LenteraBio
LenteraBio, 2025; Volume 14, Issue 1: 92-104
p-ISSN: 2252-3979 e-ISSN: 2685-7871
https://journal.unesa.ac.id/index.php/lenterabio/index

The Abundance and Diversity of Plankton as a Bioindicator of the Quality of Coastal Waters of the Coastal Fishing Site of Paiton District of Probolinggo

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Article History:
Received:
1-October-2024
Revised:
21-January-2025
Available online:
23-January-2025
Published regularly:
31-January-2025

Abstract
The utilization of the Paiton TPI coastal area as a fish market and boat repair site, and its proximity to the Paiton power plant industry, can impact the plankton ecosystem. A decline in the plankton population will affect the life cycle within the ecosystem, particularly fish, mangrove ecosystems, and human livelihoods. The plankton diversity index and plankton abundance serve as bioindicators to assess water quality. This study aimed to determine the relationship between plankton abundance and diversity with the physical-chemical parameters in the Paiton TPI coastal area. This exploratory research employed a purposive sampling method conducted at five stations with varying characteristics. Plankton identification was carried out at the Ecology Laboratory, FMIPA UNESA, and analyzed using the Shannon-Weiner diversity index and the Weltch plankton abundance index formulas. Data were analyzed using the bivariate Pearson correlation test. The results showed that plankton diversity in the Paiton TPI coastal waters comprised 16 divisions, 62 species, and 488 plankton individuals, with plankton diversity index of 3.3282, indicating unpolluted conditions, and a plankton abundance of 10.844 ind/L, categorizing the waters as oligotrophic. All parameters met quality standards except for DO (<5 mg/L) and clarity (<3 m). Temperature, clarity, pH, and DO were positively correlated, while salinity, TSS, TDS, turbidity, BOD, CO_2, ammonia, and COD were negatively correlated with plankton diversity and abundance indices.

Keywords: coastal biodiversity; paiton fish auction place; water analysis; water quality index
How to Cite: Afifah K, Purnomo T, 2025. The Abundance and Diversity of Plankton as a Bioindicator of The Quality of Coastal Waters of The Coastal Fishing Site of Paiton District of Probolinggo. LenteraBio; 14(1): 92-104
DOI: https://doi.org/10.26740/lenterabio.v14n1.p92-104

INTRODUCTION

Fish Auction Place (TPI) is a market place for buying and selling fish/seafood located inside a fish landing port (PPI) under the supervision of the Fisheries Service or Local Government (BPS, 2016). TPI Paiton is located in the eastern region of Probolinggo, precisely on Jalan Lapangan Tembak, Pesisir Hamlet, Sumberanyar Village, Paiton Sub-district, Probolinggo Regency, East Java. The location of TPI Paiton is close to PLTU Paiton, approximately 6 km, so the location of PLTU Paiton can be seen directly from TPI Paiton.

The utilization of the Paiton TPI coastal area as a central hub for buying and selling fishermen's catches also serves as a place to access various services, such as auctions, net repairs, and engine and boat maintenance for fishing preparations (IPP Paiton, 2021). However, the environmental conditions near the coast, which is close to the Paiton power plant industry, contribute to solid and liquid waste pollution. Organic solid waste includes fish body parts such as heads, tails, entrails, fins, and scales. Meanwhile, liquid waste consists of fish blood and floor-washing water (Juliardi et al., 2013). Domestic waste comes from fish market waste and waste from fish auction sites, such as garbage, laundry detergent, and soap, as well as waste from net repair areas, including unused nets; engine repair areas, including oil waste; and ship repair areas, including wood, paint, and fuel residue. Indaryanto and Saifullah (2015) stated that several ship-related activities potentially contribute hazardous heavy metal waste to the environment, such as during oil changes, engine cooling processes, and ship repairs. Gholizadeh et al. (2016) mentioned that anthropogenic activities around aquatic areas could impact ecosystem changes, posing a threat to aquatic organisms, especially plankton. The reduction or loss of plankton affects the life cycle within the ecosystem. This impact will be felt in fish populations, mangrove ecosystems, and human life, particularly for those dependent on the sea for their livelihood (Halidah, 2016). Poor water quality can also serve as a medium for spreading diseases and infections due to harmful substances present in the water (Priyanto, 2011).

Plankton is a group of microscopic aquatic biota that live passively, and their movements are influenced by waves, currents, and water movements. Based on how they get nutrients, plankton are divided into two, namely phytoplankton (vegetable) and zooplankton (animal) (Nugraha and Hismayasari, 2011; Kurniawan, 2018). The role of plankton as primary producers and the starting point of the chain can make plankton a bioindicator of the health and trophic status of water bodies because each plankton species has varying environmental adaptability. Plankton species that have high tolerance can live and grow in polluted waters and extreme conditions, while sensitive plankton species cannot adapt and grow (Ankita et al., 2021). The growth rate and development of plankton are influenced by physical, chemical, and biological factors such as temperature, pH, DO, BOD, depth, CO_2, current flow velocity, turbidity, salinity, transparency, light, available nutrients, etc. (Elayaraj et al., 2014).

The importance of plankton in the aquatic ecosystem of the Paiton TPI coastal area, the lack of data, and the limited information regarding the relationship between physical-chemical water parameters and plankton diversity and abundance indices in the region highlight the need for an analysis of the physical-chemical water parameters concerning plankton diversity and abundance as indicators of water quality in the coastal waters of the Fish Auction Center (TPI) in Paiton District, Probolinggo Regency. Therefore, this study aims to determine the water quality in the coastal waters of the Fish Auction Center (TPI) in Paiton, Probolinggo Regency.

