredient that promotes the growth of phytoplankton and governs the productivity of water. Phosphate supplementation induces meiosis and results in a significant rise in the quantity of 4C cells during zygote division (Kalinina et al., 2023). Phosphate ester is a type of chemical connection that occurs when a phosphate group binds to two hydroxyl groups of another molecule. The presence of this bond is commonly observed in nucleotide and nucleic acid configurations, namely in DNA and RNA.

Phosphate ester is the primary constituent of dissolved organic phosphorus in the ocean. It serves as a crucial supplier of phosphate nutrition for phytoplankton organisms. The molecular pathways involved in the use of phosphate ester by phytoplankton exhibit distinct characteristics (Bell et al., 2020). The transcriptome reactions of phytoplankton to ATP and G6P circumstances exhibit significant similarities, however the methods of Phosphate ester consumption within the same species might vary considerably (Xiaohua et al., 2023). Deviations from optimal phosphate concentrations can significantly influence aquatic ecosystems. Eutrophication, the phenomenon of excessive development of phytoplankton, may be triggered by high concentrations of phosphates. Following the death and breakdown of phytoplankton, the decomposition process diminishes the oxygen levels in the water, posing a threat to the survival of other marine species. Ensuring the equilibrium of coastal aquatic ecosystems necessitates the careful regulation of phosphate and other nutrient levels in the water. Nevertheless, evaluating the impact of coastal zone phosphate on the worldwide cycle has proven challenging thus far due to the scarcity of metabolic data and ambiguities surrounding factors such as respiration, exchange mechanisms in the open ocean, and air-sea biogas (Sanjuan-Delmás et al., 2020).

Silicate is needed for the formation of cell walls in diatoms. The correlation between silicate concentration and phytoplankton abundance was weak (R=0.386). A determination coefficient of 14% indicated that about 14% of the variability in phytoplankton abundance might be accounted for by changes in silicate concentration. The remaining 86% was attributed to other variables not accounted for in this research. The association between silicate and phytoplankton abundance at the research location was low, and most of the variability in phytoplankton abundance could not be ascribed to silicate concentration. The relationship between silica content and diatom abundance was low because phytoplankton normally require small amounts of silica. Additional elements, such as the presence of other nutrients, temperature, light, and other environmental conditions, exert a more significant influence on the quantity of phytoplankton in aquatic environments (Abakumov & Kozitskaya, 2023). The combination of salinity changes and silica ($SiO3$) distribution has a key impact on the composition of phytoplankton communities (Xu et al., 2022).

The ecological implications of the weak correlation between silica and phytoplankton reflectance can provide insight into the dynamics of aquatic ecosystems, particularly in terms of species diversity, food chain structure, and environmental stability. Silica is an essential nutrient for the growth of diatoms, a type of phytoplankton that has a silica-based cell wall (Makareviciute-Fichtner et al., 2024). If the correlation between silica and phytoplankton reflectance is weak, this suggests that other phytoplankton groups that do not require silica, such as dinoflagellates or cyanobacteria, may be more dominant in the phytoplankton community. Such phytoplankton community diversification may indicate that the ecosystem is undergoing changes in species composition, potentially altering food chain dynamics and ecological interactions in the long term.

4. Conclusion

The coastal waters of Maitara Island are classified as oligotrophic based on measurements of the nitrate and phosphate concentrations contained in the waters. The concentrations of nitrate, phosphate, and silica had a very strong correlation (R=0.823) with phytoplankton abundance. Partially, the correlation between nitrate concentration and phytoplankton abundance was very strong (R=0.729). Meanwhile, phosphate concentration had a moderately significant correlation with phytoplankton abundance (R=0.577). However, the correlation between silica concentration and phytoplankton abundance was considered weak (R=0.386). High concentrations of nitrate and phosphate in coastal waters lead to increased abundance of phytoplankton. However, high levels of silica can only increase the abundance of certain groups of diatoms, because other groups such as dinoflagellates and cyanobacteria do not require silica for their growth processes.

