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Evaluation of Mangrove Ecosystem Quality in Bawean Island, East Java Using Phytoplankton as Bioindicators

Qathrunnada Salsabila*, Catur Retnaningdyah, and Luchman Hakim

Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya, Malang, East Java, Indonesia, 60115. Indonesia

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*) Corresponding author:
E-mail: naasalsabila@student.ub.ac.id

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Abstract

The mangrove ecosystems in Bawean Island are degraded due to anthropogenic activities and land conversion. Plantation has been carried out periodically, and this has continued in several mangrove ecosystems. This study was conducted to evaluate the physicochemical water quality of several mangrove ecosystems on Bawean Island, as well as phytoplankton as bioindicators. The evaluation of mangroves in Bawean Island was carried out at 11 locations based on different naturalness and human activities surrounding. The physical and chemical parameters of water observed were air temperature, water temperature, pH, TSS, dissolved oxygen (DO), biochemical oxygen demand (BOD), salinity, conductivity, nitrate, and orthophosphate. Community structure and plankton diversity measured include the Importance Value Index (IVI), Shannon-Wiener diversity index (H'), Simpson dominance index (Id), evenness index (E), trophic diatom index (TDI), and pollution tolerant value (%PTV). The physical parameters of water chemistry show that it meets the quality standards based on Indonesian Government Regulation No. 22 of 2021, except for nitrate and orthophosphate, but it is still under plankton tolerant. A total of 63 species from 7 phytoplankton classes were found based on the importance value index. Based on the TDI index, mangrove ecosystems Sawahmulya, Sidogedungbatu, Hijau Daun, Pamona, Pasir Putih, Sungai Rujing, Bangsal, Jherat Lanjheng, and Lebak were classified as eutrophic while Pulau Cina and Dekatagung were hyper-eutrophic. Based on %PTV, the Hijau Daun mangrove is the best mangrove ecosystem, while other mangroves were classified as moderately and heavily polluted.

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1. Introduction

The mangrove ecosystem is a transitional ecosystem between the land and the sea located along the coast and river estuaries (Serosero *et al.*, 2020). Mangrove ecosystems support the survival of various biota, act as the largest carbon stock storage, and protect the coast from flooding, waves, and erosion (Getzner and Islam, 2020). The area of mangroves in East Java, Indonesia, was 18.253.771 Ha in 2013 (Saputro, 2009). However, the global loss of mangrove forests has reached 35% in the last 20 years (Carugati *et al.*, 2018) and reduced to 11.800 Ha in 2019 in East Java (Rudianto *et al.*, 2020). One of the mangrove ecosystems in East Java is the Bawean Island mangrove ecosystem, with a total area of 1782 Ha dominated by *Rhizophora* spp. and *Sonneratia* spp. (Armono *et al.*, 2018).

Globally, mangrove ecosystems have the highest productivity due to their high biomass (Tanner *et al.*, 2019). Mangrove ecosystems provide various benefits for coastal areas and communities. Mangrove ecosystem services comprise provisioning services (providing wood as fuel and building materials), regulating services (protecting from flooding and erosion control), supporting services (as a breeding and spawning ground for fish), cultural services (as eco-tourism) (Getzner and Islam, 2020). Increasing human activities, such as industrial activities, land conversion into settlements, aquaculture, plantations, agriculture, and tourism, might degrade ecosystems, damaging their service ecosystem quality functions (Loreau, 2010). Degraded mangrove ecosystems can be restored through restoration (Aini *et al.*, 2020); (Hilmi *et al.*, 2020). Mangroves can act as phytoremediation to restore ecosystem services to their original state (Camacho *et al.*, 2020). Restoration is a program to restore degraded ecosystems to return to their original ecological function and biodiversity integrity (Abelson *et al.*, 2020). Restoration programs successfully improving the function is indicated by increased mangrove ecosystem services, such as improving the physical and chemical quality of the environment and the vegetation and biota diversity in mangroves (Ferreira *et al.*, 2015; Retnaningdyah *et al.*, 2022). Mangrove ecosystems are commonly evaluated using the physicochemical parameters of the water quality (Febriansyah *et al.*, 2022).

Physicochemical parameters reflecting water quality for mangrove ecosystems include temperature, pH, DO, BOD, conductivity, nitrate, orthophosphate, and turbidity (Febriansyah *et al.*, 2022). Phytoplankton can also be a bioindicator of the quality of mangrove ecosystems (Febriansyah *et al.*, 2023) due to their short life cycle, low mobility, and quick response to environmental changes. Community structure and phytoplankton diversity are widely used for measuring the health of aquatic ecosystems through the trophic diatom index (TDI) and percentage of pollution tolerant value (%PTV) indices (Singh *et al.*, 2017; Wu *et al.*, 2014). However, previous studies focused on the mangrove community structure and carbon stock in the Hijau Daun and Pasir Putih mangrove ecosystem (Fikroh *et al.*, 2021), and no evaluation was conducted regarding water quality in the several mangrove ecosystems in Bawean Island. Evaluating the water quality in mangrove ecosystems based on different anthropogenic activities to determine the condition of pollution around mangroves on Bawean Island, which are widely utilized by communities for building materials, fuel, firewood, food, and eco-tourism, is important.

Land conversion into ponds, plantations, and agriculture has reduced the mangrove ecosystem areas on Bawean Island (Fikroh *et al.*, 2021). We aim to analyze the quality of several mangrove ecosystems on Bawean Island based on water physicochemical parameters, hemeroby index, naturalness index, and bioindicators such as phytoplankton community and diversity structure. Furthermore, it is expected to become a recommendation of mangrove ecosystem management for the local government in maintaining the quality and developing restoration programs for some degraded mangrove ecosystems.

2. Materials and Methods

2.1 Materials

In this study, we use CuSO4 and 4% formalin for plankton. We use a water sampler and a plankton net, and then we place the sample in a flacon bottle. We measured the water using a conductivity meter, pH meter, TSS meter, DO meter, thermometer, and spectrophotometry.

2.1.1 Ethical approval

This study does not require ethical approval because it does not use experimental animals.

2.2 Study Site and Sample Collection

Sampling of water, mangrove vegetation, and phytoplankton was conducted in July 2023 at 11 mangrove ecosystems of Bawean Island, namely Sawahmulya, Sungai Rujing, Hijau Daun, Sidogedungbatu, Pamona, Pasir Putih, Bangsal, Dekatagung, Jherat Lanjheng, Lebak, and Pulau Cina (Figure 1). Water quality measurements, phytoplankton identification, and data analysis were conducted in July – November 2023 at the Laboratory of Ecology and Tropical Ecosystem Restoration, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya, Indonesia.

