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Composition and Distribution of Phytoplankton in the Banda Sea: Implications for Aquatic Productivity

Frederika S. Pello[1]*, Simon Tubalawony[2]

[1]Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Pattimura University, Maluku, Indonesia

[2]Department of Marine Science, Faculty of Fisheries and Marine Science, Pattimura University; Maluku, Indonesia

***Corresponding author: rikapello@yahoo.com**

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ABSTRACT

The Banda Sea is one of Indonesia's deep-sea ecosystems with complex oceanographic dynamics influenced by monsoons and upwelling phenomena. Phytoplankton, as primary producers, play a crucial role in the marine food chain and overall water productivity. This study aimed to analyze the composition, distribution, and abundance of phytoplankton in the Banda Sea and to evaluate its implications for marine productivity. Sampling was conducted at 18 stations at a depth of 1 meter using a Nansen bottle, followed by filtration with a Kitahara net. Phytoplankton identification and quantification were carried out using a microscope and cell counting methods. The results showed that phytoplankton were dominated by Bacillariophyceae (61%), followed by Dinophyceae (33%) and Cyanophyceae (6%). Chaetoceros was the most abundant genus, followed by Rhizosolenia, Bacteriastrum, and Trichodesmium. Cluster analysis using the Bray-Curtis similarity index grouped the study stations into five clusters based on phytoplankton community similarity. The dominance of diatoms indicated that this area has high primary productivity, supported by upwelling that transports nutrients from deeper layers to the surface. The findings contribute to understanding the ecological dynamics of the Banda Sea and provide insights for sustainable fisheries management.

INTRODUCTION

The Banda Sea is one of Indonesia's deep-water ecosystems, characterized by unique oceanographic features, with current dynamics influenced by monsoons and seasonal upwelling phenomena **(Moore *et al*., 2003; Sediadi, 2004a)**. As part of Fisheries Management Area (WPP) 714, the Banda Sea holds significant fisheries potential, particularly for pelagic fish resources that are highly dependent on primary productivity in these waters **(Besewni *et al*., 2011)**. The productivity of these waters is largely determined by the abundance and composition of phytoplankton, which serve as primary producers in the marine food chain **(Lalli & Parsons, 1997)**. However, research on the spatial distribution of phytoplankton and its contribution to the productivity of the Banda Sea remains limited.

Phytoplankton plays a key role in marine ecosystems, not only as the primary energy source for trophic webs but also as indicators of aquatic ecosystem health **(Odum & Barrett, 2005)**. Their composition and distribution are influenced by various environmental factors, including temperature, salinity, nutrient availability, and water circulation patterns **(Lubis *et al*., 2023)**. Previous studies have shown that the Banda Sea is dominated by the Bacillariophyceae (diatoms), which contribute significantly to the productivity of these waters **(Kesaulya *et al*., 2023)**. However, changes in the distribution and abundance of phytoplankton due to oceanographic factors such as upwelling and thermal stratification require further investigation.

The upwelling phenomenon in the Banda Sea during the southeast monsoon brings nutrients from deeper layers to the surface, which can significantly enhance phytoplankton productivity **(Adnan, 1990; Moore *et al*., 2003)**. However, the variability in phytoplankton abundance across seasonal transitions and its impact on water productivity remain poorly studied. Some studies suggest that phytoplankton communities in tropical waters can undergo shifts in composition due to environmental changes, affecting the structure of zooplankton and fish communities that depend on them **(Pattipeilohy & Watratanich, 2014)**. Therefore, a deeper understanding of phytoplankton composition dynamics in the Banda Sea is essential to support the sustainable management of its aquatic resources.

Previous studies comparing phytoplankton communities in the Java Sea and the Banda Sea found that phytoplankton abundance and composition in the Banda Sea were more variable, likely due to differences in water depth and the more complex current dynamics **(Yuneni *et al*., 2013)**. Additionally, research by **Sediadi (2004b)** indicated that phytoplankton communities on the Banda Islands undergo significant fluctuations during the monsoon transition period, affecting the distribution of dominant species such as Chaetoceros and Rhizosolenia. This suggests that phytoplankton dynamics in the Banda Sea are influenced not only by local factors but also by interactions with regional oceanographic systems.