MATERIALS AND METHODS

This explorative research was conducted from September 2023 to January 2024. Sampling was conducted at five stations with different characteristics and a distance of ± 200 m between stations in the Coastal Waters of TPI Paiton Beach, Sumberanyar Village, Paiton District, Probolinggo Regency, East Java. Each station has 3 sampling points (edge I, center, and edge II) and 3 replicates, totaling at 45 replicates. Station 1 was located at coordinates 7°42'21.4 "S 113°31'22.4 'E, station 2 at coordinates 7°42'24.2 'S 113°31'28.4 'E, station 3 at coordinates 7°42'21.9 'S 113°31'34.2 'E, station 4 at coordinates 7°42'18.5 'S 113°31'34.1 'E, and station 5 at coordinates 7°42'13.3 'S 113°31'31.3 "E (Figure 1).

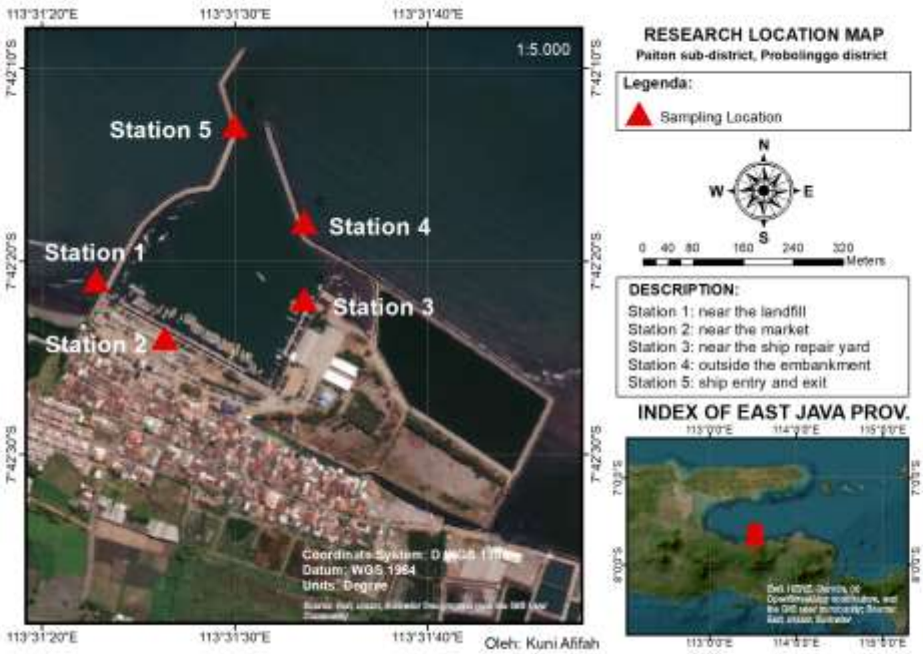

Figure 1. Research location of TPI Paiton (ArcGIS)

This study used the "purposive sampling" method. Samples were collected during high tide between 08:00 and 12:00 WIB under sufficient sunlight by placing a No. 25 plankton net on the water surface at a depth of 20 cm. The filtered water samples in the plankton net were then transferred into

10 ml vial bottles. Subsequently, 2–3 drops of 4% formalin were added, and the bottles were labeled according to the sampling station.

Identification of plankton diversity and abundance was carried out by shaking the water sample in a 10 mL vial bottle slowly until homogeneous, then the water sample was taken using a drop pipette, then ten drops (1 mL) of water sample were dropped into the Sedgewick Rafter Counting Chamber (SRCC) and covered with cover glass. After that, the samples were observed using a 100x magnification light microscope by observing morphological differences, documented, and identified to the species level using the website www.marinespecies.org to facilitate the identification process. In addition, identification was carried out using guidebooks such as the Marine Zooplankton of Southern Britain identification book from Conway (2012) and Identifying Marine Phytoplankton from Tomas (1997), scientific journals, or ebooks.

Measurements of temperature (thermometer), clarity (Secchi disk), salinity (refractometer), pH (pH meter), DO (dissolved oxygen meter), CO_2 (titration method), TDS (total dissolved solids meter), and BOD (biochemical oxygen demand using DO meter) were conducted directly at the research site. Testing for ammonia and COD parameters was carried out at the Nutrition Laboratory, Department of Health Nutrition, Faculty of Public Health, Airlangga University. Meanwhile, measurements of TSS (total suspended solids), turbidity, and the plankton analysis and identification stages were conducted at the Ecology Laboratory, Biology Study Program, Faculty of Mathematics and Natural Sciences, Surabaya State University.

The test results of physical and chemical parameters were compared with the seawater quality standards listed in Government Regulation No. 22 of 2021 concerning environmental management, protection, and management. Then, the water quality in the coastal area of TPI Paiton was analyzed descriptively to determine whether it meets the quality standards or not.