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References

Abakumov, A. I., & Kozitskaya, I. S. (2023). Mathematical Model of Phytoplankton Interspecific Competition for Food Resource. *Mathematical Biology and Bioinformatics*, *18*(12), 568–579. https://doi.org/10.17537/2023.18.568

Adharini, R. I., & Probosunu, N. (2021). Struktur Komunitas dan Kelimpahan Fitoplankton dan Zooplankton pada Musim Penghujan di Zona Intertidal Pantai Selatan Yogyakarta. *Jurnal Kelautan Tropis*, *24*(2), 167–176.

https://doi.org/10.14710/jkt.v24i2.10206

Adhiambo, R., Mensah, P. K., & Acheampong, E. (2023). Widespread Geographical Disparities in Phytoplankton Ecology Research in the Face of Climate Change: A Review. *Water (Switzerland)*, *15*(24). https://doi.org/10.3390/w15244288

Agus, E. L., Pribadi, R., & Subagiyo, S. (2019). Fluktuasi Fitoplankton pada Kawasan Konservasi Rajungan Perairan Betahwalang Demak. *Jurnal Kelautan Tropis*, *22*(2), 191. https://doi.org/10.14710/jkt.v22i2.6296

Antoni, J. S., Almandoz, G. O., Ferrario, M. E., Hernando, M. P., Varela, D. E., Rozema, P. D., Buma, A. G. J., Paparazzo, F. E., & Schloss, I. R. (2020). Response of a natural Antarctic phytoplankton assemblage to changes in temperature and salinity. *Journal of Experimental Marine Biology and Ecology*, *532*, 151444. https://doi.org/https://doi.org/10.1016/j.jembe.2020.151444

Armiani, S., & Harisanti, B. M. (2021). Hubungan Kemelimpahan Fitoplankton dengan Faktor Lingkungan di Perairan Pantai Desa Madayin Lombok Timur. *Jurnal Pijar Mipa*, *16*(1), 75–80. https://doi.org/10.29303/jpm.v16i1.1862

Aryawati, R., Bengen, D. G., Prartono, T., & Zulkifli, H. (2017). Abundance of Phytoplankton In The Coastal Waters of South Sumatera. *Ilmu Kelautan: Indonesian Journal of Marine Sciences*, *22*(1), 31. https://doi.org/10.14710/ik.ijms.22.1.31-39

Ayu, D., Sari, P., Hutami, R. D., Azizi, A., & Fairus, S. (2019). Analysis of Water Quality Based On Phytoplankton Abundance And Number of Nutrients. *Agricultural Science*, *3*(1), 57–72. http://agriscience.scientific-work.org/index.php/agriscience/article/view/33

Baird, R. B., Eaton, A. D., & Rice, E. W. (2017). Standard Methods for the Examination Water and Wastewater. In *Standard Methods for the Examination of Water and Wastewater*. https://yabesh.ir/wp-content/uploads/2018/02/Standard-Methods-23rd-Perv.pdf

Baksir, A., Akbar, N., Tahir, I., Haji, I., Ahmad, M., & Kotta, R. (2018). Struktur Komunitas Hutan Mangrove Di Pulau Sibu Kota Tidore Kepulauan Provinsi Maluku Utara. *Jurnal Enggano*, *3*(2), 178–196. https://doi.org/10.31186/jenggano.3.2.178-196

Bell, D. W., Pellechia, P. J., Ingall, E. D., & Benitez-Nelson, C. R. (2020). Resolving marine dissolved organic phosphorus (DOP) composition in a coastal estuary. *Limnology and Oceanography*, *65*(11), 2787–2799. https://doi.org/https://doi.org/10.1002/lno.11552

Carstensen, J., Klais, R., & Cloern, J. E. (2015). Phytoplankton blooms in estuarine and coastal waters: Seasonal patterns and key species. *Estuarine, Coastal and Shelf Science*, *162*, 98–109. https://doi.org/https://doi.org/10.1016/j.ecss.2015.05.005

Çelekli, A., Öztürk, B., & Kapı, M. (2014). Relationship between phytoplankton composition and environmental variables in an artificial pond. *Algal Research*, *5*, 37–41. https://doi.org/https://doi.org/10.1016/j.algal.2014.05.002

Chang, C. W., Miki, T., Ye, H., Souissi, S., Adrian, R., Anneville, O., Agasild, H., Ban, S., Be'eri-Shlevin, Y., Chiang, Y. R., Feuchtmayr, H., Gal, G., Ichise, S., Kagami, M., Kumagai, M., Liu, X., Matsuzaki, S. I. S., Manca, M. M., Nõges, P., Hsieh, C. hao. (2022). Causal networks of phytoplankton diversity and biomass are modulated by environmental context. *Nature Communications*, *13*(1), 1–11. https://doi.org/10.1038/s41467-022-28761-3

Davis, C. C. (1955). The marine and fresh-water plankton. Michigan State Univ. In *Ann Arbor. xi*. Michigan State University.

