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Assessment of Water Quality Status, Nutrients, and Phytoplankton Communities in the Coastal Zone of East Aceh Regency, Indonesia

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ABSTRACT

Due to rapid urban development in the coastal area of the East Aceh Regency, water quality degradation and marine pollution issues become the primary concern in this region. Moreover, seasonal observation of water quality and phytoplankton has yet to be assessed. This study aimed to determine the control of seasonal water quality and nutrients over phytoplankton abundance throughout the East Aceh coast. Direct field measurements and laboratory analyses were performed to collect the primary data, whereby the sampling period was conducted during the displacement toward the ebb tide. We assessed the water quality parameters using a modified CWQI (coastal water quality index). Furthermore, linear regression and principal component analysis were performed as the basis of statistical analyses. The phytoplankton abundance was higher in April than in September, with most Bacillariophyceae and Dinophyceae in all observed stations. Except for DO and turbidity, the assessed water quality parameters (temperature, TDS, conductivity, salinity, sulfide, and TOM) are feasible for marine biota. Of particular concern, the East Aceh coast is characterized by poor-good water quality, with the CWQI value ranging from 40 to 90. Based on the regression and PCA analyses, N and P nutrients significantly control the phytoplankton abundance like a "seesaw" between April and September, with a respective coefficient determination of about 50%. Because of the tremendously high phosphate observed in April, the water condition tended to be P-limited and vice versa for September. On the other hand, instead of evoking the phytoplankton growth, each water quality parameter has a specific influence in characterizing phytoplankton communities in the study area.

Keywords: CWQI, coastal environment, East Aceh coast, statistical analyses.

INTRODUCTION

Marine pollution is a common issue in Indonesia's archipelago, particularly in the coastal zone, where the dynamic and change in water quality parameters vary depending on the source intake, season, and oceanographical states (Wisha et al., 2022). The increase in the industrial regions and the anthropogenic activities in many capital cities contributes to the increase in marine pollution cases (Qu et al., 2018). Many scholars have reported the impact of water quality degradation on marine biota and coastal ecosystems (Ondara et al., 2019; Rudi et al., 2012; Wisha et al., 2018, 2021; Wouthuyzen et al., 2015). Therefore, regular monitoring and studies are necessary to control the pollution level in a water area.

Aceh Province, situated on the northernmost tip of Sumatra Island, is well-known for its mesmerizing scenery and marine tourism. However, aside from Banda Aceh City, coastal pollution is recently reported in the East Aceh Regency due to increased urban development in the coastal area (Kasmini & Batubara, 2023; Rahmadi et al., 2023). Many rivers and estuaries throughout East Aceh Regency periodically supply anthropogenic-sourced wastes, resulting in pollutant accumulation in the coastal area. Moreover, significant developments, such as the settlement and industrial area in the coastal zone, also contribute to local water quality degradation.

On the other hand, East Aceh Regency is directly bordered by the Malacca Strait, where the ocean circulation from the Indian Ocean and Bengal Bay significantly controls the water motion in the coastal area (Koropitan et al., 2021). This circulation relates to the distribution of anthropogenic wastes in marine ecosystems (Wisha et al., 2022). Since the water quality parameters in the coastal zone are easily degraded depending on seasons and hydro-oceanographical conditions (Cho et al., 2020), seasonal monitoring is crucial to determine the pollution level in East Aceh Regency.

Aside from direct surveys in water quality conditions, phytoplankton abundance is a biological parameter that can be a bio-indicator determining the pollution level (Villanoy et al., 2011). Phytoplankton is a marine autotroph biota that is imperative to support the food chain as the primary producer in the ocean (Yusuf et al., 2021). Meanwhile, phytoplankton is also sensitive to changes in water environmental conditions, whereby a slight degradation in water quality could impact the decrease of phytoplankton communities (Purnamaningtyas et al., 2018). Thus, determining the abundance of phytoplankton could reflect the water condition.

Studies revealing the seasonal characteristics of phytoplankton communities in East Aceh Regency are not clearly elucidated, whereby Balqis et al. (2021) only surveyed the phytoplankton abundance and communities in one coastal village and only considered the mangrove area. On the other hand, the primary environmental factor determining the characteristics of phytoplankton communities has never been assessed. A previous study only examined the water quality in one or two rivers in the East Aceh Regency (Rahmadi et al., 2023). Therefore, determining the phytoplankton communities and water quality status is crucial for environmental monitoring. Furthermore, since the rapid urban development in the coastal area takes place in East Aceh Regency, the high accumulation of anthropogenic wastes in the coastal zone will increase the potency of nutrient pollution and enrichment, and these aspects should be investigated. As such, this study aims to determine the seasonal water quality status and nutrient pollution and their influence on shaping the phytoplankton communities throughout the East Aceh Regency coastal area. Aside from examining the actual environmental condition, this study is also expected to be a basis for further local regulation regarding coastal pollution and management.

MATERIALS AND METHODS

Study site and data collection

This research was conducted in the Aceh Timur coastal waters, Aceh Province, Indonesia (Figure 1). Generally, Aceh Timur Regency is characterized by lowland, hilly areas, swamps, and mangrove forest, with an elevation of about 0−308 m above sea level. The topographical condition of this region is divided into four classes: 0–2%, 2–15%, 5–40%, and >40%. Industrial activities in the surrounding coastal zone led to environmental degradation due to increased anthropogenic waste. Therefore, a water quality assessment is necessary to study its seasonal patterns in the Aceh Timur coastal area.

The primary data was collected using stratified sampling (Wisha et al., 2016). Sampling was conducted twice, from 22 to 26 April and 15 to 19 September 2015, at eight stations, focusing on Madat (station 1), Simpang Ulim (station 2), Arakundo (station 3), Geuleumpang (station 4), Peureulak (station 5), Parek (station 6), Bayeun (station 7), and Lebuk Buni (station 8) (Figure 1). The primary data were obtained directly in the field measured using a water quality checker TOA DKK (temperature, depth, transparency, conductivity, pH, dissolved oxygen, and dissolved organic matter) (Kusumaningtyas et al., 2014) and the other chemical and biological parameters were analyzed in the laboratory (nutrients and phytoplankton).

In addition to the field survey, samplings were conducted during the same tidal conditions (the displacement toward ebb tides), when the coastal water elevation was getting lower than the river, and the river-sourced pollutant distribution took place in the study area. Thus, we could precisely compare the sampling results during the same tidal conditions (Ondara et al., 2019). For the April survey, the sampling was conducted at the end of the spring tidal condition, while in September,

