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Plankton Community Structure in the Estuaries of Banten Bay, Banten Province, Indonesia

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Abstract: Estuaries in Banten Bay support fisheries activities by serving as critical habitats for plankton communities, which form the foundation of the aquatic food web. This study aims to determine the structure of plankton communities, both phytoplankton and zooplankton, as baseline data for fisheries management in Banten Bay estuaries. Fieldwork was conducted in April and October 2021 at four estuaries in Banten Province: Karangantu, Wadas, Cengkok Estuary, and Pamong. Water samples were collected for plankton identification and analysis of physical and chemical water quality parameters in situ and laboratory. Key structural attributes, including Shannon - Wiener diversity index (*H'*), evenness index (*E*), dominance index (*C*), trophic status, and canonical correspondence analysis (CCA), were also assessed. The highest abundance of phytoplankton was found in the Karangantu estuary, while the highest abundance of zooplankton was observed in the Pamong estuary, with overall abundance higher in April. Phytoplankton diversity was highest in Karangantu in October, whereas zooplankton diversity peaked in April. Plankton diversity indicated slight to moderate pollution levels, and trophic status analysis revealed eutrophic to hypertrophic conditions across the estuaries, suggesting high nutrient levels that support fish productivity. CCA revealed significant correlations between environmental variables and plankton composition and abundance. Mitigation strategies are recommended to monitor the growth of *Chaetoceros* sp. and *Bacteriastrum* sp., especially during the dry season. Long-term monitoring of water quality and plankton dynamics is essential in other estuaries of Banten Bay to assess nutrient loading impacts and develop strategies to mitigate harmful algal blooms. These efforts are critical to ensuring sustainable fisheries management in the region.

Keywords: phytoplankton; zooplankton; plankton community structure; estuary; Banten Bay

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1. Introduction

Estuaries, the regions where a river meets the sea, are brackish water environments with highly variable salinity levels ranging from 10 to 32‰, influenced significantly by tidal cycles (Ducklow and Shiah, 1993). In Banten Bay, estuaries such as Karangantu, Wadas, Cengkok, Pamong, and Terate serve as important fishing grounds, supporting the livelihoods of local fishermen. However, the intense human activities surrounding these estuaries necessitate regular monitoring of water quality and plankton populations, which are vital as fish feed, to ensure the sustainability of capture fisheries in the region. Understanding species' presence or notable absence in relation to shifts in physico-chemical conditions offers crucial insights into how environmental changes influence or limit the functioning of estuarine ecosystems (Downie *et al*., 2024). Phytoplankton is found globally and exhibits diversity that varies along latitudinal, longitudinal, and altitudinal gradients. Their community structure is primarily shaped by bottom-up factors, including nutrient availability, temperature, and light. Consequently, shifts in land use and climate that alter local environmental conditions significantly threaten the ecological balance of phytoplankton communities (Mancuso *et al*., 2021).

Plankton exhibits a wide range of body sizes with significant ecological and physiological implications. Their size influences their ability to assimilate dissolved nutrients from the environment and to position themselves at optimal depths with suitable light and suitable for growth (Peters, 1983). Phytoplankton, often referred to as algae, are simple autotrophic organisms and represent one of the largest groups of photosynthetic organisms in aquatic ecosystems. Meanwhile, zooplankton are heterotrophic, unicellular, or multicellular organisms that act as consumers in the food web of microorganisms (Bathmann and Marine Zooplankton Colloquium, 2001).

Plankton is essential as a biological indicator of water quality and tropical status because they respond quickly to environmental changes. Phytoplankton acts as an energy transducer that converts solar energy into chemical energy (food) and as a mediator, sharing the cycle of elements such as carbon, nitrogen, and sulfur. Meanwhile, zooplankton passes this energy to a higher tropic to link energy from producers to other consumers (Rissik *et al*., 2008). Phytoplankton serve as valuable indicators of environmental shifts, offering insights into how ecosystems respond and adapt to climate change. Additionally, research on phytoplankton can guide the development of strategies to mitigate and adapt to the adverse impacts of a changing climate (Eker-Develi *et al*., 2022).

Each group of plankton has specific environmental requirements to survive, making them highly sensitive to any physical, chemical, and biological changes in the environment. Phytoplankton size variation (pico- <2 µm, nano- ≥2–20 µm, micro- ≥20–200 µm, and macroplankton- > 200 µm) is related to environmental conditions and plays a vital role in carbon cycling and ecological functions, such as energy transfer through the aquatic food chain. The size distribution also affects their survival by influencing their sinking rate and stability. This distribution, in turn, is shaped by the intricate hydrodynamic processes within estuarine ecosystems (Wai New *et al*., 2022).

Several studies have examined plankton in various locations within Banten Bay. Mulyadi (1989) investigated fluctuations and the composition of the phytoplankton community in the mangrove waters of Dua Island. Alianto *et al*. (2008) analyzed the primary productivity of phytoplankton and its relationship with nutrients and light intensity in Banten Bay. Farchan *et al*. (2008) explored the phytoplankton community and water quality in Bojonegara, while Ronauli *et al*. (2022) focused on phytoplankton biodiversity and their role as pollution bioindicators in the coastal waters of Bojonegara. However, information on the plankton community structure in Banten Bay's estuaries remains limited. This gap underscores the importance of the current study, which aims to analyze species composition and abundance, integrate statistical data analysis, and examine water quality factors influencing plankton composition. The findings will serve as baseline data and provide recommendations for sustainable fisheries management in Banten Bay estuaries.

2. Materials and Methods

2.1. Sampling sites

This study was conducted at four estuaries in Banten Bay, located in the city and district of Serang, Banten Province (Figure 1): Karangantu Estuary (station 1), Wadas Estuary (station 2), Cengkok Estuary (station 3), and Pamong Estuary (station 4). These sampling stations were designated to represent fishing grounds locations in Banten Bay, each with different characteristics of the environmental conditions around the estuary. Iron processing industries, sugar industries, fish auctions, and residential areas surround Wadas Estuary. Karangantu Estuary features fishing ports, residential areas, and tourist attractions. Cengkok Estuary is characterized by aquaculture, agriculture activities, and fishermen's settlements. Pamong Estuary is dominated by agricultural and residential areas. Sampling was conducted in April and October 2021 to capture variability in environmental conditions.