Effendi, H. (2007). *Telaah Kualitas Air Bagi Pengelolaan Sumber Daya dan Lingkungan Perairan* (5th ed.). Kanisus. http://bit.ly/2Dsjkj6

Eppley, R. W., Renger, E. H., & Harrison, W. G. (1979). Nitrate and phytoplankton production in southern California coastal waters. *Limnology and Oceanography*, *24*(3), 483–494. https://doi.org/10.4319/lo.1979.24.3.0483

Firdaus, M., Hatanaka, K., & Saville, R. (2021). Mangrove forest restoration by fisheries communities in lampung bay: A study based on perceptions, willingness to pay, and management strategy. *Forest and Society*, *5*(2), 224–244. https://doi.org/10.24259/fs.v5i2.12008

Fitriyah, A., Zainuri, M., & Indriyawati, N. (2021). Hubungan Nitrat Terhadap Kelimpahan Fitoplankton Pada Saat Air Pasang di Muara Ujung Piring, Bangkalan. *Prosiding Seminar Nasional Hasil Penelitian Pertanian, Perikanan Dan Kelautan*, 8–13.

https://ilmukelautan.trunojoyo.ac.id/wp-content/uploads/2022/05/Fitriyah-et-al.pdf

Flynn, K. J., Kimmance, S. A., Clark, D. R., Mitra, A., Polimene, L., & Wilson, W. H. (2021). Modelling the Effects of Traits and Abiotic Factors on Viral Lysis in Phytoplankton. *Frontiers in Marine Science*, *8*(May), 1–23. https://doi.org/10.3389/fmars.2021.667184

Friesen, S. D., Dunn, C., & Freeman, C. (2018). Decomposition as a regulator of carbon accretion in mangroves: a review. *Ecological Engineering*, *114*, 173–178. https://doi.org/https://doi.org/10.1016/j.ecoleng.2017.06.069

George, B., Nirmal Kumar, J. I., & Kumar, R. N. (2012). Study on the influence of hydro-chemical parameters on phytoplankton distribution along Tapi estuarine area of Gulf of Khambhat, India. *The Egyptian Journal of Aquatic Research*, *38*(3), 157–170. https://doi.org/https://doi.org/10.1016/j.ejar.2012.12.010

Glibert, P. M., Wilkerson, F. P., Dugdale, R. C., Raven, J. A., Dupont, C. L., Leavitt, P. R., Parker, A. E., Burkholder, J. M., & Kana, T. M. (2016). Pluses and minuses of ammonium and nitrate uptake and assimilation by phytoplankton and implications for productivity and community composition, with emphasis on nitrogen-enriched conditions. *Limnology and Oceanography*, *61*(1), 165–197. https://doi.org/10.1002/lno.10203

Hornung, M. (1999). The Role of Nitrates in the Eutrophication and Acidification of Surface Waters. In W. S. Wilson, A. S. Ball, & R. H. Hinton (Eds.), *Managing Risks of Nitrates to Humans and the Environment* (pp. 155–174). Woodhead Publishing. https://doi.org/https://doi.org/10.1533/9781845693206.155

Inomura, K., Pierella Karlusich, J. J., Dutkiewicz, S., Deutsch, C., Harrison, P. J., & Bowler, C. (2023). High Growth Rate of Diatoms Explained by Reduced Carbon Requirement and Low Energy Cost of Silica Deposition. *Microbiology Spectrum*, *11*(3), 1–11. https://doi.org/10.1128/spectrum.03311-22

Jewson, D. H. (1992). Size reduction, reproductive strategy and the life cycle of a centric diatom. *Philosophical Transactions - Royal Society of London, B*, *336*(1277), 191–213. https://doi.org/10.1098/rstb.1992.0056

