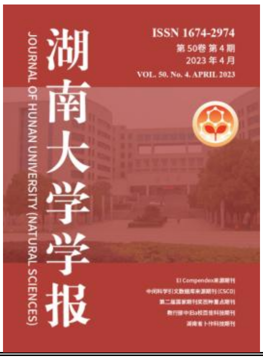

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Phytoplankton Saprobity as Pollution Bioindicator: A Study of Genera *Chaetoceros* in Port of Tanjung Emas Waters, Semarang

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Abstract: Water fertility is an assessment of the condition of organism diversity in relation to aquatic ecosystems. PTES (Port of Tanjung Emas, Semarang) is a major port in Java Sea waters and a domestic port for commercial vessels. Its water condition is influenced by the activities of both commercial and fishing vessels. This research applied a descriptive method with cluster sampling, including a group of samples in the port pool and samples from outside the port pool as a control station (comparator). The research aimed to analyze pla nkton fertility through the analysis of plankton abundance (N) and analyze factors that support the fertility of the waters, such as physicochemical parameters. In this research, *diatoms* (*Bacillariophyceae*) were found as a class that dominated in the waters with a dominance rate of 95%, meaning that the waters were in β-mesosaprobic condition (moderately polluted). The novelty of this research was the finding of toxic *Chaetoceros*, which dominated in the waters, resulting in the disappearance of other genera and lower organism abundance and diversity at a higher level. This abundance was a bioindicator that triggered heavy pollution (α-mesosaprobic). Regression analysis showed that phytoplankton abundance was determined by brightness, nitrate, turbidity, and zooplankton abundance. Using factor analysis, there were five factors that affected the total saprobic index (TSI); the largest factor was influenced by the first components (41.49%), including salinity, brightness, temperature, pH, DO, nitrate, and SI.

Keywords: Port of Tanjung Emas, water fertility, total saprobic index, factor analysis, physicochemical parameters.

浮游植物腐生作为污染生物指示剂：三宝垄丹戎艾马斯水域港口角毛藻属的研究

摘要：水肥力是对与水生生态系统相关的生物多样性状况的评估。聚四氟乙烯（三宝垄丹戎艾玛斯港）是爪哇海域的主要港口，也是国内商船港口。它的水质状况受到商船和渔船活动的影响。本研究采用整群抽样的描述性方法，包括港口池内的一组样本和港口池外的样本作为控制站（比较站）。该研究旨在通过分析浮游生物丰度（否）来分析浮游生物的生育能力，并分析支持水域生育能力的因素，如理化参数。本次研究发现硅藻（杆菌科）是水域中的优势类，优势率为95%，这意味着水域处于β-

中氧状态（中度污染）。这项研究的新颖之处在于发现了有毒的角毛藻，它在水域中占主导地位，导致其他属的消失，并在更高层次上降低了生物的丰度和多样性。这种丰度是引发重度污染（α-中氧环境）的生物指示剂。回归分析表明，浮游植物丰度由亮度、硝酸盐、浊度和浮游动物丰度决定。使用因子分析，有五个因素影响总腐烂指数（TSI）；盐度、亮度、温度、酸碱度、做、硝酸盐、国际单位制等第一成分影响最大的因素（41.49%）。

关键词：丹绒艾玛斯港，水肥力，总腐烂指数，因子分析，理化参数。

Introduction

Plankton is an organism that forms the basis of the food chain. Its abundance plays an important role in aquatic ecosystems. The abundance is influenced by light availability and water flow rate [1]. Plankton is the defining factor of waters fertility, determined by its aquatic environment such as temperature, light, and nutrients; the other factors include human activities such as agriculture and settlement, which possibly affect the waters trophic status [2]. Water fertility is also influenced by chlorophyll-a, a green pigment found in algae or plants [3].

Semarang waters are located in Semarang Bay on the northern coast of Java, connecting the waters of Kendal and Demak (6^0-7^0 S and 110^0-111^0 E) [4]. In Semarang Bay, the estuary of Bodri River of Kendal is located in its western area and Wulan River of Demak in its eastern area. In the western area of PTES waters, there is the Garang River that empties into BKB (Banjir Kanal Barat) and Siangker, and in the east of PTES (Port of Tanjung Emas Semarang) are BKT (Banjir Kanal Timur) rivers. Semarang Bay is a coastal area that is part of the waters. This area is dangerous due to pollution, eutrophication, and urbanization, which threaten the coastal ecosystem and are influenced by anthropogenic activities and nutrient inputs from the land [5].

Saprobity is a water condition in which organic matter such as plankton exists. Four groups of saprobity include polysaprobic, α-mesosaprobic, β-mesosaprobic, and oligosaprobic [6]. Water saprobity can be used as a pollution bioindicator by calculating the value of TSI (Total Saprobic Index) and SI (Saprobic Index) of phytoplankton. Water in the western area of PTES, at the estuary of BKB, was indicated as oligosaprobic or lightly polluted by organic matter, while its saprobity was indicated as β-mesosaprobic and oligosaprobic (lightly and very lightly polluted) [7]. Waters in Wedung, Demak, the eastern area of Semarang Bay, were also indicated as oligosaprobic/β-mesosaprobic (lightly polluted) [8].

The research conducted in the eastern area of Semarang Bay in the waters of Mangunharjo indicated a low and medium diversity index, medium and high uniformity, and an absence of genera dominance [9]. On the other hand, in Maron waters, there was a low dominance index and a high diversity index [10]. The upstream of the BKB River, Garang River, was identified as moderately polluted, with a predominance of phytoplankton such as *Chaetoceros sp.* and *Ceratium sp.* [11].

This research aimed: a) to analyze the physico-chemical parameters, b) to analyze phytoplankton abundance (N), diversity (H’), uniformity (e), dominance (D), SI (Saprobic Index), and TSI (Total Saprobic Index), c) to analyze multiple regression between the dependent variables (phytoplankton abundance) and the independent variables (brightness, nitrate content, turbidity, and zooplankton abundance), d) to perform One Way ANOVA to compare the abundance of phytoplankton or zooplankton found at the port basin waters and at the control station (the estuary of BKT and Siangker), e) to analyze factors affecting TSI using factor analysis, and f) to analyze class differences in phytoplankton using cluster analysis.

1. Materials and Methods

1.1. Study Area and Sampling Stations

The research was conducted in the Port of Tanjung Emas Semarang (PTES) in Central Java, Indonesia, from July to September 2016 during high tide and low tide, with 10 research stations: 8 stations at the port basin and 2 stations located outside the port, at the estuary of Siangker and BKT. A descriptive method was applied explaining symptoms or circumstances with no experiment [12]. The random sampling technique was used to collect the samples. The research was conducted at $6^0$57.059’ – $6^0$56.207' S and $110^0$25.150’ – $110^0$26.599' E. The eight stations, station 1 (the estuary of Kali Baru) to station 8 were located at the port basin, station 9 was at the estuary of BKT, and station 10 was at the estuary of Siangker (Fig. 1).