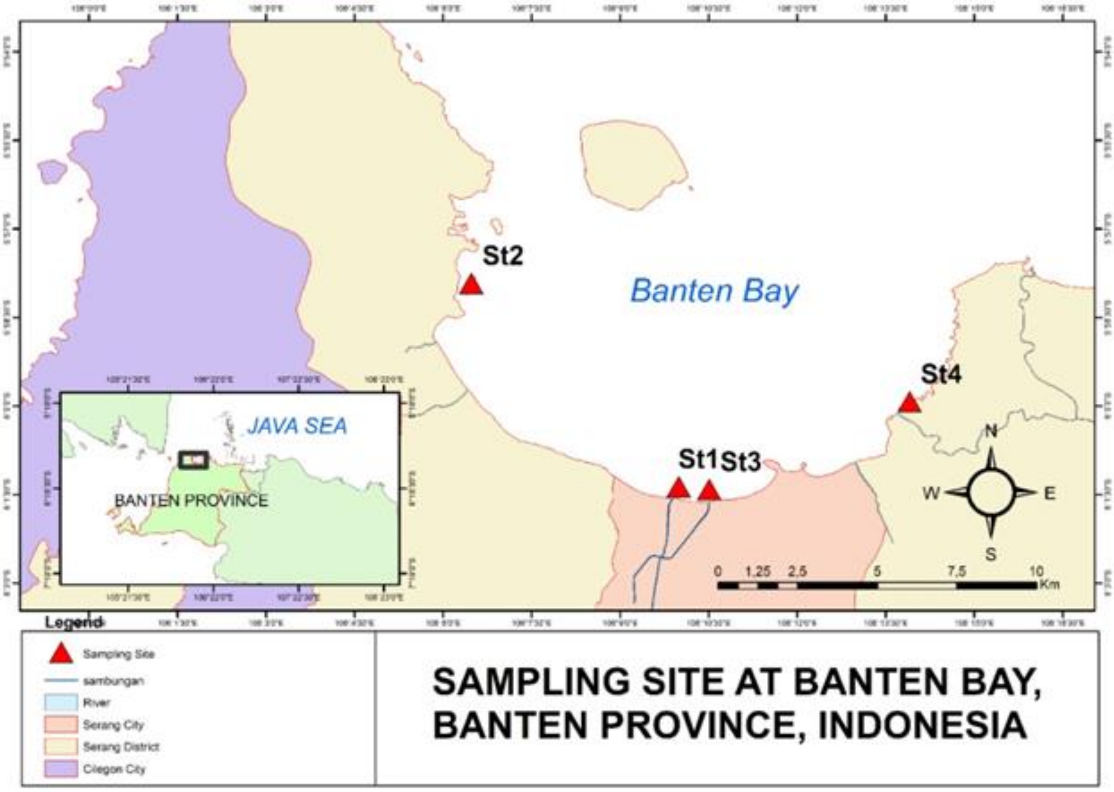

Figure 1. Map of sampling locations in the estuaries of Banten Bay.

2.2. Samples collection and analysis

Water samples were collected as composite samples from three depths: the surface, the Secchi depths level, and near the bottom of water bodies. Water transparency was measured using a Secchi disk. Physical and chemical parameters, including pH, dissolved oxygen, water temperature, total dissolved solids (TDS), turbidity, conductivity, salinity, and oxidation-reduction potential (ORP), were measured in situ using the Water Quality Checker (WQC) Horiba. Water currents were assessed using a Flowatch current meter.

Laboratory analyses were performed for parameters such as total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), and chlorophyll-a, following APHA (2017) standard methods. Composite water samples (250 mL) for TN and TP analysis were preserved with sulfuric acid (H_2SO_4) to adjust the pH to 2, and then TN was analyzed using the destruction and brucine method. At the same time, TP was analyzed using the destruction and ascorbic acid method. TSS was determined by filtering 250 ml of composite water samples through GF/A filter paper, followed by the gravimetric method. Chlorophyll-a was measured by filtering 250 mL of water through GF/F filter paper and analyzing the filtrate spectrophotometrically. Plankton samples, including phytoplankton and zooplankton, were collected using a plankton net with a mesh size of 25 µm. Two liters of surface water from each station were filtered through the net, transferred into a 10 mL plankton bottle, and preserved with Lugol's solution. Plankton enumeration was performed using a microscope and a Sedgewick Rafter Counting Cell (SRCC) following APHA (2017). Species identification was based on Davis's (1955) and Smith's (1977) manuals. Plankton abundance was calculated with the formula as follows:

$$N = \frac{1}{V} x \frac{Ja}{Jb} x \frac{Vt}{Vs} x n \quad \text{....(1)}$$

where;

N = number of plankton abundance (cell/mL)
V = volume of filtered water sample (mL)

Vt = volume of water sample (L)
Vs = volume of sample in Sedgewick Rafter (mL)
Ja = number of box in Sedgewick Rafter
Jb = number of identification box in Sedgewick Rafter
n = number of plankton obtained (cell)

2.3. Data Analysis

2.3.1 Shannon -Wiener diversity index (*H'*)

Species diversity shows the number of types of organisms found in an area. The most widely used relative diversity index is the Shannon-Wiener diversity index (H') or the Shannon diversity index or Shannon index (Dash and Dash, 2009). The Shannon-Wiener diversity index is a measure of diversity that combines species richness and relative abundance. The Shannon – Wiener index value is obtained by the following formula (Wilhm and Dorris, 1968):

$$H' = \sum_{i=1}^{S} p_i \ln p_i \qquad ....(2)$$

where;
H' = Diversity index
pi = ni /N (proportion of the total number of individuals that belong to i - th species)
ni = the number of individuals of species i
S = total number of species