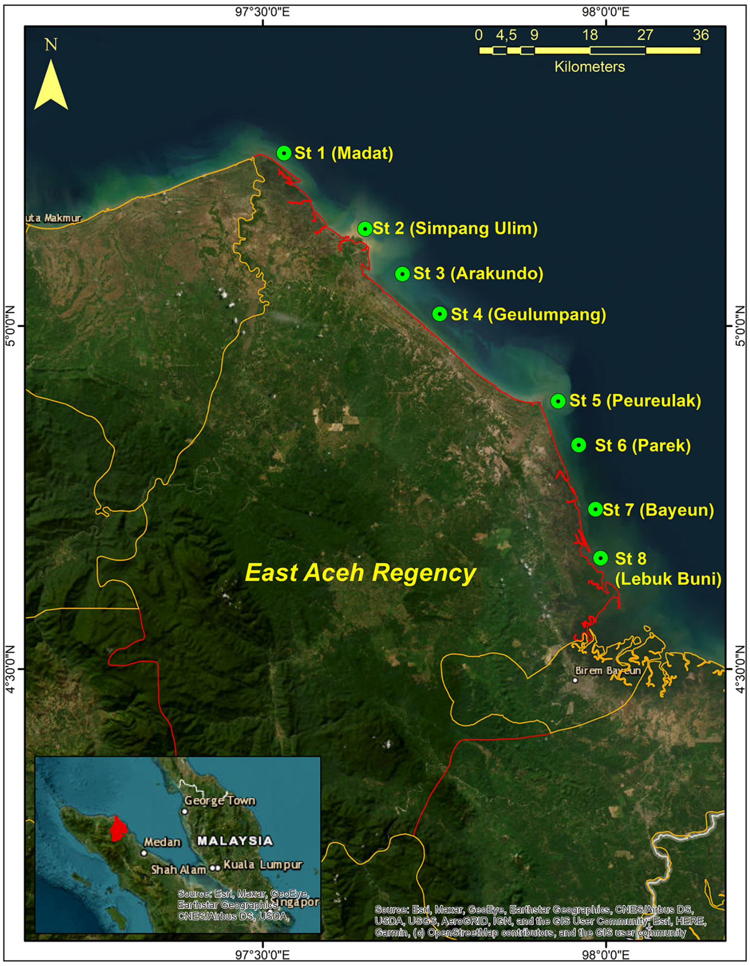

Figure 1. Study site and sampling stations

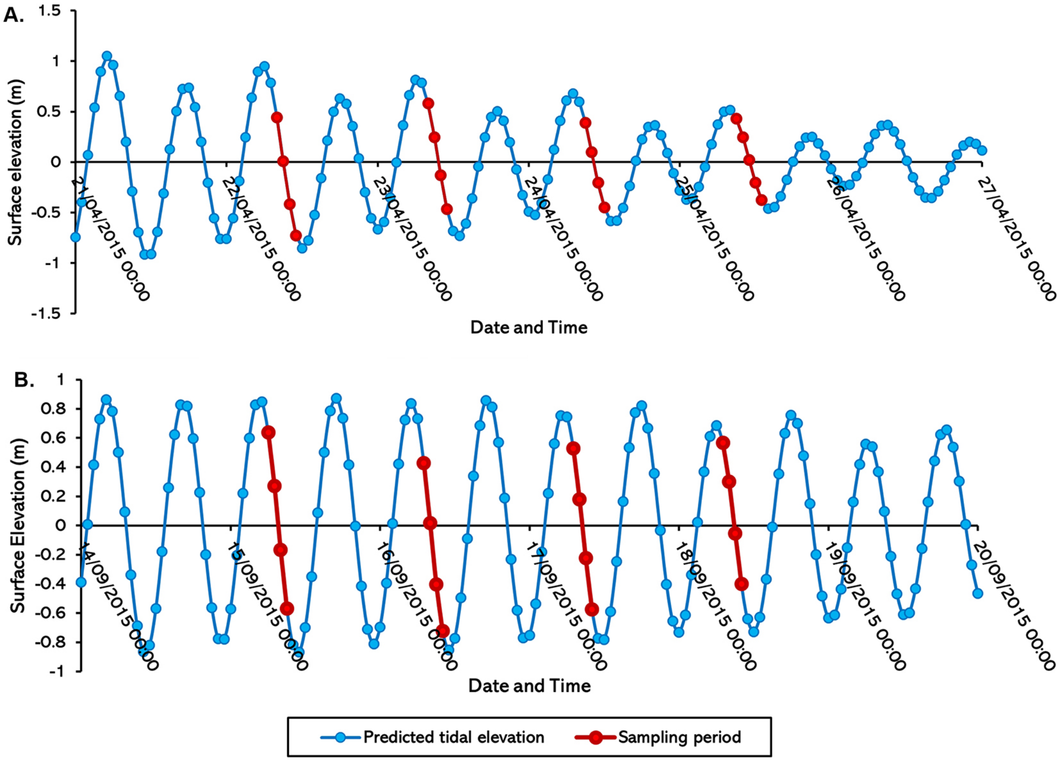

Figure 2. Tidal prediction during field survey in April (a) and in September (b)

the sampling was conducted in the middle of the spring tidal phase (Figure 2).

Phytoplankton samples were taken on the water's surface, which was withdrawn for 10 minutes at a constant speed. Phytoplankton were collected using a 76 μm phytoplankton net. The plankton samples obtained were then stored in bottles and preserved using 4% formalin. Each plankton net's mouth is equipped with a "flowmeter" to measure the volume of water entering the net. Measurement of filtered water volume is calculated by the following formula:

$$V = R \times a \times p \tag{1}$$

where: V – filtered water volume (m^3);
R – Number of rotations of the flowmeter vanes;
a – area of the mouth of the net;
p – the length of the water column (m) traveled for one rotation.

On the other hand, water samples for nutrient analysis were placed in a labeled bottle. The N and P compounds were prepared by adding four drops of H_2SO_4. In addition to P-nutrient analysis, the preparation was done without pickling (Wisha et al., 2018). The prepared samples were covered using aluminum foil and stored in a cool box.

Phytoplankton analysis

We employed a method proposed by APHA (American Public Health Association) in 2005 to analyze water quality parameters (Purnamaningtyas & Mujiyanto, 2021). The preserved phytoplankton samples were then analyzed using a Sedgewick Rafter method utilizing a light microscope with 100 times magnification. Identification books were used to identify the types of phytoplankton (Boyd, 1990; Davis, 1955; Yamaji, 1979). The phytoplankton abundance was estimated by employing the "Lackey Drop Microtranset Counting" as follows:

$$N_f = F_f \times n_f \tag{2}$$

$$F_f = \frac{A_f}{a_f \times L_f} \times \frac{V_2}{V_1} \times \frac{1}{V_f} \tag{3}$$

where: N_f – the abundance of phytoplankton (ind/L);
F_f – correction factor;
n_f – the amount of identified phytoplankton (ind);
A_f – the area of glass cover (mm^2);
a_f – the wide field of view (mm^2);
L_f – the number of visual fields;
V_1 – one drop of pipette volume (mL);
V_2 – sampled water volume (mL);
V_f – volume of filtered water in the field using a plankton net (L).

Nutrient analysis

Water samples prepared in the field were then filtered using a nitrocellulose membrane, with pore size and diameter of about 0.45 μm and 47 mm, respectively. The filtered samples were then stored in a refrigerator. The nutrient contents were analyzed using a spectrophotometric device with a specific wavelength. Nitrate was identified by applying a wavelength of 410 nm, whereby brucine was also identified. The detection of ammonia concentration was performed by applying a 640 nm wavelength with a range of 0.01 to 0.6 mg/L. Unlike the previous analyses, nitrites were determined within an acidic condition, with pH ranging from 2 to 2.5, resulting from the nitrite reaction to azo compounds. The scarlet color yielded was then analyzed in the spectrophotometer applying a 543 wavelength (Wisha & Maslukah, 2017).

On the other hand, determining phosphate concentration was done by applying ascorbic acid levels. The primary stage of this analysis is the blue phosphomolybdic complex compounds formation. This compound was reduced by ascorbic acid to gain a molybdenum complex with blue color. The color intensity from the above analysis was detected as the phosphorus concentration. The wavelength set for this analysis is 700-880 nm (Butler, 1984).

Coastal water quality index assessment

According to the number of analyzed parameters, it is sufficient to be assessed to determine the water quality status in the study area. The water quality index is an effective tool for determining the water quality status and is easy to understand (Gupta et al., 2003). We used the coastal water quality index (CWQI) derivation according to (Jha et al., 2015) with a slight modification in the parameter used for the assessment, as follows:

$$CWQI = \sum \left(\frac{k}{V_i}\right) \times V_r \tag{4}$$

Table 1. The standard value used in the CWQI assessment

Parameter	Unit	Standard quality	Source
Temperature	°C	Natural (less than 2 °C changes are allowed)	Water Quality Standard Number 22 in 2021
Turbidity	NTU	5	Water Quality Standard Number 22 in 2021
Total dissolved solid (TDS)	mg/L	35,000	(Moran, 2018)
pH	-	7 – 8.5	Water Quality Standard Number 22 in 2021
Conductivity	mS/cm	55	Water Quality Standard Number 22 in 2021
Salinity	$^{o}/_{oo}$	Natural (less than 5% changes toward the seasonal average are allowed)	Water Quality Standard Number 22 in 2021
Sulfide	mg/L	0.01	Water Quality Standard Number 22 in 2021
Dissolved oxygen (DO)	mg/L	>5	Water Quality Standard Number 22 in 2021
Total organic matter (TOM)	mg/L	-	Water Quality Standard Number 22 in 2021
Nitrite	mg/L	0.008−0.01	(Jiwarungrueangkul et al., 2023)
Nitrate	mg/L	0.06	Water Quality Standard Number 22 in 2021
Ammonia	mg/L	0.3	Water Quality Standard Number 22 in 2021
Phosphate	mg/L	0.015	Water Quality Standard Number 22 in 2021

Table 2. CWQI ranking criteria (Jha et al., 2015)

CWQI range	Category
0–25	Very poor
26–50	Poor
51–70	Moderate
71–90	Good
91–100	Very good

where: k – constant of proportionality;
V_i – recommended permissible limit of the ith parameter;
V_r – rating of each parameter (within a scale of 0 to 100).

The rating scale is based on the concentration parameter as per standard quality. In this case, we employed a national water quality standard for marine biota established by the Indonesian government, regulation number 22 in 2021 (Table 1). Moreover, other standards based on several previous studies were also considered. After tabulating all sub-indices considered in the CWQI, we rank the result by comparing it to CWQI ranking criteria, as shown in Table 2.

Statistical analyses

The statistical analyses used in this study consisted of two stages. The first analysis was stepwise regression (Agostinelli, 2002) to examine how strong the influence of water quality is in determining the abundance of phytoplankton. This analysis was performed using a statistical program, version 10, associated with Microsoft Excel. Meanwhile, the second analysis was principal component analysis (PCA) to determine the relationship among parameters in each observation station. The number of factors used in the multi-variable is quantified based on the cumulative number of representative roots. The calculation of PCA was performed using Past software version 4.03 (Hammer et al., 2001). The considered variables have different units, so they should be standardized beforehand. The standardization formula is as follows:

$$z = \frac{(y - \bar{x})}{sd} \tag{5}$$

where: z – the standardized value from the assessed variables;
y – the value of the assessed variables;
$\bar{x}$ – the mean value of the assessed variables;
sd – standard deviation of the assessed variables.

RESULTS AND DISCUSSION

The abundance of phytoplankton

The results of phytoplankton analysis are shown in Tables 3 and 4. The phytoplankton consisted of four classes identified from the April survey and two classes observed in September. We identified one genus of Cyanophyceae, one Chlorophyceae, 29 Bacillariophyceae, and 8

Dinophyceae. Overall, even though the identified genera were more variable and abundant in April, the total genera were generally higher during September. The highest abundance was observed in Kuala Arakudo (station 3), with 1,143,666 cells/L; the lowest abundance was found in Simpang Ulim (station 2), with 52,371 cells/L.