The novelty of this study lies in its analysis of phytoplankton abundance in the Banda Sea, directly linked to water productivity. Most previous studies have primarily focused on phytoplankton community composition without associating it with ecological implications for the food chain and fisheries stocks. By employing a quantitative approach and ecological statistical analysis, this research aimed to provide new insights into how changes in phytoplankton distribution can influence overall water productivity. The findings of this study will contribute significantly to sustainable fisheries management, particularly in understanding the role of phytoplankton as an indicator of water productivity.

Thus, the primary objective of this study was to analyze the composition and distribution of phytoplankton in the Banda Sea and to evaluate their implications for water productivity. This research will help identify the abundance patterns of key phytoplankton species and how environmental factors influence phytoplankton community dynamics. The results are expected to serve as a foundation for more effective marine ecosystem management policies, particularly in maintaining ecological balance and fisheries sustainability in the Banda Sea region.

MATERIALS AND METHODS

1. Description of the study sites and data sampling

This study was conducted in late October 2023 in the Banda Sea**,** Central Maluku Regency. The selection of research locations was based on the oceanographic characteristics of the waters, with a total of 18 observation stations distributed across the study area (Fig. 1). Astronomically, the study site is located at coordinates 4° 32‘20” - 4° 32‘35" South Latitude and 129° 51‘35“- 129° 56‘25" East Longitude (Table 1). The coordinates of each station were determined using a Global Positioning System (GPS) Model 76CSx to ensure accuracy in mapping the research locations.