Jiashun, L., Kaidian, Z., Ling, L., Yujie, W., & Senjie, L. (2023). Phosphorus nutrition strategies in a symbiodiniacean species: Implications in coral-alga symbiosis facing increasing phosphorus deficiency in future warmer oceans. *National Natural Science Foundation of China*, 5061. https://doi.org/https://doi.org/10.5061/dryad.k98sf7md2

Kalinina, V., Berdieva, M., Aksenov, N., & Skarlato, S. (2023). Phosphorus deficiency induces sexual reproduction in the dinoflagellate Prorocentrum cordatum. *Scientific Reports*, *13*(1), 14191. https://doi.org/10.1038/s41598-023-41339-3

Kamruzzaman, M., Basak, K., Paul, S. K., Ahmed, S., & Osawa, A. (2019). Litterfall production, decomposition and nutrient accumulation in Sundarbans mangrove forests, Bangladesh. *Forest Science and Technology*, *15*(1), 24–32. https://doi.org/10.1080/21580103.2018.1557566

Lin, S., Litaker, R. W., & Sunda, W. G. (2016). Phosphorus physiological ecology and molecular mechanisms in marine phytoplankton. *Journal of Phycology*, *52*(1), 10–36. https://doi.org/https://doi.org/10.1111/jpy.12365

Liqoarobby, R., Sunardi, Suparman, Y., & Fadilah, K. (2021). Aqueous Systems of Dissolved Oxygen in Reservoir. *E3S Web of Conferences*, *249*, 1–4. https://doi.org/10.1051/e3sconf/202124903015

Liu, X., Li, Y., Shen, R., Zhang, M., & Chen, F. (2022). Reducing nutrient increases diatom biomass in a subtropical eutrophic lake, China–Do the ammonium concentration and nitrate to ammonium ratio play a role? *Water Research*, *218*, 118493. https://doi.org/https://doi.org/10.1016/j.watres.2022.118493

Makareviciute-Fichtner, K., Matthiessen, B., Lotze, H. K., & Sommer, U. (2024). Nutrient enrichment alters phytoplankton biomass and composition via silicon limitation. *Frontiers in Marine Science*, *11*(March), 1–12. https://doi.org/10.3389/fmars.2024.1289768

Martiny, A. C., Hagstrom, G. I., DeVries, T., Letscher, R. T., Britten, G. L., Garcia, C. A., Galbraith, E., Karl, D., Levin, S. A., Lomas, M. W., Moreno, A. R., Talmy, D., Wang, W., & Matsumoto, K. (2022). Marine phytoplankton resilience may moderate oligotrophic ecosystem responses and biogeochemical feedbacks to climate change. *Limnology and Oceanography*, *67*(S1), S378–S389. https://doi.org/10.1002/lno.12029

Matus-Hernández, M. Á., Martínez-Rincón, R. O., Aviña-Hernández, R. J., & Hernández-Saavedra, N. Y. (2019). Landsat-derived environmental factors to describe habitat preferences and spatiotemporal distribution of phytoplankton. *Ecological Modelling*, *408*, 108759. https://doi.org/https://doi.org/10.1016/j.ecolmodel.2019.108759

Meirinawati, H., & Muchtar, M. (2017). Fluktuasi Nitrat, Fosfat dan Silikat di Perairan Pulau Bintan. *Jurnal Segara*, *13*(3), 141–148. https://doi.org/10.15578/segara.v13i3.6493

Muhammad, M., Khairunnisa, K., & Musafira, F. (2023). Analisis Kesuburan Perairan Di Krueng Geukuh , Aceh Utara Berdasarkan Sebaran Nitrat dan Fosfat Terhadap Kelimpahan Fitoplankton. *Jurnal Kelautan Dan Perikanan Indonesia*, *3*(2), 66–78. http://jurnal.unsyiah.ac.id/JKPI

Mulyadi, Ulqodry, T. Z., Aryawati, R., Isnaini, & Surbakti, H. (2019). The characteristic of phytoplankton distribution at Sugihan Estuary, South Sumatera. *Jurnal Kelautan Tropis*, *22*(1), 19–26. https://doi.org/10.14710/jkt.v22i1.3178