The plankton diversity index was calculated using the Shannon-Wiener Diversity Index (H') formula (Hedriansyah et al., 2018):

$$H' = -\Sigma Pi \ln Pi$$

Where:
H' = Shannon-Wiener Diversity Index
Pi = Proportion of plankton species (S/N)
S = Number of individuals of a plankton species
N = Total number of plankton species
In = Logarithm of the total number of plankton individuals

The plankton abundance index was calculated using the Welch (1952) Abundance Index formula (Afif et al., 2014):

$$N = \frac{(a \times 1000) \times c}{V}$$

Where:
N = Plankton abundance per liter
a = Average number of plankton from all counts in the Sedgewick Rafter Counting Cell (SRCC) with a capacity of 1 ml
c = Volume of filtered water (ml)
V = Volume of water sampled (L)

Relative abundance was calculated using the Odum (1993) Relative Abundance formula (Zakiyah and Mulyanto, 2020).

$$RA = ni/N \times 100\%$$

Where:
RA = Relative abundance
Ni = Number of individuals of the first species
N = Total number of individuals

Inferential statistical techniques were employed in the analysis. To ascertain whether there is a relationship or correlation between the diversity index and the physical-chemical characteristics of the water, the gathered data will be examined using the Bivariate Pearson correlation test with SPSS software version 23. An overview of the water quality in the Paiton TPI coastal area will be provided by using the analysis results to classify the degree of water pollution according to plankton diversity and abundance indices.

RESULTS

Based on research conducted in the Coastal Waters of the Paiton Fish Auction Site (TPI), Probolinggo Regency, 9 divisions of phytoplankton were found (Table 1), including: Chlorophyta (5 species), Bacillariophyta (19 species), Euglenozoa (1 species), Myzozoa (13 species), Charophyta (2 species), Cryptophyta (1 species), Ochrophyta (2 species), Haptophyta (1 species), and Cyanobacteria (5 species). While there are 7 zooplankton divisions (Table 1), including Euglenophyta (2 species), Ciliophora (4 species), Amoebozoa (2 species), Rotifera (1 species), Arthropoda (2 species), Nemathelminthes (1 species), and Chaetognatha (1 species). The total number of plankton is 16 divisions, 62 species, and 488 individuals. Consisting of phytoplankton and zooplankton.

In addition to the species found, Table 1 also describes the diversity and abundance of plankton in the coastal waters of the Paiton Fish Auction Site (TPI), Probolinggo Regency. While the measurement results of physico-chemical parameters in the coastal waters of TPI Paiton Beach are presented in Table 2 and Table 3 describes the relationship between plankton diversity index and physical - chemical parameters using Pearson Bivariate Correlation Analysis..

Table 1. Species name, number of individuals per station, plankton abundance index, and plankton diversity index at TPI Paiton Beach, Probolinggo Regency.

No	Species Name	Number of Individuals per Station					Total Individuals and RA		
		S1	S2	S3	S4	S5			
		In[1]	In	In	In	In	In	PAI	RA[2]
Division Chlorophyta									
1	*Botryococcus* sp.	0	1	1	1	0	3	0.067	0.615%
2	*Chlamydomonas* sp.	2	2	1	5	8	18	0.400	3.689%
3	*Hormidiopsis* sp.	1	2	2	0	0	5	0.111	1.025%
4	*Tetraselmis* sp.	1	0	0	7	4	12	0.267	2.459%
5	*Scenedesmus* sp.	0	1	0	2	2	5	0.111	1.025%
Division Bacillariophyta									
6	*Coscinodiscus* sp.	1	0	0	2	1	4	0.089	0.820%
7	*Melosira* sp.	1	3	2	4	2	12	0.267	2.459%
8	*Rhizosolenia* sp.	5	8	5	11	15	44	0.978	9.016%
9	*Proboscia* sp.	0	0	0	6	2	8	0.178	1.639%
10	*Pseudosolenia* sp.	2	3	0	7	9	21	0.467	4.303%
11	*Dactyliosolen* sp.	0	0	0	4	3	7	0.156	1.434%
12	*Isthmia* sp.	1	0	0	3	2	6	0.133	1.230%
13	*Cerataulina* sp.	5	5	3	3	0	16	0.356	3.279%
14	*Eucampia* sp.	2	4	2	5	1	14	0.311	2.869%
15	*Odontella* sp.	3	5	3	6	9	26	0.578	5.328%
16	*Chaetoceros* sp.	5	7	3	13	8	36	0.800	7.377%
17	*Gyrosigma* sp.	0	2	5	2	0	9	0.200	1.844%
18	*Plagiotropis* sp.	0	2	1	0	0	3	0.067	0.615%
19	*Cymbella* sp.	1	0	0	1	0	2	0.044	0.410%
20	*Nitzschia* sp.	2	3	1	2	5	13	0.289	2.664%
21	*Lioloma* sp.	0	0	0	1	1	2	0.044	0.410%
22	*Striatella* sp.	4	2	2	7	5	20	0.444	4.098%
23	*Grammatophora* sp.	1	0	0	4	2	7	0.156	1.434%
24	*Fragilaria* sp.	0	5	2	0	1	8	0.178	1.639%
Division Euglenozoa									
25	*Euglena* sp.	0	1	0	2	0	3	0.067	0.615%
Division Myzozoa									
26	*Gymnodinium* sp.	0	0	3	0	2	5	0.111	1.025%
27	*Cochlodinium* sp.	2	4	2	5	6	19	0.422	3.893%
28	*Warnowia* sp.	3	1	0	4	3	11	0.244	2.254%
29	*Karenia* sp.	1	0	1	0	0	2	0.044	0.410%
30	*Karlodinium* sp.	0	0	2	0	0	2	0.044	0.410%
31	*Polykrikos* sp.	1	3	0	5	1	10	0.222	2.049%
32	*Prorocentrum* sp.	0	0	1	0	2	3	0.067	0.615%
33	*Gonyaulax* sp.	2	4	0	0	1	7	0.156	1.434%
34	*Alexandrium* sp.	0	0	0	0	1	1	0.022	0.205%
35	*Coolia* sp.	0	0	3	0	0	3	0.067	0.615%
36	*Peridiniopsis* sp.	1	1	3	1	2	8	0.178	1.639%
37	*Glenodinium* sp.	2	0	1	0	0	3	0.067	0.615%
38	*Protoperidinium* sp.	0	0	0	0	1	1	0.022	0.205%
Division Charophyta									
39	*Penium* sp.	0	1	0	0	0	1	0.022	0.205%
40	*Pleurotaenium* sp.	0	0	2	0	0	2	0.044	0.410%
Division Cryptophyta									