At station 1 (Mandat), the abundance of phytoplankton in April was higher than in September, with a deviation of 65,039 cells/L. The

Table 3. The abundance of phytoplankton in every observation station during April survey

Phytoplankton	Observation stations							
	Station1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Cyanophyceae class								
Trichodesmium sp.	14,154	-	5,662	-	14,154	-	2,831	11,323
Chlorophyceae class								
Pediastrum sp.	-	14,154	-	-	-	-	-	-
Bacillariophyceae class								
Asterionella sp.	-	-	21,231	76,433	-	-	-	-
Bacillaria sp.	-	-	-	-	-	-	-	-
Bacteriastrum sp.	-	-	-	-	-	-	192,498	2,831
Biddulphia sp.	15,570	1,415	244,869	5,662	89,172	336,872	35,386	16,985
Campylodiscus sp.	-	-	-	-	-	-	-	-
Cerataulina sp.	11,323	-	48,125	5,662	15,570	32,555	7,077	1,415
Chaetoceros sp.	28,309	-	302,902	215,145	19,816	53,786	339,703	475,584
Cococcneis sp.	-	-	-	-	-	-	1,415.428	-
Corethron sp.	-	-	-	-	-	-	-	5,662
Coscinodiscus sp.	32,555	12,739	26,893	89,172	39,632	24,062	59,448	73,602
Cyclotella sp.	-	-	2,831	-	-	-	-	-
Cylindrothecasp	-	-	19,816	-	-	-	-	-
Dytilum sp.	-	-	-	12,739	2,831	-	-	16,985
Flagillaria sp.	7,077	-	-	9,908	-	-	4,246	1,415
Guinardia sp.	-	-	-	-	-	-	-	-
Hemiaulus sp.	2,831	-	48,125	-	2,831	15,570	1,415	-
Lauderia sp.	2,831	-	4,246	-	-	28,309	2,831	32,555
Leptocylindrus sp.	-	-	-	2,831	-	-	-	4,246
Licmophora sp.	-	-	-	-	-	-	-	-
Navicula sp.	-	1,415	1,415	-	-	2,831	12,7389	-
Nitzchia sp.	16,985	22,647	4,246	22,647	14,154	69,356	7,077	19,816
Planktonella sp	1,415	-	-	-	-	-	4,246	2,831
Pleurosigma sp.	1,415	-	1,415	2,831	1,415	-	16,985	18,401
Rhizosolenia sp.	9,908	-	291,578	21,231	18,401	273,178	111,819	15,570
Strepthoteca sp.	2,831	-	-	9,908	14,154	121,727	14,154	33,970
Triceratium sp.	-	-	2,831	-	-	-	14,154	2,831
Thalassionema sp.	-	-	-	7,077	5,662	-	-	8,493
Dinophyceae class								
Ceratium sp.	33,971	-	21,231	21,231	29,724	31,139	59,448	113,234
Dinophysis sp.	33,970	-	41,047	-	14,154	52,371	19,816	16,985
Dictyocha sp.	-	-	-	-	-	-	-	-
Pissodinium sp	-	-	-	-	-	-	-	-
Protoperidinium sp.	14,154	-	11,323	1,415	62,279	11,323	55,202	26,893
Prorocentrum sp.	-	-	-	-	-	-	15,570	1,415
Pryrocistis sp.	-	-	43,878	-	24,062	-	8,493	2,831
Pyrophacus sp.	-	-	-	-	-	-	-	-
Total cells/L	229,299	52,371	1,143,666	503,892	368,011	1,053,079	973,815	905,874
Total genera	16	5	19	15	16	13	22	23

highest abundance was detected in the Bacillariophyceae class and genus *Coscinodiscus sp.* in April and September surveys. Coscinodiscus is a significant genus to ocean food webs and carbon export (Qu et al., 2018), widespread from the higher latitude toward the tropical region, followed by Dinophyceae, Cyanophyceae, and Chlorophyceae classes (Ferrario et al., 2008). Similar to station 1, Coscinodiscus predominated the surrounding coastal area of station 2, with an abundance ranging from 12,578 to 24,062 cells/L, getting more abundant in September. The other predominant genera are *Chaetoceros* in April and *Nitzchia* in September, with respective abundance of 9,908 and 22,647 cells/L. In this station, the phytoplankton abundance was

Table 4. The abundance of phytoplankton in every observation station during September survey

Phytoplankton	Observation stations							
	Station1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Bacillariophyceae class								
Bacillaria sp.	8,493	-	-	1,415	-	1,415	-	-
Bacteriastrum sp.	4,246	-	-	12,739	-	4,246	12,739	4,246
Biddulphia sp.	2,831	8,493	19,816	7,077	14,154	18,400	19,816	2,831
Campylodiscus sp.	2,831	-	-	-	-	-	-	-
Cerataulina sp.	-		-	-	-	-	12,739	32,555
Chaetoceros sp.	11,323	9,908	4,246	21,231	28,309	11,323	-	-
Cococcneis sp.	1,415	-	-	-	-	-	56,617	38,217
Corethron sp.	-	-	-	-	-	-	-	-
Coscinodiscus sp.	35,386	24,062	42,463	19,816	35,386	108,988	11,323	35,386
Cyclotella sp.	1,415	-	-	-	-	-	-	-
Cylindrothecasp	-	-	-	-	-	123,142	9,908	-
Dytilum sp.	1,415	7,077	7,077	2,831	8,493	16,985	1,415	-
Flagillaria sp.	-	-	-	-	-	8,493	2,831	-
Guinardia sp.	5,662	1,415	8,493	-	-	1,415	-	4,246
Hemiaulus sp.	-	-	-	2,831	-	1,415	-	-
Lauderia sp.	8,493	4,246	35,386	12,739	15,570	-	-	-
Leptocylindrus sp.	1,416	1,415	-	2,831	1,415	-	-	-
Licmophora sp.	-	-	-	-	-	59,448	9,908	1,415
Navicula sp.	-	-	-	21,232	-	5,662	11,323	2,831
Nitzchia sp.	1,415	1,415	5,662	7,077	5,662	-	58,033	2,8309
Planktonella sp	-	-		1,415	-	63,694	8,493	-
Pleurosigma sp.	2,831	1,415	1,415	1,415	2,831	191,083	12,739	7,077
Rhizosolenia sp.	38,217	16,985	15,570	32,555	32,555	-	-	-
Strepthoteca sp.	1,415	-	-	-	-	32,555	-	-
Triceratium sp.	-	-	-	-	-	-	5,662	-
Thalassionema sp.	-	-	-	-	-	2,831	-	24,062
Dinophyceae class								
Ceratium sp.	22,647	8,493	14,154	8,493	9,908	15,570	11,323	18,401
Dinophysis sp.	1,415	1,415	11,323	5,662	14,154	7,077	-	1,415
Dictyocha sp.	1,415	-	-	-	-	-	-	-
Pissodinium sp	1,415	-	-	-	-	-	-	-
Protoperidinium sp.	8,493	4,246	1,415	1,415	14,154	4,246	15,570	2,831
Prorocentrum sp.	-	-	-	-	-	1,415	1,415	-
Pryrocistis sp.	-	-	1,415	1,415	1,415	7,077	-	5,662
Pyrophacus sp.	-	-	1,415	1,415	-	21,231	-	1,415
Total cells/L	164,190	90,587	169,851	165,605	184,006	707,714	261,854	210,898
Total genera	21	13	14	19	13	22	17	16

higher in September than in April, with a deviation of about 38,216 cells/L.

At station 3, the highest abundance of phytoplankton was in April at 1,143,666 cells/L. The highest abundance was in the Bacillariophyceae class of the genus *Chaetoceros* 302,902 cells/L, *Rhizosolenia* 291,578 cells/L, and *Biddulphia* 244,869 cells/L. The abundance of plankton in September was 169,851 cells/L, with the highest abundance in the genus *Coscinodiscus* at 42,463 cells/L, *Lauderia* at 35,386 cells/L, and *Biddulphia* at 19,816 cells/L. The Bacillariophyceae class was more dominant at station 3 than the previous station, with a total abundance ranging from 165,605 to 503,892 cells/L and increasing in April. The most abundant genera were *Chaetoceros* (215,145 cells/L), *Cocinodiscus* (89,172 cells/L), *Astrinella* (76.433 sel/L), *Rhizosolenia* (32,555 cells/L), and *Navicula* (21,231 cells/L).

A similar pattern was observed at station 4, where Bacillariophyceae showed predomination in the surrounding seawater. It was more abundant in April than in September. The most dominant genera were *Biddulphia* 89,172 cells/L, *Cocinodiscus* 39,632 cells/L, *Rhizosolenia* 32,555 cells/L, *Navicula* 21,231 cells/L and *Chaetoceros* 21,232 cells/L.

The second-highest abundance of phytoplankton observed in April was found at station 5, with a total of 1,053,079 cells/L. The most abundant genera during this season were *Biddulphia* (336,872 cells/L), *Rhizosolenia* (273,178 cells/L), and *Streptholeca* (121,727 cells/L). On the other hand, the highest amount of identified phytoplankton in September was also detected, reaching 905,874 cells/L. Different dominant genera were also observed, whereby during this season, the most abundant genera were *Pleurosigma* (191,083 cells/L), *Planktonella* (63,694 cells/L), and *Liemophora* (59,448 cells/L).

The remnant stations are Bayeun and Lebuk Buni (stations 7 and 8), where the Bacillariophyceae was the majority class observed in these stations. The total amount of observed phytoplankton in April was generally higher than September, with a deviation of about 712,000 and 694,975 cell/L for Bayeun and Lebuk Buni stations, respectively. The most abundant genera during the April survey were *Chaetoceros* (475,584 cells/L), *Bacteriastrum* (192,498 cells/L), *Rhizosolenia* (111,819 cells/L), *Coscinodiscus* (73,602 cells/L), and *Lauderia* (32.555 cells/L). While during the September survey, the most abundant genera were *Nitzchia* (58,033 cells/L, *Cococcneis* (56,617 cells/L), *Biddulphia* (19,816 cells/L), and *Coscinodiscus* (35,386 cells/L).

Overall, the Bacillariophyceae class was the most dominant on the East Aceh coast, with the highest abundance genera of *Chaetoceros*, *Rhizosolenia*, *Biddulphia*, and *Coscinodiscus*. This finding is consistent with previous studies whereby *Cahetoceros* and *Rhizosolenia* are the diatom genera with a wide range of distribution in water (Asiah et al., 2021; Wisha et al., 2018). The high amount of diatom (Bacillariophyceae) over the Indonesian seas is also identified by several scholars (Gao et al., 2018; Purnamaningtyas et al., 2018; Purnamaningtyas & Mujiyanto, 2021; Yusuf et al., 2021). The predominance of diatom in the East Aceh coastal area indicates the nutrient-rich coastal ecosystem (Malviya et al., 2016). On the other hand, the increase in seawater CO_2 could stimulate diatom's growth and photosynthetic efficiency (Harvey et al., 2019; Qu et al., 2018). The dominance of phytoplankton genera relies on water quality and pollution levels (Yusuf et al., 2021). Therefore, water quality assessment at the same observation station on the East Aceh coast is crucial to examining the most influential environmental parameters shaping phytoplankton abundance.

