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Phytoplankton diversity as a health indicator of coastal ecosystems in Prigi Bay, Trenggalek District, East Java, Indonesia

CATUR RETNANINGDYAH[1,♥], LUCHMAN HAKIM[1], ENDANG ARISOESILANINGSIH[1], SUMANI[2], RAHMANTA SETIAHADI[3], MUKHTASOR[4]

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya. Jl. Veteran, Ketawanggede, Lowokwaru, Malang 65145, East Java, Indonesia. Tel./fax.: +62-341-575841, ♥email: catur@ub.ac.id
[2]Universitas PGRI Madiun. Jl. Setia Budi No.85, Kanigoro, Kartoharjo, Madiun 63118, East Java, Indonesia
[3]Universitas Merdeka Madiun. Jl. Serayu No.79, Pandean, Taman, Madiun 63133, East Java, Indonesia
[4]Institut Teknologi Sepuluh Nopember. Jl. Teknik Kimia, Keputih, Sukolilo, Surabaya 60111, East Java, Indonesia

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Abstract. *Retnaningdyah C, Hakim L, Arisoesilaningsih E, Sumani, Setiahadi R, Mukhtasor. 2025. Phytoplankton diversity as a health indicator of coastal ecosystems in Prigi Bay, Trenggalek District, East Java, Indonesia. Biodiversitas 26: 2198-2209.* This study aims to evaluate the water quality of several coastal ecosystems in the Prigi Bay, Watulimo Sub-district, Trenggalek District, East Java, Indonesia, based on water physicochemical parameters and phytoplankton diversity as bioindicators. Water and plankton sampling were conducted in six coastal ecosystems (Beach of Pasir Putih, Karanggongso, Mutiara, Guo Boto, Prigi, and Karang Pegat). The water physicochemical parameters evaluated include DO, TSS, turbidity, salinity, pH, conductivity, BOD, nitrate, orthophosphate, H_2S, and oil-grease. A total of 10 L of water was filtered with a plankton net. Then, the phytoplankton species were identified, and the abundance of each type was calculated. The data obtained were used to determine taxa richness, total density, evenness, dominance index, diversity index, Trophic Diatom Index (TDI), and Percentage Pollution Tolerant Value (%PTV). The study results showed that the physical-chemical quality of water in all research areas met the national and international quality standards concerning seawater quality standards for marine biota, except nitrate, orthophosphate, and oil-grease. A total of 40 species were found in the six coastal ecosystems in the Watulimo area. The abundance of phytoplankton from the Bacillariophyceae was always the highest in all locations, ranging from 67-78%. Phytoplankton diversity is relatively high (4.38-4.84). There is no species dominance or even distribution. The quality of water in coastal ecosystems in the Watulimo area, based on the TDI, is classified as eutrophic. Based on %PTV, there is no indication of organic material pollution except for the Prigi Beach ecosystem, which is included in the lightly polluted organic material category. High human activities around Prigi Beach have impacted the increasing turbidity and orthophosphate content, resulting in high levels of eutrophication and organic material pollution, as indicated by an increase in %PTV and TDI values.

Keywords: Bacillariophyceae, bioindicators, Trophic Diatom Index

INTRODUCTION

Watulimo Sub-district is one of coastal areas in Trenggalek District, East Java, Indonesia. The district has various potentials in the ecotourism, aquaculture, and fisheries sectors. Coastal tourism destinations in Watulimo Sub-district include Prigi Beach, Pasir Putih Beach, Karanggongso, Mutiara, Damas Beach, and several other beaches, making the sub-district an important area (Parmawati et al. 2017). The livelihoods of the surrounding population primarily depend on fishing, with many local fishermen relying on marine capture and aquaculture as their primary sources of income. This area is also included in the center of the fisheries business in the southern part of the coast of Java Island (Parmawati et al. 2017; Luthfi et al. 2019). The production of marine capture fisheries in the Watulimo Sub-district reached 26,136.74 tons in 2023, double the amount in 2022 (BPS 2024).

Community activities such as boat tours, fishing, fish smoking, and household activities around the coast in Watulimo Sub-district can affect the quality of waters on several beaches (Luthfi et al. 2019). These anthropogenic activities can increase organic pollutants in freshwater, marine, and estuarine ecosystems, including mangrove ecosystems, further influencing water quality and ecosystem health (Febriansyah et al. 2022, 2023; Retnaningdyah et al. 2022, 2024a). In addition to anthropogenic factors, natural factors such as sea tides and drastic changes in temperature and climate also significantly affect water quality and the growth of several marine organisms (Hilmi et al. 2020). Fluctuating environmental conditions can affect the survival of aquatic organisms such as phytoplankton, macroalgae, coral reefs, and fish (Blewett et al. 2022). Water quality parameters that play an important role in supporting the life of marine organisms are temperature, Total Suspended Solids (TSS), pH, dissolved oxygen, water turbidity, salinity, nitrate, and orthophosphate (Luthfi et al. 2019; Retnaningdyah et al. 2024a, b). Phytoplankton is an autotrophic microalgae community capable of eukaryotic or prokaryotic photosynthesis because it contains chlorophyll. Phytoplankton generally act as primary producers of the trophic levels in an aquatic ecosystem (Hilmi et al. 2020). Plankton also contributes to the nutrient cycle because it produces organic compounds. Plankton can convert inorganic nutrients into carbohydrates and produce oxygen for water bodies (Rahayu et al. 2021; Titaley et al. 2021).

Due to their essential role, the presence of phytoplankton can provide information regarding the potential productivity of an aquatic ecosystem, especially marine ecosystems. Phytoplankton have a short life cycle and high sensitivity to environmental changes. Phytoplankton are highly effective bioindicators for coastal ecosystems due to their rapid response to environmental changes, high sensitivity to pollutants, and diverse, abundant communities. As primary producers, they play a crucial role in the aquatic food web, and their population variations can reflect the overall ecosystem health. Monitoring phytoplankton is a cost-effective approach, and their susceptibility to nutrient levels and other forms of organic pollution, light, and temperature makes them excellent indicators of water quality changes. Additionally, they can bioaccumulate toxins, offering direct assessments of pollution levels. Recent studies highlight their importance in maintaining ecosystem functionality and monitoring environmental health (Hemraj et al. 2017; Otero et al. 2020; Lestari et al. 2021; Chevrollier et al. 2022; Fernandez-González et al. 2022; Febriansyah et al. 2023). Several biotic indices that use phytoplankton diversity as a bioindicator of environmental change have been developed, such as the Trophic Diatom Index (TDI) to determine the trophic status of waters and the Percentage Pollution Tolerant Value (%PTV), which indicates the level of organic pollution in waters (Wu et al. 2014; Febriansyah et al. 2023; Salsabila et al. 2024).

The increase of organic pollutants in waters impacts an aquatic ecosystem. So, it is important to evaluate water quality. The physicochemical quality of water can be evaluated based on temperature, TSS, Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), pH, salinity, and conductivity. These parameters are then compared with seawater quality based on the Government Regulation of the Republic of Indonesia No. 22 of 2021 for marine biota. The quality of marine ecosystems can also be evaluated using phytoplankton as a biological indicator (Febriansyah et al. 2022, 2023; Salsabila et al. 2024). This study aimed to assess water quality in several coastal ecosystems in the Watulimo area based on water physicochemical parameters and biological indicators using phytoplankton. The findings of this study on water quality in coastal ecosystems are anticipated to motivate the government and local authorities in Watulimo Sub-district to recognize the importance of balancing human activities with the conservation of biodiversity.

MATERIALS AND METHODS

Study area

Evaluation of the quality of the coastal ecosystem included a sampling of water quality and phytoplankton conducted at six coastal ecosystems (Guo Boto, Prigi, Karang Pegat, Pasir Putih, Karanggongso, and Mutiara Beach) in the Watulimo Sub-district, Trenggalek District, East Java, Indonesia (Figure 1, Table 1). These beaches were selected due to their location in the Prigi Bay region, where the local government plans to enhance them for marine tourism development. Water and plankton samples were collected at all research sites in August 2024. Analysis of several water qualities and identification of phytoplankton were carried out at the Tropical Ecosystem Ecology and Restoration Laboratory, Microbiology Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya, Malang, and Perum Jasa Tirta I Malang Laboratory, East Java.