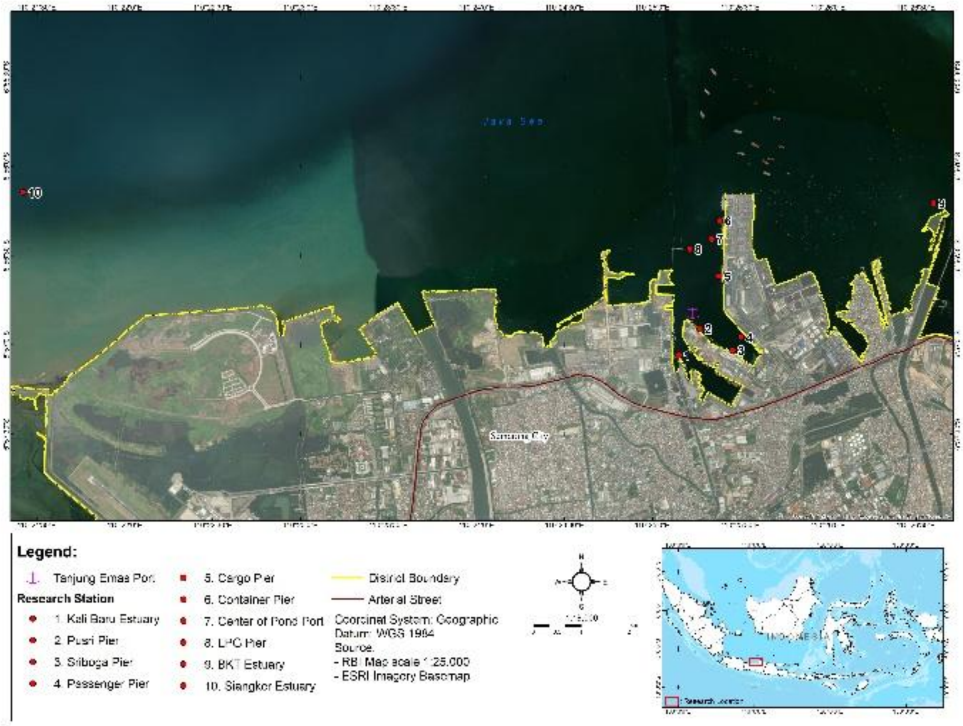

Fig. 1 Sampling location (Indonesian earth map & ESRI imagery basemap)

Fig. 2 shows the process of research on water fertility, starting from location determination to identification. The field team involved an identification officer from Diponegoro University, Semarang; and assistance from the Regional Health Laboratory team. The identification of plankton using identification from Yamaji (Fig. 2).

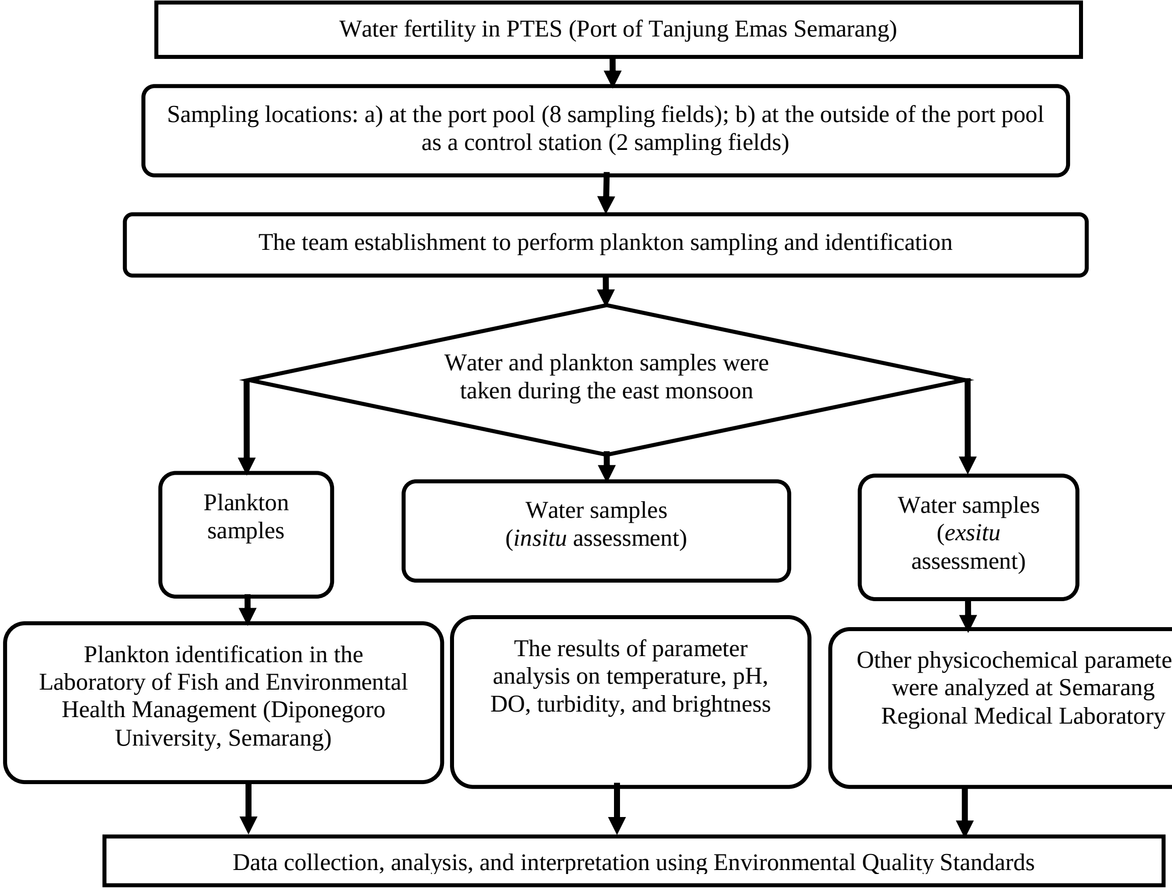

Fig. 2 Flowchart of the research methodology (The authors' elaboration)

1.2. Sample Collection and Analysis

The samples of plankton were obtained using 80 m mesh size plankton net. The sampling was conducted three times at each station. The samples were obtained by filtering 100 l seawater using a plankton net and 3.3 l buckets [13]. The filtered seawater was then put into bottles of 150 ml and preserved in lugol. Some samples of water were also collected for measurement of physicochemical parameters. The parameters included temperature, pH, DO (Dissolved Oxygen), TDS (Total Dissolved Solid), turbidity, brightness, salinity, TSS (Total Suspended Solid), BOD (Biological Oxygen Demand), phosphate, nitrate, sulfide, and phenol. There were some parameters that were possibly measured directly in the sites, including temperature, salinity, DO, turbidity, and brightness; the rest were measured in the laboratory. Plankton were identified in the laboratory using Yamaji's identification guide [14].

Plankton abundance was measured using the following formulas [13, 15]:

$$N = \frac{T}{L} \text{ x } \frac{P}{p} \text{ x } \frac{V}{v} \text{ x } \frac{L}{w} \tag{1}$$

where N - number of plankton per liter, T - area of glass cover (mm^2), P - number of plankton enumerated, p - number of sites observed, V - volume of filtered plankton samples (ml), v - volume of samples in Sedgewick Rafter (ml), w - volume of filtered water/plankton samples.

Diversity was analyzed using the Shannon-Wiener Diversity Index [13]:

$$H' = -\sum_{i=1}^{n} p_i \ln p_i \tag{2}$$

where H' - diversity index, $P_i = \frac{n_i}{N}$, n - number of types.

The uniformity index was obtained by comparing the Diversity Index to its maximum value [13, 16]:

$$e = \frac{H'}{H'_{max}} \tag{3}$$

where e - uniformity index, H' - diversity index, H'_{max} = ln S, S - the total number of species.

The dominance index was used to identify which particular species of plankton dominated in the waters, using Simpson's dominance index [13]:

$$D = \left(\frac{N_i}{N}\right)^2 \tag{4}$$

where D - dominance index, Ni - number of individuals of each type, N - the total number of individuals.

The saprobic index (SI) was calculated using the following formula [17, 18]:

$$SI = \frac{1C+3D+1B-3A}{1A+1B+1C+1D} \tag{5}$$

where SI - saprobic index, A - number of genera or species in polysaprobic group, B - number of genera or species in α-mesosaprobic group, C - number of genera or species in β-mesosaprobic group, D - number of genera or species in oligosaprobic group.

The Trophic Saprobic Index (TSI) was used to calculate the saprobity using Trosap analysis as follows [13, 17]:

$$TSI = \frac{1(nC)+3(nD)+1(nB)-3(nA)}{1(nA)+1(nB)+1(nC)+1(nD)} \text{ x } \frac{nA+nB+nC+nD+nE}{nA+nB+nC+nD} \tag{6}$$

where TSI - Trophic Saprobic Index, nA - number of individuals from polysaprobic group, nB - number of individuals from α-mesosaprobic group, nC - number of individuals from β-mesosaprobic group, nD - number of individuals from oligosaprobic group, nE - number of individuals from other groups.