Aside from the dominance of diatoms in April and September, the second largest communities found were from Dinophyceae class, which was more observed in September. *Ceratium* and *Protoperidinium* were the most dominant genera found in all observation stations, with an abundance on average of about 13,623.495 and 6,546.354 cells/L, respectively. This phytoplankton class is susceptible to nutrients, light, temperature, and salinity (John & Flynn, 2000; Liu et al., 2001). The primary dissolved nutrients in the water (N:P) shape the community of Dinophyceae, which is significant in supporting photosynthesis and growth (Li et al., 2000). Therefore, assessing the nutrient status in the study area is imperative to understand the impact of environmental status on phytoplankton abundance. This aspect will be elucidated in the following subsection.

Concerning the seasonal variation of phytoplankton in the study area, the abundance during the dry season (southwest monsoon) was lower compared to the wet season (northeast monsoon). This condition has been previously elucidated by Cho et al. (2020), whereby the abundance of diatom is characterized by the magnitude of rainfall, water quality, and biotic compositions

Water quality data

Based on two times of field measurement (April and September), two parameters were generally abnormal (exceeding/below the standard quality) in all stations (turbidity and dissolved oxygen). However, the other parameters showed an excellent level for supporting marine biota (Figure 3). Overall, the water quality status was not considerably altered during two different seasons unless one/two stations where significant changes in magnitude were observed.

Water temperature on the East Aceh coast was generally higher in September than in April, ranging from 30 to 32.5 °C and 29 to 32 °C, respectively (Figure 3a). A significant temperature difference was observed at station 4 (Geulumpang), where the temperature increased by more than 2 °C. Even though based on the quality standard established by the Indonesian government in regulation number 22 in 2021, there are no specific standards for seawater temperature (it is dependent on the natural condition of every evaluated area), the sufficiently high temperature observed on the East Aceh coast will impact the local ecosystem, such as coral reefs. According to Wisha et al. (2021), the ideal temperature for coral reef ecosystem should be around 28 °C. Temperature is a significant parameter in the coastal environment, whereby the temperature changes could affect the other environmental parameters and directly/indirectly impacts marine biota in the locality. Furthermore, the high-value temperature evokes the toxicity level in water by triggering the deposition of dissolved heavy metals and even nutrients (Simanjuntak, 2009).

Turbidity value in the study area generally exceeded the standard quality for supporting marine biota (>5 NTU) (Figure 3b) in all seasons and stations. The highest turbidity was observed in station 5 (Peureulak), particularly during September, reaching 45 NTU. Estuaries in the surrounding station 5 reflect the suspended sediment intake derived from the land transported by the runoff system, thereby increasing the turbidity (Ávila et al., 2021). However, the remnant stations showed a similar pattern during the two measurements, with a turbidity value ranging from 6 to 30 NTU.

Total dissolved solids (TDS) and pH parameters were most likely suitable for the ecosystem and showed an agreement with the quality standard (see Table 2), with a value of about 35,000 mg/L and 8, respectively (Figures 3c and d). The value of TDS was almost equal between the two measurements, and no significant difference was observed. On the other hand, even though the lowest value of pH was identified at station 8 (Lebuk Buni), the other stations showed a similar value (pH>8) in April and September as well.

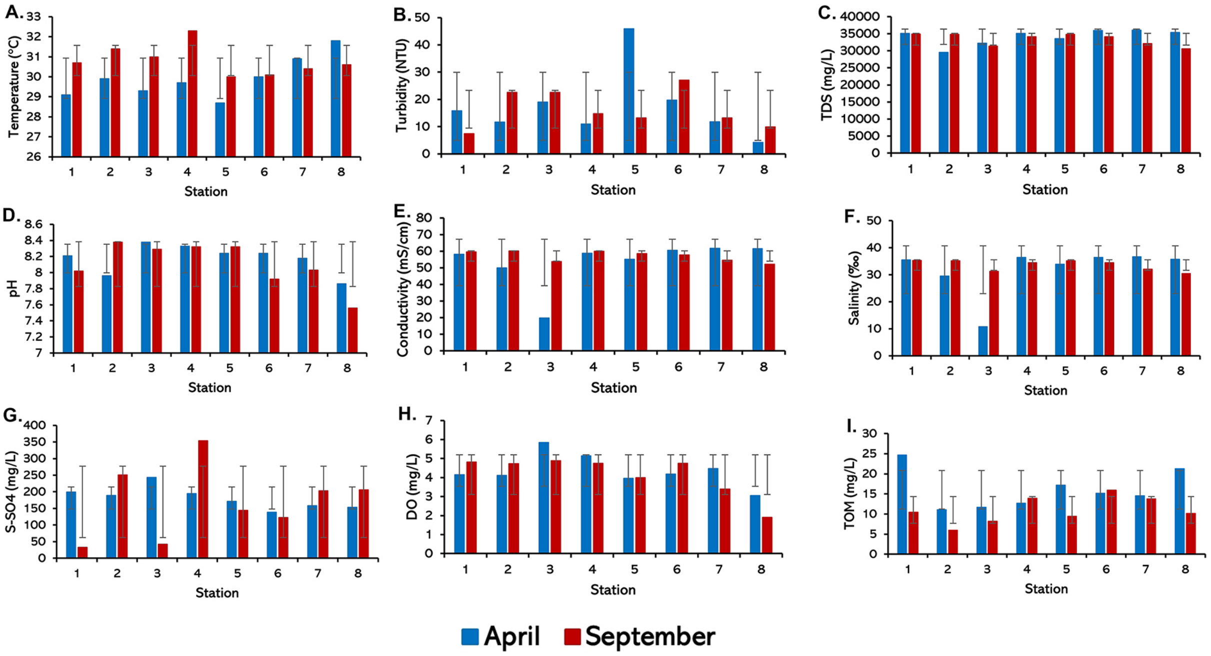

Figure 3. Water quality in the study area observed in April (blue bars) and September (red bars). Water temperature (a); turbidity (b); TDS (c); pH (d); conductivity (e); salinity (f); sulfate (g); dissolved oxygen (h); and total organic matter (i). The grey lines within the bars denote the standard deviation of every data

A similar pattern between conductivity and salinity was observed in every station. The higher salinity, the higher conductivity, ranging from 20 to 67 mS/cm and 12 to 38 $^{o}/_{oo}$ (Figures 3e and f). Compared to the standard quality established by the Indonesian government in regulation number 22 in 2021, conductivity and salinity parameters are suitable for supporting marine ecosystems, except for the observation result at station 3, where tremendously low values of these parameters were observed, particularly in April.

Varying sulfate concentrations were observed in the northern study area, particularly at stations 1, 2, and 4, where the value was arbitrarily erratic during April and September with a deviation of about >150 mg/L (Figure 3g). The ununiform sulfate concentration was detected during September, ranging from 30 to 350 mg/L. While in April, it tended to be more stable in every station ranging from 140 to 250 mg/L.

Concerning the DO value, generally, it was very typical for supporting water ecosystems in several stations, with a value of about five mg/L during April and September (Figure 3h). However, the April data showed a <5 mg/L trend at stations 1, 2, 5, 6, and 8. The DO was relatively low in the southernmost area (stations 7 and 8), reaching 2.5 mg/L, indicating a hypoxia tendency (Wisha et al., 2021). By contrast, the opposite condition was observed in total organic matter (TOM) results, whereby toward the south of the study area, the TOM concentration tended to be higher, ranging from 6 to 20 mg/L. Generally, there were no considerable changes between April and September data.

Nutrient concentrations and its role in the water environment

Table 5 shows the water nutrient data on the East Aceh coast. Overall, the N and P nutrient concentration was higher in April than in September, with an average deviation of 0.4 mg/L. Nitrate concentration ranged from 0.001 to 0.346 mg/L in April and 0.01 to 0.013 mg/L in September. The highest concentration was observed at stations 2 and 8, reaching 0.3 mg/L. According to the quality standard established by the Indonesian Government number 22 in 2021, the allowed nitrate concentration is supposed to be around 0.06 mg/L. Hence, the nitrate enrichment was found at stations 8, where the nitrate ranged from 0.013 to 0.177 mg/L. The unutilized and regular intake of nitrate from estuaries could trigger nitrate enrichment in water, which may cause a toxic environment (John & Flynn, 2000). However, the nitrate value was generally below the standard in the other stations, indicating that nitrate pollution is minimal, even though a sufficiently high nitrate was observed at stations 2 and 5, ranging from 0.023 to 0.346 mg/L during the April survey.

Unlike nitrate, nitrite concentration was sufficiently higher in all observed stations in two measurement periods, which was more than standard quality (>0.015 mg/L). Nitrite ranged from 0.01 to 0.681 mg/L in April and 0.01 to 0.527 mg/L in September, respectively (Table 5). The highest concentration was observed at station 2, with more than 0.5 mg/L nitrite. The nitrite concentration, significantly above the quality standard, relates to the previously elucidated low dissolved oxygen and nitrate. In this case, due to the low content of oxygen, the nitrobacteria could not work optimally to transform nitrite compounds to nitrate, thereby hampering the N cycle in the study area (Wisha et al., 2018; Wisha & Maslukah, 2017).