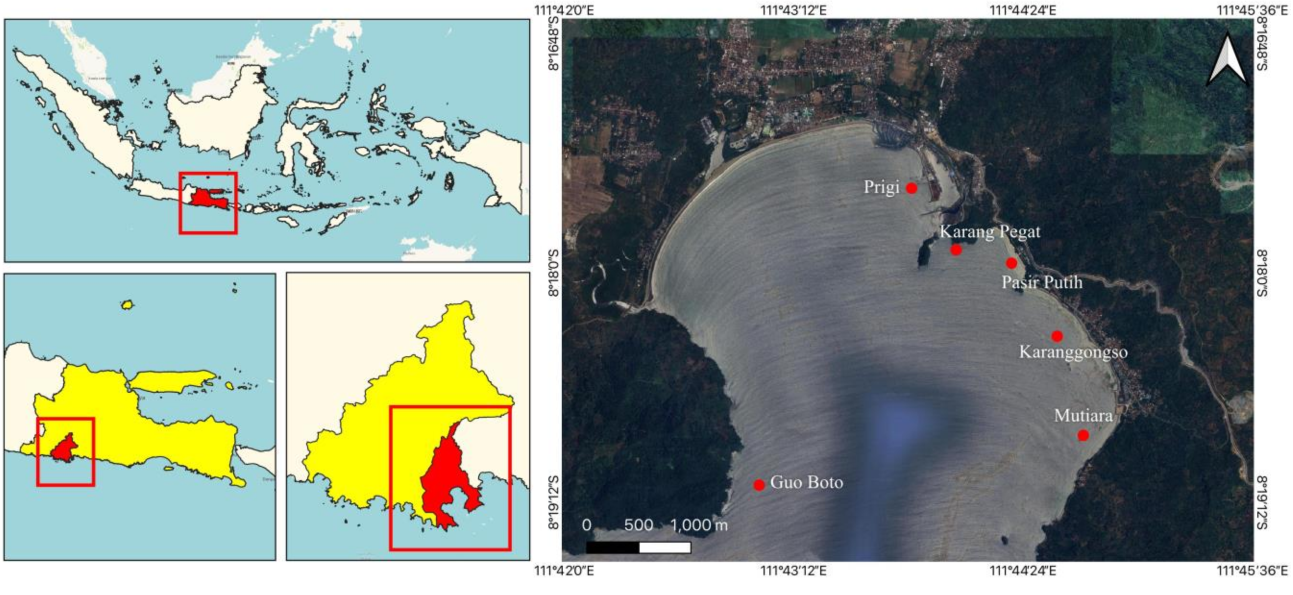

Figure 1. Study site in the Prigi Bay of the Watulimo Sub-district, Trenggalek District, East Java, Indonesia

Table 1. Geographic information and description of the research site

Location	**Geographic coordinates**	**Brief description**
Pasir Putih	8°17'56.9"S 111°44'20.4"E	Beach with white sand and ecotourism
Karanggongso	8°18'19.8"S 111°44'34.7"E	Sandy beach with a bit of silt and clay, tourism activity with some guesthouses and residential areas
Mutiara	8°18'50.9"S 111°44'42.9"E	Beach with rocky substrate with sand and a little silt, sunset views, and tourism activity
Guo Boto	8°19'06.5"S 111°43'01.2"E	The coastal cliffs are frequently visited to view the red cave from the boat
Prigi	8°17'33.4"S 111°43'49.0"E	Beach with port activity, fish auction area, and fish processing facilities, and near a river heavily polluted with domestic waste
Karang Pegat	8°17'52.7"S 111°44'03.0"E	Located between Prigi and Pasir Putih and near a small island, there is a fish cage farming activity

Procedures

Water sampling and quality assessment

Water sampling in each selected coastal ecosystem was carried out at 6 points as repetitions of the study, except for Pasir Putih Beach, Karanggongso Beach, which had eight sampling repetitions. At each site, samples were collected from the littoral zone, approximately 100 meters from the high tide line. All water sampling activities were conducted on the same day, between 10:00 and 12:00 a.m. Surface water samples of 1000 mL were collected using sample bottles and subsequently stored in an ice box for laboratory analysis. The DO, TSS, turbidity, salinity, pH, and conductivity measurements were carried out in situ, while BOD, nitrate, orthophosphate, H_2S, and oil-grease analyses were carried out in the Laboratory.

Phytoplankton sampling and identification

Phytoplankton samples were collected from surface water at the precise site of water sampling. Water was taken using a water sampler as much as ±10 L and filtered using a plankton net with a mesh size of 30 (Retnaningdyah et al. 2024a). The phytoplankton samples obtained were put into a flacon bottle containing 2 mL drops of 4% formalin and 1 mL of $CuSO_4$ solution for preservation. The application of $CuSO_4$ serves to preserve the chlorophyll in phytoplankton, thereby facilitating the identification of these organisms (Kondzior and Butarewicz 2018). Phytoplankton samples were taken as much as 1 mL and placed in the Sedgewick-Rafter Cell (SRC) counting chamber (Akter et al. 2015). Phytoplankton samples were then observed using a light microscope, and the number of phytoplankton found from the 1st box to the 1000th box was counted. Then, the density of each phytoplankton species found was converted using the formula. Furthermore, identification was carried out using the identification key book according to Castellani and Edwards (2017) and Santhanam et al. (2019). The formula used to calculate phytoplankton abundance is as follows (Akter et al. 2015).

$$N = \frac{T}{L} \times \frac{p1}{p2} \times \frac{V1}{V2} \times \frac{1}{W}$$

Where,
N : Plankton abundance (ind/L)
T : Number of squares in SRC (1000)
L : Number of squares in one field of view
P1 : Number of plankton observed
P2 : Number of SRC squares observed
VI : Volume of water in the sample bottle
V2 : Water volume in SRC squares
W : Volume of filtered water

Data analysis

The data from the physical-chemical parameters of water obtained from each location were input into Microsoft Excel and compiled. The data were then calculated to perform a difference test using SPSS. The One-way ANOVA test was used to perform a difference test on each water and sediment physical-chemical parameter at the observed location. If the data distribution was normal and the data variance obtained was homogeneous, the Tukey HSD test was conducted. Data that were not normally distributed and heterogeneous data variances were tested with the Games Howell test, and continued with the Brown-Forsythe test.

The data from the identification and calculation of phytoplankton obtained were then subjected to descriptive analysis using Microsoft Excel. Analysis of the community structure and diversity of phytoplankton included taxa richness, total density, Shannon-Wiener Diversity Index (H’), Simpson Dominance Index, and Evenness Index (E). The trophic status and degree of organic matter pollution in the coastal aquatic ecosystem are assessed using abundance data from various phytoplankton species, particularly diatoms, which serve as bioindicators. This assessment is based on the Percentage Pollution Tolerant Value (%PTV) and the Trophic Diatom Index (TDI) (Salsabila et al. 2024; Wu et al. 2014).

The evenness index is used to determine the evenness of the number of individuals of each species in a community. The E value is determined using the following equation (Salsabila et al. 2024):

$$\mathrm{E} = \frac{\mathrm{H'}}{\mathrm{Hmax}}$$

Where,
E : Evenness index
H’ : Diversity index
Hmax : Number of taxa

Simpson Dominance Index was determined using this equation (Wu et al. 2014):

$$Id = Ni(Ni-1) \times \mathrm{N}(\mathrm{N}-1)$$

Where,
Id : Simpson Dominance Index
Ni : Number of individuals of species i
N : Total number of individuals found

The Shannon-Wiener Diversity Index shows the abundance of a species in a community. The H' value is determined by this equation (Wu et al. 2014):

$$H' = -\sum_{i=1}^{s} Pi^2 \log Pi$$

Where,
H' : Shannon-Wiener Diversity Index
s : Total number of species in a community
P_i : The number of species i to the total number of species

Trophic Diatom Index (TDI) determines an ecosystem's eutrophication level. Classification of water quality based on TDI values ranges from 0-100. According to Wu et al. (2014), the TDI value can be calculated using the equation:

$$WMS = \sum_{i=1}^{n}(ai \times si \times vi) / \sum_{i=1}^{n}(ai \times vi)$$

Where**,**
ai : The proportion of all individuals in the sample that belong to species i
n : Total number of species in the sample
si : Pollution sensitivity (1-5) of species i
vi : Indicator value (1-3) of species i

$$TDI = (WMS \times 25) - 25$$

Where,
TDI : Trophic Diatom index
WMS : Weighted average sensitivity (Wu et al. 2014)

The percentage of Pollution Tolerant Values (%PTV) describes an ecosystem's level of organic pollution. The maximum %PTV value is 100% and is said to have increased organic pollution if the value reaches 20%. The %PTV value is obtained from calculating the abundance of tolerant diatoms such as *Navicula* spp., *Nitzschia* spp., *Gomphonema* spp., and *Sellaphora* spp. with the total number of diatoms that can be seen using the following equation (Febriansyah et al. 2023).

$$\%PTV = \frac{Abundance\ of\ tolerant\ taxa}{total\ taxa\ abundace}$$

RESULTS AND DISCUSSION

Physicochemical quality of water in several coastal ecosystems in Watulimo Sub-district, Trenggalek District

The analysis of physicochemical parameters in several coastal ecosystems in the Watulimo area includes pH, conductivity (S/m), salinity (%), TSS (mg/L), turbidity (NTU), DO (mg/L), BOD (mg/L), nitrate (mg/L), orthophosphate (mg/L), H_2S (mg/L), and oil-grease content (mg/L), which is presented in Table 2. The pH value of seawater in several coastal ecosystems in the Watulimo area ranges from 8.04-8.08. This pH value has met the standard value for seawater quality for the benefit of marine biota based on the Government Regulation of the Republic of Indonesia PP RI No. 22 of 2021, Attachment VIII concerning Sea Water Quality Standards for Marine Biota, which requires a pH value between 7-8.5. This value also met the international standard from the EPA/Environmental Protection Authority, which specifies a range of pH values 6.5-8.5. The optimal pH value for plankton growth and supporting aquatic life ranges from 6.5-8 (Wassie and Melese 2017). The pH value can be influenced by the amount of chemical and organic pollutants in the waters and the intensity of light that plays a role in photosynthesis. Changes in pH values can affect the metabolism and survival of an organism (Darojat et al. 2020; Raven et al. 2020; Retnaningdyah et al. 2022).