2.3 Research Design

This is ex post facto research that was used to observe causal effects occurring in the field. This method was conducted by observing the effects of changes in the independent variables, mangrove ecosystems in Bawean island, and the dependent variable: physicochemical parameters of water, hemeroby index, naturalness index, community structure, and phytoplankton diversity. Sampling stations were determined by purposive random sampling based on different mangrove characteristics (natural mangroves or mangrove gap filling between natural mangroves and planted mangrove areas) and anthropogenic activities.

2.4 Water Samples Collection and Measurement of Physicochemical Parameters

The water sample was obtained from three sites in triplicate at all 11 locations (Figure 1). Approximately 2 L of water samples were collected using a water sampler and stored in a sample bottle. The physicochemical measurements, including air temperature, water temperature, pH, TSS, conductivity, salinity, and DO, were conducted at the field. The water sample was also brought into the Laboratory of Ecology and Tropical Ecosystem Restoration, Universitas Brawijaya, for analysis, including BOD, nitrate, and orthophosphate measurements.

2.5 Phytoplankton Samples Collection, Identification, and Enumeration

Phytoplankton sampling was conducted in three sites in triplicate at all 11 locations (Figure 1). Approximately 2 L of phytoplankton samples were obtained using a water sampler and filtered using plankton mesh (10 - 30 mesh size). Phytoplankton samples were placed into a flacon bottle with 10 drops of 4% formalin and 5 drops of $CuSO_4$, respectively. In the Sedgewick-Rafter cell counting chamber, 1 mL of phytoplankton samples were placed (APHA, 2005). Phytoplankton samples were observed under a 200x magnification light microscope, and the number of phytoplankton found from the 1st box to the 1000th box was counted. Next, the density of each phytoplankton species was converted using the formula and was converted using the formula (APHA, 2005). Phytoplankton was identified using the iden-

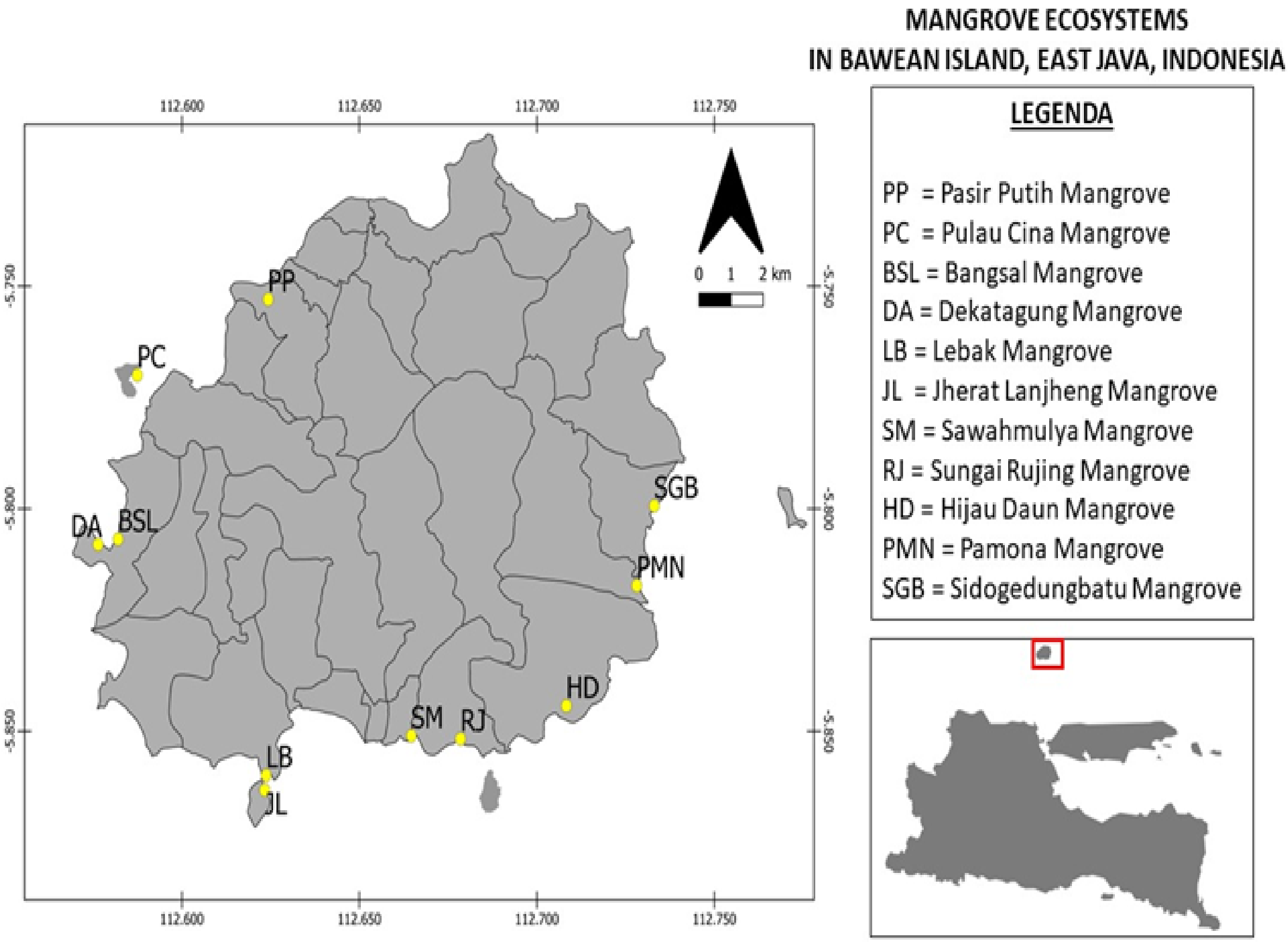

Figure 1. Mangrove ecosystems study site

tification key book according to (Gell, 1999; Du Buf and Bayer, 2002; Van Vuuren *et al.,* 2006; Bellinger and Sigee, 2010). Phytoplankton abundance was calculated using the formula given by APHA (2005):

$N = T/L \times p1/p2 \times V1/V2 \times 1/W$..............................(i)

Where :

N = the abundance of plankton (ind/L)

T = the number of boxes in SRC (1000 boxes)

L = the number of boxes in one field of view

p1 = the number of observed plankton

p2 = the number of SRC boxes observed

V1 = the volume of water in the sample bottle

V2 = the volume of water in the SRC box

W = the volume of filtered water

The data obtained from identifying and calculating phytoplankton were descriptively analyzed using Microsoft Excel. Analysis of bioindicators includes the Important Value Index (IVI), Shannon-Wiener Diversity Index (H'), Simpson's Dominance Index (Id), Evenness Index (E). In addition, %PTV and TDI were used to determine water quality using phytoplankton as bioindicators.