1.3. Statistical Analysis

Multiple linear regression analysis is defined as a regression model that estimates the relationship between two or more independent variables (X1, X2,.... X_n) and variable Y. This analysis was used to determine the direction of the relationship between independent variables and dependent variables in order to estimate the dependent variables value when they increase or decrease. In this research, the following formula was employed [19]:

$$Y' = a + b_1X_1 + b_2X_2 + \ldots\ldots + b_nX_n \tag{7}$$

where Y' - dependent variable (predicted value), X_1 and X_2 - independent variable, a - constant (value of Y' if X_1, X_2…….X_n = 0), and b - regression coefficient (value of increase or decrease). In this research, the Y' value represented phytoplankton abundance, the dependent variable. On the other hand, the independent variables consisted of brightness, nitrate content, turbidity, and zooplankton abundance.

Analysis of Variance (Anova) test, also known as One Way Anova, was used to test the relationship between one dependent variable and one or more independent variables. ANOVA was employed to analyze the main effects and results of the interaction between categorical and metric-dependent variables [20].

The hypothesis of phytoplankton abundance during high tide stated that H_0 = the means of abundance found at the port basin (station 1 to 8) and at the control station (the estuary of BKT and Siangker) were equal while H_a = the means of abundance found at the port basin and at the control station (the estuary of BKT and Siangker) were unequal. The hypothesis of phytoplankton abundance during low tide stated that H_0 = the means of abundance at the eight stations were equal, while H_a = the means of abundance at the eight stations were unequal. The hypothesis of zooplankton abundance during high tide stated that H_0 = the means of abundance at the three stations (the port basin and the estuary of BKT and Siangker) were equal, while H_a = the means of abundance at the three stations were unequal. The hypothesis of zooplankton abundance during low tide stated that H_0 = the means of abundance at the three stations were equal while H_a = the means of abundance at the three stations were unequal.

Factor analysis was performed to reduce the independent variables into fewer variables. There were some stages in this analysis, including factor analysis, factor testing using the Barlett test of Sphericity and Measure of Sampling Adequancy (MSA), factoring process, rotation process, and interpretation of factor naming. Cluster analysis was used to group the data based on similar characteristics. This analysis is known as classification analysis, which uses a hierarchy method [21]. The calculation was done using IBM SPSS Version 25.

2. Results

The water temperature ranged from 27.89 to 30.61^{0}C, while the mean temperature was 29.89^{0}C. The temperature at the estuary of BKT (Station 9), which was different from the mean temperature at the port basin, still met the quality standards. The pH ranged from 6.75 to 7.66, with the highest value found at Station 3, while the lowest was at the estuary of BKT. These findings indicated that the water in this area was more acidic than the port basin. The pH still met the quality standard. The DO content ranged from 5.61 mg/l to 9.79 mg/l. The lowest was found at the estuary of BKT, while the highest was found at the cargo pier (Station 5). The DO value in these waters still met the quality standard. The TDS content ranged from 462.59 to 556.42 mg/l. The lowest value was found at the container pier (Station 6), while the highest was found at the Sriboga pier (Station 3). The TDS content still met the quality standard. The mean value of turbidity of all stations 95.83 NTU; the lowest value was found at the estuary of BKT (26.86 mg/l), while the highest was found at the passenger pier (Station 4). These values found both at the port basin and the estuary of BKT, did not meet the quality standard.

The mean brightness value was 0.94 m with the maximum brightness found at the passenger pier (Station 4). This value did not meet the quality standard. The mean value of salinity was 28.39 ppt, with the lowest value found at the estuary of BKT, while the highest value was found at the cargo pier (Station 5). It still met the quality standard. The mean value of TSS was 84.81 mg/l, with the highest found in the middle of the port output (Station 7) and the lowest found at the container pier. It exceeded the quality standard. The mean value of BOD content was 0.39 mg/l. The highest value was found in the middle of the port basin (0.46 mg/l), while the lowest value was found at was at the container pier (0.34 mg/l). The BOD found both at the port basin and at the estuary of BKT exceeded the quality standard. The mean value of phosphate content was 0.89 mg/l, with the lowest value being at the estuary of Kali Baru (Station 1) while the highest was at the LPG pier (Station 8).

Outside the port basin, the phosphate content increased, indicating that the water flowed out of the port, while at the estuary of BKT, the content decreased. This condition showed that there was no correlation between the port basin and the estuary of BKT. In other words, the water flowed from the port basin to the eastern area. This content exceeded the quality standard. The value of nitrate ranged from 0.23 mg/l (Station 2) to 0.55 mg/l (the estuary of BKT) with a mean value of 0.3 mg/l. This content exceeded the quality standard. The mean value of sulfide content was 0.03 mg/l, exceeding the quality standard. The mean value of phenol content was 0.03 mg/l, indicating that it slightly exceeded the quality standard. In terms of DO, turbidity, brightness, salinity, and nitrate, the estuary of BKT had shown different values compared to the findings at the port basin (Table 1).

Table 1 The values of physicochemical parameters at the stations (The authors' elaboration)

Parameters	**Sampling Field**									**Quality Standards [22]**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Temperature (^{0}C)	29.46	30.51	30.14	30.16	30.19	29.83	30.61	30.18	27.89	28-32
Ph	7.24	7.43	7.66	7.58	7.43	7.19	7.25	7.46	6.75	7-8.5
DO (mg/l)	6.67	6.73	6.69	6.64	9.79	7.08	7.06	7.18	5.61	> 5
TDS (mg/l)	554.42	548.67	556.42	535.59	545.75	462.59	520.5	516.92	469.5	2000
Turbidity (NTU)	44.01*	88.83*	64.74*	367.85*	62.63*	51.45*	105.45*	50.66*	26.86*	< 5
Brightness (m)	0.89*	1.04*	0.99*	1.23*	1.19*	0.99*	0.93*	0.88*	0.3*	3-5
Salinity (ppt)	27.49	28.93	29.03	29.08	29.22	28.55	29.2	28.79	25.19	33-34
TSS (mg/l)	44.42*	76.25*	60.75*	32.75*	38.25*	25.84*	262.5*	155.75*	66.75*	20-80
BOD (mg/l)	0.38*	0.38*	0.4*	0.38*	0.36*	0.34*	0.46*	0.44*	0.38*	20
Phosphate (mg/kg)	0.38*	0.81*	1.22*	0.53*	0.68*	0.99*	1.17*	1.52*	0.75*	0.015
Nitrate (mg/l)	0.33*	0.23*	0.33*	0.23*	0.23*	0.25*	0.23*	0.28*	0.55*	0.008
Sulfide (mg/l)	0.03*	0.03*	0.03*	0.03*	0.02*	0.02*	0.03*	0.03*	0.02*	0.01
Phenol (mg/l)	0.04*	0.04*	0.03*	0.04*	0.04*	0.03*	0.03*	0.03*	0.03*	0.02

* The parameter did not meet the quality standard.

The equality of variance test (homogeneity) was performed on the phytoplankton abundance during high tide found at the port basin and the control station (the estuary of BKT and Siangker), with the hypothesis that H_0 = the variances of the three stations were equal while H_a = the variances of the three stations were unequal. With the test result and $P_{value} > 0.05$, it was obtained that $0.856 > 0.05$, indicating that H_0 was accepted; the variances of the three stations were equal. This two-sided test with a significance level of 5% resulted in F_{count} of 0.027, with n of 18 (n-3 = 15), F_{table} was found 3.682. This means that $F_{count} < F_{table}$ ($0.027 < 3.682$), indicating that H_0 was accepted. Thus, the abundances found at the port basin and the control station (the estuary of BKT and Siangker) were equal. In the Tukey HSD test, in order to assess the difference in abundance between the three stations, the significance between the port basin and the estuary of BKT was 0.981, while the significance between the port basin and the estuary of Siangker was 1. Since 0.981 and 1 were higher than 0.05, there was no significant difference in abundance found at the port basin and at the control station.