No	Species Name	Number of Individuals per Station					Total Individuals and RA		
		S1	S2	S3	S4	S5			
		In[1]	In	In	In	In	In	PAI	RA[2]
41	*Rhodomonas* sp.	0	1	0	1	0	2	0.044	0.410%
Division Ochrophyta									
42	*Chromulina* sp.	0	0	0	3	1	4	0.089	0.820%
43	*Vaucheria* sp.	2	2	0	4	2	10	0.222	2.049%
44	*Spirulina* sp.	3	2	0	4	4	13	0.289	2.664%
Division Haptophyta									
45	*Prymnesium* sp.	1	1	0	2	0	4	0.089	0.820%
Division Cyanobacteria									
46	*Synechococcus* sp.	0	0	0	4	4	8	0.178	1.639%
47	*Gloeocapsa* sp.	1	0	0	1	1	3	0.067	0.615%
48	*Oscillatoria* sp.	2	0	0	5	2	9	0.200	1.844%
49	*Planktothricoides* sp.	0	1	2	0	0	3	0.067	0.615%
Division Euglenophyta									
50	*Astacia* sp.	0	0	1	1	0	2	0.044	0.410%
51	*Lepocinclis* sp.	0	1	0	1	0	2	0.044	0.410%
Division Ciliophora									
52	*Askoella* sp.	1	0	0	0	2	3	0.067	0.615%
53	*Vaginicola* sp.	0	1	0	3	2	6	0.133	1.230%
54	*Uronema* sp.	1	0	0	0	1	2	0.044	0.410%
55	*Pseudoblepharisma* sp.	0	0	2	0	0	2	0.044	0.410%
Division Amoebozoa									
56	*Mayorella* sp.	1	2	0	4	5	12	0.267	2.459%
57	*Thecamoeba* sp.	2	1	0	3	3	9	0.200	1.844%
Division Rotifera									
58	*Paraseison* sp.	0	0	0	1	1	2	0.044	0.410%
Division Arthropoda									
59	*Tortanus* sp.	0	0	0	1	3	4	0.089	0.820%
60	*Hansenocaris* sp.	0	0	0	2	0	2	0.044	0.410%
Division Nemathelminthes									
61	*Anisakis* sp.	1	0	0	0	0	1	0.022	0.205%
Division Chaetognatha									
62	*Parasagitta* sp.	0	0	2	1	0	3	0.067	0.615%
Number of Individuals		**64**	**82**	**58**	**154**	**130**	**488**	**10.844**	100%
Number of Phytoplankton		**58**	**77**	**53**	**137**	**113**		**438**	
Number of Zooplankton		**6**	**5**	**5**	**17**	**17**		**50**	
Number of Species		**33**	**32**	**27**	**43**	**40**		**62**	
H'[3]		**3.324**	**3.244**	**3.179**	**3.525**	**3.369**		**3.3282 ± 0.132**	
[4]N (Ind/L)		**7.111**	**9.111**	**6.444**	**17.1111**	**14.444**		**10.844 ± 4.705**	

Description : [1]In = Number of Individuals, [2]RA = Relative Abundance, [3]H' = Plankton Diversity Index, [4]N = Plankton Abundance Index, Phytoplankton = no. 1 - 49, Zooplankton = no. 50 - 62

Based on the results of the calculations in Table 1, it shows that differences in the number of individuals and species at each station affect the value of the diversity index and abundance of plankton. The index value of plankton diversity in the coastal TPI Paiton Probolinggo Regency in a row from the highest to the lowest is station 4 with a value of 3.535, station 5 with a value of 3.369, station 1 with a value of 3.324, station 2 with a value of 3.244, and station 3 with a value of 3.179. The index value of plankton abundance in the coastal TPI Paiton Probolinggo Regency in a row from highest to lowest is station 4 with a value of 17.111 ind/L, station 5 with a value of 14.444 ind/L, station 2 with a value of 9.111 ind/L, station 1 with a value of 7.111 ind/L, and station 3 with a value of 6.444 ind/L.