Conductivity has a value that varies between 5.16 S/m and 5.24 S/m (Table 2). The high minerals influence high conductivity values in water. In addition, highly ionized salts can also increase the conductivity value in water because salt is a good electrical conductor (Nindarwi et al. 2021; Manamani and Bensouilah 2023). The highest salinity value was found in the Prigi Beach and Karang Pegat ecosystems, namely 34.75%, and the lowest value was identified in the Mutiara Beach ecosystem, 33.75% (Table 2). Salinity values can affect the physiological responses of several marine biota by disrupting the processes of photosynthesis, respiration, and reproduction. The salinity levels are also additionally affected by the influx of river water, as observed at two research sites, the estuary, which causes variations in value (Manamani and Bensouilah 2023). The salinity standard value suitable for marine life is between 33% and 34%.

The turbidity level can be seen from the Total Suspended Solids (TSS) and turbidity in the water. The results showed that total suspended solids in the coastal ecosystem of the Watulimo area range from 5.07-5.63 mg/L, while the turbidity value is 1,035-1,638 NTU. This turbidity value generally meets the standard quality values set for marine life, especially coral and seagrass, as well as marine tourism, which requires a maximum TSS value of 20 mg/L and a maximum turbidity value of 5 NTU. The high TSS value in the Prigi Beach ecosystem is due to the large amount of waste from fish processing, causing the water turbidity to increase. TSS positively correlates with turbidity, where the higher the turbidity value, the higher the TSS value in a body of water (Hilmi et al. 2020). Variations in TSS values can also affect the abundance of phytoplankton. The lower TSS value caused the higher the abundance of phytoplankton in a body of water. Conversely, high suspended solids in waters can inhibit sunlight penetration and subsequently reduce the primary productivity of macroalgae and phytoplankton in waters (Sew and Todd 2020). The TSS value is positively correlated with turbidity, where the higher the TSS, the turbidity will also increase. One factor that influences the turbidity value is ocean currents, which have a speed and direction that can carry the distribution of suspended solids throughout the waters (Luthfi et al. 2019).

Table 2. Water quality profile in several coastal ecosystems in the Watulimo area, Trenggalek, East Java, Indonesia

Locations	pH	Conductivity (S/m)	Salinity (%)	TSS (mg/L)	Turbidity (NTU)	DO (mg/L)	BOD (mg/L)	Nitrate (mg/L)	Orthophosphate (mg/L)	H_2S (mg/L)	Oil-Grease (mg/L)
Pasir Putih	8.04+0.05ab	5.24+0.29a	33.92+0.67ab	5.07+0.31a	1.05+0.54a	5.43+0.27a	2.62+1.25ab	0.070+0.047a	0.009+0.008a	0.0018+0.0000a	1.040+0.145a
Karanggongso	8.08+0.02b	5.24+0.18a	34.00+0.00ab	5.31+0.07ab	1.04+0.24a	5.63+0.21a	2.43+1.25ab	0.049+0.033a	0.006+0.006a	0.0019+0.0002a	1.166+0.259a
Mutiara	8.04+0.04ab	5.16+0.01a	33.75+0.46a	5.49+0.07bc	1.25+0.63a	5.54+0.11a	3.09+0.88ab	0.071+0.056a	0.008+0.013a	0.0018+0.0000a	0.994+0.002a
Guo Boto	8.05+0.01a	5.16+0.01a	33.88+0.35ab	5.63+0.12c	1.50+0.66a	5.36+0.18a	2.33+0.89ab	0.074+0.040a	0.020+0.024ab	0.0024+0.0014a	0.995+0.003a
Prigi	8.04+0.04ab	5.15+0.01a	34.75+0.46b	5.75+0.10c	1.64+0.46a	5.17+0.43a	1.98+1.39a	0.104+0.058a	0.035+0.035b	0.0019+0.0019a	1.124+0.232a
Karang Pegat	8.08+0.02b	5.17+0.01a	34.75+1.04b	5.59+0.10c	1.33+0.30a	5.49+0.13a	3.64+0.41b	0.142+0.103a	0.037+0.037b	0.0018+0.0018a	1.059+0.178a
Indonesian Standard*	7-8.5	-	33-34	Coral: 20	<5	>5	20	0.06	0.015	0.01	1
ASEAN Standard**	-	-	-	<10% increase over seasonal average	-	>4	-	0.06	0.015	-	0.14
EPA***	6.5-8.5	-	-	-	<5	>5	-	Vary <10% from natural condition	Vary <10% from natural condition	0.002	Not detectable as visible film or discoloration

Note: The same notation for each parameter shows no significant difference based on the ANOVA test, followed by Tukey HSD, except for the pH, conductivity, and DO parameters based on Brown Forsythe, followed by Games Howell at α 0.05. *: Seawater quality standards for Marine Biota (PP RI No. 22 of 2021) Appendix VIII; **: ASEAN Marine Water Quality Criteria for Aquatic Life Protection; ***: Environmental Protection Authority (EPA): Marine Water Quality Regulations to protect aquatic life. Sign of - means no standard

The DO value varies between 5.17 mg/L and 5.63 mg/L and meets the quality standards based on PP RI no. 22 of 2021, ASEAN marine water quality criteria, and the EPA standard for aquatic life protection, which requires a minimum of 4 and 5 mg/L (Table 2). DO levels in water will affect the respiratory activity of aquatic organisms. Each organism has a specific tolerance range for oxygen levels in water (Hass et al. 2014). The low organic matter content in the water likely causes the relatively high DO levels in seawater. In contrast, low DO values can be caused by anthropogenic activities such as water tourism, fish processing, and houses that produce a lot of organic and inorganic solid waste (Retnaningdyah et al. 2022). The DO value that can support plankton life ranges from 4-6.5 mg/L. Low DO values can affect water quality, decreasing physiological activity in the marine ecosystem (Luthfi et al. 2019).

BOD values varied between 1.98 mg/L and 3.64 mg/L (Table 2). The BOD levels of all research locations were low and met the standard values set for marine tourism of a maximum of 10 mg/L and for marine biota of a maximum of 20 mg/L. The BOD value can indicate the total oxygen microorganisms use in the aerobic metabolism of organic matter from anthropogenic activity. The levels of this organic matter can affect changes in the community structure of aquatic organisms. Each organism has a tolerance range that varies for organic matter, either narrow or wide (Retnaningdyah et al. 2021). The higher the BOD value, the higher the amount of dissolved oxygen depletion for oxidation in a water system (Mizwar and Surapati 2020).

Nitrate levels vary between 0.049 mg/L and 0.142 mg/L (Table 2). Nitrate levels in all locations did not meet the quality standards, both national and international, which require a maximum of 0.06 mg/L, except at Karanggongso Beach. The optimal nitrate levels for plankton growth range from 0.9-3.5 mg/L. The presence of organic solid waste from fallen leaves, rotting wood, litter, and anthropogenic activities around the ecosystem impacts high nitrate and orthophosphate levels (Nindarwi et al. 2021; Retnaningdyah et al. 2021).

Orthophosphate levels vary between 0.006 mg/L and 0.037 mg/L (Table 2). Orthophosphate levels indicate that the Pasir Putih, Karanggongso, and Mutiara beach ecosystems have met the national and international quality standards with a maximum value of 0.015 mg/L. High orthophosphate levels are caused by high anthropogenic activities, such as households that produce organic and inorganic solid waste and tourism activities around the mangroves (Malik et al. 2015). This is in accordance with the research results showing that the Prigi and Karang Pegat locations have the highest orthophosphate levels because they are close to household activities and fish processing. The optimal orthophosphate value for plankton growth ranges from 0.27-5.51 mg/L (Rahayu et al. 2021). High levels of nitrate and orthophosphate can trigger eutrophication, resulting in algae blooming (Retnaningdyah et al. 2021).