In the equality of variance test using the abundance found in the eight stations, the hypothesis stated that H_0 = the variances of the eight stations were equal while H_a = the variances of the eight stations were unequal. With P_{value} of 0.491, which was > 0.05, it means that the variances of the eight stations were equal. With F_{count} of 0.181, the confidence level of 95% (a = 5%), df_7 (n-8) or 56-8 (52), so F_{table} was 2.192. $F_{count} < F_{table}$ (0.181 < 2.191) indicating that H_0 was accepted; the means of abundance at the eight stations were equal or the values were not significantly different. Based on the Tukey HSD test, the significance value of the mean abundance found in “station 1 – station 2” was 0.999, “station 1 – station 3” was 1, “station 1 – station 4” was 1, “station 1 – station 5” was 0.999, “station 1 – station 6” was 1, “station 1 – station 7” was 1, and “station 1 – station 8” was 1. Overall, the significance values were > 0.005, indicating that the means of abundance in all stations were equal (not significantly different).

In the variance diversity test, the hypothesis stated that H_0 = the variances of the three groups were equal and H_a = the variances of the three groups were unequal. The significance value obtained was 0.117. This value was > 0.05 (0.117 > 0.05). Thus, the variances of the three stations were equal. Levene statistics showed that the lower the value the higher the homogeneity would be. It was obtained that F_{count} was 0.956, with an alpha of 0.05, df_2 (n-3) or 12–3 = 9, so F_{table} was 4.256. Thus, it means that $F_{count} < F_{table}$ (0.956 < 4.256). H_0 was accepted; the means of abundance at the three stations were equal. In the Post Hoc test, which was used to identify which groups were equal or unequal, it was obtained that the port basin - the estuary of BKT was 0.578, while the port basin - the estuary of Siangker was 0.423. Thus, the significance value > 0.05 (0.578 and 0.423 > 0.05). H_0 was accepted; the three stations were equal (the zooplankton groups of the port basin, the estuary of BKT, and the estuary of Siangker were equal).

The significance value obtained in the variance diversity test was 0.385, where H_0 = the variances of the three groups were equal and H_a = the variances of the three groups were unequal. Since 0.385 > 0.05, the variances of the three groups were equal. F_{count} was 0.228, with a confidence level of 95% (a = 5%), df_2 (n-3) = 13. So, F_{table} was 3,806. Based on these findings, $F_{count} < F_{table}$ (0.228 < 3.806). Thus, H_0 was accepted; the abundances at the three stations were equal. Based on the interpretation of the Tukey HSD test (Post Hoc test), it was obtained that the findings at the port basin and the estuary of BKT were 0.865, while those at the port basin and the estuary of Siangker were 0.804. Since the probability value was > 0.05, the mean of abundance at the port basin and at the estuary of BKT or Siangker was equal.

Based on the multiple regression equation, it was obtained that $Y = -31,287.88 + 19,187.07\ X_1 + 54,652.96\ X_2 - 15\ X_3 + 119.01\ X_4$. It can be interpreted that if the phytoplankton abundance was -31,287.88 ind/l, the brightness, nitrate content, turbidity, and zooplankton abundance were zero. In other words, it can be stated that there would be no phytoplankton abundance if there were no brightness, nitrate, turbidity, or zooplankton abundance. The increase in brightness unit (m) resulted in the mean phytoplankton abundance reaching 19,187.07 ind/l. The increase in nitrate levels (mg/l) resulted in the mean phytoplankton abundance reaching 54,652.96 ind/l. Based on the turbidity value, if there was a decrease in each unit turbidity (NTU), the phytoplankton abundance would increase by 15 ind/l. In zooplankton abundance, if there was an increase in the abundance of each zooplankton unit (ind/l), the phytoplankton abundance would increase by 119.01 ind/l. The coefficient of determination showed that R^2 = 0.218 or 21.8%, indicating that the phytoplankton abundance depended on brightness, nitrate content, turbidity, and zooplankton abundance by 21.8%, while the rest (78.2%) was due to other variables that were not contained in the model.

During low tide, there were seven classes of phytoplankton: *Bacillariophyceae, Chrysophyceae, Dinophyceae, Cyanophyceae, Zygnematophyceae, Mediophyceae,* and *Coscinodiscophyceae*. Class *Bacillariophycea* had the highest number of genera; there were 26 genera. In class *Dinophyceae*, there were 6 genera, while in class *Chrysophyceae*, there were 3 genera. In the other classes, including *Cyanophyceae, Zygnematophyceae, Mediophyceae,* and *Coscinodiscophycea*, there was only one genera. The phytoplankton abundance ranged from 13,623 to 77,352 ind/l, with a mean value of 51,283.81 ind/l at the eight stations. The highest abundance was found at station 2 and the lowest was at station 6. Class *Bacillariophyceae* dominated the community with a dominance value of 95%, while class *Cyanophyceae* was only 2%. The dominant genera in this class were *Chaetoceros*, ranging from 8,074.31 to 43,280.97 ind/l (mean of the abundance of 28,432.51 ind/l) (Table 2).

Table 2 Phytoplankton during low tide (The authors' elaboration)

No.	**Class**	**Genera**
1	*Bacillariophyceae*	*Skeletonema sp., Chaetoceros sp., Asterionella sp., Rhizosolenia sp. Nitzschia sp., Pleurosigma sp., Streptotheca sp., Coscinodiscus sp. Thalassiothrix sp., Navicula sp., Biddulphia sp., Guinardia sp. Bacteriastrum sp., Thallassionema sp., Thalassiosira sp., Cyclotella sp. Amphora sp., Eucampia sp., Synedra sp., Gyrostigma sp., Cocconeis sp. Triceratium sp., Hemiaulus sp., Pinnularia sp., Diatoma sp. Prorocentrum sp.*
2	*Chrysophyceae*	*Pyrocystis sp., Dictyocha sp., Peridinium sp.*
3	*Dinophyceae*	*Protoperidium sp., Ceratium sp., Dinophysis sp., Pyrophacus sp. Noctiluca sp., Dissodinium sp.*
4	*Cyanophyceae*	*Coelosphaerium sp., Anabaenopsis sp., Oscillatoria sp.*
5	*Zygnematophyceae*	*Athrodesmus sp.*
6	*Mediophyceae*	*Plantoniella sp.*
7	*Coscinodiscophyceae*	*Dityllum sp.*

During high tide, class *Bacillariophyceae* was also found dominating with 30 genera. On the other hand, in class *Dinophyceae*, 4 genera were found; there were only one genera in each class. The mean abundance during high tide was 23,225.4 ind/l, ranging from 15,776.7 ind/l (Station 7) to 35,564.4 ind/l (Station 8). The mean dominance of class *Bacillariophyceae* was 22,336.5 ind/l, followed by class *Cyanophyceae* (523.25 ind/l), and the lowest was class *Mediophyceae* (29.79 ind/l) (Table 3).

Table 3 Phytoplankton during high tide (The authors' elaboration)

No.	**Class**	**Genera**
1	*Bacillariophyceae*	*Skeletonema sp., Chaetoceros sp., Asterionella sp., Rhizosolenia sp. Nitzschia sp., Pleurosigma sp., Streptotheca sp., Coscinodiscus sp. Thalassiothrix sp., Navicula sp., Biddulphia sp., Guinardia sp. Bacteriastrum sp., Thallassionema sp., Thalassiosira sp., Cyclotella sp. Amphora sp., Surirella sp., Eucampia sp., Sydnedra sp., Peridinium sp. Hellosira sp., Gyrosigma sp., Coconeis sp., Triceratium sp. Odonthella sp., Hemialus sp., Melosira sp., Fragilaria sp., Rhabdonema sp.*
2	*Mediophyceae*	*Plantoniella sp.*
3	*Coscinodiscophyceae*	*Dityllum sp.*
4	*Cyanophyceae*	*Oscillatoria sp.*
5	*Chrysophyceae*	*Pyrocystis sp.*
6	*Dinophyceae*	*Protoperidium sp., Noctiluca sp., Ceratium sp., Phyrophacus sp.*

During low tide, within the zooplankton group, five classes were found, including *Crustaceans, Ciliates, Sarcodina*, *Tentaculata*, and *Rotifers*. Within class *Crustaceans*, there were 26 genera: 13 genera in class *Ciliates*, 2 genera in class *Sarcodina*, 2 genera in class *Rotifers*, and one genera in class *Tentaculata*. The mean zooplankton abundance during low tide was 154.2 ind/l and 67.62 ind/l (with the mean value of 112.3 ind/l). The highest abundance was found in station 2, while the lowest was found at the estuary of BKT (Station 10). *Ciliates* had the highest abundance, followed by *Crustaceans* and *Sarcodina*. The mean of phytoplankton abundance outside the port basin (the estuary of Siangker and BKT) tended to be lower than that at the port basin. The mean abundance of *Globigerina* (class *Sarcodina*) had the highest abundance (38.75 ind/l), followed by *Tintinnopsis* and *Leprotintinnus sp.* (class *Ciliates*); the lowest was *Oithona sp.* (class *Crustaceans*) (Table 4).