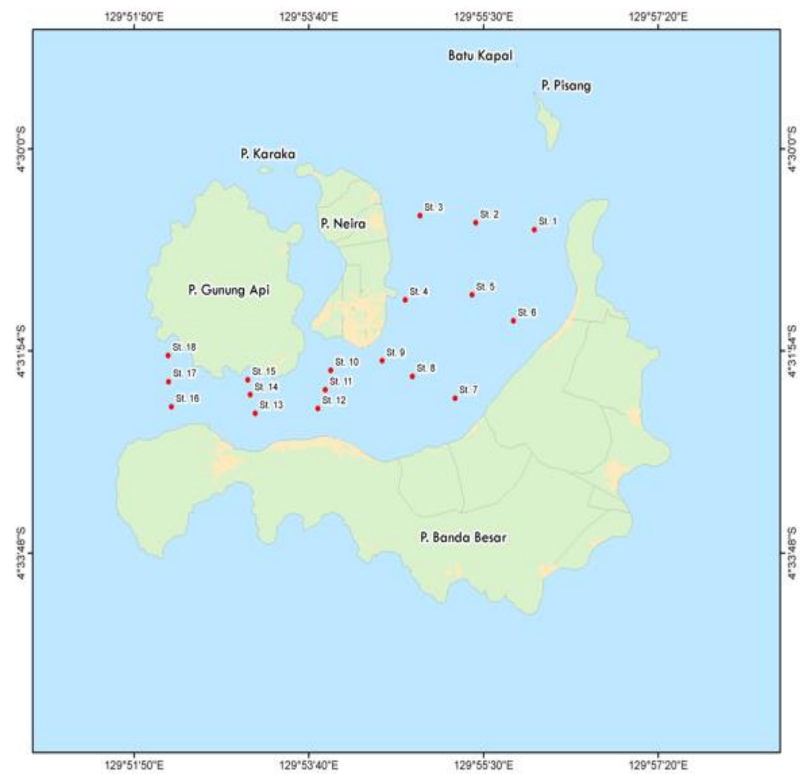

Fig. 1. Map of study site and the sampling station

Table 1. Coordinate point of sampling location

Station	Longitude	Latitude
St. 1	129° 56' 2.000" E	4° 30' 45.700" S
St. 2	129° 55' 25.100" E	4° 30' 41.700" S
St. 3	129° 54' 50.000" E	4° 30' 37.700" S
St. 4	129° 54' 40.700" E	4° 31' 25.300" S
St. 5	129° 55' 22.700" E	4° 31' 22.500" S
St. 6	129° 55' 48.800" E	4° 31' 37.100" S
St. 7	129° 55' 12.000" E	4° 32' 20.800" S
St. 8	129° 54' 45.200" E	4° 32' 8.500" S
St. 9	129° 54' 26.100" E	4° 31' 59.600" S
St. 10	129° 53' 53.800" E	4° 32' 5.060" S
St. 12	129° 53' 45.700" E	4° 32' 26.600" S
St. 11	129° 53' 50.346" E	4° 32' 16.039" S
St. 13	129° 53' 6.207" E	4° 32' 29.285" S
St. 14	129° 53' 3.055" E	4° 32' 18.813" S
St. 15	129° 53' 1.500" E	4° 32' 10.400" S
St. 16	129° 52' 13.400" E	4° 32' 25.600" S
St. 17	129° 52' 11.600" E	4° 32' 11.500" S
St. 18	129° 52' 11.400" E	4° 31' 56.700" S

2. Data sampling and phytoplankton analysis

Phytoplankton sampling was conducted at a depth of one meter from the water surface using a 5-liter Nansen bottle. The collected water samples were then filtered using a Kitahara-type phytoplankton net with the following specifications: 0.30-meter mouth diameter**,** 1-meter net length**,** and 25µm mesh size. This filtration process aimed to effectively concentrate the phytoplankton present in the water samples.

After filtration, the collected phytoplankton samples were preserved using formalin solution at a final concentration of 4% to maintain cell integrity and minimize degradation during storage. In the laboratory, the samples were allowed to settle for 24 hours to separate planktonic organisms from the water before further analysis.

Phytoplankton identification was performed using an Olympus electric microscope, with magnification adjusted to observe phytoplankton cell morphology. The identification process followed the taxonomic references of **Yamaji (1979)** and **Tomas (1997)** to determine the genus of each phytoplankton species found in the samples. After identification, phytoplankton cell counts were conducted to determine abundance, using the formula developed by **Huliselan *et al.* (2007)**:

$$D = \frac{Nf \times Vp}{V}$$

Where:

D : phytoplakton abundance (cell/l)

Nf : number of cells withing 1 ml (sub-sample)

Vp : dilution volume

V : volume of filtered water (l)

The calculated phytoplankton abundance from each station was used to analyze the distribution and community composition of phytoplankton in the Banda Sea.

3. Statistical analysis

To determine the distribution patterns and phytoplankton assemblages at each station, a similarity analysis was conducted using the Bray-Curtis similarity index **(Clarke & Warwick, 2001)**. This index measures the similarity in phytoplankton community composition between stations based on abundance data obtained from laboratory counts.

Before analysis, phytoplankton abundance data were transformed using the log (X+1) formula to enhance data normality and reduce the impact of scale differences among species. Additionally, data were standardized to ensure that variations in abundance across species did not disproportionately influence the results.

The Bray-Curtis analysis results were visualized as a station clustering dendrogram, illustrating the similarity relationships in phytoplankton composition across different study locations. All analyses were performed using PRIMER-5 software, specifically designed for biological community analysis in aquatic ecosystems.

RESULTS AND DISCUSSION

1. Composition of phytoplankton types

The phytoplankton composition in the Banda Sea was dominated by three major classes: Bacillariophyceae (diatoms), Dinophyceae (dinoflagellates), and Cyanophyceae (cyanobacteria). Bacillariophyceae was the most dominant, comprising two main orders, Centrales and Pennales, which included various genera such as *Chaetoceros, Coscinodiscus, Rhizosolenia,* and *Thalassiosira* (Fig. 2). Dinophyceae was primarily represented by the genera *Ceratium*, *Gonyaulax,* and *Alexandrium*, while Cyanophyceae was solely represented by the genus *Trichodesmium*. This composition reflects the characteristics of tropical waters with high primary productivity, supported by nutrient availability and current dynamics in the Banda Sea (Table 2).