Table 2. Test results of physico-chemical parameters in the coastal waters of TPI Paiton Beach

No.	Parameter	Standard	Unit	Average per station					Average and SD	M/TM
				1	2	3	4	5		
1	**Temperature**	28-32	°C	32.4	32.5	31.6	34.3	32.5	32.66 ± 0.887	**M**
2	**Transparency**	>3	m	1.4	1.2	1.2	1.6	1.6	1.4 ± 0.179	**TM**
3	**Salinity**	>30	ppt	33.8	30.1	32.6	29.9	32	31.68 ± 1.491	**M**
4	**TSS**	<80	mg/L	0.302	0.295	0.307	0.296	0.295	0.299 ± 0.005	**M**
5	**TDS**	<2000	mg/L	1791	1758	1816.6	1746.9	1767.3	1776.0 ± 24.979	**M**
6	**Turbidity**	<5	NTU	0.36	0.77	0.43	0.18	0.26	0.40 ± 0.204	**M**
7	**pH**	6,5-8,5	-	8.15	7.68	8.13	8.08	8.15	8.04 ± 0.181	**M**

8	**BOD**	<10	mg/L	4.39	4.29	4.41	2.26	2.87	3.64 ± 0.903	**M**
9	**DO**	>5	mg/L	4.50	4.55	4.71	5.54	5.12	4.88 ± 0.394	**TM**
10	**CO_2**	<15	mg/L	6.0	6.1	4.2	2.2	2.2	4.1 ± 1.722	**M**
11	**Ammonia**	<0,3	mg/L	0.164	0.147	0.124	0.112	0.083	0.126 ± 0.028	**M**
12	**COD**	<25	mg/L	6.98	6.83	6.75	6.69	6.40	6.73 ± 0.192	**M**

Description: M = meets the quality standards according to Government Regulation No. 22 of 2021, TM = does not meet the quality standards according to Government Regulation No. 22 of 2021, SD = standard deviation

Based on the results of physico-chemical measurements at five stations with three repetitions at each sampling point (Table 2), temperature, salinity, TSS, TDS, turbidity, pH, BOD, CO_2, ammonia, and DO of Paiton TPI waters meet the quality standards set by Government Regulation No. 22 of 2021 concerning environmental management, protection, and management. However, brightness and DO do not meet the quality standards.

Table 3. Relationship of plankton diversity index with physical and chemical parameters using Pearson Bivariate Correlation Analysis

Parameter	Relationship between Diversity Index and Water Quality r (calculated)	Category
Temperature	+0.847**	Very strong positive
Transparency	+0.892**	Very strong positive
Salinity	-0.225	Weak negative
***Total Suspended Solid* (TSS)**	-0.038	Weak negative
***Total Dissolved Solid* (TDS)**	-0.676**	Very strong negative
Turbidity	-0.414**	Very strong negative
pH	+0.208	Weak positive
***Biological Oxygen Demand* (BOD)**	-0.854**	Very strong negative
***Dissolved Oxygen* (DO)**	+0.759**	Very strong positive
CO_2	-0.488**	Very strong negative
Ammonia	-0.371*	Strong negative
***Chemical Oxygen Demand* (COD)**	-0.299*	Strong negative

Description: (**) = significant level <0.01, (*) = significant level <0.05, (-) = has a negative correlation, (+) = has a positive correlation.

Based on Table 3, it can be seen that there is a relationship between physical and chemical factors with the plankton diversity index, which can be seen from the correlation coefficient value of physical and chemical parameters showing results below 0.05, which means significant or has a correlation. Physical and chemical parameters that have a positive correlation with the plankton diversity index are temperature, brightness, and DO, while physical and chemical parameters that have a negative correlation with the plankton diversity index are TDS, turbidity, BOD, CO_2, ammonia, and COD. Meanwhile, salinity, TSS, and pH parameters have a very low or insignificant correlation level.

DISCUSSION

Water quality in the coastal waters of TPI Paiton Beach, Probolinggo Regency, in terms of physico-chemical and biological parameters measured at 5 stations with different characteristics showed that the morning sampling time resulted in more phytoplankton found than zooplankton (Rusdiyani and Purnomo, 2020), because in the morning phytoplankton are on the surface of seawater to get sunlight, while zooplankton tend to migrate to the seabed when sunlight intensity is high and return to the surface of seawater when light intensity is low (Japa et al., 2013). In this study, 9 divisions of phytoplankton were found (Table 1), including: Chlorophyta (5 species), Bacillariophyta (19 species), Euglenozoa (1 species), Myzozoa (13 species), Charophyta (2 species), Cryptophyta (1 species), Ochrophyta (2 species), Haptophyta (1 species), and Cyanobacteria (5 species). While there are 7 zooplankton divisions (Table 1), including Euglenophyta (2 species), Ciliophora (4 species), Amoebozoa (2 species), Rotifera (1 species), Arthropoda (2 species), Nemathelminthes (1 species), and Chaetognatha (1 species). The total number of plankton is 16 divisions, 62 species, and 488 individuals. Consisting of phytoplankton and zooplankton.

The identification results (Table 1) show that phytoplankton at each station is dominated by the Bacillariophyta division with a total of 19 species. The Bacillariophyceae or diatom division has the ability to survive in certain environments and is the most widely found phytoplankton group in waters and plays a role in contributing fundamentally to marine productivity, especially in coastal waters (Ningrumsari, 2022). Diatoms can be used as bioindicators of water quality because they can describe and respond to physico-chemical changes in waters in the short and long term (Ananingtyas et al., 2018). Lantang and Pakidi (2015) explained that the ability of this class of phytoplankton to easily adapt to its environment, withstand extreme conditions, and have a high reproduction rate compared to other types of phytoplankton; they can double in 18-36 hours. That's why this division is more dominant than other divisions.

The most abundant Bacillariophyceae division found was the *Rhizosolenia* sp., with a total of 44 individuals, a plankton abundance of 0.978 ind/L, and a relative abundance of 9.016%. In the research of Afif et al. (2020), it was mentioned that the abundance of *Rhizosolenia* sp. can cause the abundance of other phytoplankton to decrease. This is related to competition for nutrients that are mostly obtained by *Rhizosolenia* sp.. In addition, water conditions that are considered suitable for the growth of the *Rhizosolenia* sp. and the adaptability of this species that is resistant to extreme conditions can also increase its abundance.