IVI or important value index, is a quantitative parameter used to describe the dominant influence of a species on a community. The IVI value was obtained from the following formula (Barnes and Mann, 1994):

$IVI = KR + FR$..(ii)

Where :

IVI = important value index

KR = the sum of the relative abundance

FR = relative frequency values and was expressed in % units

The Evenness index was used to determine the evenness of the number of individuals of each species in a community. The value of E can be determined by the formula (Krebs, 1994):

$E = H'/H_{max}$...(iii)

Where :

E = the evenness index value

H' = the Shannon-Wiener index

Hmax = the number of species

Simpson's dominance index (Id) describes the dominance status of a community in an ecosystem. Simpson's dominance index can be determined by the formula (Babu *et al.,* 2013):

$Id = Ni(Ni-1) \times N(N-1)$..................................... (iv)

Where :

Id = the Simpson dominance index value

N = the number of individuals of the i-th species

N = total individuals found

The Shannon-Wiener diversity index indicates the abundance of a species in a community. The value of H' is determined by the formula (Wu *et al.,* 2014):

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

Where :

H'= the value of the Shannon-Wiener diversity index

S = the total number of species in the community

Pi = the number of species i to the total number of species

Trophic Diatom Index (TDI) is a calculation that determine the level of phytoplankton eutrophication in an ecosystem. According to Wu *et al.* (2014), the TDI value can be calculated by the formula:

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

Where:

WMS = the weighted average sensitivity, which can be determined by the formula:

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

Where :

ai = the proportion of all individuals in the sample that belong to the species i

n = the total number of species in the sample

si = the pollution sensitivity (1- 5) of the species i

vi = the indicator value (1-3) of the species i (Wu *et al.,* 2014).

Percentage of Pollution Tolerant Values (%PTV) describes the level of organic pollution in an ecosystem. The classification of the %PTV value level is <20% is free of significant organic pollution, 21 - 40% is some evidence of organic pollution, 41 - 60% is organic pollution likely to contribute significantly to eutrophication of the site, and >61% is the site is heavily contaminated with organic pollution (Wu *et al.,* 2014). The %PTV value is obtained from the calculation of 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 in (Kelly and Whitton, 1995) using the formula:

%PTV = (Abundance of tolerant taxa)/(total taxa abundace)..(viii)

2.6 Hemeroby and Naturalness Index

The hemeroby measures the land use and the level of human disturbance in an ecosystem using vegetation classification rules. The equation used to calculate the Hemeroby Index value is as follows (Tian *et al.,* 2020):

$$HI = \sum_{i=1}^{n} fn \times Hi \quad \text{(ix)}$$

Where :

HI = the Hemeroby Index

n = the number of hemeroby degrees

fn = the proportion of landscape types with Hi

Hi = the degree of hemeroby

The naturalness index was used to observe land use and human activities in the research locations using environmental services. Several parameters were used to determine the naturalness index, such as biotic elements, energy input, level of fragmentations, and artificial elements (Machado, 2004).

2.7 Analysis Data

The data of water physicochemical parameters were encoded and compiled using Microsoft Excel. Furthermore, data were analyzed using a One-Way ANOVA analysis of variance by SPSS 16.0 to determine the different water physicochemical parameters at each location. Data with normal distribution and homogeneous variance were analysed using the Tukey HSD test; data with heterogeneous variance were analyzed using the Brown-Forsythe test and continued using Games Howell; abnormal data were analyzed using the Mann-Whitney test and continued using Kruskal Wallis.

3. Results and Discussion

3.1 Physico-chemical Water Quality at Mangrove Ecosystems of Bawean Island

The profile of physicochemical parameters in several mangrove ecosystems on Bawean Island, including air temperature (°C), water temperature (°C), pH, TSS (mg/L), conductivity (mS/cm), DO (mg/L), BOD (mg/L), nitrate (mg/L), and orthophosphate (mg/L) are shown in Table 1. The physicochemical parameters differ in several mangrove ecosystems on Bawean Island. The air temperature was from 26-33.63°C, and the differences in temperature were caused by the differences in sampling time: Lebak (26°C) and Sawahmulnya (33.63°C) at 4:30 and 12:00 p.m. Water temperature still maintain seawater quality standards regarding marine biota in mangrove ecosystems based on Government Regulation No. 22 of 2021 (28-32°C) in Table 1, which varied between 26.33-29.37°C, with the lowest temperature on Pulau Cina and the highest on Dekatagung. Water temperature can affect the metabolism, growth, and survival of all aquatic biota, and the optimal temperature for plankton ranges from 22-32°C (Hilmi *et al.,* 2020; Singh *et al.,* 2017).

The pH value met the seawater quality standards regarding marine biota in mangrove ecosystems based on Government Regulation Number 22 of 2021, varying between 7.61-8.10, with the lowest value in the Sidogedungbatu mangrove ecosystem and the highest in Pulau Cina (Table 1). The pH of the Sidogedungbatu mangrove ecosystem was lower than that of other locations due to high human activities in the vicinity, such as rice fields, boat docks, and domestic household wastes. The optimal pH value for plankton growth and supporting aquatic life is 6.5-8 (Wassie and Melese, 2017). The pH value can be influenced by the amount of chemical and organic pollutants in the water, including light intensity for photosynthesis. The changes in pH value affect the metabolism and survival of an organism (Retnaningdyah *et al.,* 2022; Darojat *et al.,* 2020).

TSS values varied between 1.34-8.87 mg/L, with the lowest and the highest values in Pasir Putih and Sawahmulya, and met the quality standards based on Government Regulation Number 22/2021 (Table 1). The high TSS value in the Sawahmulya mangrove ecosystem is due to household wastes that increase water turbidity. TSS is correlated to turbidity, where a high turbidity value increases the TSS value in a body of water (Hilmi *et al.,* 2020). Variations in TSS values can also affect phytoplankton abundance: a low TSS value indicates high phytoplankton abundance in a water body (Sew and Todd, 2020).

Conductivity values varied between 42.97-49.80 mS/cm, with the highest and lowest values in Jherat Lanjheng and Lebak mangroves and Bangsal (Table 1). The high conductivity value was influenced by minerals from twigs or leaves falling into the water. In addition, ionized salt increases the conductivity in a water body because salt is a good conductor of electricity (Manamani and Bensouilah, 2023; Nindarwi *et al.,* 2021). This condition was related to the high salinity value in the Jherat Lanjheng and Lebak mangrove ecosystems, 3.33 and 3.60‰, respectively.