Table 4 Zooplankton during low tide (The authors' elaboration)

No.	**Class**	**Genera**
1	*Crustaceans*	*Nauplius oithona, Stylonichia sp., Calanus sp., Microstella sp. Macrostella sp., Nauplius calanus, Euterpina sp., Nauplius acartia Nauplius eurytemora, Parvocalanus sp., Oithona sp., Canthocalanus sp. Acartia sp., Ctenocalanus sp., Nauplius tigriopus, Paracalanus sp. Tigriopus sp., Nauplius calanus, Corycaeus sp., Eurytemora sp. Nauplius, Phronima sp., Evadne sp., Undinopsis, Metridia sp., Sapphirina sp.*
2	*Ciliates*	*Steenstrupiella sp., Metacylis sp., Sticholonche sp., Undella sp., Lionotus sp. Coddonellopsis sp., Coxliella sp., Tintinnopsis, Leprotintinnus sp., Favella sp. Eutintinnus sp., Rhabdonellopsis sp., Epiplocylis sp.*
3	*Sarcodina*	*Sticholonche sp., Globigerina sp.*
4	*Tentaculata*	*Notholca sp.*
5	*Rotifera*	*Branchionus sp., Trochophora sp.*

During high tide, within the zooplankton group, four classes were found, including *Crustaceans*, *Ciliates*, *Sarcodina*, and *Tentaculata*. There were 21 genera within the class *Crustaceans*, 9 genera within the class *Ciliates*, 2 genera within the class *Sarcodina*, and one genera within class *Tentaculata*. The mean abundance in these conditions ranged from 26.95 to 170.1 ind/l, with a mean value of 115.72 ind/l. Station 5 had the highest abundance, while the estuary of BKT (Station 10) had the lowest. The class with the highest abundance was *Ciliates* (80.59 ind), followed by *Crustaceans* (33.81 ind/l). The lowest was *Tentaculata*. *Tintinnopsis* had the highest mean of abundance (38.48 ind/l), followed by *Leprotintinnus* (36.31 ind/l) (both belong to class *Ciliates*); *Nauplius acartia* (4.35 ind/l) had the highest abundance in class *Crustaceans* (Table 5).

Table 5 Zooplankton during high tide (The authors' elaboration)

No.	**Class**	**Genera**
1	*Crustaceans*	*Nauplius oithona, Stylonichia sp., Calanus sp., Microsetella sp., Macrosetella sp. Nauplius calanus, Euterpina sp., Nauplius acartia, Naulius eurytemora Parvocalanus sp., Oithona sp., Eucalanus sp., Canthocalanus sp., Acartia sp. Nauplius tigriopus, Paracalanus sp., Tigriopus sp., Clausocalanus sp. Nauplius, Pseudocalanus sp., Miracia sp.*
2	*Ciliates*	*Amphorella sp., Tintinnopsis, Leprotintinnus sp., Favella sp., Stenosemella sp. Eutinninnus sp., Steenstrupiella sp., Metacylis sp., Lionotus sp.*
3	*Sarcodina*	*Globigerina sp., Sticholonche sp.*
4	*Tentaculata*	*Notholca sp.*

The phytoplankton abundance during low tide in the *Bacillariophyceae* class ranged from 13,069.66 to 74,640.85 ind/l. The mean value was 49,180.26 ind/l. The lowest abundance was found at station 6, while the highest was found at station 2. The abundance within this class was the highest among the others. The mean abundance within class *Chrysophyceae* was 194.19 ind/l; the highest value was found at Station 5 and the lowest at Station 4. Thus, the water was more likely to flow to the cargo pier to the passenger pier. The mean abundance of class *Dinophycea* was 600.98 ind/l. The lowest was found at the estuary of Kali Baru (5.31 ind/l), while the highest was found at the cargo pier (2,165.6 in/l).

In class *Cyanophyceae*, the mean abundance was 774.11 ind/l. The lowest abundance value was at the container pier (35.03 ind/l) and the highest was at the passenger pier (2,144.48 ind/l). *Zygnematophyceae* was found only at station 6 with an abundance of 53.08 ind/l. The mean abundance of class *Mediophyceae* was 234.83 ind/l. The lowest was found at station 8, while the highest was at station 5 (1475.58 ind/l). The abundance of *Coscinodiscophyceae* ranged from 0 to 877.57 ind/l with a mean value of 292.82 ind/l. The highest abundance was found at Puri Pier (Station 2) and the lowest was at Station 8 (LPG pier) (Fig. 3).

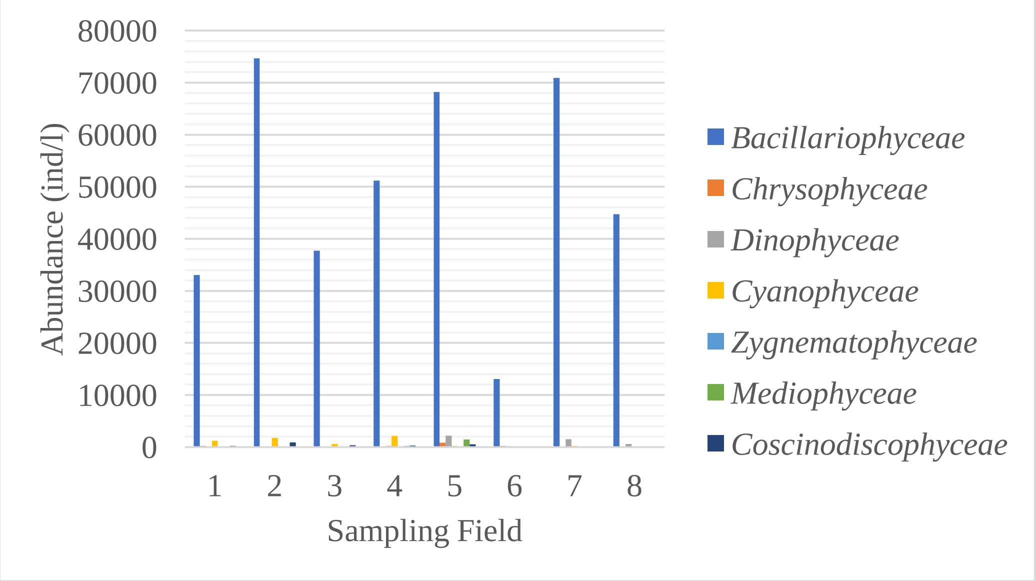

Fig. 3 Phytoplankton abundance during low tide (The authors' elaboration)

The mean of abundance during high tide within class *Bacillariophyceae* reached 22,336.5 ind/l. The highest was at station 8 (33,699.6 ind/l) and the lowest was at station 7 (15,565.1 ind/l). The mean of abundance of class *Mediophyceae* was 29.8 ind/l. The lowest was found at stations 3, 4, 6 and 7, while the highest was found at the estuary of Kali Baru (244.16 ind/l). The mean abundance of class *Coscinodiscophycea* was 154 ind/l. The highest abundance was at the LPG pier (Station 8). No abundance was found at the estuary of BKT. The abundance of *Cyanophyceae* ranged from 1.06 to 3,397.03 ind/l with a mean value of 523.25 ind/l. The lowest was at Station 7 (the middle of the port basin) and the highest was at the passenger pier (Station 4). The mean of abundance in class *Crysophyceae* was 77.49 ind/l. The highest value was found on the LPG pier (530.79 ind/l), while at stations 1, 3, 4, 5, 6, 7 and 9, there was no abundance in that class. The highest abundance in class *Dinophycea* was found at the container pier (Station 6), reaching 265.39 ind/l. At Stations 4 and 5, there was no abundance of phytoplankton in this class, with a mean value of 104.41 ind/l. During high tide, the abundance of *Bacillariophyceae* dominated the waters, followed by *Cyanophyceae* and *Coscinodiscophyceae* (Fig. 4).