The Species diversity based on the Shannon-Wiener diversity index is divided into three criteria, namely:

H' < 1 = low species diversity
1< *H'* <3 = moderate species diversity
H' >3 = high species diversity

In addition, the Shannon-Wiener diversity index was applied to evaluate water quality, with the resulting values indicating the level of pollution level in the water (Lee *et al.,* 1978):

H' > 2.0 = not polluted
H' 2.0 - 1.5 = slightly polluted
H' 1.5 - 1.0 = moderately polluted
H' < 1.0 = heavy polluted

2.3.2. Evenness index (E)

Evenness represents the relative abundance of species within a community and reflects the distribution pattern of biota. Pielou's Evenness Index (1966) was used to assess this metric:

$$E = \frac{H'}{ln\,S} \qquad ....(3)$$

where;
E = Evenness index
H' = Diversity index
S = The number of species in the community

The evenness index value is between 0 – 1. An index value of 0 indicates low evenness, signifying the dominance of a single species within the community. Conversely, an index value of 1 indicates high evenness, where all species in the community have an equal number of individuals.

2.3.3. Simpson dominance index (*C*)

Evenness represents the relative abundance of species within a community and reflects the distribution pattern of biota. Pielou's Evenness Index (1966) was used to assess this metric:

$$D = \sum (n_i/N)^2 \qquad ....(4)$$

where;
D = Simpson Diversity Index
Ni = the number of individuals in species i
N = The total number of species

This index is used to assess the complexity of a community. Simpson's diversity index ranges from 0 to 1, with a value of 1 indicating maximum dominance, which occurs when only a single species is present.

2.3.4. Trophic Index

Estimation of water fertility level as Trophic Index (TRIX) applying equation from Vollenweider *et al*. (1998):

$$TRIX = \frac{k}{n}\sum_{i}^{n} \frac{(log\,M - log\,L)}{(log\,U - log\,L)} \qquad ....(5)$$

where;
K = Scaling factor
N = The amount of four parameters, including phosphorous, chlorophyll-a, dissolved oxygen, and nitrogen
M = Parameter value
Log U = Upper limit (average of log M+ 2SD)
Log L = Lower limit (average of log L– 2SD)
SD = Standard Deviation

The Trophic index criteria is :

TRIX < 2 = Oligotrophic
2 ≤ *TRIX* <4 = Mesotrophic
4 ≤ *TRIX* <6 = Eutrophic
TRIX ≥ 6 = Hypertrophic

2.3.5. Canonical Correspondence Analysis (CCA)

The relationship between plankton species and aquatic environmental factors was tested using canonical correspondence analysis (CCA), a multivariate statistical analysis. CCA identifies the "best" synthetic gradients from field data by forming maximal linear combinations of environmental variables and biological community responses. This approach is particularly effective in elucidating how multiple species respond simultaneously to environmental factors, whether based on observational data or experimental designs (Ter Braak and Verdonschot, 1995). The analysis was performed using PAST version 4.04 software.

3. Result

The abundance of phytoplankton in the estuaries of Banten Bay is presented in Table 1 and illustrated in Figure 2 - 5. The phytoplankton community indices for the four estuaries are detailed in Table 2.

Table 1. Phytoplankton abundance in the estuaries of Banten Bay

Infor-mation	Station 1		Station 2		Station 3		Station 4	
	April	October	April	October	April	October	April	October
Number of species	20	22	17	16	15	21	14	18
Abundance (cell/mL)	136,971,014	3,297,103	37,00,001	37,756,523	96,313,045	9,721,741	14,073,914	5,727,540

Table 2. Phytoplankton community indices in the estuaries of Banten Bay

Index	Station 1		Station 2		Station 3		Station 4	
	April	October	April	October	April	October	April	October
Diversity	1.34	2.58	1.17	0.84	1.02	2.26	1.50	1.82
Evenness	0.45	0.84	0.41	0.30	0.38	0.74	0.57	0.63
Dominance	0.40	0.10	0.51	0.61	0.5	0.16	0.33	0.24