Sulfide (H_2S) levels in several coastal ecosystems in the Watulimo Trenggalek area range from 0.0018-0.0024 mg/L. The maximum limit for sulfide levels for marine tourism is 0.002 mg/L, while the life of the required biota is 0.01 mg/L. The sulfide levels in the coastal waters of Watulimo have met the quality standards for marine life and marine tourism, except for the Guo Boto Waters, which have a value of 0.0024 mg/L, exceeding the set value. High sulfide levels are positively correlated with high organic matter levels, with low DO so that high organic matter degradation can occur anaerobically, which increases H_2S levels.

The oil-grease levels at the research location range from 0.995 to 1.166 mg/L. The maximum oil-grease grease levels required for marine tourism are 1 mg/L. The water on the Guo Boto and Mutiara beaches has met the oil-grease content standards, while other waters have levels that exceed the quality standards. Nevertheless, the concentrations of oil-grease at all research sites did not meet the ASEAN marine standard for aquatic life protection, which requires a maximum limit of 0.14 mg/L. Oil and grease represent one of the most prevalent forms of pollution in marine environments, with estimates suggesting that between 1 to 10 metric tons of oil enter the ocean from various sources, leading to significant accumulation along coastlines. Oil and grease are composed of volatile hydrocarbons or oil resulting from incomplete combustion emissions from engines, which are often found in higher concentrations than oil that is directly discharged into the sea. The origins of oil and grease pollution include oil spills from tanker leaks, runoff from rivers, domestic waste, and maritime transportation (Ariani et al. 2016; Khozanah et al. 2021). Additionally, oil released into the ocean from tourism and fishing vessels is transported by water dynamics, ultimately reaching the coastal region of Watulimo Beach.

Community structure and phytoplankton diversity in several coastal ecosystems in Watulimo Sub-district, Trenggalek District

A total of 40 taxa of phytoplankton were found in all coastal ecosystems in the Watulimo Sub-district, Trenggalek, which are included in seven classes, namely Bacillariophyceae, Chlorophyceae, Cyanophyceae, Dinophyceae, Euglenophyceae, Trebouxiophyceae, and Ulvophyceae (Table 3, Figure 2). Class Bacillariophyceae has the highest number of genera (25 genera). The class of Cyanophyceae has 6 genera, and the other classes have 1-3 genera. The total density of phytoplankton ranged from 479.6 to 1532.4 cells/L. The abundance of phytoplankton from Class Bacillariophyceae was always the highest in all locations, ranging from 67-78% compared to the abundance of other Classes. Bacillariophyceae is one of the phytoplankton classes that have an important role in the food chain in the water in fresh and marine ecosystems. Species of phytoplankton belonging to the Bacillariophyceae class are typically recognized for their significant resilience to organic pollutants (Samanta and Bhadury 2015).

Phytoplankton from the Bacillariophyceae class found in all coastal ecosystems with high densities (>25 cells/L) are *Cocconeis*, *Chaetoceros*, *Coscinodiscus*, *Leptocylindrus*, *Rhizosolenia*, *Stephanodiscus*, and *Thalassiosira* (Figures 2 and 3). *Cocconeis* is generally found in all types of aquatic habitats from freshwater to seawater, especially in the meso to eutrophic range (Al-Handal et al. 2019; Holmes et al. 2022). *Chaetoceros* is a type of phytoplankton that can adapt to waters with alkaline pH and is tolerant to organic pollutants in the mesosaprobic category (Tjahjono et al. 2023). The diatoms of *Coscinodiscus* spp., *Chaetoceros* spp., and *Rhizosolenia* spp. are often found and capable of adapting to coastal waters with a wide range of salinity, temperature, nutrients, and light intensity (Suteja et al. 2021). *Thalassiosira* sp., has an important role in the primary production of waters with high organic pollutants (Samanta and Bhadury 2015).

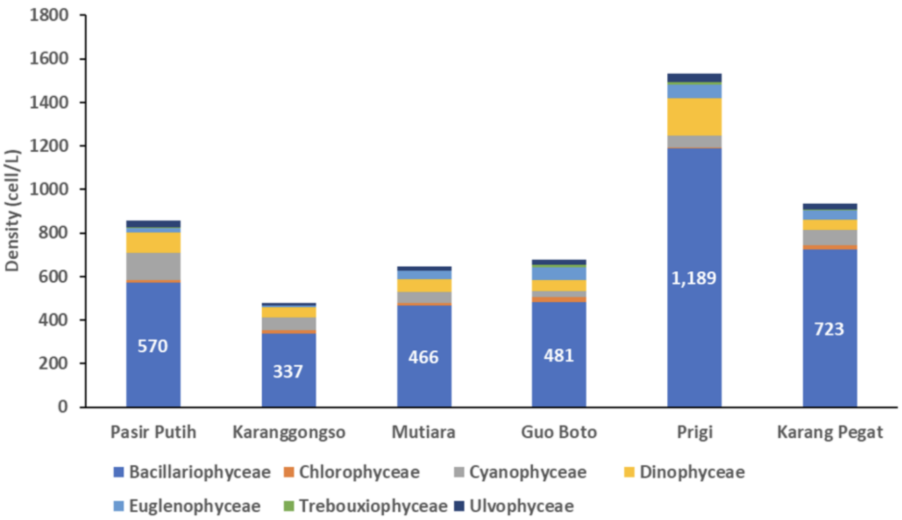

Figure 2. Abundance variance of each phytoplankton class in several coastal ecosystems in Watulimo, Trenggalek, East Java, Indonesia

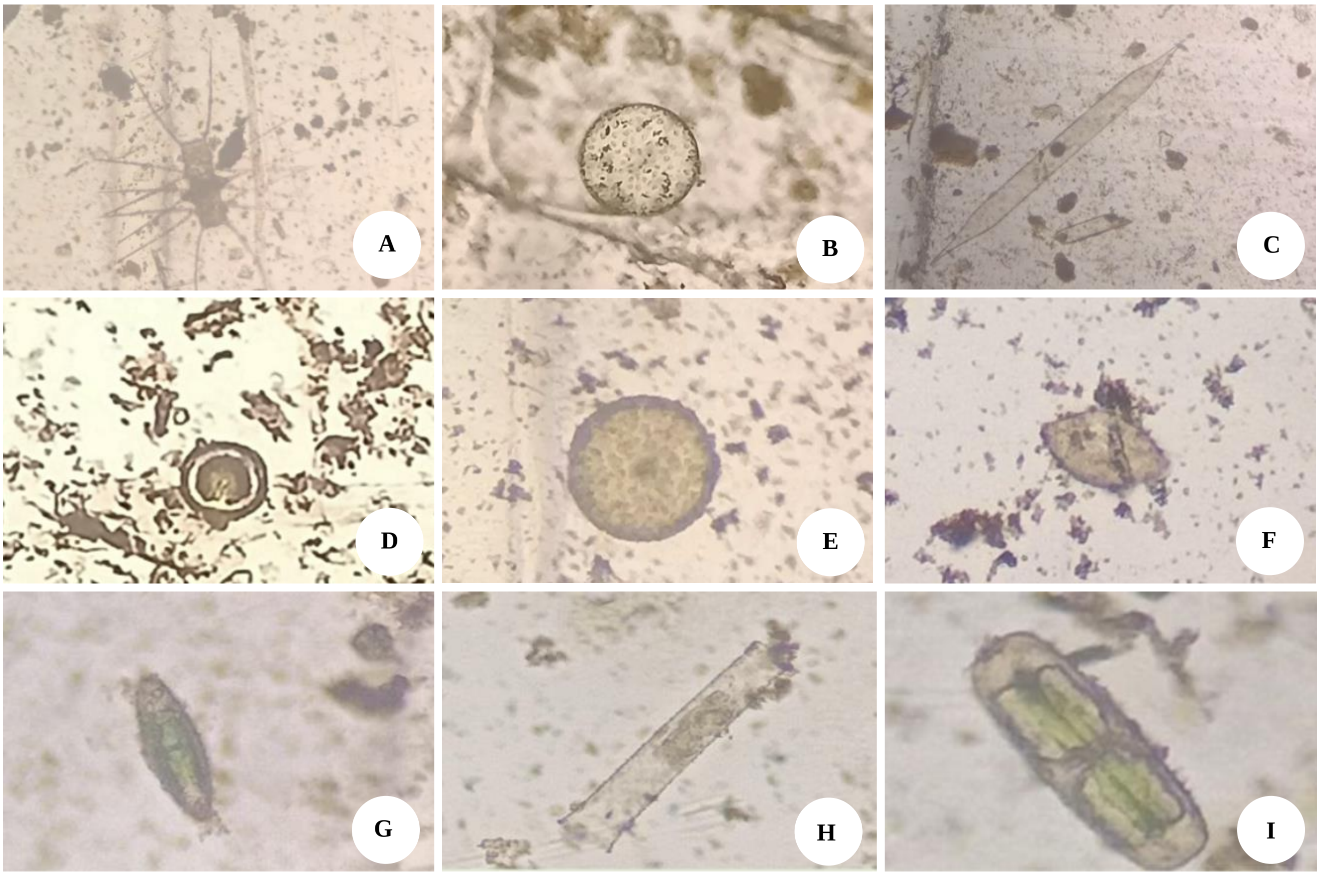

Figure 3. Dominant phytoplankton in several coastal ecosystems in Watulimo, Trenggalek, East Java, Indonesia. A. *Chaetoceros*; B. *Coscinodiscus*; C. *Rhizosolenia*; D. *Stephanodiscus*; E. *Thalassiosira*; F. *Cocconeis*; G. *Nitzschia*; H. *Leptocylindrus*; I. *Entomoneis*