Zooplankton is dominated by the Ciliophora division, with a total of 4 species. The ciliophora division can adapt and live in dirty waters and polluted environmental conditions (Fadilatin et al., 2022). The most commonly found Ciliophora division is the *Vaginicola* sp., with a total of 6 individuals, plankton abundance of 0.133 ind/L, and relative abundance of 1.230%. Besides the *Vaginicola* sp., the dominating zooplankton of the *Mayorella* sp. had a plankton abundance of 0.267 ind/L and a relative abundance of 2.459%. Amoeba of the *Mayorella* sp. can live in many places, both in the sea, freshwater, and soil (Glotova et al., 2018). The abundance of the *Mayorella* sp. can occur because protozoa have the ability to survive in non-ideal environments, can use organic matter (detritus) as a food source, and have a faster reproductive cycle than other classes of organisms (Widyarini et al., 2017).

The plankton diversity index at TPI Paiton Beach, Probolinggo Regency as a whole has an average of 3.3282 (Table 1). Although each station has different conditions, water quality is in the range of quality standards or meets quality standards. Based on Shannon Weaner plankton diversity index criteria, the coastal TPI Paiton Probolinggo Regency has moderate plankton diversity because the plankton diversity index value is in the range of 2.3026-6.9076 (Odum, 1994). Based on the criteria of water pollution, waters in the coastal TPI Paiton Probolinggo are76 classified as low polluted, indicated by the index value of planktodiversity > >2.00 but the DO of water <6.5 mg/(Lee, et al., 1978). The criteria for coastal environmental conditions at TPI Paiton Beach, Probolingg Regency based on the diversity index are very stable and very good because they have a diversity index value of >2.41 (Shabrina et al., 2020). These results indicate that differences in the number of individuals and species at each station affect the value of the plankton diversity index (Nurmalitasari and Sudarsono, 2023). Lutfiana (2022) explained that if there are species whose numbers are much greater than others, plankton diversity will be lower.

The coastal waters of TPI Paiton, Probolinggo Regency recorded a plankton abundance index of 10,844 ind/L (Table 1). Based on Landner's (1976) plankton abundance criteria, the coastal waters of TPI Paiton, Probolinggo Regency, are categorized as oligotrophic waters, which are waters with low fertility levels and phytoplankton abundance ranging from 0 to 2,000 ind/L (Nirasari et al., 2018). This condition is attributed to plankton migration and the timing of sample collection during seasonal transitions, leading to unstable water conditions (Tambaru et al., 2020). Additionally, in this study, zooplankton was found to be less common than phytoplankton due to differences in growth rates between the two types of plankton. Zooplankton have longer reproductive cycles compared to phytoplankton, and there are carnivorous and omnivorous fish whose primary food source is plankton (Lutfiana, 2022).

Based on the identification results (Table 1), it shows that the high plankton diversity index (3.535) and plankton abundance index (17.111 ind/L) at station 4 and the low value of the plankton diversity index (3.179) and plankton abundance index (6.444 ind/L) at station 3 are caused by the characteristics and location of the waters outside the harbor embankment and far from the source of pollution so that the level of pollution is lower than the station, which is inside the embankment area and near the source of pollution. Indaryanto and Saifullah (2015) stated that there are several ship activities that have the potential to contribute heavy metal waste that is harmful to the environment, such as the circulation process of engine coolant, engine oil changes, and ship repairs. The presence of heavy metal pollution and other waste pollution in the water area certainly affects the aquatic ecosystem, especially plankton.

The diversity and abundance index of plankton species in a body of water is influenced by environmental factors, such as the water's physicochemical parameters (Lutfiana, 2022). This indicates a relationship between the diversity and abundance index of plankton and the water quality conditions in the coastal waters of TPI Paiton, Probolinggo Regency, based on physicochemical parameters. According to Lubis (2021), the plankton diversity index provides information about water conditions because plankton play an important role in indicating the status of the aquatic environment.

Based on the measurements conducted (Table 2 and Table 3), it was found that the temperature in the coastal waters of TPI Paiton, Probolinggo Regency, ranging between 31.6°C and 32.5°C, is still considered optimal for plankton growth, which is 24 to 32°C (Hainuna, 2015), and complies with the quality standards set by Government Regulation No. 22 of 2021. The water temperature in the coastal waters of TPI Paiton has a very strong positive correlation with the plankton diversity index (0.847) (Leidonald et al., 2022). Temperature changes affect phytoplankton abundance as they are associated with various biological processes within phytoplankton, including metabolism rate, respiration, reproduction, migration, biomass, chlorophyll-a content, and biochemical composition (Zainal et al., 2023). The high temperature at station 4 (34.3°C) accelerates plankton growth rates, resulting in a higher plankton diversity index at station 4 (3.535) compared to other stations (Mustari et al., 2018).

The water clarity in the coastal waters of TPI Paiton, Probolinggo Regency, ranging from 1.2 m to 1.6 m, meets the optimal clarity for aquatic organism growth, which is >0.45 m (Suardiani et al., 2018). The water clarity in the coastal waters of TPI Paiton has a very strong positive correlation with the plankton diversity index (0.892). According to the research conducted, station 4 has the highest plankton diversity index of 3.535 with a clarity of 1.6m, while station 3 has the lowest plankton diversity index of 3.179 with a clarity of 1.2m. The low diversity index at station 3 is attributed to high levels of human activity that produce waste and a significant amount of suspended particles (Patty et al., 2021), which reduce the intensity of light absorbed by the water, thereby decreasing the photosynthesis rate in plankton (Samudera and Suryono, 2021).