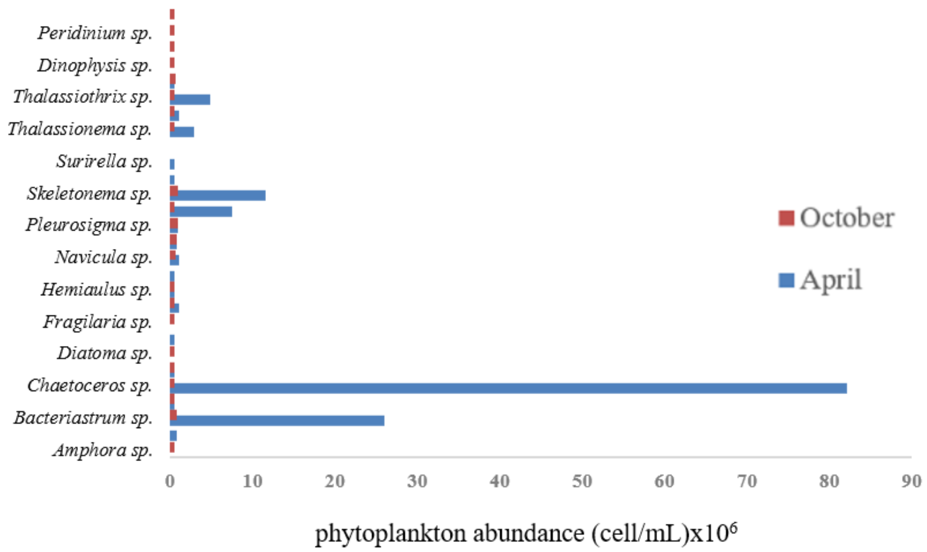

Figure 2. Phytoplankton abundance at Station 1

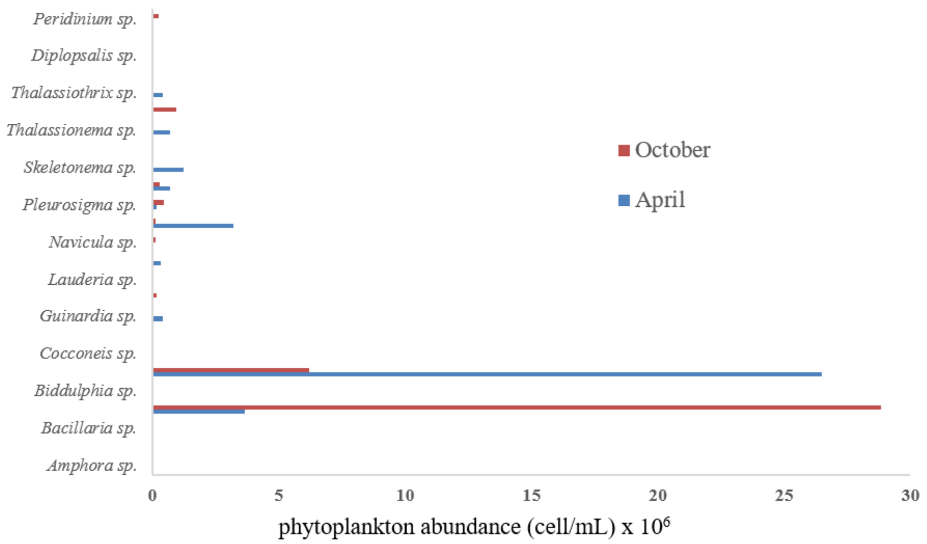

Figure 3. Phytoplankton abundance at Station 2

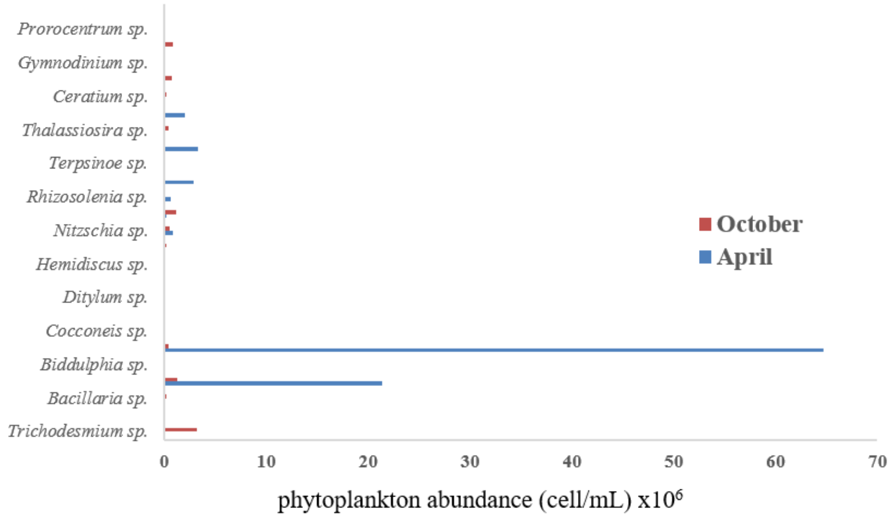

Figure 4. Phytoplankton abundance at Station 3

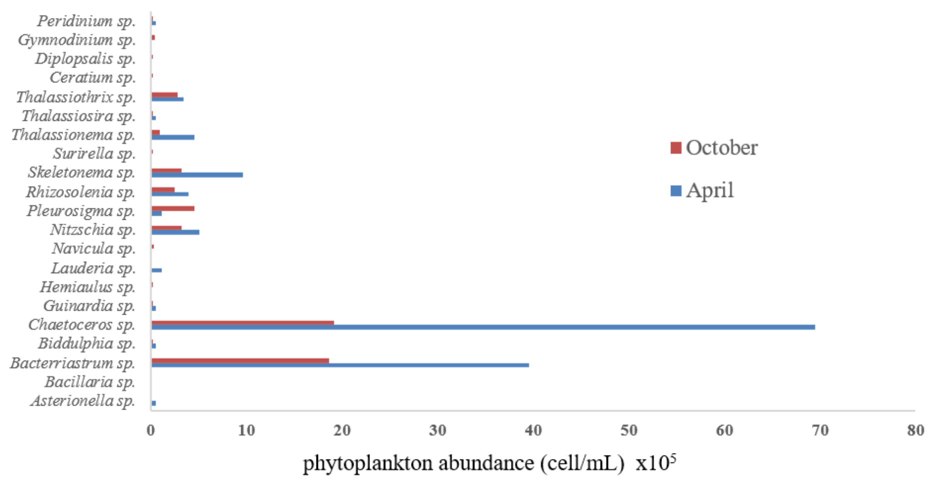

Figure 5. Phytoplankton abundance at Station 4

The abundance of zooplankton in the estuaries of Banten Bay is presented in Table 3 and Figures 6–9, while the zooplankton community indices for the four estuaries are detailed in Table 4. The result of physical and chemical analysis can be seen in Table 5. The result of the trophic index can be seen in Table 6. The result of CCA can be seen in Figure 10.