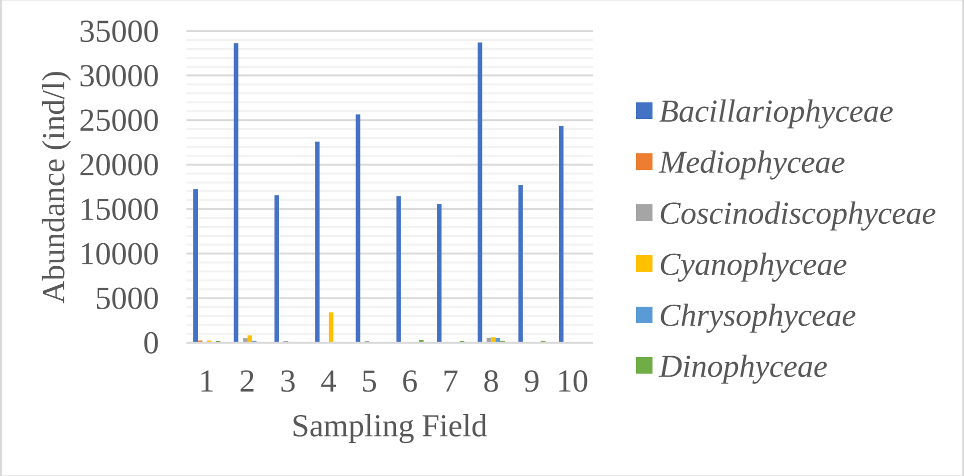

Fig. 4 Phytoplankton abundance during high tide (The authors’ elaboration)

In the zooplankton group, during low tide, the mean abundance of class *Crustaceans* was 42.4 ind/l. The lowest abundance was found at Station 6, while the highest was found at station 1. The mean abundance in *Ciliates* was 65.89 ind/l; the highest abundance was at Station 9 and the lowest was at Station 2. The highest abundance of *Sarcodina* was found at Station 7 (14.01 ind/l), while the lowest was found at the estuary of BKT. *Tentaculata's* abundance was found only at the estuary of BKT (0.42 ind/l). It agreed with *Rotifers* abundance found only at Station 5 (0.32 ind/l). Zooplankton abundance within class *Ciliates* dominated in the waters during low tide, followed by *Crustaceans* dan *Sarcodina* (Fig. 5).

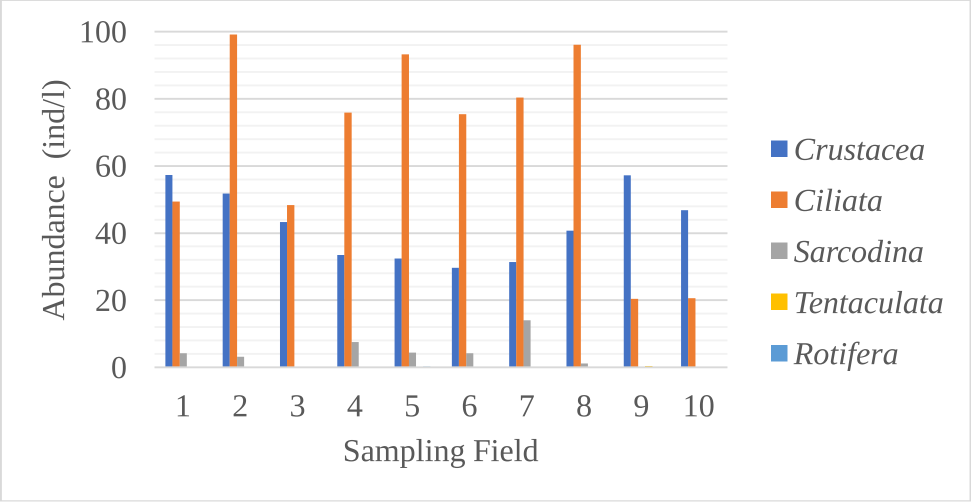

Fig. 5 Zooplankton abundance during low tide (The authors’ elaboration)

Zooplankton's composition during high tide consisted of *Crustaceans*, *Ciliates*, *Sarcodina*, and *Tentaculata*. The mean abundance in class *Crustaceans* was 33.81 ind/l, ranging from 20.29 to 59.45 ind/l; the lowest was found at station 4 and the highest value was found at Station 6. In class *Ciliates*, the mean abundance was 80.59 ind/l; the lowest was found at the estuary of Siangker (Station 10), while the highest was at Station 2 (140.66 ind/l). The mean of abundance in class *Sarcodina* reached 1.17 ind/l; the highest abundance was at Station 4, while at Stations 3 and 5, class *Sarcodina* was not found within the waters. *Tentacula* abundance was found only at Stations 1 and 10. During low tide, class *Ciliates* dominated the community, followed by *Crustaceans* (Fig. 6).

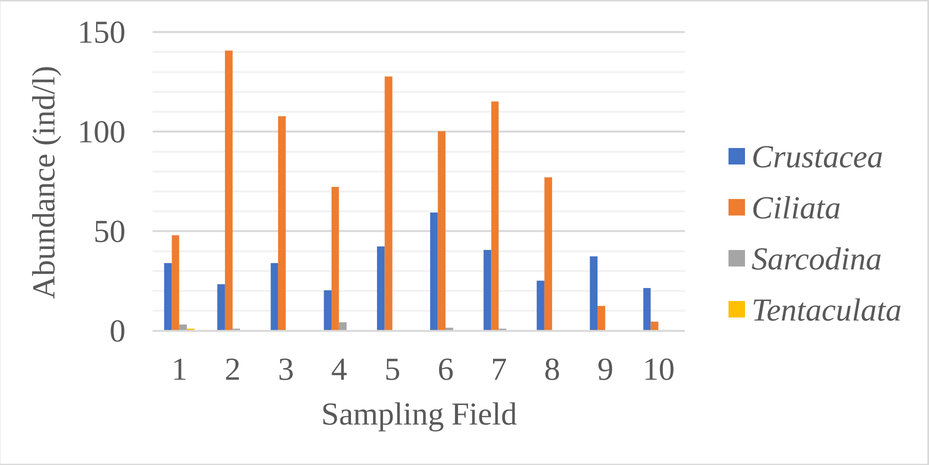

Fig. 6 Zooplankton abundance during high tide (The authors' elaboration)

Plankton diversity during high tide ranged from 1.16 to 1.93 and from 1.1 to 1.74 during low tide, indicating low diversity and high pollution. During high tide, the plankton uniformity (e) ranged from 0.51 to 0.77, while during low tide, it ranged from 0.48 to 0.69. This uniformity index indicated that the community was unstable. The mean value of the dominance index during high and low tides was 0.37 and 0.45, respectively; the dominance value during high tide ranged from 0.23 to 0.49; and the value during low tide ranged from 0.28 to 0.56. The value of plankton dominance in PTES waters found that there were no genera dominating the community.

The value of SI during high tide ranged from 0.77 to 1.08 (with a mean value of 0.94), while during low tide, it ranged from 0.77 to 0.98 (with a mean value of 0.88). The TSI value ranged from 1.23 to 1.57 during high tide and from 1.15 to 1.56 during low tide. The mean values of TSI during high and low tides were 1.36 and 1.32, respectively. Based on this value, the waters were classified as β-mesosaprobic, moderately polluted (Table 6).