The salinity in the coastal waters of TPI Paiton, Probolinggo Regency, ranging from 29.9 ppt to 33.8 ppt, is categorized as low (Meirinawati and Iskandar, 2019) but still supports phytoplankton to survive, reproduce, and perform photosynthesis optimally in these waters (Yuliana, 2014). It also complies with the quality standards set by Government Regulation No. 22 of 2021. The salinity in the coastal waters of TPI Paiton has a weak negative correlation with the plankton diversity index (-0.225) (Priska et al., 2020). Based on the research conducted, station 4 recorded the highest plankton diversity index at 3.535 with a salinity of 29.9 ppt, while station 3 had the lowest diversity index at 3.179 with a salinity of 32.6 ppt. Yudhatama et al. (2019) stated that salinity affects the presence and distribution of zooplankton, as evidenced by the occurrence and distribution of certain zooplankton species at varying salinity levels in the waters of Bonang Subdistrict, Demak Regency.

Total Suspended Solids (TSS) in the coastal waters of TPI Paiton, Probolinggo Regency, ranging from 0.295 mg/L to 0.307 mg/L, is categorized as low (0–100 mg/L) (PermenLH No. 1, 2010). However, these results still comply with the quality standards set by Government Regulation No. 22 of 2021. The TSS values in the coastal waters of TPI Paiton have a weak negative correlation with the plankton diversity index (-0.038). Based on the research conducted, station 4 recorded the highest plankton diversity index at 3.535 with a TSS of 0.296 mg/L, while station 3 had the lowest diversity index at 3.179 with a TSS of 0.295 mg/L. The higher TSS value at station 3 indicates that the water condition at this location is relatively polluted, hindering light penetration into the water. Consequently, this reduces photosynthesis, growth, and the abundance of phytoplankton (Pratama, 2019; Ma'arif and Hidayah, 2020).

Total Dissolved Solids (TDS) in the coastal waters of TPI Paiton, Probolinggo Regency, ranging from 1,746.9 mg/L to 1,816.6 mg/L, falls within the species range of TDS for seawater, which is 500–30,000 ppm (Moran, 2018). The TDS values in the coastal waters of TPI Paiton have a very strong negative correlation with the plankton diversity and abundance index (-0.676) (Haribowo et al., 2021) because high TDS levels can reduce light penetration in the water, thereby inhibiting the photosynthesis rate in phytoplankton. The low plankton diversity index at station 3 (3.179) may be attributed to the high TDS concentration (1,816.6 mg/L) compared to other stations, leading to pollution and aquatic organism mortality due to decreased plankton productivity.

The turbidity of the coastal waters of TPI Paiton, Probolinggo Regency, ranging from 0.18 NTU to 0.77 NTU, is categorized as low and meets the quality standards set by Government Regulation No. 22 of 2021. Diniariwisan dan Thoy (2023) stated that water turbidity can hinder phytoplankton photosynthesis by reducing sunlight penetration to the bottom of the water. The turbidity in the coastal waters of TPI Paiton has a very strong negative correlation with the plankton diversity index (-0.414). The high turbidity exceeding the optimal limit at station 3 (0.43 NTU) resulted in a low plankton diversity index (3.179) due to decreased plankton productivity (Sukarti et al., 2012).

The pH of the coastal waters of TPI Paiton, Probolinggo Regency, ranging from 7.68 to 8.15, is classified as good for marine waters (alkaline pH) and complies with the quality standards set by Government Regulation No. 22 of 2021. The pH value affects the biochemical processes in water and the growth of phytoplankton (Syamiazi et al., 2015). The pH in the coastal waters of TPI Paiton has a weak positive correlation with the plankton diversity and abundance index (0.208), influenced by photosynthetic activity of marine organisms, water temperature, salinity, dissolved oxygen (DO), phosphate, nitrate, oxidation processes, rainfall, and terrestrial influences such as river water flow and waste discharge (Patty et al., 2021; Melinda et al., 2021; Leidonald et al., 2022; Priska et al., 2020). Zainal et al. (2023) explained that low pH can disrupt microalgae growth by reducing enzyme activity, limiting cell motility, and halting photosynthesis processes. Station 4 recorded the highest plankton diversity index at 3.535 with a pH of 8.08, while station 3 had the lowest diversity index at 3.179 with a pH of 8.13. This indicates that pH does not significantly affect the plankton diversity and abundance index in this study.

The Biochemical Oxygen Demand (BOD) of the coastal waters of TPI Paiton, Probolinggo Regency, ranging from 2.26 mg/L to 4.41 mg/L, is classified as low and meets the quality standards set by Government Regulation No. 22 of 2021. The BOD value in the coastal waters of TPI Paiton has a very strong negative correlation with the phytoplankton diversity and abundance index (-0.854) (Amin and Purnomo, 2021; Sanjaya, 2023). Daroini and Arisandi (2020) stated that organic material content in water, dissolved oxygen (DO) levels, temperature, salinity, pH, water clarity, and overall water conditions are some factors influencing BOD levels. Afwa et al. (2021) explained that organic matter content in waters can increase due to waste from households, agriculture, industry, and organic debris from land entering the water. The high BOD at station 3 (4.41 mg/L) can reduce DO levels, resulting in a low diversity index at station 3 (3.179) due to the suboptimal processes of growth, respiration, and reproduction in plankton. The higher BOD at station 3 compared to other stations also indicates that the waters at station 3 are more polluted than those at other stations.