Ammonia concentration ranged from 0.44 to 1.55 mg/L in April and 0.13 to 1.913 mg/L in September, respectively (Table 5). Generally, almost in all observed stations, the ammonia value was above the allowed value for supporting biological

Table 5. Detected nutrient concentration in the study area

Station	N-NO$_2$ (mg/L)		N-NO$_3$ (mg/L)		N-NH$_4$ (mg/L)		DIN (mg/L)		DIP (P-PO$_4$) (mg/L)	
	April	September	April	September	April	September	April	September	April	September
1	0.005	0.001	0.454	0.005	0.971	1.456	1.431	1.462	0.201	0.005
2	0.346	0.004	0.681	0.527	1.556	1.300	2.583	1.831	0.582	0.059
3	0.002	0.002	0.360	0.180	0.001	1.913	0.361	2.095	0.042	0.010
4	0.001	0.001	0.310	0.001	1.100	1.685	1.411	1.686	0.188	0.024
5	0.023	0.002	0.559	0.002	0.444	0.700	1.025	0.704	0.735	0.001
6	0.001	0.007	0.001	0.038	1.414	0.130	1.414	0.175	0.012	0.001
7	0.006	0.011	0.001	0.001	0.701	0.230	0.706	0.241	0.011	0.001
8	0.177	0.013	0.488	0.146	0.658	1.071	1.322	1.230	0.269	0.001

life, which is supposed to be around 0.3 mg/L. The pattern of ammonia concentration in each station was similar to nitrate and nitrite, where the highest value was found at station 2, reaching 1.5 mg/L in April. While in September, the highest ammonia value was observed at station 3, with a concentration of 1.9 mg/L. The value of ammonia shows that the N fixation and ammonification processes take place very well. In water, cyanobacteria could bind free N (N_2) from the atmosphere (Wisha et al., 2018). This process is called N fixation yielding an ammonia compound, whereby the resulting organic N can be used by autotroph biota to support the growth process (Igarashi & Seefeldt, 2003). On the other hand, the ammonia resulted from ammonification, with the role of decomposers, will produce protein N or amino acids (Igarashi & Seefeldt, 2003; Li et al., 2013).

A contrary phosphate concentration was observed during April and September surveys. In April, the concentration was tremendously high in all stations ranging from 0.01 to 0.735 mg/L. By contrast, in September, the phosphate concentration was deficient, with almost undetectable value. The range of phosphate values was about 0.001 to 0.059 mg/L (Table 5). According to Indonesian government regulation number 22 in 2021, the standard phosphate concentration in water should be around 0.015 mg/L to support biota life.

Meanwhile, the detected phosphate value in the study area was considerably high, particularly in April. This state reflects that the potency of blooming may be high. As a limited nutrient in water, phosphate plays a significant role in controlling the growth of autotroph biota, and concentration ranging from 0.35 to 0.1 mg/L or higher could potentially induce algal blooms (eutrophication) (Zhang et al., 2017). On the other hand, the tremendously low phosphate observed in September reflected P input from the surrounding land or sources. Within the water environment, phosphate undergoes dissolution and precipitation, transforming into inorganic phosphate, soluble inorganic phosphate, and polyphosphate. From these cycles, the biological, organic, and inorganic phosphates will be deposited in the sediment because of its instability as a gas, so the concentration of P in the water column (dissolved phosphate) is limited (Griffin, 2017). In addition, it should be noted that in the following discussion, we use the total speciation of nitrogen (dissolved inorganic nitrogen/DIN) and total inorganic phosphorus equal to P-PO4 (DIP) to compare the ratio of N:P and other nutrient analyses.

Water quality index assessment

Based on the water quality and nutrient parameters evaluation, the variation in water quality index value between April and September is shown in Figure 4. Overall, CWQI value varies considerably in every station, ranging from 40 to 90, whereby stations 1 to 3 and 5 tend to increase, and stations 4, 6, 7, and 8 show a downward trend. Furthermore, except for station 3 (good water category), the remnant stations are categorized as moderate and poor water quality.

At station 1, the water quality was getting better in September, whereby in April, it was categorized as moderate water quality, and it changed to good water quality, with an increased CWQI value of about 11.57%. On the

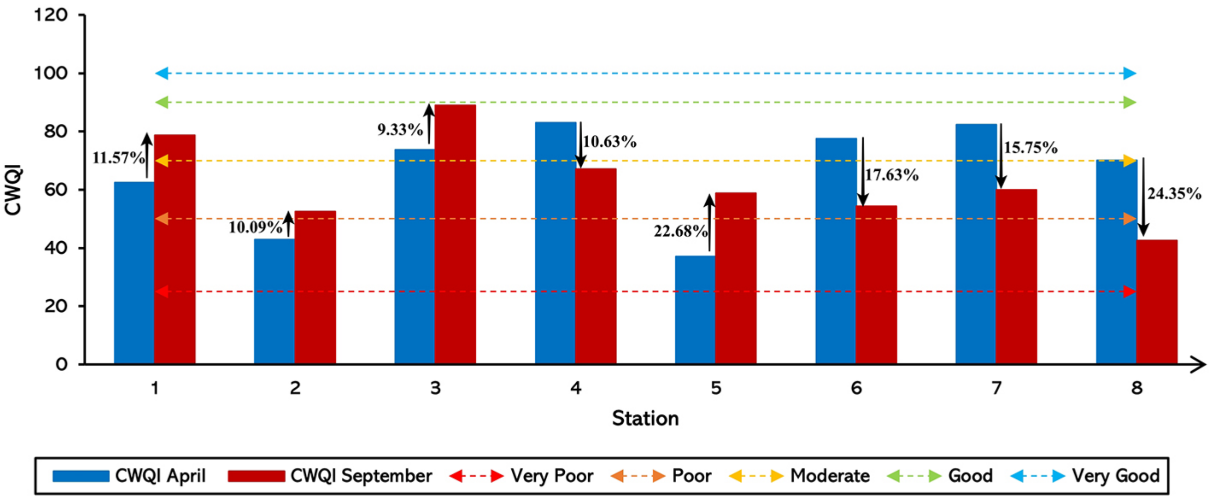

Figure 4. The results of coastal water quality assessment in the study area during the two different seasons

other hand, the lowest CWQI value was observed at station 2, which it was categorized as poor water quality in April and moderate water quality in September, with an increased value of about 10.09%. By contrast, the best water quality status was found at station 3, where based on the CWQI value, it was categorized as good water quality both in April and September, even though the CWQI value increased in September with a deviation of about 9.33%. Unlike the previously described stations, the CWQI value at station 4 declined from April to September, with a decline of about 10.63%.

Similar to station 2, the CWQI value calculated at station 5 showed an increased state from April to September, even though the status changed from poor to moderate water quality; percentage-wise, the increased value was approximately 22.68%. The same condition was observed at stations 6 and 7, whereby the CWQI value decreased by about 17.63% and 15.75% from April to September, given a category from good to moderate water quality. The last station (station 8) showed a similar pattern with stations 6 and 7, but the CWQI value changed from moderate water quality in April to poor water quality in September, with a decline of about 24.35%.

Compared to the abundance of phytoplankton, the water quality did not solely shape the communities. Good water quality could only sometimes ensure the state of phytoplankton communities. Key factors, such as nutrients, should have a higher influence on phytoplankton growth and abundance. Therefore, we will assess the influence of nutrients on shaping the phytoplankton communities in the following subsection.

N and P limitations and its influence on the abundance of phytoplankton

Figure 5 illustrates the unstable N:P ratios in all observed stations during April and September. Overall, an opposite condition between April and September was observed like a “seesaw”, whereby phosphate concentration was tremendously high in April and vice versa in September. The higher the ratio value, the greater the nitrogen

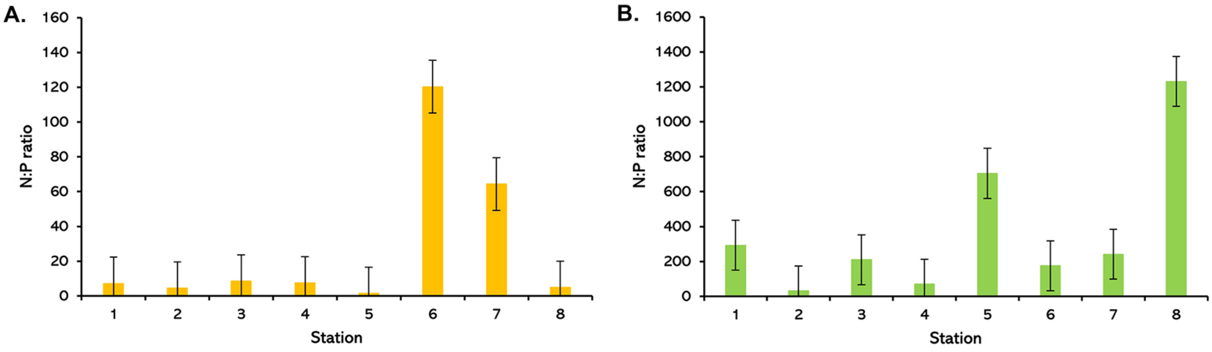

Figure 5. The N/P ratio in the study area for April survey (a) and September survey (b)

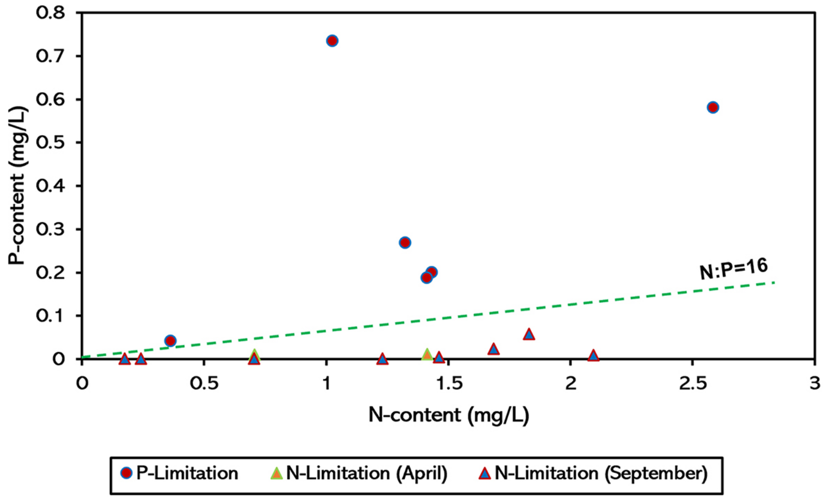

Figure 6. N and P contents compared to the natural state of N/P limitation in the study area

intake in the water environment, thereby evoking an imbalanced nutrient condition.