While the highest salinity value was found in Lebak (3.60‰), the lowest was found in the Bangsal mangrove ecosystem (2.73‰) because it was in an

Table 1. Physicochemical water quality profile in several mangrove ecosystems of Bawean Island

Location	Physico-chemical Parameters (Mean ± StDev)									
	Air Temperature (°C)*	Water Temperature (°C)*	pH*	TSS (mg/L) *	Conductivity (mS/cm) **	Salinity (‰) *	DO (mg/L) ***	BOD (mg/L) ***	Nitrate (mg/L) ***	Orthophosphate (mg/L) ***
Sawahmulya	33.63 ± 1.72^{abc}	27.00 ± 0.72^{ab}	7.81 ± 0.08^{a}	8.87 ± 2.14^{ab}	48.10 ± 0.44^{a}	3.07 ± 0.06^{a}	2.65 ± 0.19^{a}	3.07 ± 1.16^{b}	0.159 ± 0.009^{a}	0.040 ± 0.016^{a}
Sungai Rujing	29.53 ± 1.33^{abc}	27.03 ± 0.38^{a}	7.83 ± 0.20^{a}	7.04 ± 2.91^{ab}	47.60 ± 1.76^{ab}	3.20 ± 0.20^{ab}	2.76 ± 0.16^{a}	3.11 ± 0.39^{b}	0.111 ± 0.017^{a}	0.031 ± 0.010^{a}
Hijau Daun	29.73 ± 1.21^{abc}	27.07 ± 0.35^{a}	8.08 ± 0.03^{a}	2.07 ± 0.68^{ab}	48.97 ± 0.06^{b}	3.13 ± 0.06^{a}	3.05 ± 0.06^{a}	1.77 ± 0.27^{ab}	0.160 ± 0.110^{a}	0.026 ± 0.014^{a}
Sidogedungbatu	29.00 ± 0.87^{abc}	26.87 ± 0.32^{a}	7.61 ± 0.23^{a}	5.64 ± 2.84^{ab}	47.83 ± 1.07^{ab}	3.23 ± 0.06^{ab}	2.33 ± 0.21^{a}	1.95 ± 0.82^{ab}	0.090 ± 0.015^{a}	0.036 ± 0.007^{a}
Pamona	30.87 ± 0.12^{c}	28.00 ± 0.44^{ab}	7.70 ± 0.16^{a}	4.65 ± 2.36^{ab}	45.83 ± 4.81^{ab}	2.93 ± 0.21^{ab}	2.48 ± 0.22^{a}	2.15 ± 0.61^{ab}	0.131 ± 0.019^{a}	0.013 ± 0.011^{a}
Pasir Putih	31.83 ± 1.12^{abc}	27.93 ± 0.25^{a}	8.10 ± 0.03^{a}	1.37 ± 0.22^{ab}	49.37 ± 0.51^{bcd}	3.23 ± 0.15^{ab}	2.53 ± 0.16^{a}	0.88 ± 0.39^{a}	0.085 ± 0.016^{a}	0.007 ± 0.003^{a}
Bangsal	30.23 ± 0.40^{bc}	28.07 ± 1.04^{ab}	7.93 ± 0.12^{a}	1.70 ± 0.38^{ab}	42.97 ± 10.02^{ab}	2.73 ± 0.81^{ab}	2.67 ± 0.26^{a}	2.15 ± 0.55^{ab}	0.115 ± 0.055^{a}	0.019 ± 0.021^{a}
Dekatagung	31.90 ± 0.70^{bc}	29.37 ± 0.06^{b}	7.88 ± 0.23^{a}	2.31 ± 0.71^{ab}	49.20 ± 0.10^{c}	3.20 ± 0.20^{ab}	2.19 ± 0.59^{a}	1.99 ± 0.90^{ab}	0.101 ± 0.024^{a}	0.053 ± 0.034^{a}
Jherat Lanjheng	27.97 ± 0.06^{b}	28.00 ± 0.44^{ab}	7.98 ± 0.12^{a}	1.87 ± 0.65^{ab}	49.80 ± 0.10^{d}	3.33 ± 0.21^{ab}	2.56 ± 0.36^{a}	1.49 ± 0.31^{ab}	0.128 ± 0.019^{a}	0.025 ± 0.006^{a}
Lebak	26.00 ± 0.00^{a}	26.63 ± 0.64^{ab}	7.89 ± 0.08^{a}	2.50 ± 0.10^{b}	49.80 ± 0.26^{d}	3.60 ± 0.20^{ab}	2.54 ± 0.08^{a}	0.72 ± 0.14^{a}	0.117 ± 0.041^{a}	0.032 ± 0.003^{a}
Pulau Cina	27.67 ± 1.53^{abc}	26.63 ± 1.15^{ab}	8.10 ± 0.06^{a}	2.57 ± 0.29^{a}	49.60 ± 0.65^{cd}	3.50 ± 0.00^{b}	2.92 ± 0.11^{a}	3.17 ± 0.44^{b}	0.149 ± 0.065^{a}	0.010 ± 0.014^{a}
Water Quality Standard (Indonesia Ministry of Environment Regulation Number 22/2021)	-	28 - 32	7 – 8.5	80	-	3.40	>5	20	0.006	0.015

Description: Same notation indicates no significant difference based on *) Brown-Forsythe test followed by Games Howell; **) Kruskal Wallis test followed by Mann Whitney; ***) One Way ANOVA test followed by Tukey α0.5

estuary (Table 1). The difference in salinity value is influenced by the sampling location in an estuary. According to Manamani and Bensouilah (2023), waters influenced by river flow have lower salinity than marine waters, which have high salinity due to high evaporation.

DO values varied between 2.19-3.05 mg/L and did not meet the quality standards based on PP RI-Number 22 of 2021, with the lowest DO values found in the Dekatagung mangrove and the highest in Hijau Daun (Table 1). Low DO values in all locations are caused by anthropogenic activities, such as land conversion into ponds, ecotourism, and residential houses that produce a lot of organic and inorganic waste (Retnaningdyah *et al.,* 2022). DO values that can support plankton life range from 4-6.5 mg/L (Aini *et al.,* 2020).

BOD values varied between 0.72-3.17 mg/L, with the lowest and highest value found in the Lebak mangrove ecosystem and Pulau Cina (Table 1). The BOD value meets the quality standard based on PP RI Number 22 of 2021. BOD can indicate the amount of total oxygen microorganisms use in an aerobic metabolism of organic matter from mangrove litter, such as leaves, propagules, and twigs. A high BOD value indicates a high amount of dissolved oxygen depletion for oxidation in an aquatic system (Mizwar and Surapati, 2020).