Table 3. Community structure and phytoplankton diversity of several coastal ecosystems in the Watulimo, Trenggalek, East Java, Indonesia

Class/Order	Family	Genus/Species	Density (%) in the coach of					
			Pasir Putih	Karang-gongso	Mutiara	Guo Boto	Prigi	Karang Pegat
Bacillariophyceae								
Achnanthales	Cocconeidaceae	*Cocconeis* sp.	5.40	6.34	11.84	7.85	3.90	7.45
Aulacoseirales	Aulacoseiraceae	*Aulacoseira* sp.	1.71	2.33	0.76	2.73	2.54	0.63
Bacillariales	Bacillariaceae	*Nitzschia* sp.	1.18	3.22	0.48	1.25	6.98	0.76
Chaetocerotanae	Chaetocerotaceae	*Bacteriastrum* sp.	2.06	2.40	1.70	0.40	2.08	0.94
		Chaetoceros spp.	6.95	6.87	7.86	3.42	6.31	4.96
Coscinodiscales	Coscinodiscaceae	*Coscinodiscus* spp.	6.17	3.95	8.40	7.85	9.08	7.13
Cymbellales	Cymbellaceae	*Cymbella* sp.	2.20	3.00	1.22	1.83	2.88	4.48
Fragilariales	Fragilariaceae	*Meridion* sp.	0.30	0.00	0.00	0.00	0.00	0.31
		Synedra sp.	1.20	1.54	0.00	0.00	2.72	4.53
Hemiaulales	Hemiaulaceae	*Eucampia* sp.	4.21	1.89	1.81	0.93	2.42	1.26
		Hemiaulus sp.	0.79	1.04	0.99	0.08	0.31	0.86
Leptocylindrales	Leptocylindraceae	*Leptocylindrus* sp.	6.01	8.56	9.41	10.39	5.96	9.08
Naviculales	Naviculaceae	*Navicula* sp.	0.33	1.06	0.00	0.00	2.59	0.47
		Gyrosigma spp.	1.09	0.94	0.47	4.57	1.44	0.96
		Pleurosigma sp.	0.50	0.88	0.54	1.05	1.37	0.24
Rhizosoleniales	Rhizosoleniaceae	*Rhizosolenia* spp.	6.18	9.33	8.34	7.30	3.98	6.94
		Guinardia sp.	1.57	1.06	1.09	1.27	0.94	0.70
Surirellales	Entomoneidaceae	*Entomoneis* sp.	1.90	1.94	2.02	1.81	2.87	0.26
	Surirellaceae	*Surirella* sp.	0.42	1.28	0.25	0.00	0.00	0.00
Tabellariales	Tabellariaceae	*Tabellaria* sp.	0.00	0.00	0.00	0.49	0.54	0.34
Thalassiosirales	Lauderiaceae	*Lauderia* sp.	2.83	2.18	1.40	1.94	1.74	2.50
	Skeletonemaceae	*Skeletonema* sp.	2.56	2.27	2.03	1.30	3.44	4.17
	Stephanodiscaceae	*Stephanodiscus* sp.	6.89	4.90	5.49	10.85	7.53	11.15
	Thalassiosiraceae	*Thalassiosira* sp.	3.53	3.17	5.24	3.48	5.99	6.94
Triceratiales	Triceratiaceae	*Odontella* sp.	0.54	0.15	0.64	0.18	0.00	0.30
Chlorophyceae								
Oedogoniales	Oedogoniaceae	*Oedogonium* sp.	1.60	3.63	1.73	3.56	0.30	2.36
Sphaeropleales	Hydrodictyaceae	*Pediastrum* sp.	0.14	0.00	0.00	0.00	0.00	0.00
Cyanophyceae								
Chroococcales	Microcystaceae	*Merismopedia* spp.	2.23	2.13	1.33	1.31	1.90	0.72
		Microcystis sp.	3.64	1.86	1.73	0.83	0.63	0.64
Chroococcidiopsidales	Aliterellaceae	*Gloeocapsa* sp.	3.27	4.00	4.06	0.73	0.80	5.74
Oscillatoriales	Oscillatoriaceae	*Oscillatoria* sp.	0.73	0.11	0.00	0.62	0.00	0.00
Spirulinales	Spirulinaceae	*Spirulina* sp.	0.48	0.29	0.00	0.00	0.00	0.00
Synechococcales	Synechococcaceae	*Synechococcus* sp.	4.23	4.04	0.79	0.44	0.18	0.26
Dinophyceae								
Gonyaulacales	Ceratiaceae	*Ceratium* spp.	3.78	4.73	2.46	3.13	4.62	1.58
	Lingulodiniaceae	*Lingulodinium* sp.	1.63	0.88	1.29	0.10	0.42	0.00
Prorocentrales	Prorocentraceae	*Prorocentrum* spp.	5.14	3.47	5.78	4.65	6.17	3.31
Euglenophyceae								
Euglenales	Phacaceae	*Phacus* sp.	2.65	1.77	5.61	8.74	4.10	4.79
Trebouxiophyceae								
Chlorellales	Oocystaceae	*Oocystis* sp.	0.40	0.00	0.00	1.78	0.78	0.37
Ulvophyceae								
Cladophorales	Cladophoraceae	*Cladophora* sp.	0.77	1.00	0.36	0.00	0.16	0.07
Ulotrichales	Ulotrichaceae	*Ulothrix* sp.	2.80	1.80	2.89	3.13	2.34	2.80
	Total density (Cell/L)		857.5	479.6	647.1	677.4	1532.4	934.9
	Taxa richness (Genus)		39	36	32	33	34	35
	Shannon-Wiener Diversity Index (H')		4.84	4.76	4.38	4.39	4.62	4.40
	Evenness (E)		0.92	0.92	0.88	0.87	0.91	0.86
	Simpson Dominance Index (Id)		0.04	0.04	0.06	0.06	0.05	0.06

The evenness index shows a value that varies between 0.86 and 0.92, which indicates high evenness, while the Simpson Dominance Index shows a value variation between 0.04 and 0.06, which indicates low dominance, demonstrating that no particular phytoplankton was found to dominate the entire coastal ecosystem of the Watulimo area. (Table 3). It is known that the evenness index correlates with the Simpson Dominance Index. If the Id value approaches 0, then there is no dominance, and species distribution is even in an ecosystem (Wu et al. 2014). This is also supported by the density data of each phytoplankton taxa, which shows that the distribution of species in each location is even, and there are no particular species that dominate the coastal ecosystem of the

Watulimo area, Trenggalek (Table 3).

The Shannon-Wiener Diversity Index (H ') has a value variation between 4.38 and 4.84. It shows that the coastal water ecosystem in the Watulimo area, Trenggalek District, is not polluted by toxic pollutants because the diversity is relatively high (Table 3). The H’ value of phytoplankton is in the category of not being polluted by toxic pollutants if H’>3 (Junaidi and Azhar 2018). Toxic substances do not contaminate the coastal ecosystem in the Watulimo Sub-district; however, the area exhibits a relatively high level of organic pollutants, as evidenced by the dominance of plankton species from Bacillariophyceae (Samanta and Bhadury 2015). This is due to various human activities such as water tourism, fish processing, and ports that can increase the presence of organic pollutants in an aquatic ecosystem. This aligns with the results of observations of water's physical and chemical quality, which show that the levels of nitrate and orthophosphate in Table 2 are relatively high and have exceeded the national and international standard quality values.