Table 3. Zooplankton abundance in the estuaries of Banten Bay

Information	Station 1		Station 2		Station 3		Station 4	
	April	October	April	October	April	October	April	October
Number of species	11	7	4	6	8	8	7	6
Abundance (number/mL)	203,478	118,695	104,65	135,651	79,130	251,522	262,825	98,912

Table 4. Zooplankton community indices in the estuaries of Banten Bay

Index	Station 1		Station 2		Station 3		Station 4	
	April	October	April	October	April	October	April	October
Diversity	1.99	1.22	1.22	1.24	1.81	0.9	1.51	1.12
Evenness	0.83	0.63	0.88	0.69	0.87	0.43	0.78	0.63
Dominance	0.18	0.44	0.32	0.40	0.20	0.61	0.26	0.4

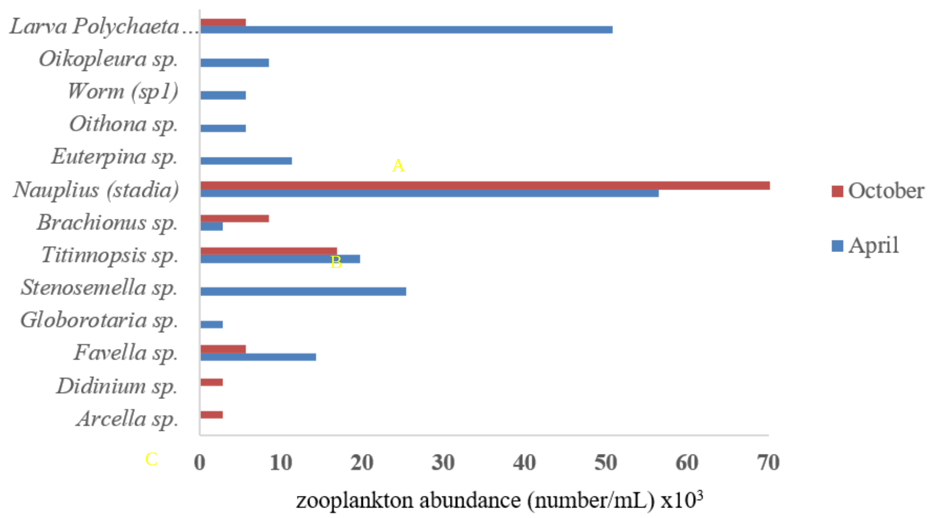

Figure 6. Zooplankton abundance at Station 1

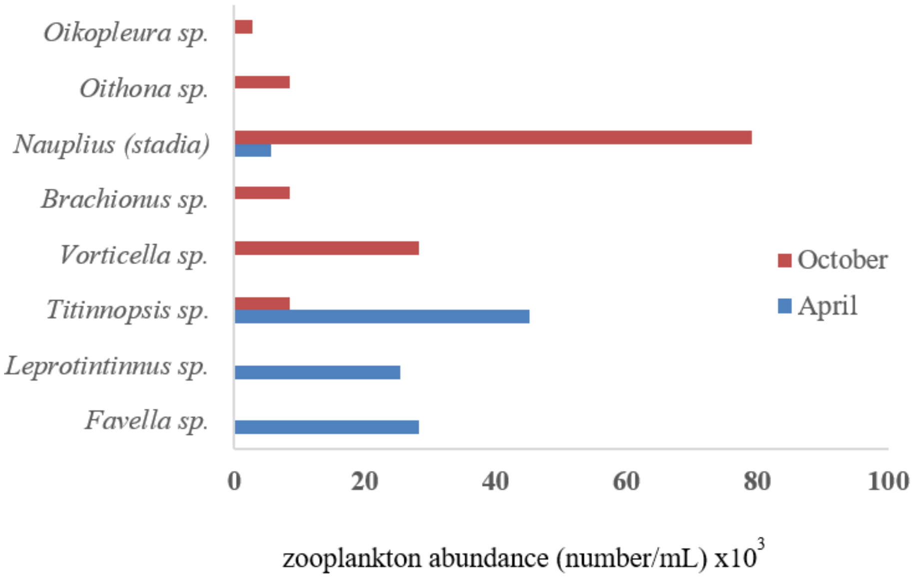

Figure 7. Zooplankton abundance at Station 2

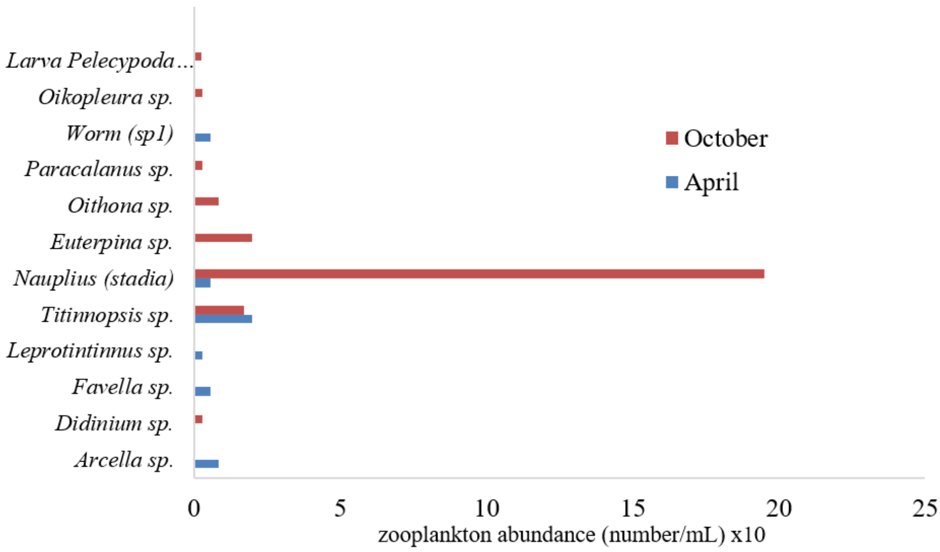

Figure 8. Zooplankton abundance at Station 2

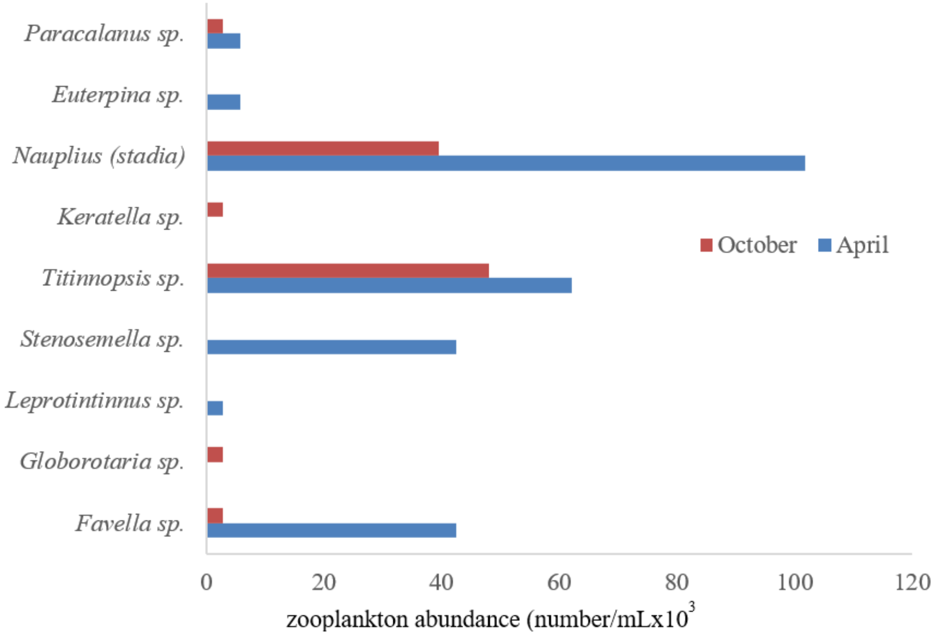

Figure 9. Zooplankton abundance at Station 4

Table 5. Result of physical and chemical analysis on estuary water samples in Banten Bay

Parameter	**Analytical Result**							
	Station 1		**Station 2**		**Station 3**		**Station 4**	
	April	October	April	October	April	October	April	October
Water Depth (cm)	120	138	135	151	140	156	80	120
Sechi Depth (cm)	10	26	88	69	20	42	60	20
Water Current (m/s)	0.2	0.9	n.d	0.2	0.6	0.5	0.1	0.9