Nitrate levels varied between 0.085-0.160 mg/L, with the lowest and highest values in Pasir Putih and Hijau Daun (Table 1). Nitrate levels at all locations did not meet the quality standards according to Government Regulation Number 22/2021. Optimal nitrate levels for plankton growth range from 0.9-3.5 mg/L (Nindarwi *et al.,* 2021). High household activities and organic waste from leaf litter, fallen branches, and decaying trees can lead to high levels of nitrate and orthophosphate (Prihatno *et al.*, 2021).

Orthophosphate levels varied between 0.007-0.053 mg/L, with the lowest and highest values in Pasir Putih and Dekatagung (Table 1). Orthophosphate levels show that the mangrove ecosystems of Pasir Putih, Pamona, and Pulau Cina meet the quality standards based on Government Regulation Number 22/2021. High orthophosphate levels are caused by high anthropogenic activities, such as households producing organic and inorganic waste and tourist activities around mangroves (Malik *et al.,* 2015). This concurs with the results of our study, showing that the Dekatagung mangrove has the highest orthophosphate levels because it is close to residential areas and chicken farming. The optimal orthophosphate value for plankton growth ranges from 0.27-5.51 mg/L (Rahayu *et al.,* 2021).

The physicochemical quality of water in all mangrove ecosystems of Bawean Island met the seawater quality standards for mangrove biota based on Indonesian Government Regulation number 22 of 2021, except nitrate and orthophosphate. Community awareness is needed not to dispose of domestic waste or agricultural and aquaculture waste directly into the sea. It is also necessary to form local community groups that focus on preserving and developing mangrove ecosystem restoration activities to increase mangrove diversity.

3.2 Hemeroby and Naturalness Index at Mangrove Ecosystems of Bawean Island

According to Tian *et al.* (2020), human disturbance categories comprise seven ahemorobic (almost no human impact), oligohemerobic (low human impact), mesohemerobic (moderate human impact), β-euhemerobic (moderate-strong human impact), α-euhemerobic (strong human impact), polyhemerobic (very strong human impact), and metahemerobic (too strong human impact). Hijau Daun mangrove ecosystem belongs to the oligohemerobic category; Sungai Rujing, Jherat Lanjheng, and Pulau Cina mangroves belong to mesohemerobic; Sawahmulya and Lebak mangroves belong to β-euhemerobic; Sidogedungbatu and Pasir Putih mangroves belong to α-euhemerobic, while Bangsal and Dekatagung mangroves belong to polyhemerobic (Figure 2). Hemeroby index expresses high anthropogenic activity in an ecosystem with a high score (Retnaningdyah *et al.,* 2019).

The naturalness index is used to express the quality of an ecosystem where it occurs as "without artificial influence", "completely natural", and "completely artificial". Pamona and Hijau Daun mangrove ecosystems are classified as natural mangrove ecosystems compared to other locations (Figure 2). The naturalness index value is inversely proportional to the hemeroby index, where the higher the naturalness, the lower the hemeroby (Retnaningdyah *et al.,* 2019).

3.3 Phytoplankton Community Structure and Diversity at Mangrove Ecosystems of Bawean Island

In Bawean Island, 63 species from 7 phytoplankton classes were found in 11 mangrove ecosystems. The richness of phytoplankton taxa had spatial variations in all locations (Figure 3). Most phytoplankton species (42) were found in the Sawahmulya mangrove ecosystem, while only 25 species were found in Dekatagung, with each location showing variation in species values. The composition and structure of the phytoplankton community is shown by the importance index value (IVI). In the mangrove ecosystem of Sungai Rujing and Lebak there are two codominant