To determine the nutritional status and organic pollution in waters, several indices were calculated, namely the Trophic Diatom Index (TDI) and the Percentage Pollution Tolerant Value (%PTV). TDI is an index used to determine the level of eutrophication in an aquatic ecosystem. The coastal ecosystem of the Watulimo area shows that the waters are in the eutrophic category, with TDI values ranging from 56.8 to 71.8 (Figure 4). Classification of water quality based on TDI values ranging from 0-100 is divided into 4 categories based on trophic level, namely TDI values ranging from 0-24, including oligo-eutrophic, meaning that the waters have low nutrients and primary productivity. TDI values range from 25-49, including meso-eutrophic, meaning that the waters have moderate nutrients and primary productivity. TDI values range from 50-74, including eutrophic, meaning that the waters have high nutrients and productivity and low water transparency. TDI values ranging from 75-100 are hyper-eutrophic, meaning that the waters have very high nutrient content and primary productivity (Wu et al. 2014). This is due to the high human activity around the Watulimo coastal ecosystem. Many organic pollutants pollute the ecosystem (Retnaningdyah et al. 2022, 2024a).

The Percentage Pollution Tolerant Value (%PTV) indicates the level of organic pollution in an ecosystem with a maximum value of 100% (Figure 5), and an increase in organic pollution is said to occur if it reaches above 20%. The %PTV value is calculated by comparing the abundance of tolerant Diatoms (*Gomphonema* sp., *Navicula* spp., *Sellaphora* spp., and *Nitzschia* spp.) with the total number of diatoms obtained (Wu et al. 2014; Febriansyah et al. 2023). The results of the %PTV calculation on several beaches in the Watulimo area ranged from 1.9-16.0%, which include Pasir Putih Beach, Karanggongso, Mutiara, Guo Boto, and Karang Pegat. Meanwhile, Prigi Beach has a %PTV value of 26.8%. Based on this %PTV index, it can be seen that in the coastal ecosystem of the Watulimo area, no organic pollutants were found in all locations except Prigi Beach, which was polluted by light organic matter. Organic pollution in the Prigi area is caused by fish preservation activities near the sampling location, either by grilling, smoking, or salting. In this process, some fish organs that are not processed are discarded into the environment, and certain chemicals are added. The %PTV value positively correlates with TDI, where eutrophication increases if organic pollutants are high. High organic pollutants can be caused by anthropogenic activities, which can then trigger the growth of several types of diatoms, which are indicators of organic pollutants (Wu et al. 2014; Samanta and Bhadury 2015).

Differences in water quality in several beaches in the Watulimo area based on physicochemical parameters and community structure profiles, diversity, and several biotic indices of phytoplankton in multivariate can be seen from the biplot analysis using PCA. The results of the biplot analysis using Principal Component Analysis (PCA) showed that the percentage variance was 74.69% with a component value of 46.6% and component 2 of 28.09% (Figure 6). Based on the results of this analysis, it can be seen that the Pasir Putih and Karanggongso ecosystems have better quality, which is characterized by the highest diversity and richness of phytoplankton taxa, as well as the lowest phytoplankton dominance index with the lowest turbidity and orthophosphate levels with moderate eutrophication and free organic matter pollution levels which the value of %PTV is moderate. Meanwhile, the Mutiara and Guo Boto Beach ecosystems have medium turbidity and orthophosphate levels, moderate eutrophication status (TDI), free of organic pollution with the lowest value of %PTV, which has an impact on phytoplankton diversity and taxa richness, which are also lower.

The results of the Biplot analysis also show that Prigi Beach has the worst quality, characterized by the highest levels of turbidity and orthophosphate, as well as the highest value of TDI and %PTV with the status of eutrophication is moderate, and some evidence of organic pollution. This biplot analysis reveals a positive relationship between the degree of organic pollution, as represented by the %PTV value, and the diversity of phytoplankton species. Aerobic microorganisms decompose organic matter, subsequently releasing essential nutrients such as orthophosphate and nitrate that are vital for the growth of phytoplankton (Reinl et al. 2022; Prasetiyono et al. 2024). High orthophosphate content can increase the abundance and diversity of phytoplankton in an ecosystem (Nindarwi et al. 2021). The Karang Pegat coastal ecosystem at certain locations adjacent to Prigi Beach also has a quality similar to Prigi. The low quality of the coastal ecosystem in Prigi is caused by high anthropogenic activities around the coast, such as processing, preserving, or salting fish, ports, and TPI (Fish Auction Place) on Prigi Beach. High human activity around the ecosystem can increase pollution from organic and inorganic solid waste (Adyasari et al. 2021; Retnaningdyah et al. 2024b). In addition, land conversion into settlements, agriculture or plantations, fisheries, and tourism activities can further cause high levels of pollutants entering the ecosystem, both from anthropogenic solid waste and synthetic fertilizers and pesticides. This high anthropogenic activity can result in the decline of water and sediment quality (Semium et al. 2020; Erdős et al. 2022).

The results of the Biplot analysis also show that the high level of organic pollution and eutrophication in coastal water ecosystems, as reflected in the %PTV and TDI values, have a positive relationship or are directly proportional to the high levels of orthophosphate and turbidity of water bodies. Anthropogenic activities are thought to have impacted the high levels of solid waste, especially organic waste, around the coast. This can impact sediment and water quality changes, especially organic materials, nutrients, and turbidity, reducing phytoplankton diversity (Adyasari et al. 2021; Reinl et al. 2022; Prasetiyono et al. 2024). The results of observations of the presence of solid waste along the coast show the presence of various macro-anthropogenic solid waste, including plastic and non-plastic waste (glass, cloth, rubber, diapers, iron, and organic materials). This anthropogenic solid waste mainly comes from plastic food and beverage packaging, followed by household appliances, buildings, and clothing (Lechthaler 2020; Kesavan et al. 2021). Apart from human activities around the coast, solid waste in coastal ecosystems can also come from other areas because the beach in the Watulimo Sub-district area is a bay. If it enters the sea, this macro anthropogenic solid waste can get stuck in the coral reef substrate, inhibiting its growth. Plastic waste wrapped around rocky substrates can also damage and cause the death of benthic marine biota, especially coral reefs, macroalgae, and echinoderms. This study is limited by focusing on the part of the marine ecosystem's biodiversity, particularly the pelagic zone, while overlooking others, such as the benthic zone. Consequently, further research is crucial to evaluate the health of this marine biodiversity. These investigations will guide the necessary management strategies if the local government intends to develop this beach into a marine ecotourism destination.

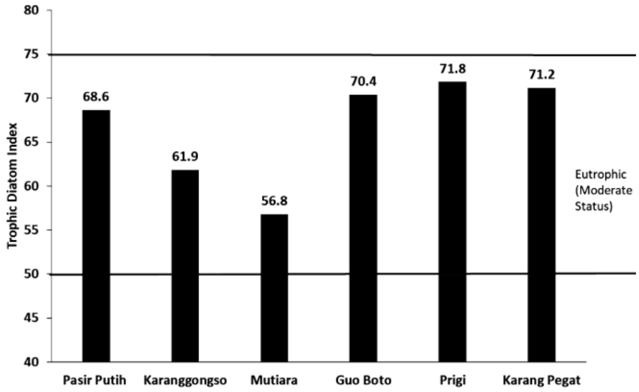

Figure 4. Status of eutrophication levels of several coastal ecosystems in Watulimo, Trenggalek, East Java, Indonesia, based on the Trophic Diatom Index

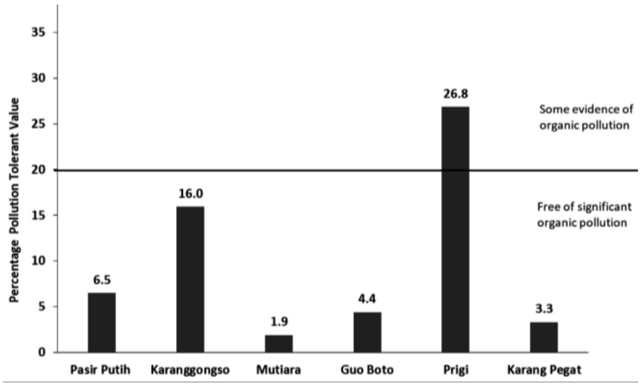

Figure 5. Status of organic pollution in the waters of several coastal ecosystems in Watulimo, Trenggalek, East Java, Indonesia, based on the Percentage Pollution Tolerant Value (%PTV)