Naselli-Flores, L., & Padisák, J. (2023). Ecosystem services provided by marine and freshwater phytoplankton. *Hydrobiologia*, *850*(12–13), 2691–2706. https://doi.org/10.1007/s10750-022-04795-y

Nurmalitasari, M., & Sudarsono, S. (2023). Keanekaragaman Plankton Dan Tingkat Produktivitas Primer Antara Dua Musim Di Perairan Kabupaten Bantul. *Kingdom (The Journal of Biological Studies)*, *9*(1), 16–34. https://doi.org/10.21831/kingdom.v9i1.18156

Oktaviana, C. I., Muskananfola, M. R., & Purnomo, P. W. (2023). Analisis Kesuburan Perairan Berdasarkan Klorofil-a, Nitrat dan Ortofosfat di Pantai Pasir Putih Wates, Kaliori, Rembang. *Life Science*, *12*(1), 40–51. https://journal.unnes.ac.id/sju/index.php/LifeSci

Paiki, K., & Kalor, J. D. (2017). Distribusi Nitrat Dan Fosfat Terhadap Kelimpahan Fitoplankton Di Peraiaran Pesisir Yapen Timur. *JFMR-Journal of Fisheries and Marine Research*, *1*(2), 65–71. https://doi.org/10.21776/ub.jfmr.2017.001.02.3

Palit, K., Rath, S., Chatterjee, S., & Das, S. (2022). Microbial diversity and Ecological interactions of microorganisms in the mangrove ecosystem: Threats, vulnerability, and adaptations. *Environmental Science and Pollution Research*, *29*(22), 32467–32512. https://doi.org/10.1007/s11356-022-19048-7

Patty, S. I., Arfah, H., & Abdul, M. S. (2015). Zat Hara (Fosfat, Nitrat), Oksigen Terlarut dan pH Kaitannya Dengan Kesuburan di Perairan Jikumerasa, Pulau Buru. *Jurnal Pesisir Dan Laut Tropis*, *3*(1), 43. https://doi.org/10.35800/jplt.3.1.2015.9578

Rahmah, N., Zulfikar, A., & Apriadi, T. (2022). Kelimpahan Fitoplankton dan Kaitannya dengan Beberapa Parameter Lingkungan Perairan di Estuari Sei Carang Kota Tanjungpinang. *Journal of Marine Research*, *11*(2), 189–200. https://doi.org/10.14710/jmr.v11i2.32945

Rahmatiza, Y., Lase, Y., & Yulmila. (2020). Keanekaragaman Benthos Di Perairan Pantai Kaca Kacu Deudap Pulo Aceh, Kabupaten Aceh besar. *Prosiding Seminar Nasional Biotik 2020*, 218–221.

Roflin, E., & Zulvia, F. E. (2021). *Kupas Tuntas Analisis Korelasi*. Penerbit NEM. https://books.google.co.id/books?id=SAc7EAAAQBAJ

Roy Chowdhury, P., Banerjee, M., & Petrovskii, S. (2024). A two-timescale model of plankton–oxygen dynamics predicts formation of oxygen minimum zones and global anoxia. *Journal of Mathematical Biology*, *89*(1), 1–34. https://doi.org/10.1007/s00285-024-02107-7

Sabar, M., Irfan, M., Nursanti, Samman, A., Salim, F. D., & Bahtiar. (2023). Penyuluhan Pelestarian Ekosistem Lamun (Seagrass) pada Masyarakat Pantai Kastela, Pulau Ternate Counseling. *Aquana Jurnal Pengabdian Kepada Masyarakat*, *4*(1), 18–24. http://aquana.ulm.ac.id/index.php/aquana/article/view/58/50

Sabar, M., Samman, A., Serosero, R. H., & Kadir, M. A. (2022). Kerapatan Jenis Mangrove dan Dinamika Nitrat (NO 3) pada Sedimen di Pulau Manomadehe, Kecamatan Jailolo Selatan, Kabupaten Halmahera Barat. *Agrikan - Jurnal Agribisnis Perikanan*, *15*(2), 370–380. https://doi.org/10.52046/agrikan.v15i2.1216

Safitri, A., Zayadi, H., Si, S., Si, M., Laili, I. S., & Si, M. (2023). Hubungan Keanekaragaman Fitoplankton Dengan Kandungan Nitrat dan Fosfat di Sungai