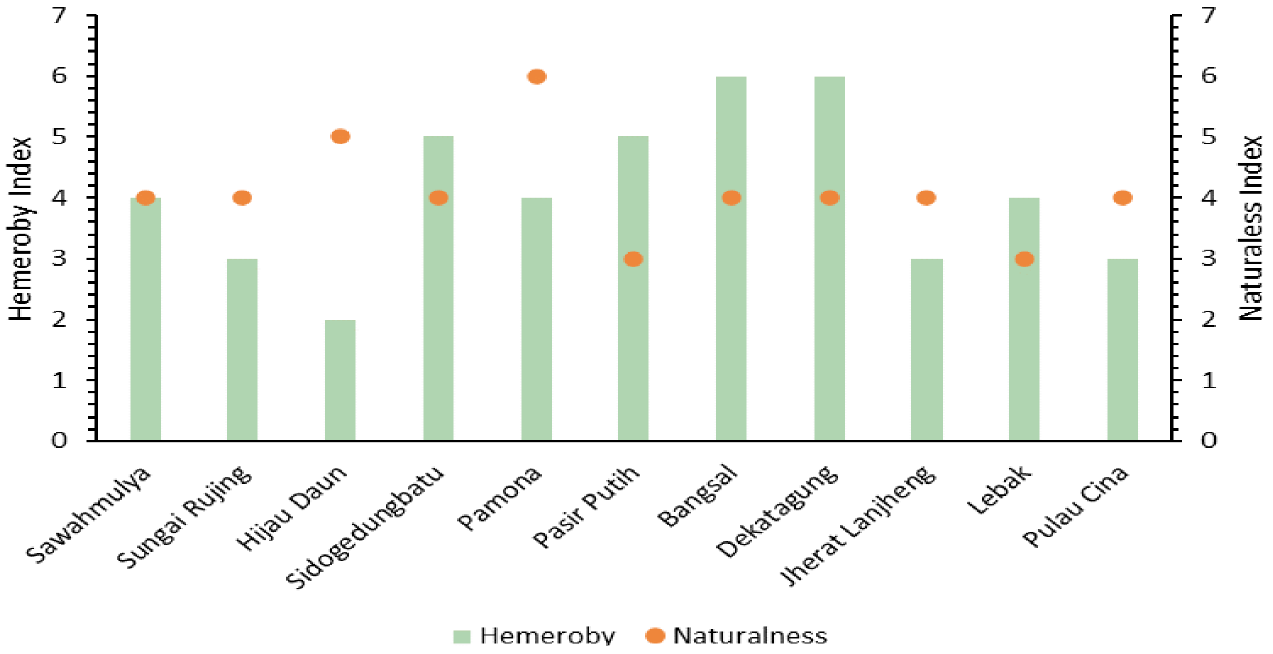

Figure 2. Hemeroby and naturalness index at mangrove ecosystems of Bawean Island

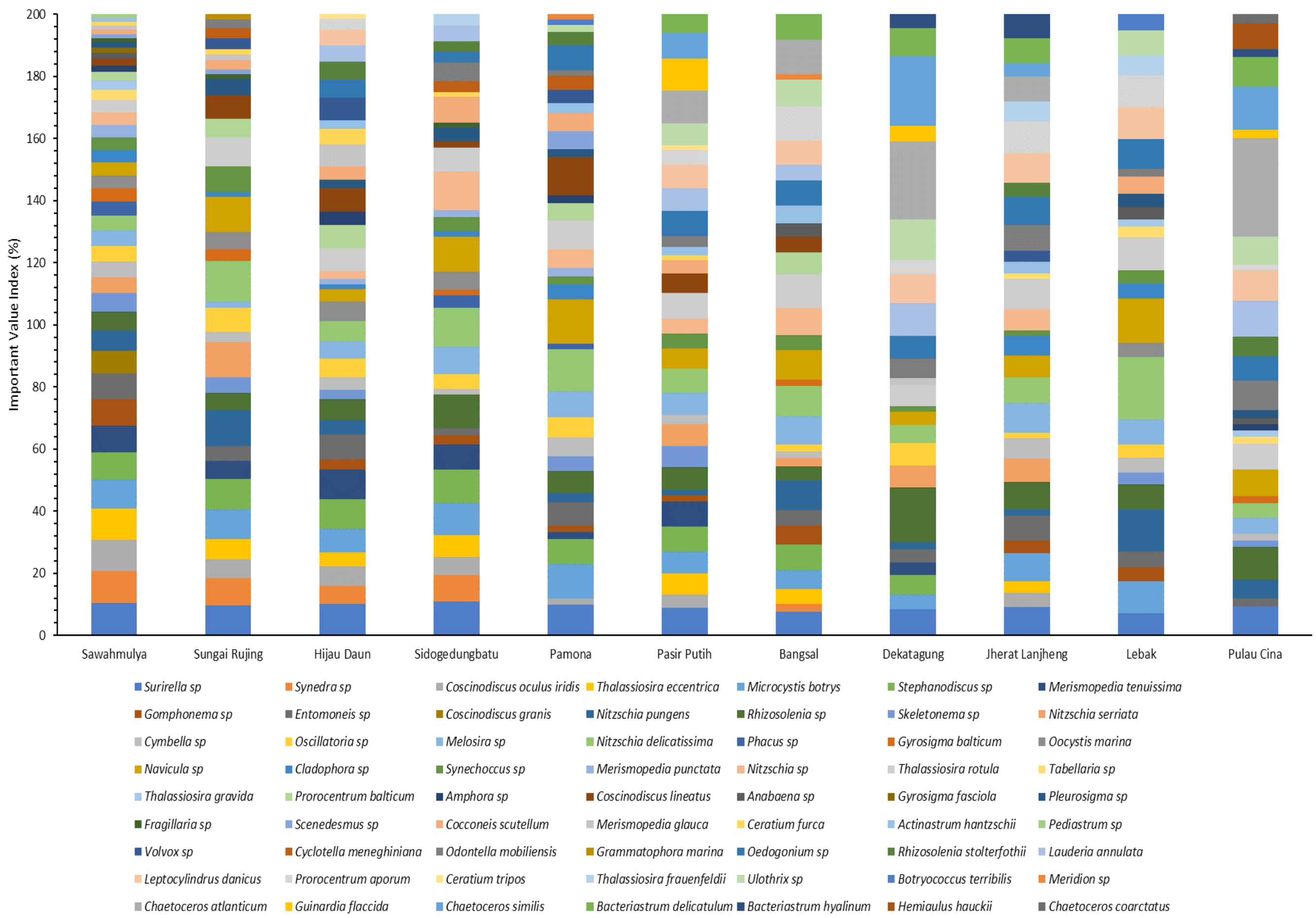

Figure 3. Important value index of phytoplankton at mangrove ecosystems of Bawean Island

species: *Nitzschia delicatissima* (IVI values 13.26% and 19.35%) and *N. pungens* (11.58% and 13.16%). In Sidogedungbatu and Pamona mangroves, there are two codominant species: *N. delicatissima* (12.40% and 13.53%) and *Navicula* sp. (11.26% and 14.34%). Two codominant species were found in Dekatagung and Pulau Cina mangroves: *Chaetoceros atlanticum* (24.65% and 30.87%) and *C. similis* (22.09 and 13.37%). In the Sawahmulya mangrove ecosystem, three codominant species were found: *Surirella* sp. *Synedra* sp. and *Coscinodiscus oculus oridis,* with an IVI of 10.38%, 10.26%, and 10.23%. Three codominant species were found in the Hijau Daun mangrove: *Surirella* sp. (10.17%), *Merismopedia tenuissima* (9.66%), and *Entomoneis* sp. (8.02%). Codominant species were also found in the Pasir Putih mangrove: *Surirella* sp. (8.82%), *C. atlanticum* (10.65%), and *Guinardia flaccida* (10.20%). Three codominant species were found in the Bangsal mangrove: *C. atlanticum* (11.19%), *Prorocentrum aporum* (11.01%), and *Thalassiosira rotula* (10.95%). Moreover, three codominant species were also found in the Jherat Lanjheng mangrove: *P. aporum* (9.93%), *T. rotula* (9.62%), and *Leptocylindrus danicus* (9.30%).

IVI also shows that phytoplankton from the Bacillariophyceae class were found in all mangrove ecosystems of Bawean Island, including *N. delicatissima, Navicula* sp., *Surirella* sp., *T. rotula*, and *Rhizosolenia* sp. (Figure 3). Bacillariophyceae has an important role in brackish waters, rivers, and marine ecosystems' food chains. The presence of species from the Bacillariophyceae class illustrates the organic level of pollutants because this phytoplankton has a high tolerance to pollutants (Samanta and Bhadury, 2015). *Nitzschia* sp. and *Navicula* sp. diatoms with a high tolerance to water contaminated with organic pollutants (Onyema, 2013). *Thalassiosira* sp. is important in the primary production of water and is found in waters with high organic pollutants (Samanta and Bhadury, 2015). *Surirella* sp. is a microphytobenthos and epiphyte commonly found in brackish water mangrove ecosystems (Mandal *et al.,* 2023).