Table 6 The calculation of diversity index, uniformity, dominance, SI and TSI (The authors' elaboration)

Index	**Condition**	**Station**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
H'	High tide	1.93	1.64	1.84	1.8	1.43	1.43	1.16	1.78	1.35	1.28
	Low tide	1.74	1.52	1.5	1.34	1.5	1.3	1.41	1.1	1.2	1.3
e	High tide	0.77	0.65	0.77	0.69	0.57	0.59	0.61	0.68	0.51	0.51
	Low tide	0.69	0.6	0.59	0.55	0.57	0.55	0.55	0.48	0.61	0.61
D	High tide	0.23	0.34	0.26	0.29	0.43	0.41	0.48	0.31	0.49	0.49
	Low tide	0.28	0.37	0.39	0.44	0.41	0.49	0.44	0.55	0.56	0.52
SI	High tide	1.08	0.77	0.98	0.92	0.88	0.92	0.87	1.03	0.96	0.95
	Low tide	0.93	0.91	0.93	0.82	0.82	0.88	0.83	0.77	0.95	0.98
TSI	High tide	1.57	1.27	1.53	1.43	1.38	1.27	1.27	1.39	1.23	1.23
	Low tide	1.56	1.49	1.48	1.38	1.31	1.18	1.15	1.15	1.24	1.29

Based on the factor analysis, 19 variables were analyzed, including temperature, pH, DO, TDS, turbidity, brightness, salinity, TSS, BOD, phosphate, nitrate, sulfide, phenol, phytoplankton abundance, zooplankton abundance, diversity index (H'), uniformity index (e), and dominance (D). Out of 19 variables included and extracted, five factors were obtained, reaching 94.49%; factors 1 to 5 were 41.49%, 24.21%, 15.36%, 7.15%, and 6.28% respectively. Factor 2 was the factor with the highest value, followed by factors 1 and 3. The communality table shows that the values of all variables were 1, describing the five factors that reflected the cumulative value reaching 94.49% of total variance. The variable with the highest value was phenol (0.996) while the lowest was nitrate (0.914). Based on the matrix and varimax rotated table components, five factors were obtained. The factor with the highest value was factor 1 (41.49%), which was influenced by salinity (0.97) > brightness (0.91) > temperature (0.91) > pH (0.83) > DO (0.64) > SI (-0.62) > nitrite (-0.91). The second factor (with influence value of 24.21%) correlated to e (0.98) > H' (0.96) > TDS (0.76) > sulfide (0.65) > D (-0.95). The third factor (with influence value of 15.36%) consisted of BOD (0.97) > TSS (0.91) > phosphate (0.7). The fourth factor (with influence value of 7.15%) depended on phytoplankton abundance (0.77) > phenol (0.7) > zooplankton abundance (0.64). The fifth factor (with influence value of 6.28%) was turbidity (0.91). Factors 1-5 were labeled as chemical parameters, biological factors, external factors productivity, and turbidity (Fig. 7).

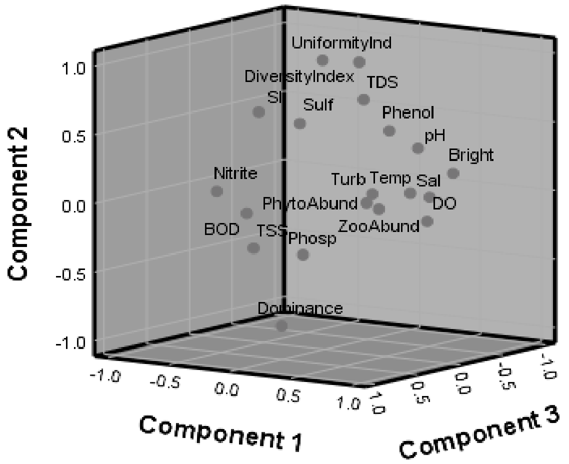

Fig. 7 The plot of components affecting TSI (The authors' elaboration)

Based on cluster analysis of phytoplankton class, correlation between *Bacillariophyceae*, *Chrysophyceae*, *Dinophyceae*, *Cyanophyceae*, *Zygnematophyceae*, *Mediophycea*, and *Coscinodiscophyceae* was found, represented in two clusters. In phytoplankton class, *Crysophyceae* (cluster 2) and *Mediophyceae* (cluster 6) had the nearest euclidean distance (0.046), followed by *Crysophyceae* - *Zygnematophyceae*, *Crysophyceae* - *Mediophyceae*, *Crysophyceae* - *Dinophyceae*, and last, *Crysophyceae* - *Cyanophyceae* (0.13), while *Bacillariphyceae* dan *Chrysophycae* had the furthest distance (6.925) (Fig. 8).

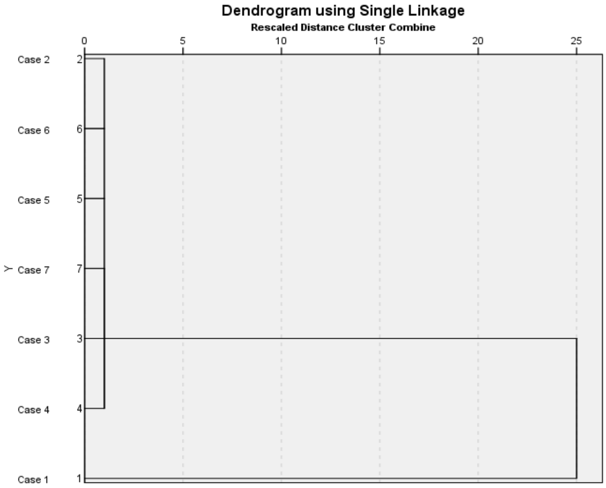

Fig. 8 Clustering of phytoplankton classes (The authors' elaboration)

3. Discussion

The value of DO in PTES waters ranged between 5 and 9 mg/l. DO values > 5 mg/l indicated that the waters were lightly polluted. This was in contrast to the conditions at the upstream of the Musi River, with saprobity index on mesosaprobic phase, due to the accumulation of nutrients [23]. A positive correlation was found between phytoplankton abundance and nitrate content. This finding was different from the research conducted at the estuary of Batang Arau, Padang, stating that there was a negative correlation between nitrate and diatom abundance; the higher the nitrate content was, the lower the diatom diversity would be [24]. The phytoplankton abundance was also influenced by ammonia content, but they correlated negatively; the higher the ammonia content the lower the phytoplankton abundance would be [25].

The correlation between phytoplankton abundance and nitrate showed a positive but weak correlation (coefficient of determination was 0.19). In addition to nitrate, the correlation between phytoplankton abundance and phosphate was also weak (14%) [26]. PTES waters contained high phytoplankton abundance (> 12,000 ind/l) and were eutrophic; the diatom class dominated the community. This condition was in line with the research conducted at Obi's waters Island, North Maluku. The saprobity value indicated that it belonged to β-mesosaprobic phase [27].

Chaetoceros is constituent genera of the saprobic index of α-mesosaprobic so it is not suitable for aquaculture activities. This condition was evidenced by the discovery of genera *Nitzchia*, *Synedra*, and *Flagillaria*, which were tolerant to high levels of organic pollution [1]. In PTES waters, some genera that are the constituent organisms of α-mesosaprobic were found, including *Chaetoceros sp.*, *Nitzschia sp.*, *Navicula sp.*, *Protoperidium sp.*, *Ceratium sp.*, *Dinophysis sp.*, *and Oscillatoria sp.* (Table 7). In Mayangan waters, Probolinggo, it was also found that there was dominance of genera *Chaetoceros* and *Skeletonema*, leading to water blooming. This condition potentially causes respiratory disorders in biota [28].