In April, except for stations 6 and 7, the remnant stations showed a lower N:P ratio value (less than 16), showing that the P concentration was really high, ranging from 0.04 to 0.7 mg/L. By contrast, in September, the N:P ratios were tremendously high (more than 100), indicating that the P content was very low, ranging from 0.001 to 0.05 mg/L and the N nutrient and its derivatives were predominant in water of the study area. These ratios show the potency of algal-bloom, mainly controlled by N and P nutrients. Anthropogenic activities likely shape the nutrient intake from the land to the coastal area of East Aceh (Balqis et al., 2021), whereby the high nutrient concentrations are resulted from the husbandry wastes and the high level of detergent utilization (Wisha et al., 2018).

The discrimination of the N:P ratio for N- and P-limited sites is shown in Figure 6. For the stations with N:P ratio > 16, the phytoplankton abundance is P-limited (there is a very low concentration of P), while for N:P<16, it shows that the N limits the phytoplankton abundance and communities. For N:P ratio equals to 16, either N or P may limit the phytoplankton productivity or those two elements are co-limiting (Tessier & Raynal, 2003; von Oheimb et al., 2010).

No station having an N:P ratio equals to 16. However, there is one station (station 4) having a N:P ratio of about 20 observed in September. According to Wisha et al. (2018), N will be more controlling the growth of the autotroph biota within an N:P ratio of 20. Generally, almost all stations were P-limited in April, which only two stations with low Phosphate in the condition of N-limited. By contrast, due to the very low and undetectable P in September, all stations were N-limited. Concerning the phytoplankton communities, there were several genera that were not found in September due to the limitation of P content, such as *Trichodesmium* and *Pediastrum.* This state shows that specific genera of phytoplankton is sensitive to the change or an imbalanced condition of N:P ratio (von Oheimb et al., 2010).

The N and P content on the East Aceh coast are mainly determined by the supply of N:P ratios. A very high N reflects a situation where N is more available relative to P; in such situation, the total P could be high and the N is not necessarily high anymore. The total N and P have a specific influence on phytoplankton production, whereby they have a special limitation on the phytoplankton growth. N and P, together with other nutrients, such as carbon and silicate, control the abundance of phytoplankton in the water environment (Wagenhoff et al., 2011).

Based on the linear regression analysis shown in Figure 7, N and P equally determined the phytoplankton abundance in April, with the respective R^2 of about 0.5, even though the P content was more limiting the water, with a deviation of about 0.02 (Figure 7a). In this case, phytoplankton abundance is set as the dependent variable, while the nutrients are the independent variables. On the other hand, a different condition was identified in September, whereby the N-nutrient determined the phytoplankton abundance, with a coefficient determination of about 48%. While the P-nutrients only determined 18% of phytoplankton communities (Figure 7b). Hence, a 32% variance of the dependent variable (phytoplankton abundance) was explained by other factors. Many scholars have proven that the high productivity of P evokes the bacterial population and respiration rates, thereby

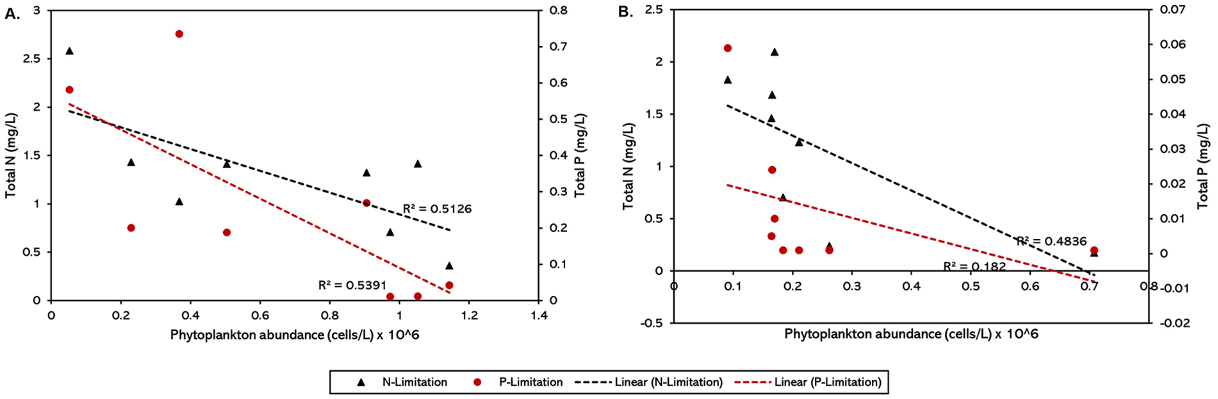

Figure 7. The correlation between the abundance of phytoplankton and the nutrient content in the study area based on April survey (a) and September survey (b)

inducing anoxia and hypoxia conditions (Pan et al., 2021; Zhang et al., 2017). Furthermore, the release of P could deteriorate the water condition due to eutrophication reinforcement. Thus, P is the limiting factors shaping the water quality of an area. However, N also plays a significant role in triggering eutrophication, therefore, N and P controls should be considered in managing water pollution due to eutrophication (Pan et al., 2021; Wisha et al., 2018; Wisha & Maslukah, 2017).

The relationship between water quality parameters and phytoplankton communities

To determine the specific correlation between water quality parameters, nutrients, and phytoplankton abundance, we analyze those data using a principal component analysis (PCA), as shown in Figures 8 and 9. The total variance reaches 81.73% and 75.85% for April and September data, respectively.

Principal component 1 (PC1) accounted for 38.22% of the variance for the April data. This function is characterized by the high loadings of temperature, conductivity, salinity, TDS, nitrite, and ammonia (Figures 8a and b). The negative correlation of PC1 shows that DO, pH and sulfate are less correlated. The principal component 2 (PC2) explains 27.06% of the total variance. The positive axis is characterized by nutrients (ammonia, nitrite, nitrate, and phosphate) and sulfate. On the other hand, it is negatively correlated with salinity, temperature, conductivity, TOM, TDS, DO, and pH. The presence of turbidity in the positive axis of the principal component 3 (PC3) shows the possible influence of turbidity in shaping the abundance of phytoplankton.

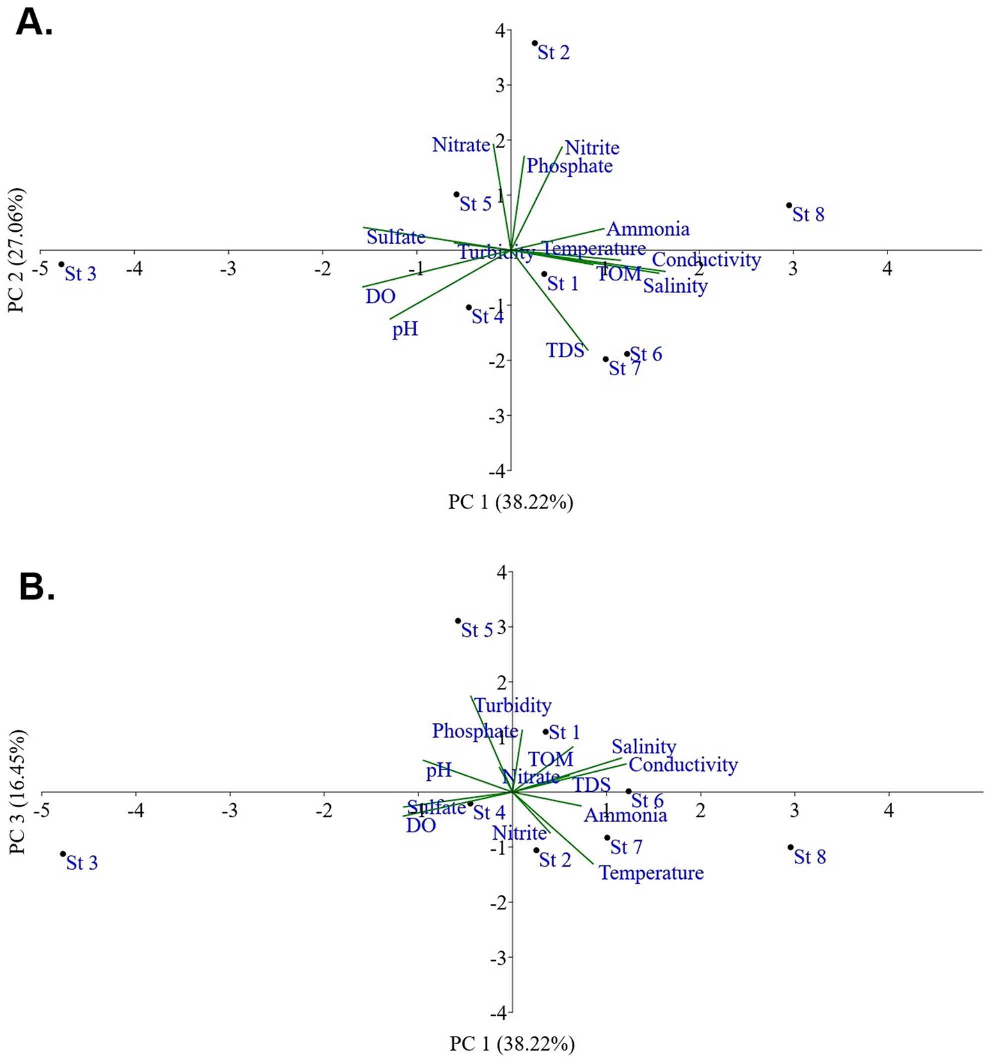

Figure 8. The predominance water quality controls in every station based on the PCA for April survey; PC1 vs. PC2 (a); PC1 vs. PC3 (b)

In contrast, the determination of water quality parameters in shaping the phytoplankton abundance based on the September data differs from the April one. The PC1 (38.22% of the total variance) is positively correlated with nitrate, phosphate, pH, DO, conductivity, TDS, and salinity. TOM and nitrite show a negative correlation in PC1. The PC2 determines 21.05% of the total variance, positively correlated with nitrate, phosphate, ammonia, and temperature, and negatively correlated with TOM, salinity, conductivity, TDS, and DO (Figure 9a). Moreover, the presence of salinity, conductivity, and TDS in the positive axis of the PC3 shows that these parameters also play a slight role in determining the phytoplankton abundance (Figure 9b).