The Dissolved Oxygen (DO) levels in the coastal waters of TPI Paiton, Probolinggo Regency, ranging from 4.50 mg/L to 5.54 mg/L, fall under the moderate pollution category (Daroini and Arisandi, 2021) because the DO value is greater than 5 mg/L and it does not meet the quality standards set by Government Regulation No. 22 of 2021. Air diffusion, disposal of household and industrial waste containing organic materials, photosynthesis rate, temperature, water turbulence, and atmospheric pressure are some factors influencing dissolved oxygen levels (Samudera et al., 2021; Sugianti and Astuti, 2018). The DO value in the coastal waters of TPI Paiton has a very strong positive correlation with the plankton diversity and abundance index (0.759) (Leidonald et al., 2022; Mariyati, 2020). The high DO at station 4 (5.54 mg/L) compared to other stations leads to station 4 having the highest plankton diversity index (3.535), which is attributed to the more optimal oxidation and reduction of organic and inorganic materials compared to other stations.

Carbon dioxide (CO_2) levels in the coastal waters of TPI Paiton, Probolinggo Regency, ranging from 2.2 mg/L to 6.1 mg/L, are considered safe for aquatic organisms (Al Idrus, 2018) and meet the quality standards set by Government Regulation No. 22 of 2021. Several factors that can influence the low CO_2 levels in the waters include photosynthesis and respiration of plants and animals, the decomposition (oxidation) of organic matter by microorganisms, calcium carbonate deposition, atmospheric diffusion, rainfall, water passing through organic soils, and water quality parameters such as pH, dissolved oxygen, alkalinity, light, and the presence of waste pollution (Al Idrus, 2018). The carbon dioxide (CO_2) levels in the coastal waters of TPI Paiton have a very strong negative correlation with the plankton diversity index (-0.488) (Amin and Purnomo, 2021). The high CO_2 levels at station 3 (4.2 mg/L) cause a decrease in dissolved oxygen levels, thus hindering plankton productivity and resulting in a lower plankton diversity index compared to other stations (3.179) (Al Idrus, 2018).

The ammonia levels in the coastal waters of TPI Paiton, Probolinggo Regency, range from 0.083 mg/L to 0.164 mg/L, which are considered low and safe for aquatic organisms (Hamonangan and Yuniarto, 2022) and meet the quality standards set by Government Regulation No. 22 of 2021. Ammonia largely comes from human activity waste, such as agricultural runoff and industrial waste, as well as from the decomposition of organic matter from plants and animal carcasses (Yuan et al., 2017). Ammonia also acts as a nutrient that stimulates the growth of phytoplankton and fish. However, excessive ammonia levels can cause eutrophication and disrupt aquatic ecosystems (Hamuna et al., 2018; Gutheri et al., 2018). The ammonia levels in the coastal waters of TPI Paiton have a strong negative correlation with the plankton diversity and abundance index (-0.371). The high ammonia levels at stations 3 (0.124 mg/L) and 1 (0.164 mg/L) indicate that these waters contain high levels of anthropogenic pollutants (Hamonangan and Yuniarto, 2022), which disrupt plankton productivity and result in low plankton diversity indices (station 3: 3.179; station 1: 3.324).

The Chemical Oxygen Demand (COD) in the coastal waters of TPI Paiton, Probolinggo Regency, ranges from 6.40 mg/L to 6.98 mg/L, which is considered low and meets the quality standards set by Government Regulation No. 22 of 2021. Since most compounds are more easily oxidized chemically than biologically, the COD value is usually higher than the BOD value (Haerun et al., 2018). The COD levels in the coastal waters of TPI Paiton have a strong negative correlation with the plankton diversity and abundance index (-0.299), due to the high oxygen demand required to chemically degrade organic matter (Priska et al., 2020). The high COD levels at stations 1 (6.98 mg/L) and 3 (6.75 mg/L), compared to other stations, are attributed to the accumulation of pollutants from human activities, such as domestic and household waste (Simangunsong, 2023), and their proximity to pollution sources (Afwa et al., 2021). This leads to a decrease in oxygen levels and low plankton diversity indices (station 1: 3.324 and station 3: 3.179).

CONCLUSION

The water quality of the coastal waters of the Paiton Fish Auction Site (TPI), Probolinggo Regency in terms of plankton diversity index 3.3282 indicates moderate diversity, unpolluted waters, and stable environmental conditions and plankton abundance index 10.844 ind/L indicates oligotrophic waters. While water quality in terms of physico-chemical parameters shows that the parameters of temperature, salinity, TSS, TDS, turbidity, pH, BOD, CO_2, ammonia, and COD meet the quality standards (Government Regulation No. 22 of 2021), while the parameters of brightness and DO do not meet the quality standards. Brightness less than 3m and DO values ranging from 4.50 mg/L - 5.54 mg/L are categorized as moderately polluted.

ACKNOWLEDGEMENTS

We thank Almazahra Aulia Rasyada for her help during the research. And finally, thank you to the reviewers and editors of the LenteraBio journal who have guided and provided advice in completing this article.

CONFLICT OF INTEREST

There is no conflict of interest.

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