The E values varied between 0.815-0.949, indicating high evenness, and Id varied between 0.039-0.107, indicating low dominance (Table 2). E is correlated to Id, where if the Id value is close to 0, then there is no dominance in the ecosystem, and the distribution of species is even (Wu *et al.,* 2014). H' varied between 3.784-4.892, indicating that the mangrove ecosystem is free from pollutants because the diversity is high in all mangrove ecosystems (Table 2). The H' value of plankton is categorized as unpolluted if H'>3, moderately polluted if H' = 1-3, and heavily polluted if H'<1 (Junaidi and Azhar, 2018).

TDI is used to determine the level of phyto plankton eutrophication in an ecosystem. The classifi cation of water quality based on the TDI value ranges from 0 to 100 (Wu *et al.,* 2014). The Dekatagung and Pulau Cina mangrove ecosystems showed hypereutrophic wters with TDI values of 75 and 79.13, respectively, while other mangrove ecosystems showed eutrophic status ranging from 63.88 to 73.42 (Figure 4A). The Dekatagung mangrove ecosystem is proximal to residential areas and chicken farms. Hence, there is a lot of organic waste, as indicated by the highest orthophosphate and hemeroby index values. TDI values are positively correlated to activities around mangrove ecosystems with a high disturbance intensity (Retnaningdyah *et al.,* 2022).

On the other hand, the percentage of pollution tolerant value (%PTV) indicates the level of organic pollution in an ecosystem. The maximum %PTV value

Table 2. Variation of phytoplankton biotic index at mangrove ecosystems of Bawean Island

Location	Evenness Index	Simpson Dominance Index	Shannon-Wiener Index
Sawahmulya	0.893	0.044	4.813
Sungai Rujing	0.89	0.052	4.527
Hijau Daun	0.939	0.039	4.892
Sidogedungbatu	0.895	0.051	4.554
Pamona	0.902	0.05	4.661
Pasir Putih	0.949	0.04	4.786
Bangsal	0.944	0.044	4.679
Dekatagung	0.815	0.107	3.784
Jherat Lanjheng	0.949	0.042	4.702
Lebak	0.894	0.067	4.297
Pulau Cina	0.821	0.103	4.001

is 100%; a %PTV reaching 20% indicates organic pollution. The %PTV in the Bawean Island mangrove ecosystem was 33.58%-78.02% (Figure 4B). The %PTV value shows that the Hijau Daun ecosystem is free from organic pollutants, Sawahmulya and Pulau Cina mangroves are moderately polluted by organic pollutants, and other locations are heavily polluted by organic pollutants. The %PTV value positively correlates to TDI, where eutrophication will increase if organic pollutants are high. High organic pollutants can be caused by anthropogenic activities and diatoms, such as *Nitzschia* sp. and *Navicula* sp., the bioindicators of organic pollutants (Samanta and Bhadury, 2015; Wu *et al.,* 2014).

3.4 Correlation between Phytoplankton Community and Diversity Structure with Physicochemical Water Quality, Hemeroby and Naturalness Index in Several Mangrove Ecosystems of Bawean Island

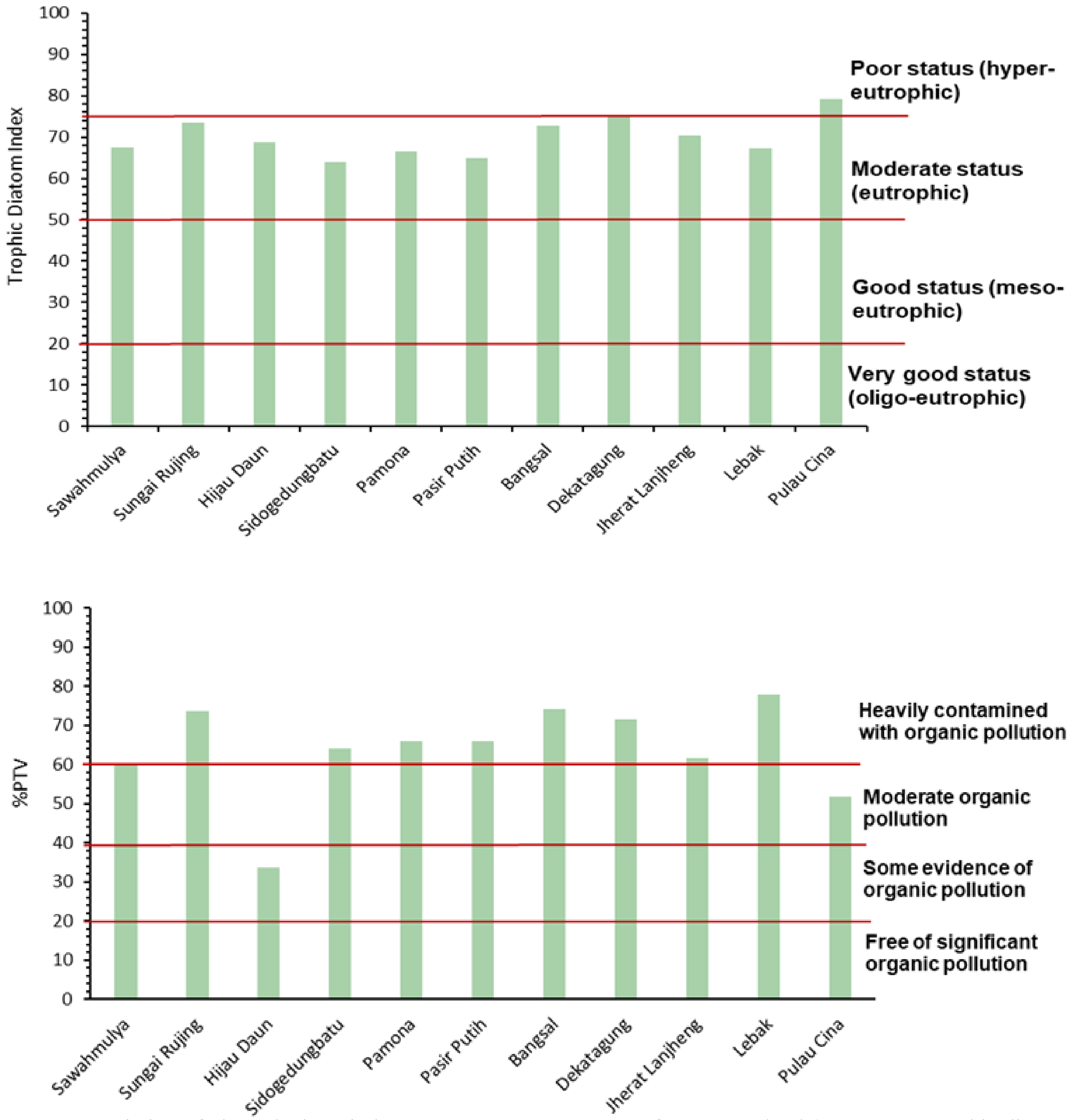

Figure 4. Variation of phytoplankton index at mangrove ecosystems of Bawean Island (Notes: A = Trophic diatom index; B = %Pollution tolerant value)