The PCA analysis also shows that the influence of each parameter in every station varies considerably. Based on the April data assessment, station 1 is possibly controlled by several water quality parameters, such as TDS, TOM, salinity, conductivity, and temperature. In contrast, only the TDS parameter controls station 6. Any assessed parameters do not solely determine stations 2, 3, and 8. Nutrients and sulfate determine station 5, and station 4 is possibly correlated with pH. These data also show that nitrate, nitrite, and phosphate are really correlated in determining the water condition. TOM, temperature, salinity, and conductivity are also on the same page.

On the other hand, in September, turbidity and pH are correlated with each other, followed by nutrients and temperature-sulfate. Moreover, the other parameters also show high correlation, such as DO, conductivity, salinity, and TDS. Concerning the role of each parameter in every station, station 3 is determined by nutrient variability. Stations 1 and 5 are possibly controlled by salinity,

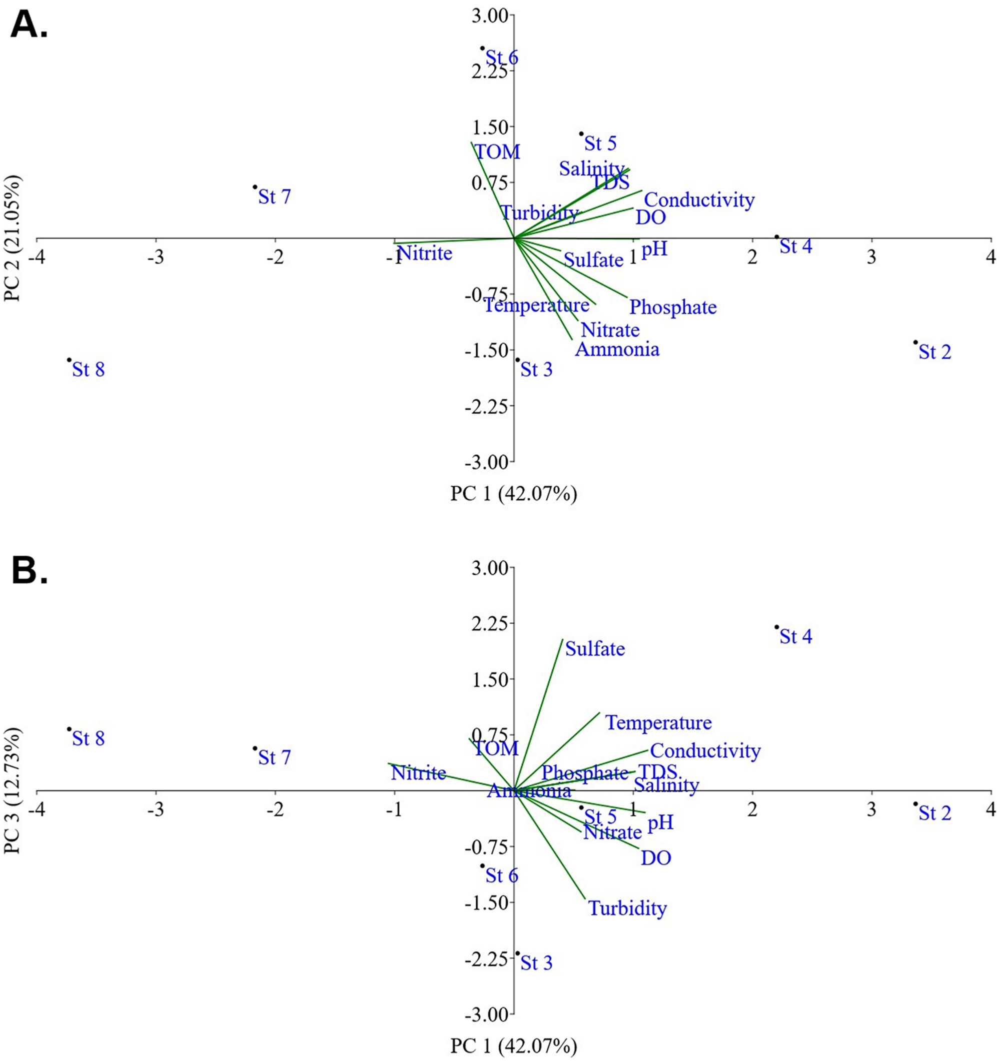

Figure 9. The predominance water quality controls in every station based on the PCA for September survey; PC1 vs. PC2 (a); PC1 vs. PC3 (b)

conductivity, TDS, and DO, while the remnant stations seem to be controlled by all parameters, even though the influence is not too significant.

Overall, every water quality parameter has a unique influence on phytoplankton. The most exciting finding is that the high phytoplankton abundance in stations 3, 6, 7, and 8 closely relates to the nutrient content (N and P). This statement is also proven by the high correlation analysis with a 50% value of coefficient determination of the N and P parameter. However, aside from phytoplankton dependent on nutrients, the water quality parameters, such as temperature, TDS, salinity, conductivity, TDS, pH, and turbidity, also shape the phytoplankton communities in the East Aceh coastal area.

CONCLUSION

Phytoplankton in the East Aceh coastal area was more abundant in April than in September, with the most abundant genera of diatoms (Bacillariophyceae). Turbidity exceeded the water quality standard, while DO was less than the allowed standard. The remnant parameters seem promising to support marine life on the East Aceh coast. The low DO value and sufficiently high nitrite closely relate to the low nitrate concentration, indicating the N cycle disruption. On the other hand, the high concentration of ammonia reflects that the ammonification process takes place well. The unstable phosphate content during April and September shows that P becomes the limiting factor in the environment, proven by the significant correlation between N, P, and phytoplankton abundance, with a coefficient determination of more than 50%.

The CWQI value shows that the study area is characterized by moderate to good categories, even though poor water quality is also observed in several stations. The water quality parameter did not solely shape the phytoplankton community; conversely, phytoplankton abundance was more determined by nutrients. However, each water quality parameter has a unique and specific influence on triggering phytoplankton growth.

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REFERENCES

1. Agostinelli, C. 2002. Robust stepwise regression. Journal of Applied Statistics, 29(6). https://doi.org/10.1080/02664760220136168
2. Asiah, N., Sukendi, S., Harjoyudanto, Y., Junianto, J., Yustiati, A. 2021. Water Quality Analysis Based on Plankton Community Structure in Kampar River, Riau Province. IOP Conference Series: Earth and Environmental Science, 695(1). https://doi.org/10.1088/1755-1315/695/1/012005
3. Ávila, R.A., Orozco, P.M.S., Andrade, M.M., Möller, O.O. 2021. Temporal variability of suspended-solids concentration in the estuarine channel of patos lagoon, southern Brazil. Water (Switzerland), 13(5). https://doi.org/10.3390/w13050646
4. Balqis, N., Rahimi, S.A. El, Damora, A. 2021. Keanekaragaman dan kelimpahan fitoplankton di perairan ekosistem mangrove Desa Rantau Panjang, Kecamatan Rantau Selamat, Kabupaten Aceh Timur. Jurnal Kelautan Dan Perikanan Indonesia, 1(1).
5. Boyd, C.E. 1990. Water quality in ponds for aquaculture. Agriculture Experiment Station, Auburn University.
6. Butler, E.I. 1984. A manual of chemical and biological methods for sea water analysis. Deep Sea Research Part A. Oceanographic Research Papers, 31(12). https://doi.org/10.1016/0198-0149(84)90086-4
7. Cho, I.H., Kim, H.K., Lee, M.H., Kim, Y.J., Lee, H., Kim, B.H. 2020. The effect of monsoon rainfall patterns on epilithic diatom communities in the hantangang river, Korea. Water (Switzerland), 12(5). https://doi.org/10.3390/w12051471
8. Davis, C.C. 1955. The marine and fresh-water plankto*n* (Volume 369). Michigan State University Press.
9. Ferrario, M.E., Almandoz, G., Licea, S., Garibotti, I. 2008. Species of Coscinodiscus (Bacillariophyta) from the Gulf of Mexico, Argentina and Antartic waters; morphology and distribution. Nova Hedwigia, 133.
10. Gao, C., Fu, M., Song, H., Wang, L., Wei, Q., Sun, P., Liu, L., Zhang, X. 2018. Phytoplankton pigment pattern in the subsurface chlorophyll maximum in the South Java coastal upwelling system, Indonesia. Acta Oceanologica Sinica, 37(12). https://doi.org/10.1007/s13131-018-1342-x
11. Griffin, N.J. 2017. The rise and fall of dissolved phosphate in South African rivers. South African Journal