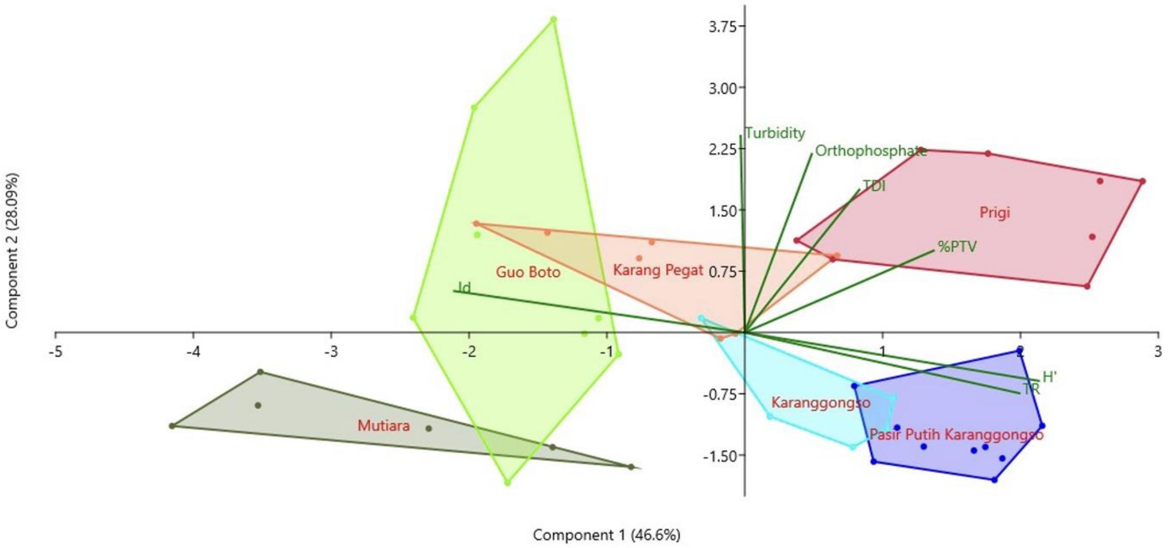

Figure 6. Grouping of ecosystem quality of several beaches based on water quality and phytoplankton in Watulimo Sub-district, Trenggalek, East Java, Indonesia

Based on the results of this study, it can be concluded that the physical-chemical quality of water in all coastal ecosystems in the Watulimo area meets the quality standards based on national and international standards concerning seawater quality standards for marine biota, except nitrate, orthophosphate, and oil-grease. A total of 40 species were found in 6 coastal ecosystems in the Watulimo area, with the highest abundance of Class Bacillariophyceae at 67-78%. Phytoplankton diversity is relatively high and evenly distributed, and no species dominance exists. The water quality in coastal ecosystems in the Watulimo area, based on the TDI index, is classified as eutrophic, while based on %PTV, there is no indication of organic material pollution except for the Prigi Beach ecosystem. High human activities around Prigi Beach have impacted increasing turbidity and orthophosphate content, subsequently impacting high values of %PTV and TDI. These values indicate organic material pollution and the level of eutrophication of the waters. Improving the quality of the coastal water ecosystem in Watulimo can be done by controlling the human activities that increase the density of macro-anthropogenic solid waste. Solid waste management can be done by implementing the 3R or reduce, reuse, and recycle concepts.

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REFERENCES

Adyasari D, Pratama MA, Teguh NA, Sabdaningsih A, Kusumaningtyas MA, Dimova N. 2021. Anthropogenic impact on Indonesian coastal water and ecosystems: Current status and future opportunities. Mar Pollut Bull 171: 112689. DOI: 10.1016/j.marpolbul.2021.112689.

Akter S, Rahman MM, Akter M. 2015. Composition and abundance of phytoplankton population in fishponds of Noakhali District, Bangladesh. Am Eur J Agric Environ Sci 15 (11): 2143-2148. DOI: 10.5829/idosi.aejaes.2015.15.11.95317.

Al-Handal AY, Riaux-Gobin C, Jahn R, Wulff AK, Minerovic A. 2019. Two new marine species of *Cocconeis* (Bacillariophyceae) from the west coast of Sweden. Eur J Taxon 497: 1-15. DOI: 10.5852/ejt.2019.497.

Ariani F, Effendi H, Suprihatin. 2016. Water and sediment oil content spread in Dumai Coastal Waters, Riau Province, Indonesia. Egypt J Aquat Res 42 (4): 411-416. DOI: 10.1016/j.ejar.2016.08.005.

Badan Pusat Statistik (BPS). 2024. Capture Fisheries Production based on District and Type of Capture in Trenggalek District. Central Statistics Agency of Trenggalek District, Trenggalek. https://trenggalekkab.bps.go.id/id/statistics-table/2/MTcwIzI=/produksi-perikanan-tangkap-menurut-kecamatan-dan-jenis-penangkapan-di-kabupaten-trenggalek--ton-.html. [Indonesian]

Blewett TA, Binning SA, Weinrauch AM, Ivy CM, Rossi GS, Borowiec BG, Lau GY, Overduin SL, Aragao I, Norin T. 2022. Physiological and behavioral strategies of aquatic animals living in fluctuating environments. J Exp Biol 225 (9): jeb242503. DOI: 10.1242/jeb.242503.

Castellani C, Edwards M. 2017. Marine Plankton: A Practical Guide to Ecology, Methodology, and Taxonomy. Oxford University Press, Oxford. DOI: 10.1093/oso/9780199233267.001.0001.

Chevrollier LA, Koski M, Sondergaard J, Trapp S, Aheto DW, Darpaah G, Nielsen TG. 2022. Bioaccumulation of metals in the planktonic food web in the Gulf of Guinea. Mar Pollut Bull 179: 113662. DOI: 10.1016/j.marpolbul.2022.113662.

Darojat MK, Kurniawan N, Retnaningdyah C. 2020. Evaluation of water quality based on macrozoobenthos as a bioindicator in the four springs of Wana Wiyata Widya Karya Tourism Area, Cowek Village, Purwodadi District, Pasuruan Regency. J Indones Tour Dev Stud 8 (1): 1-8. DOI: 10.21776/ub.jitode.2020.008.01.01.

Erdős L, Bede-Fazekas Á, Bátori Z, Berg C, Kröel-Dulay G, Magnes M, Sengl P, Tölgyesi C, Török P, Zinnen J. 2022. Species-based indicators to assess habitat degradation: Comparing the conceptual, methodological, and ecological relationships between hemeroby and naturalness values. Ecol Indic 136: 108707. DOI: 10.1016/j.ecolind.2022.108707.

Febriansyah SC, Hakim L, Retnaningdyah C. 2022. Evaluation of mangrove water quality in Pancer Cengkrong, Trenggalek and Sine, Tulungagung, East Java, Indonesia using phytoplankton as bioindicators. Jurnal Ilmiah Perikanan Kelautan 14 (2): 297-312. DOI: 10.20473/jipk.v14i2.32459.

Febriansyah SC, Hakim L, Saptoyo, Retnaningdyah C. 2023. Phytoplankton diversity as a bioindicator of water quality mangrove ecosystems in Clungup Mangrove Conservation, Kondang Merak and Sempu Island, Malang Regency. J Trop Biodivers Biotechnol 8 (1): 1-15. DOI: 10.22146/jtbb.73002.

Fernandez-González C, Tarran GA, Schuback N, Malcolm E, Woodward S, Aristegui J, Maranon E. 2022. Phytoplankton responses to changing temperature and nutrient availability are consistent across the tropical and subtropical Atlantic. Commun Biol 5: 1035. DOI: 10.1038/s42003-022-03971-z.

Hemraj DA, Hossain MA, Ye Q, Qin J.G, Leterme SC. 2017. Plankton bioindicators of environmental conditions in coastal lagoons. Estuar Coast Shelf Sci 184: 102-114. DOI: 10.1016/j.ecss.2016.10.045.

Hilmi E, Sari LK, Amron A. 2020. The prediction of plankton diversity and abundance in mangrove ecosystem. Omni-Akuatika 16 (3): 843. DOI: 10.20884/1.oa.2020.16.3.843.

Holmes M, Campbell EE, de Wit M, Taylor JC. 2022. The impact of drought in the Karoo - Revisiting diatoms as water quality indicators in the upper reaches of the Great Fish River, Eastern Cape, South Africa. South Afr J Bot 149: 502-510. DOI: 10.1016/j.sajb.2022.06.046.

Junaidi M, Azhar F. 2018. Community structure of phytoplankton and its relationship to waters quality in Lombok Strait, North Lombok District, West Nusa Tenggara, Indonesia. Intl J Oceans Oceanogr 12 (2): 159-172.

Kesavan S, Xavier KM, Deshmukhe G, Jaiswar AK, Bhusan S, Shukla SP. 2021. Anthropogenic pressure on mangrove ecosystems: Quantification and source identification of surficial and trapped debris. Sci Total Environ 794: 148677. DOI: 10.1016/j.scitotenv.2021.148677.

Khozanah, Yogaswara D, Wulandari I. 2021. Oil and Grease (OG) content in seawater and sediment of the Jakarta Bay and its surrounding. IOP Conf Ser Earth Environ Sci 789 (1): 012015. DOI: 10.1088/1755-1315/789/1/012015.