pH	7.99	7.81	8.00	6.90	6.97	6.58	7.87	7.78
DO (mg/L)	6.31	6.89	6.37	4.85	5.67	5.91	7.22	7.79
ORP (ohm)	113	179	103.5	254.3	200.5	266.3	166.0	177.0
Water-Temp (°C)	30.93	32.96	30.64	31.45	27.98	31.14	31.03	32.93
Turbidity (NTU)	168.0	66.7	36.6	391.3	114.0	21.7	79.3	15.9
Conductivity (mS/cm)	23.8	50.8	46.0	51.0	13.7	28.3	45.9	50.4
Salinity (%)	14.4	33.4	29.8	33.4	29.7	28.3	7.9	33.0
TDS (g/L)	14.8	30.5	28.1	30.6	8.5	26.7	28.0	30.2
TSS (mg/L)	208.0	657.2	61.6	642.8	78.0	510.6	41.6	469.0
Chl-*a* (mg/m^3)	22.095	6.925	1.506	3.210	1.927	3.555	2.208	5.757
TN (mg/L)	33.463	28.450	31.495	25.777	33.092	29.193	32.127	27.634
TP (mg/L)	0.213	0.077	0.054	0.130	0.206	0.117	0.072	0.041

Table 6. Result of trophic index analysis on estuaries water sample in Banten Bay

Station	Sampling Time	TRIX value	Trophic Status
1 (Karangantu)	April 2021	7.506	hypertrophic
	October 2021	7.513	hypertrophic
2 (Wadas)	April 2021	5.027	eutrophic
	October 2021	5.077	eutrophic
3 (Cengkok)	April 2021	7.504	hypertrophic
	October 2021	7.512	hypertrophic
4 (Pamong)	April 2021	8.775	hypertrophic
	October 2021	8.788	hypertrophic

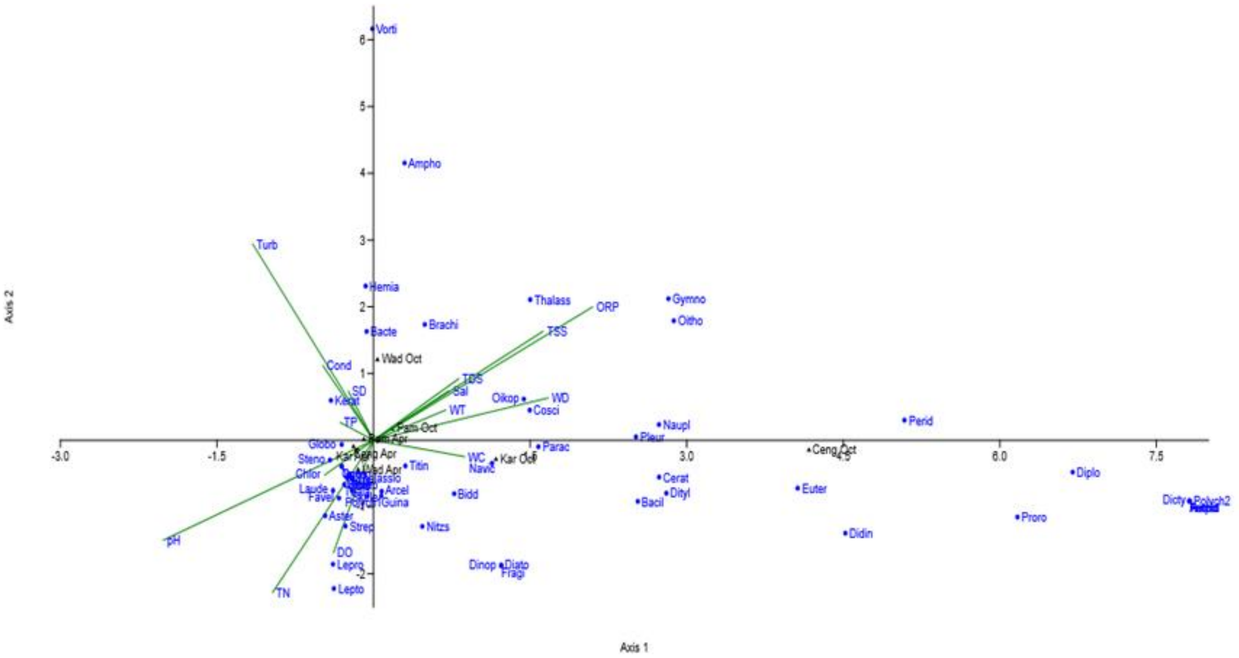

Figure 10. The result of CCA analysis found that aquatic environmental variables have a significant correlation with the composition and abundance of plankton at the study location