Compared to other Indonesian waters, the phytoplankton diversity in the Banda Sea is similar to that of the Java Sea and Makassar Strait, but with distinct species compositions. **Sediadi (2004a)** indicated that *Chaetoceros* was the dominant genus in the Banda Sea, particularly during the southeast monsoon, which is characterized by upwelling events. In contrast, a study in the Java Sea by **Putri *et al.* (2019)** found that Bacillariophyceae and Dinophyceae dominated, with *Skeletonema* and *Prorocentrum* being more abundant. Meanwhile, research in the Makassar Strait by **Sintaningsih *et al.* (2022)** reported a high abundance of *Chaetoceros*, whereas *Coscinodiscus* was present in lower numbers. These variations are likely influenced by differences in current patterns, temperature, and nutrient availability in each marine region.

Table 2. Composition of phytoplankton in Banda Sea

Class	**Order**	**Family**	**Genera**
Bacillariophyceae **(**Diatom**)**	Centrales	Biddulphiaceae	*Biddulphia*
		Chaetoceraceae	*Chaetoceros*
		Coscinodiscaceae	*Coscinodiscus*
			Planktoniella
		Hemiaulaceae	*Hemialus*
		Bacteriastraceae	*Bacteriastrum*
		Rhizosoleniaceae	*Rhizosolenia*
	Pennales	Naviculaceae	*Thalassiosira*
			Pleurosigma
		Nitzshiaceae	*Nitzshia*
		Fragilariaceae	*Thalassionema*
Dinophyceae	Dinoflagellida	Dinophyaceae	*Ceratium*
			Pyrocystis
			Protoperidinium
			Gonyaulax
			Alexandrium
			Pyrodinium
Cyanophyceae	Oscillatoriales	Oscillatoriaceae	*Trichodesmium*

Globally, the phytoplankton composition in the Banda Sea can also be compared to other tropical waters, such as the Gulf of Thailand and the South China Sea. A study by **Lim *et al*. (2017)** in the Gulf of Thailand reported a dominance of *Thalassiosira* and *Chaetoceros*, which is similar to the pattern observed in the Banda Sea, but with a lower abundance of dinoflagellates. In the South China Sea, research by **Ding *et al*. (2021)** and **Zeng *et al.* (2022)** revealed that Dinophyceae had a higher proportion compared to the Banda Sea, indicating differences in environmental dynamics between these waters.

The dominance of Bacillariophyceae in the Banda Sea suggests that this water body is rich in silica, an essential nutrient for diatom growth. This condition is supported by upwelling events in the Banda Sea, particularly during the southeast monsoon, which transports nutrients from deeper layers to the surface. This phenomenon is similar to that observed in the eastern Pacific Ocean, where upwelling systems promote the growth of large diatom populations **(Pennington *et al*., 2006)**. Diatoms play a crucial role in the marine food web as primary producers, supporting the populations of zooplankton and small pelagic fish.

Meanwhile, the presence of Dinophyceae, such as *Alexandrium* and *Gonyaulax*, requires attention, as certain species within these genera are known to produce toxins that can lead to Harmful Algal Blooms (HABs). A study by **Hallegraeff (2010)** indicated that rising temperatures and changes in ocean circulation patterns could trigger the growth of toxic dinoflagellates. In the Banda Sea, although HABs have rarely been reported, their potential occurrence should still be monitored, considering the continuously changing environmental dynamics due to climate change and anthropogenic activities.