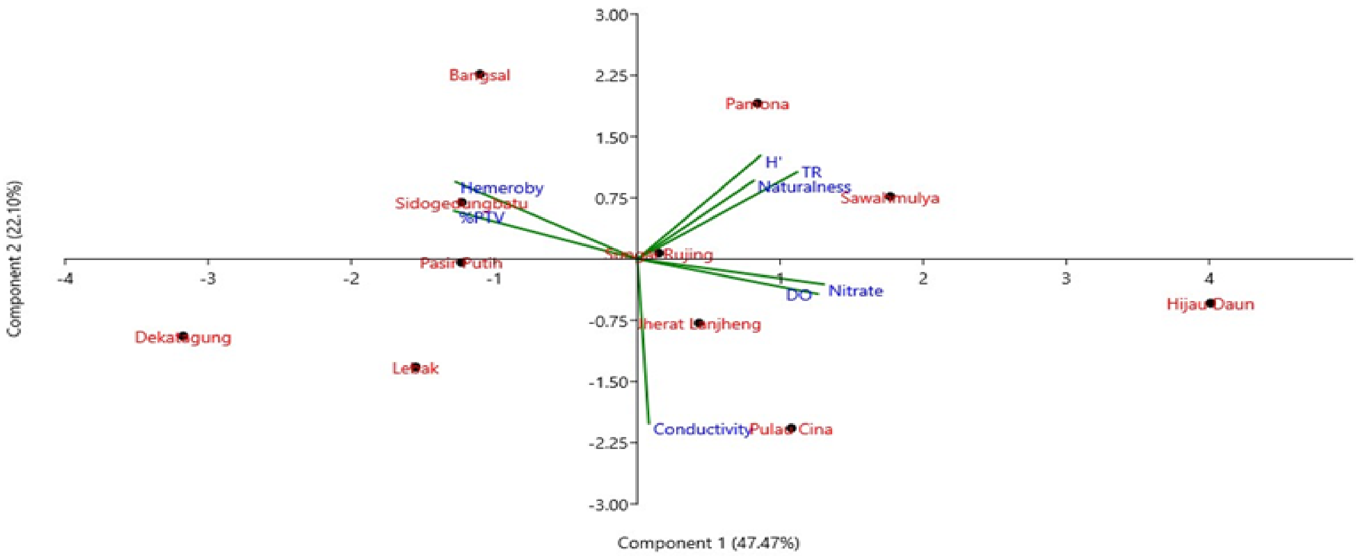

Figure 5. Correlation between physicochemical water quality and phytoplankton community structure at mangrove ecosystems using Biplot analysis (Notes: %PTV = %Pollution tolerant value (phytoplankton); H' = Shannon-Wiener diversity index (phytoplankton); TR = taxa richness (phytoplankton))

Based on a biplot analysis using Principal Component Analysis (PCA), the percent variance is 69.67%, with components 1 and 2 values of 47.47% and 22.10%. Figure 5 shows that the mangrove ecosystem of Bawean Island is divided into four groups based on the relationship between parameters. Group 1 is the Hijau Daun, Sawahmulya, and Pamona mangroves; these are the locations with the best ecosystem, characterized by naturalness, H', high taxa richness, moderate nitrate and DO levels, and low hemeroby and %PTV. The nitrate parameter positively correlates to H' and taxa richness of phytoplankton. High nitrate content can increase phytoplankton in an ecosystem (Nindarwi *et al.,* 2021). Group 2 comprises Sungai Rujing, Jherat Lanjheng, and Pulau Cina mangroves; these are fairly good mangrove ecosystems, characterized by high nitrate and conductivity, moderate naturalness, H', and taxa richness, and low hemeroby and %PTV. Group 3 is the Bangsal and Sidogedungbatu mangroves; these are classified as fairly poor ecosystems, characterized by high hemeroby and %PTV, moderate naturalness, H', and moderate taxa richness, and low nitrate and conductivity. Hemeroby index has a positive correlation with %PTV, where a high level of human disturbance results in a poor quality of ecosystems. Group 4 is the worst condition of an ecosystem, comprising Dekatagung, Lebak, and Pasir Putih mangroves, characterized by moderate hemeroby and %PTV, and very low naturalness, H', taxa richness, DO, and conductivity. These mangroves are close to human activities such as settlements, agriculture, chicken farms, and shrimp ponds. High human activity around an ecosystem can reduce ecosystem quality due to increased organic and inorganic waste (Malik *et al.,* 2015).

4. Conclusion

The physicochemical quality of water, except nitrate and orthophosphate, in all mangrove ecosystems of Bawean Island met the seawater quality stan dards for mangrove biota based on Indonesian Gov ernment Regulation number 22 of 2021. A total of 42 of 63 species belonging to the Bacillariophyceae class were found in 11 mangrove ecosystems on Bawean Island. Phytoplankton diversity is high, no dominance of species, and the species distribution is even. The water quality in Bawean Island mangrove ecosystems was classified as eutrophic, but Pulau Cina and Dekatagung were hypereutrophic based on TDI. The Hijau Daun mangrove ecosystem was the best ecosystem because it is free from organic matter pollution based on %PTV, while other locations were moderately and heavily polluted. Based on biplot analysis, mangrove ecosystems on Bawean Island are divided into four groups, where the Hijau Daun, Sawahmulya, and Pamona mangrove ecosystems were the best quality locations because they had low human disturbance and high H'. Evaluation of ecosystem services in the mangrove ecosystem of Bawean Island needs further research, namely comparing the quality of mangrove ecosystems in the north of Java Island as a negative reference site. Monitoring is needed every 5 years to determine the improvement of mangrove quality based on mangrove ecosystem services using water physicochemical quality parameters, mangrove diversity, and biological indicators in the form of organisms living in mangroves as material for evaluating the impact of restoration activities on several environmental factors in the mangrove ecosystem.

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Authors' Contributions

All authors have contributed to the final manuscript. The contribution of each author as follow, Nada; collected the data, drafted the manuscript, and designed the figures. Catur and Luchman; devised the main conceptual ideas and critical revision of the article. All authors discussed the results and contributed to the final manuscript.

Conflict of Interest

The authors declare that they have no competing interests.

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