4. Discussion

Phytoplankton abundance in Karangantu during April 2021 was higher compared to other stations, with species diversity also showing greater values. This is likely attributed to the high nutrient availability, primarily from anthropogenic sources such as transportation, tourism, fishing activities, and residential waste. The trophic status of Karangantu was classified as hypertrophic (Table 6), consistent with findings by Sugiarti *et al*. (2022), who reported a hypertrophic status for the Karangantu estuary in 2013. The chlorophyll - a, TN, and TP concentrations were higher in Karangantu than in other stations in April 2021 (Table 5). Phytoplankton growth in metabolism requires nutrients from the environment, with elevated nitrogen and phosphorus inputs from human activities triggering biomass production and eutrophication (Oduor *et al*., 2024).

In October, the highest phytoplankton abundance was recorded at Wadas (Station 2), although its diversity and evenness indices were lower than at other stations. The trophic status of Wadas in October was eutrophic, differing from different stations (Table 6). Chlorophyll-a, TN, and TP concentrations in Wadas were also lower than those observed elsewhere (Table 5). However, the dominance index value in Wadas was higher, with *Bacteriastrum* sp. (a genus within the Bacillariophyceae division) as the dominant species. This phytoplankton is known for its broad distribution in freshwater and saline habitats (Rosada and Sunardi, 2021). Environmental conditions in Wadas, including higher turbidity, dissolved oxygen (DO), and total suspended solids (TSS) concentrations, likely contributed to the dominance of *Bacteriastrum* sp. in October.

The Bacillariophyceae division, known as diatoms, is the dominant plankton group observed at the four stations. Their widespread occurrence can be attributed to their cosmopolitan nature, allowing them to thrive in diverse environments, including polluted waters (Nastiti and Hartati, 2013; Yulianto *et al*., 2014; Adriana *et al*., 2017). Diatoms' silica-based cell walls make them prone to sinking, but they exhibit competitive advantages under various nutrient concentrations, cooler temperatures, and low light conditions. They particularly benefit from frequent water column mixing, which reduces sedimentation risk through turbulent resuspension, moderates temperatures in the photic zone, and redistributes nutrients. Additionally, nutrient enrichment, decreasing temperatures, and strong mixing events, such as those caused by storms, further support diatom proliferation by enhancing nutrient availability and disrupting thermal stratification (Mancuso *et al*., 2021).

Another phytoplankton found in abundance across the four estuaries is *Chaetoceros* sp. According to Nurfadilah *et al*. (2020), similar conditions were observed in the Pangkep estuary, South Sulawesi. *Chaetoceros* sp. is a diatom known for tolerating extreme water conditions, including high turbidity levels, as Mancuso *et al*. (2021) described. Turbidity levels in the four estuaries of Banten Bay were found to be relatively high, ranging from 15.9 to 391.3 NTU (Table 5). This suggests that, in addition to the influence of nutrients that can trigger plankton blooms, turbidity significantly affects the community structure of plankton.

The abundance of *Chaetoceros* sp. and *Bacteriastrum* sp. peaked in April during the dry season but decreased in the rainy season (October). This decline may result from dilution effects during the rainy season when larger currents transport diverse phytoplankton from rivers to estuaries. Water current in April (dry season) across the four stations ranges from 0.1 to 0.55 m/s, whereas during the rainy season, they increase significantly, ranging from 0.23 to 2.88 m/s (Table 5). Estuaries are highly dynamic ecosystems that undergo significant changes along various environmental gradients, such as salinity, temperature, nutrients, and turbulence, due to the mixing of freshwater and seawater during tidal cycles (Bilbao *et al*., 2023).

Chaetoceros sp. serves as a food source for larvae and juveniles of various aquaculture species. *Chaetoceros* sp., form chains of cells with long, spiny protuberances called setae, which can clog fish gills and cause mortality, although they do not produce toxins (Medlin *et al*., 2013). Their spiny structure can adhere to fish gills, causing irritation that stimulates excessive mucus production, obstructing the respiratory system and potentially leading to fish deaths. Such impacts have been observed in regions like the Pacific Northwest of Canada and the United States (Weliyadi, 2013). Fish mortality can significantly reduce the economic value of salmon fisheries, as demonstrated by blooms of *Chaetoceros* sp. between 1980 and 1990 in British Columbia, Canada, and Washington, United States, which caused losses estimated at 35 million USD (Trainer and Yoshida, 2014). The maximum growth of *Chaetoceros* sp. occurs at pH levels between 7.9 and 8.5 (Indarmawan *et al*., 2012). Similarly, Nastiti and Hartati (2013) note that optimal pH conditions for phytoplankton growth are generally ≤8.5. During the rainy season, the abundance of *Chaetoceros* sp. is lower, likely due to the reduced pH range observed in four estuaries (6.58–7.99; Table 5), which may inhibit its growth.

The phytoplankton species diversity across four stations in Banten Bay was generally moderate (1 < H' < 3). The diversity was higher in October than in April (Table 2). The evenness index in October was generally higher across all four estuaries, while the dominance index was lower in October than in April. However, phytoplankton abundance in the estuaries tended to decrease in October. During the rainy season, dilution occurs due to stronger currents, transporting a greater variety of phytoplankton from the river to the river mouth, resulting in higher phytoplankton diversity. Conversely, the decrease in total nitrogen (TN) and total phosphorus (TP) concentrations (Table 5) led to a reduction in phytoplankton abundance in the estuaries. The availability of nutrients in estuaries is strongly influenced by freshwater input and seawater exchange. Freshwater inputs, including rivers, groundwater, and runoff, supply nutrients to the estuaries, while seawater exchange through tides dilutes nutrient concentrations (Nybakken, 1992).