Research conducted in the port of Bar in the southern Adriatic Sea showed the potential genera *Pseudi-nitzscia spp.* These genera produced domoic acid, which poisoned shellfish living in these waters. This condition was caused by vessel ballast water discharge [29]. The presence of phytoplankton *Chaetoceros* in the waters of Labuange Bay, South Sulawesi, was a bioindicator that the waters contained organic waste pollution flowing from the river estuaries and caused by super-intensive ponds. The decline in water quality led to the existence of toxic phytoplankton [30].

Table 7 Plankton found as the bioindicator of organic pollution (The authors' elaboration)

Class/Genera	**References**
Bacillariophyceae	
Chaetoceros sp.	[1]
Nitzschia sp.	[1]
Navicula sp.	[18]
Dinophyceae	
Protoperidium sp.	[31]
Ceratium sp.	[32]
Dinophysis sp.	[33]
Cyanophyceae	
Oscillatoria sp.	[18]

The diversity and uniformity indices in Panjang Island, Jepara, were considered moderate. This might be because the nutrient content was moderate. The dominance value indicated that there were no species dominating, so the waters were identified as lightly to moderately polluted (α/β-mesosaprobic) [34]. By the presence of zooplankton abundance up to 500 ind/l, PTES waters were classified as mesotrophic; they had moderate fertility. This condition also occurred in Ciletuh's waters and Sukabumi. The low uniformity was low, with one species dominate, and its mesotrophic level indicated that the waters were not suitable for aquatic organisms [35].

There was a positive correlation between TSI with DO, TSS, nitrate, and chlorophyll-α in the waters of the estuary of Bodri River, Kendal, in the western area of Semarang Bay. Its saprobity was regarded as β-mesosaprobic (0.75-1.29). Moreover, pollution-tolerant *Synedra* was also found [36]. The research was conducted at fishing ports in Bali, with a uniformity index (H') of 1.22 and a trophic saprobic index of 0.1–1.12. These findings indicated the same condition that the waters were light to moderately polluted [37]. In the research conducted in the waters of the Gulf of Banten, the TSI value was influenced by the first component, reaching 53.73%. It was also found that temperature, pH, DO and brightness affected the saprobity index; the waters were light to moderately polluted (β-mesosaprobic) [38]. On the other hand, research conducted in the southern waters of Segara Anakan, Cilacap, found that temperature and TSS had a negative influence on phytoplankton abundance, while chemical factors (such as TDS, nitrite, and pH) had a positive influence [39].

Plankton are organisms floating by tides and currents. Based on plankton diversity, the waters had relatively low diversity and the environment was in an unstable condition; based on the dominance value, no genus dominated the waters. However, in terms of abundance, it was found that there was a dominance of class *Bacillariophyceae* in the estuarine waters because these organisms were resistant to changes in water conditions and had a higher survival rate among other classes. *Chaetoceros* dominating the waters showed that these genera were resistant to polluted waters.

This research was conducted during the east monsoon, so additional information on the phenomena that occurred during the west monsoon is required. Through a comparison of the conditions during high and low tides, it is expected that there will be a water quality analysis based on the presence of plankton. This research had not included abiotic parameters such as heavy metals and physicochemical parameters to determine the contamination value. It is hoped that some other in-depth research will be conducted on Chaetoceros's influence on other genera and the impact of its existence in the waters. Port regulators should improve the supervision of the activities of commercial vessels, fishing boats, and industrial activities around the port.

4. Conclusion

Based on the research conducted in PTES, 8 of 13 physicochemical parameters (turbidity, brightness, TSS, BOD, phosphate, nitrate, sulfide, and phenol) did not meet the quality standard. The DO content exceeding 5 mg/l indicated that the waters were lightly polluted. Based on the ANOVA test, the phytoplankton abundance during high and low tides in the waters located between the port basin and the control station (the estuary of BKT and Siangker) showed the same result ($F_{count} < F_{table}$). The mean values of zooplankton abundance found at the port basin during high and low tides were also equal ($F_{count} < F_{table}$). Based on the multiple regression formula, $Y = -31{,}287.88 + 19{,}187.07\ X_1 + 54{,}652.96\ X_2 - 15\ X_3 + 119.01\ X_4$, indicating a positive correlation between phytoplankton abundance and three independent variables (brightness, nitrate content, and zooplankton abundance) and a negative correlation between phytoplankton abundance and one independent variable (turbidity).

During low tide, 7 classes of phytoplankton were found, including *Bacillariophyceae, Chrysophyceae, Dinophyceae, Cyanophyceae, Zygnematophyceae, Mediophyceae*, and *Coscinodiscophyceae*; *Bacillariophyceae* was the most dominant class (95%) with 26 genera. On the other hand, during high tide, 30 genera were found in *the Bacillariphyceae* class. The phytoplankton abundance during low tide was 51,283.81 ind/l, greater than the abundance during high tide at 23,225.4 ind/l. During low tide in the zooplankton group, 5 classes were found, including *Crustaceans, Ciliates, Sarcodina, Tentaculata*, and *Rotifers*; *Crustaceans* dominated in the waters (with 26 genera). The mean abundance was 112.3 ind/l. However, during high tide, fewer classes (4 classes) were found; crustaceans were the most dominant but had a smaller number of genera (21 genera). The average value of zooplankton abundance during high tide was greater than that during low tide.

The diversity of plankton was low, indicating that the waters were highly polluted. The uniformity index indicated that the community was in an unstable condition. Dominance was also low, indicating that there were no genera dominating. Based on their saprobic or trophic saprobic values, the waters were categorized as β-mesosaprobic (moderately polluted). In PTES waters, three classes of phytoplankton from α-mesosaprobic phase were found: *Bacillariophyceae, Dinophyceae*, and *Cyanophyceae*. *Chaetoceros*, which were pollution tolerant, dominated in waters making the waters not suitable for aquaculture activities. *Nitzschia*, *Synedra*, and *Flagillaria* showed that these waters contained a large quantity of organic discharge and were polluted due to anthropogenic activities by both commercial vessels in PTES and fishing activities around the waters of BKT.

Based on the factor analysis, there were 5 factors affecting the TSI, reaching 94.49%. Factor 1, 41.49%, was influenced by salinity (0.97) > brightness (0.91) > temperature (0.91) > pH (0.83) > DO (0.64) > SI (-0.62) > nitrite (-0.91). Based on the results of cluster analysis on phytoplankton classes, two clusters were obtained; *Bacillariophycea* was the first cluster due to its abundance, which dominated the waters, while *Chrysophyceae, Dinophyceae, Cyanophyceae, Zygnematophyceae, Mediophycea*, and *Coscinodiscophyceae* were the second cluster due to their lower level of dominance.

There were parameters that did not meet the requirements, such as BOD, phosphate, and nitrate. It showed that the higher the BOD, the lower the DO would be. Thus, a lot of oxygen was used by bacteria for the oxidation process of organic matter. The BOD content was higher than DO, indicating that the waters were polluted, possibly due to industrial, domestic, and agricultural waste. The high content of nutrients, both nitrate and phosphate, indicated that the waters were eutrophicated; *Chaetoceros*, which dominated the waters, tended to experience rapid growth (blooming). Phenol that exceeded the standard also indicated that there were excessive domestic activities done by the local communities around the port as well as at the rivers' estuaries around the port. The plankton abundance in both the port pond and the control stations (the estuaries of BKT and Siangker) was equal. The finding showed that location had no effect on the abundance, and the plankton uniformity indicated that the waters were homogeneous. The number of classes in phytoplankton found during low tide was smaller than the finding during high tide, but the number of classes in zooplankton found during low tide was higher than during high tide. During high tide, there was additional seawater and additional oxygen as well as plankton in the port pond, but this tidal factor did not affect the number of plankton classes in the waters.

However, tidal factors influenced phytoplankton abundance; the abundance was higher during low tide than during high tide. Through research on the primary productivity of phytoplankton, factors that triggered ecosystem vulnerability at the next tropic level were found. Biotic contamination conditions would trigger the vulnerability of organisms on the level above it; thus, the resilience of higher tropic-level organisms would be disrupted, such as fish deaths due to toxins produced by toxic phytoplankton.

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