Bluru Kecamatan Buduran Kabupaten Sidoarjo The Relationship between Phytoplankton Diversity and Nitrate and Phosphate Content in the Bluru River , Buduran District , Sidoarj. *E-Jurnal Ilmiah Mahasiswa Sains UNISMA Malang (JIMSUM)*, *1*(2), 74–83. https://jim.unisma.ac.id/index.php/jimsum/article/viewFile/22571/16862

Sanjuan-Delmás, D., Josa, A., Muñoz, P., Gassó, S., Rieradevall, J., & Gabarrell, X. (2020). Applying nutrient dynamics to adjust the nutrient-water balance in hydroponic crops. A case study with open hydroponic tomato crops from Barcelona. *Scientia Horticulturae*, *261*, 108908. https://doi.org/https://doi.org/10.1016/j.scienta.2019.108908

Saxena, A., Tiwari, A., Kaushik, R., Iqbal, H. M. N., & Parra-Saldívar, R. (2021). Diatoms recovery from wastewater: Overview from an ecological and economic perspective. *Journal of Water Process Engineering*, *39*, 101705. https://doi.org/https://doi.org/10.1016/j.jwpe.2020.101705

Simanjuntak, M. (2012). Kualitas Air Laut Ditinjau Dari Aspek Zat Hara, Oksigen Terlarut Dan pH Di Perairan Banggai, Sulawesi Tengah. *Jurnal Ilmu Dan Teknologi Kelautan Tropis*, *4*(2), 290–303. https://media.neliti.com/media/publications/102686-ID-none.pdf

Tilahun, A. B., Dürr, H. H., Schweden, K., & Flörke, M. (2024). Perspectives on total phosphorus response in rivers: Examining the influence of rainfall extremes and post-dry rainfall. *Science of The Total Environment*, *940*, 173677. https://doi.org/https://doi.org/10.1016/j.scitotenv.2024.173677

Tomas, C. R. (1997). *Identifying marine phytoplankton*. Elsevier.

Widayanti, T. F., Irfan, A. M., Djafar, E. M., Hakim, M. Z., Muin, A. M., Ratnawati, Riza, M., & Aswan, M. (2023). The Role of the Biological Diversity Convention in Mangroves Rehabilitation in Indonesia. *IOP Conference Series: Earth and Environmental Science*, *1181*(1), 0–10. https://doi.org/10.1088/1755-1315/1181/1/012006

Wohlgemuth, R. (2023). Advances in the Synthesis and Analysis of Biologically Active Phosphometabolites. *International Journal of Molecular Sciences*, *24*(4), 2–29. https://doi.org/10.3390/ijms24043150

Xiaohua, Z., Shuang, C., Zhengquan, G., Yulin, C., Qingshou, Y., Jiayang, Q., Xiangyong, L., & Senjie, L. (2023). Transcriptomics and physiological analyses unveil the distinct mechanisms of ATP and glucose-6-phosphate utilization in Phaeodactylum tricornutum. *Frontiers in Marine Science*, *10*(May), 1–11. https://doi.org/10.3389/fmars.2023.1163189

Xu, S., Liu, Y., Fan, J., Xiao, Y., Qi, Z., & Lakshmikandan, M. (2022). Impact of salinity variation and silicate distribution on phytoplankton community composition in Pearl River estuary, China. *Ecohydrology & Hydrobiology*, *22*(3), 466–475. https://doi.org/https://doi.org/10.1016/j.ecohyd.2022.01.004

Yuliana, Adiwilaga, E. M., Harris, E., & Pratiwi, N. T. M. (2012). Hubungan Antara Kelimpahan Fitoplankton Dengan Parameter Fisik-Kimiawi Perairan Di Teluk Jakarta. *Jurnal Akuatika*, *3*(2), 169–179.

Zhang, Z., Zhou, M., Zhong, Y., Zhang, G., Jiang, S., Gao, Y., Zhang, R., & Smith, W. O. (2020). Spatial variations of phytoplankton biomass controlled by river plume dynamics over the lower changjiang estuary and adjacent shelf based on high-resolution observations. *Frontiers in Marine Science*, *7*(October), 1–17. https://doi.org/10.3389/fmars.2020.587539