The highest zooplankton abundance was observed in Pamong in April and Cengkok in October, where hypertrophic trophic status was observed during these periods. This suggests that high nutrient levels may have influenced zooplankton abundance. The greatest species diversity of zooplankton in April occurred in Karangantu, likely due to the abundance of nutrients from human activities, such as transportation, tourism, fishing, and residential areas. Cengkok had the highest species diversity in October, corresponding with its peak zooplankton abundance (Station 3). The evenness index ranged from 0.43 to 0.88, while dominance values varied from 0.18 to 0.61, indicating that no single zooplankton species dominated the communities across the four estuaries in Banten Bay.

The abundance of zooplankton in the four estuaries of Banten Bay generally decreased in October (rainy season), likely due to reduced nutrient levels in the region, as indicated by lower concentrations of TN and TP (Table 5). Conversely, the dominance index in these estuaries tended to increase. Jiang *et al*. (2024) suggest that reductions in nitrogen and phosphorus can lead to declines in species abundance, including both phytoplankton and zooplankton, while favoring the dominance of specific species.

Nauplius calanoid, the larval stage of Crustacea, was commonly found at all four estuaries in Banten Bay. Crustaceans often hatch their eggs in coastal areas like estuaries, where food availability is high. According to Huys and Boxshall (1991), many *Nauplius calanoids* prefer estuaries for incubation due to their safer environment and abundant food resources. Besides *Nauplius calanoid*, another zooplankton species, *Titinnopsis* sp., was found abundantly at four stations. This species belongs to the protozoa group commonly observed in marine and freshwater environments. Tintinnid species within the Ciliophora group are categorized as micro-zooplankton due to their size. These organisms, recognized as critical consumers of nano-plankton at the trophic level in pelagic ecosystems, played an essential role in the food chain by serving as prey for heterotrophic organisms capable of digesting them (Durmus *et al*.,2023)

According to the diversity values for phytoplankton and pollution criteria from Lee *et al*. (1978), the water quality at station 1 ranges from non-polluted to moderately polluted, station 2 is classified from moderately polluted to heavily polluted, station 3 is non-polluted to moderately polluted, and station 4 is slightly polluted. Meanwhile, based on the zooplankton diversity values and pollution criteria from Lee *et al*. (1978), station 1 falls between slightly to moderately polluted, station 2 is moderately polluted, station 3 ranges from slightly to heavily polluted, and station 4 is moderately polluted.

Overall, the water quality across the four estuaries in Banten Bay varies from slightly polluted to moderately polluted, which is still conducive to fish growth. The trophic status of these estuaries spans from eutrophic to hypertrophic, indicating that high nutrient concentrations support a diverse range of plankton, which serve as a food source for fish.

The ordination results from CCA are shown in Figure 10. The plot displays the distribution of plankton species, with the distance between points reflecting the similarity of species. Green arrows represent key aquatic environmental variables, including water depth, Secchi depth, water current, pH, DO, ORP, water temperature, turbidity, conductivity, salinity, TDS, TSS, chlorophyll-a, TN, and TP. The first axis (CCA1) explains 53.7% of the variation in the data, while the second axis (CCA2) accounts for 21.0%. The analysis shows a significant correlation between these environmental variables and the composition and abundance of plankton in the study area. Akrimi and Gatot (2012) noted that phytoplankton growth is influenced by factors such as turbidity, photosynthesis processes, and nutrient availability. High turbidity negatively impacts water quality by reducing oxygen concentration, primarily due to limited photosynthetic activity and increased oxygen demand from organic matter degradation. Elevated turbidity also affects biota by disrupting predator-prey interactions, food availability, visibility, and overall health (Megina *et al*., 2023).

The majority of plankton species were found at all sampling stations in both April and October, with the exception of the Wadas station in October. These species were associated with environments characterized by high water temperature, pH, DO, TN, salinity, water depth, water current, TP, turbidity, TSS, and TDS. Notably, species such as *Bacteriastrum* sp. and *Chaetoceros* sp. thrived in high turbidity and low DO conditions, suggesting they are more abundant under these conditions.

Mitigation strategies should be developed to monitor the growth of *Chaetoceros* sp. and *Bacteriastrum* sp., especially during the dry season. Ongoing water quality and plankton monitoring in other estuaries within Banten Bay is recommended. Investigating the long-term effects of nutrient loading on plankton communities and exploring mitigation strategies for harmful algal blooms are crucial for supporting fisheries management in the estuaries of Banten Bay.

5. Conclusion

The highest phytoplankton abundance was observed in the Karangantu Estuary, while the highest abundance of zooplankton peaked in the Pamong Estuary. Both phytoplankton and zooplankton reached their highest abundance in April. The highest phytoplankton diversity occurred in Karangantu in October, while zooplankton diversity was greatest in Karangantu in April. Based on plankton diversity, both phytoplankton and zooplankton, the study sites were generally classified as slightly to moderately polluted. The trophic status across all four estuaries ranged from eutrophic to hypertrophic, indicating that high nutrient concentrations continue to support fish growth. CCA revealed a significant correlation between aquatic environmental variables, plankton composition, and abundance at the study locations. Mitigation strategies should focus on monitoring the growth of *Chaetoceros* sp. and *Bacteriastrum* sp., particularly during the dry season. Ongoing monitoring of water quality and plankton in other estuaries of Banten Bay is recommended. Investigating the long-term effects of nutrient loading on plankton communities and developing mitigation strategies for harmful algal blooms are crucial for supporting sustainable fisheries management in Banten Bay estuaries.

Data availability statement

All data included and used in the study is open and contains no confidential and ethically private information.

Conflict of interest

This manuscript has no identified and possible conflicts of interest among authors.

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Contributor Statement

S contributed design the topic and research methods, data collection and analysis, wrote the manuscript. **AW** and **DR** contributed data collection and analysis, wrote the manuscript. **AR**, **RN**, **SA** and **R** contributed data analysis and wrote the manuscript.

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