Kondzior P, Butarewicz A. 2018. Effect of heavy metals (Cu and Zn) on the content of photosynthetic pigments in the cells of algae *Chlorella vulgaris*. J Ecol Eng 19 (3): 18-28. DOI: 10.12911/22998993/85375.

Lechthaler S. 2020. Microplastic in der Umwelt: Betrachtung Terrestrischer und Aquatischer Bereiche. Springer Vieweg, Wiesbaden. DOI: 10.1007/978-3-658-30337-2.

Lestari HA, Samawi MF, Faizal A, Moore AM, Jompa J. 2021. Diversity and abundance of phytoplankton in the coastal waters of South Sulawesi Hasriani. Hayati 28 (3): 199-211. DOI: 10.4308/hjb.28.3.199.

Luthfi OM, Isdianto A, Supriyadi, Alifia R, Sulistianingrum NI, Prasetyoaji R, Ramadhan MIAK, Soegianto A. 2019. Physico-chemical oceanographic conditions of Prigi Bay, East Java, Indonesia. Ecol Environ Conserv 25: S199-S204.

Malik A, Fensholt R, Mertz O. 2015. Mangrove exploitation effects on biodiversity and ecosystem services. Biodivers Conserv 24 (14): 3543-3557. DOI: 10.1007/s10531-015-1015-4.

Manamani R, Bensouilah M. 2023. Water physicochemical characterization and phytoplankton diversity of arid region in Meggarine Lake, Ouargla, Algeria. Biodiversitas 24 (3): 1569-1579. DOI: 10.13057/biodiv/d240329.

Mizwar A, Surapati HU. 2020. Biological Oxygen Demand (BOD5) as bioindicator of phytoplankton diversity index in the mangrove area of Kintap Estuary, South Kalimantan. IOP Conf Ser Earth Environ Sci 448 (1): 012126. DOI: 10.1088/1755-1315/448/1/012126.

Nindarwi DD, Samara SH, Santanumurti MB. 2021. Nitrate and phosphate dynamics of phytoplankton abundance in Kanceng River, Sepuluh, Bangkalan, East Java, Indonesia. IOP Conf Ser Earth Environ Sci 679 (1): 012063. DOI: 10.1088/1755-1315/679/1/012063.

Otero J, Alvarez-Salgado XA, Bode A. 2020. Phytoplankton diversity effect on ecosystem functioning in a coastal upwelling system. Front Mar Sci 7: 592255. DOI: 10.3389/fmars.2020.592255.

Parmawati R, Leksono AS, Yanuwiadi B, Kurnianto AS. 2017. Exploration of marine tourism in Watulimo, Trenggalek District: Challenges, potentials, and development strategies. J Indones Tour Dev Stud 5 (3): 175-184. DOI: 10.21776/ub.jitode.2017.005.03.06.

PP RI No. 22 of 2021. The Republic of Indonesia Government Regulation No. 22 of 2021 Concerning the Implementation of Environmental Protection and Management, Appendix VIII Concerning Seawater Quality Standards. Republic of Indonesia Government, Jakarta. [Indonesian]

Prasetiyono E, Nirmala K, Supriyono E, Sukenda S, Hastuti YP. 2024. Evaluation of phytoplankton abundance and wastewater quality in intensive vannamei shrimp ponds in the northern coastal area of Bangka Island. J Mar Biol Assoc U K 104: e86. DOI: 10.1017/S0025315424000651.

Rahayu AP, Saad M, Fanni NA. 2021. Analysis of plankton abundance and status of water quality fish cultivation “Sawah Tambak” with overtime system in Kalitengah Subdistrict, Lamongan Regency. Adv Trop Biodivers Environ Sci 5 (1): 17-22. DOI: 10.24843/ATBES.2021.v05.i01.p03.

Raven JA, Gobler CJ, Hansen PJ. 2020. Dynamic CO_2 and pH levels in coastal, estuarine, and inland waters: Theoretical and observed effects on harmful algal blooms. Harmful Algae 91: 101594. DOI: 10.1016/j.hal.2019.03.012.

Reinl KL, Harris TD, Elfferich I, Coker A, Zhan Q, Domis LNDS, Morales-Williams AM, Bhattacharya R, Grossart HP, North RL, Sweetman JN. 2022. The role of organic nutrients in structuring freshwater phytoplankton communities in a rapidly changing world. Water Res 219: 118573. DOI: 10.1016/j.watres.2022.118573.

Retnaningdyah C, Arisoesilaningsih E, Vidayanti V, Salsabila Q, Purnomo P. 2024a. The relationship between habitat quality and the diversity of phytoplankton, zooplankton, and nekton in mangrove ecosystems of Bawean Island, Indonesia. Biodiversitas 25 (7): 3017-3026. DOI: 10.13057/biodiv/d250723.

Retnaningdyah C, Arisoesilaningsih E, Vidayanti V, Salsabila Q, Purnomo P. 2024b. Community structure and fish diversity in some mangrove ecosystems with varying levels of naturalness and human activity on Bawean Island, East Java, Indonesia. Bio Web Conf 91: 01009. DOI: 10.1051/bioconf/20249101009.

Retnaningdyah C, Febriansyah SC, Hakim L. 2022. Evaluation of the quality of mangrove ecosystems using macrozoobenthos as bioindicators in the Southern Coast of East Java, Indonesia. Biodiversitas 23 (12): 6480-6491. DOI: 10.13057/biodiv/d231247.

Retnaningdyah C, Ridlo IA, Febriansyah SC, Nusantara OB. 2021. Water quality evaluation of some mangrove ecosystems with variations of time restoration in South Malang, East Java, Indonesia. IOP Con Ser Earth Environ Sci 743 (1): 012011. DOI: 10.1088/1755-1315/743/1/012011.

Salsabila Q, Retnaningdyah C, Hakim L. 2024. Evaluation of mangrove ecosystem quality in Bawean Island, East Java using phytoplankton as bioindicators. Jurnal Ilmiah Perikanan Kelautan 16 (2): 438-451. DOI: 10.20473/jipk.v16i2.55755.

Samanta B, Bhadury P. 2015. *Thalassiosira sundarbana* sp. nov. (Bacillariophyta), an estuarine diatom from Sundarbans mangrove ecoregion based on morphology and molecular phylogeny. Phycol Res 63 (2): 102-109. DOI: 10.1111/pre.12084.

Santhanam P, Begum A, Pachiappan P. 2019. Basic and Applied Phytoplankton Biology. Springer, Singapore. DOI: 10.1007/978-981-10-7938-2.

Semium CG, Retnaningdyah C, Arisoesilaningsih E. 2020. Structural modelling of riparian tree diversity and ecosystem degradation roles in determining the water quality of springs and its drains in East Java. J Degrad Mining Land Manag 8 (1): 2431. DOI: 10.15243/jdmlm.2020.081.2431.

Sew G, Todd P. 2020. Effects of salinity and suspended solids on tropical phytoplankton mesocosm communities. Trop Conserv Sci 13 (1): 1-11. DOI: 10.1177/1940082920939760.

Suteja Y, Dirgayusa IGNP, Afdal M, Cordova MR, Rachman AR, Rintaka WE, Takarina ND, Putri WAE, Isnaini, Purwiyanto AIS. 2021. Identification of potentially harmful microalgal species and eutrophication status update in Benoa Bay, Bali, Indonesia. Ocean Coast Manag 210: 105698. DOI: 10.1016/j.ocecoaman.2021.105698.

Titaley YM, Toha AHA, Tapilatu RF. 2021. Diversity and abundance of plankton in mangrove waters. Musamus Fish Mar J 3 (2): 128-143. DOI: 10.35724/mfmj.v3i2.3451.

Tjahjono A, Wahyuni O, Sugiharto R, Wibisono Y, Prasetyo AN. 2023. Phytoplankton saprobity as pollution bioindicator: A study of *Chaetoceros* genera in Port of Tanjung Emas Waters, Semarang. J Hunan Univ Nat Sci 50 (4): 115-130. DOI: 10.55463/issn.1674-2974.50.4.11.

Wassie TA, Melese AW. 2017. Impact of physicochemical parameters on phytoplankton compositions and abundances in Selameko Manmade Reservoir, Debre Tabor, South Gondar, Ethiopia. Appl Water Sci 7 (4): 1791-1798. DOI: 10.1007/s13201-015-0352-5.

Wu N, Schmalz B, Fohrer N. 2014. Study progress in riverine phytoplankton and its use as bio-indicator: A review. Austin J Hydrol 1 (1): 1-9. DOI: austinpublishinggroup.com/hydrology/fulltext/ajh-v1-id1003.php.