of Science, 113(11–12). https://doi.org/10.17159/sajs.2017/20170020

12. Gupta, A.K., Gupta, S.K., Patil, R.S. 2003. A comparison of water quality indices for coastal water. Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering, 38(11). https://doi.org/10.1081/ESE-120024458
13. Hammer, Ø., Harper, D.A.T., Ryan, P.D. 2001. Past: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica, 4(1).
14. Harvey, B.P., Agostini, S., Kon, K., Wada, S., Hall-Spencer, J.M. 2019. Diatoms dominate and alter marine food-webs when Co2 rises. Diversity, 11(12). https://doi.org/10.3390/D11120242
15. Igarashi, R. Y., & Seefeldt, L. C. 2003. Nitrogen Fixation: The Mechanism of the Mo-Dependent Nitrogenase. In Critical Reviews in Biochemistry and Molecular Biology, 38(4). https://doi.org/10.1080/10409230391036766
16. Jha, D.K., Devi, M.P., Vidyalakshmi, R., Brindha, B., Vinithkumar, N.V., Kirubagaran, R. 2015. Water quality assessment using water quality index and geographical information system methods in the coastal waters of Andaman Sea, India. Marine Pollution Bulletin, 100(1). https://doi.org/10.1016/j.marpolbul.2015.08.032
17. Jiwarungrueangkul, T., Kongpuen, O., Yucharoen, M., Sangmanee, C., Tipmanee, D., Areerob, T., Sompongchiyakul, P. 2023. Modification and validation of an analytical method for the simple determination of nitrate in seawater by reduction to nitrite with zinc powder. Marine Chemistry, 251(February), 104235. https://doi.org/10.1016/j.marchem.2023.104235
18. John, E.H., Flynn, K.J. 2000. Growth dynamics and toxicity of alexandrium fundyense (dinophyceae): The effect of changing n:p supply ratios on internal toxin and nutrient levels. European Journal of Phycology, 35(1). https://doi.org/10.1080/09670260010001735581
19. Kasmini, L., Batubara, A.S. 2023. Microplastic contamination and growth pattern of oyster; Crassostrea gigas in a coastline. Global Journal of Environmental Science and Management, 9(4), 753–764. https://doi.org/10.22035/gjesm.2023.04.07
20. Koropitan, A.F., Barus, T.A., Cordova, M.R. 2021. Coastal Water Properties And Hydrodynamic Processes In The Malacca Strait: Case Study Northeastern Coast Of Sumatra, Indonesia. Journal of Ecological Engineering, 22(11), 16–29. https://doi.org/10.12911/22998993/142974
21. Kusumaningtyas, M.A., Bramawanto, R., Daulat, A., S. Pranowo, W. 2014. Kualitas perairan Natuna pada musim transisi. DEPIK, 3(1). https://doi.org/10.13170/depik.3.1.1277
22. Li, A., Stoecker, D.K., Coats, D.W. 2000. Mixotrophy in Gyrodinium galatheanum (Dinophyceae): Grazing responses to light intensity and inorganic nutrients. Journal of Phycology, 36(1). https://doi.org/10.1046/j.1529-8817.2000.98076.x
23. Li, Q., Wang, X.C., Zhang, H.H., Shi, H.L., Hu, T., Ngo, H.H. 2013. Characteristics of nitrogen transformation and microbial community in an aerobic composting reactor under two typical temperatures. Bioresource Technology, 137. https://doi.org/10.1016/j.biortech.2013.03.092
24. Liu, G., Janowitz, G.S., Kamykowski, D. 2001. Influence of environmental nutrient conditions on Gymnodinium breve (Dinophyceae) population dynamics: A numerical study. Marine Ecology Progress Series, 213. https://doi.org/10.3354/meps213013
25. Malviya, S., Scalco, E., Audic, S., Vincent, F., Veluchamy, A., Poulain, J., Wincker, P., Iudicone, D., De Vargas, C., Bittner, L., Zingone, A., Bowler, C. 2016. Insights into global diatom distribution and diversity in the world's ocean. Proceedings of the National Academy of Sciences of the United States of America, 113(11). https://doi.org/10.1073/pnas.1509523113
26. Moran, S. 2018. Clean water characterization and treatment objectives. In An Applied Guide to Water and Effluent Treatment Plant Design. https://doi.org/10.1016/b978-0-12-811309-7.00006-0
27. Ondara, K., Tanto, T. Al, Rahmawan, G.A., Dhiauddin, R., Wisha, U.J. 2019. Hydro-Oceanographic and Water Quality Assessments As a Basis for the Development of Offshore Aquaculture in the Weh Island, Aceh Province, Indonesia. Aceh International Journal of Science and Technology, 8(2), 76–87. https://doi.org/10.13170/aijst.8.2.12362
28. Pan, L., Dai, J., Wu, Z., Huang, L., Wan, Z., Han, J., Li, Z. 2021. Spatial and temporal variations of nitrogen and phosphorus in surface water and groundwater of Mudong river watershed in Huixian Karst Wetland, Southwest China. Sustainability (Switzerland), 13(19). https://doi.org/10.3390/su131910740
29. Purnamaningtyas, S.E., Hedianto, D.A., Riswanto. 2018. Relations of Several Physicochemical Parameters and Phytoplankton in Coastal Kubu Raya District, West Kalimantan. Jurnal Ilmu Dan Teknologi Kelautan Tropis, 9(2). https://doi.org/10.29244/jitkt.v9i2.19305
30. Purnamaningtyas, S.E., Mujiyanto. 2021. Concentration of chlorophyll-a phytoplankton as indicator of waters fertility in gerupuk bay, Central Lombok Regency-West Nusa Tenggara. IOP Conference Series: Earth and Environmental Science, 860(1). https://doi.org/10.1088/1755-1315/860/1/012082
31. Qu, P., Fu, F., Hutchins, D.A. 2018. Responses of the large centric diatom Coscinodiscus sp. to

interactions between warming, elevated CO2, and nitrate availability. Limnology and Oceanography, 63(3). https://doi.org/10.1002/lno.10781

32. Rahmadi, D., Machdar, I., Syaubari, S. 2023. Analysis of Water Quality and Quality Status in Aceh Rivers Based on Environmental Pollution Index. Jurnal Rekayasa Kimia & Lingkungan, 17(2). https://doi.org/10.23955/rkl.v17i2.28865
33. Rudi, E., Iskandar, T., Fadli, N., Hidayati, H. 2012. Impact of mass coral bleaching on reef fish community and fishermen catches at Sabang, Aceh Province, Indonesia. AACL Bioflux.
34. Simanjuntak, M. 2009. Hubungan Faktor Lingkungan Kimia, Fisika Terhadap Distribusi Plankton Di Perairan Belitung Timur, Bangka Belitung. Jurnal Perikanan, 11(1), 31–45. (in Indonesian)
35. Tessier, J.T., Raynal, D.J. 2003. Use of nitrogen to phosphorus ratios in plant tissue as an indicator of nutrient limitation and nitrogen saturation. Journal of Applied Ecology, 40(3). https://doi.org/10.1046/j.1365-2664.2003.00820.x
36. Villanoy, C., Cabrera, O., Yniguez, A., Camoying, M., de Guzman, A., David, L., Flament, P. 2011. Monsoon-Driven Coastal Upwelling Off Zamboanga Peninsula, Philippines. Oceanography, 24(1), 156–165. https://doi.org/10.5670/oceanog.2011.12
37. von Oheimb, G., Power, S.A., Falk, K., Friedrich, U., Mohamed, A., Krug, A., Boschatzke, N., Härdtle, W. 2010. N:P Ratio and the nature of nutrient limitation in Calluna-dominated heathlands. Ecosystems, 13(2). https://doi.org/10.1007/s10021-010-9320-y
38. Wagenhoff, A., Townsend, C.R., Phillips, N., Matthaei, C.D. 2011. Subsidy-stress and multiple-stressor effects along gradients of deposited fine sediment and dissolved nutrients in a regional set of streams and rivers. Freshwater Biology. https://doi.org/10.1111/j.1365-2427.2011.02619.x
39. Wisha, U.J., Dhiauddin, R., Rahmawan, G.A., Wijaya, Y.J. 2021. Preliminary identification of causes to local coral bleaching event in manjuto beach, pesisir selatan regency, west sumatra: A hydro-oceano-graphic perspective. Jurnal Ilmiah Perikanan Dan Kelautan, 13(2), 156–170. https://doi.org/10.20473/jipk.v13i2.25502
40. Wisha, U.J., Gemilang, W.A., Wijaya, Y.J., Purwanto, A.D. 2022. Model-based estimation of plastic debris accumulation in Banten Bay, Indonesia, using particle tracking - Flow model hydrodynamics approach. Ocean and Coastal Management, 217. https://doi.org/10.1016/j.ocecoaman.2021.106009
41. Wisha, U.J., Maslukah, L. 2017. Nutrient Condition of Kampar Big River Estuary: Distribution of N and P Concentrations Drifted by Tidal Bore ”Bono”. ILMU KELAUTAN: Indonesian Journal of Marine Sciences, 22(3), 37–45. https://doi.org/10.14710/ik.ijms.22.3.137-146
42. Wisha, U.J., Ondara, K., Ilham, I. 2018. The Influence of Nutrient (N and P) Enrichment and Ratios on Phytoplankton Abundance in Keunekai Waters, Weh Island, Indonesia. Makara Journal of Science, 22(4), 187–197. https://doi.org/10.7454/mss.v22i4.9786
43. Wisha, U.J., Yusuf, M., Maslukah, L. 2016. Kelimpahan fitoplankton dan konsentrasi tss sebagai indikator penentu kondisi perairan muara sungai porong. Jurnal Kelautan Dan Teknologi, 9(2), 122–129. https://doi.org/http://dx.doi.org/10.21107/jk.v9i2.1298 (in Indonesian)
44. Wouthuyzen, S., Abrar, M., Lorwens, J. 2015. Coral Bleaching Incidents of 2010 in Indonesian Waters Revealed Through Analysis of Sea Surface Temperature. Oseanologi Dan Limnologi Di Indonesia.
45. Yamaji, I. 1979. Illustration of The Marine Plankton of Japan. Hoikusha Publishing Co.
46. Yusuf, M., Robin, R., Adi, W., Hudatwi, M., Widianingsih, W., Hartati, R., Mahendrajaya, R.T., Manullang, C. 2021. Phytoplankton community structure and it’s relationships with water quality in Bangka Island, Indonesia. ILMU KELAUTAN: Indonesian Journal of Marine Sciences, 26(1). https://doi.org/10.14710/ik.ijms.26.1.37-44
47. Zhang, W., Jin, X., Liu, D., Lang, C., Shan, B. 2017. Temporal and spatial variation of nitrogen and phosphorus and eutrophication assessment for a typical arid river — Fuyang River in northern China. Journal of Environmental Sciences (China), 55, 41–48. https://doi.org/10.1016/j.jes.2016.07.004