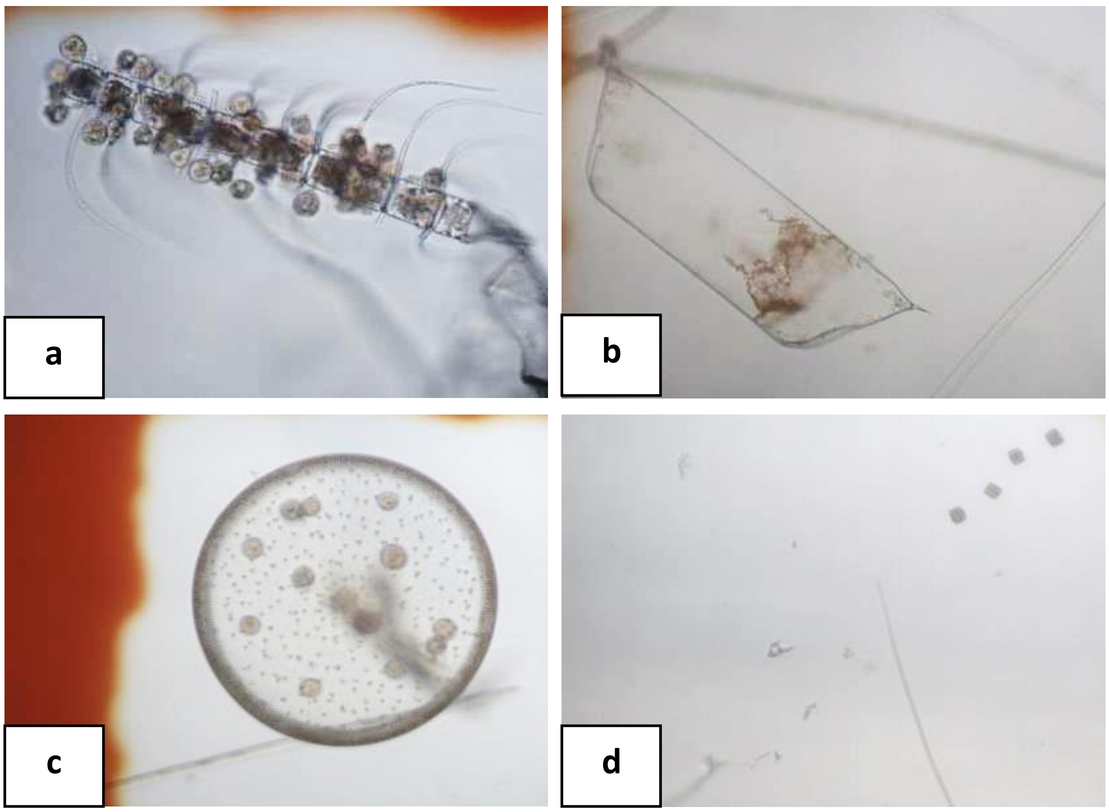

Fig. 2. Bacillariophyceae was the most dominant of phytoplankton in Banda Sea: **(a)** *Chaetoceros*; **(b)** *Rhizosolenia;* **(c)** *Coscinodiscus*; **(d)** *Thalassiosira*

The cyanobacterium *Trichodesmium* found in the Banda Sea plays a crucial role in nitrogen fixation, which is essential for oligotrophic marine ecosystems. A study by **Capone *et al*. (2005)** reported that *Trichodesmium* serves as a major nitrogen source in nutrient-poor tropical waters. Its presence in the Banda Sea indicates that this water body has an internal mechanism to sustain primary productivity, despite variations in nutrient availability. However, excessive proliferation of *Trichodesmium* may disrupt the biogeochemical nitrogen cycle and affect ecosystem balance.

Overall, the phytoplankton composition in the Banda Sea reflects a productive marine environment, with diatoms serving as key indicators of nutrient availability. Comparisons with other Indonesian waters and tropical regions reveal similar patterns, yet with specific variations influenced by oceanographic and climatic factors. Regular phytoplankton composition monitoring is essential for understanding the ecological dynamics of the Banda Sea and anticipating potential changes due to environmental and anthropogenic factors in the future.

The results presented in Fig. (3) support the findings from the previous table, confirming that Bacillariophyceae is the most dominant phytoplankton class, accounting for 61% of the total abundance. The 33% abundance of Dinophyceae indicates that this group also plays a significant role in the Banda Sea ecosystem, particularly in food web dynamics and the potential occurrence of Harmful Algal Blooms **(**HABs**)**. Meanwhile, Cyanophyceae contributes only 6%, suggesting a smaller role compared to the two dominant classes, although it remains essential for the nitrogen cycle.

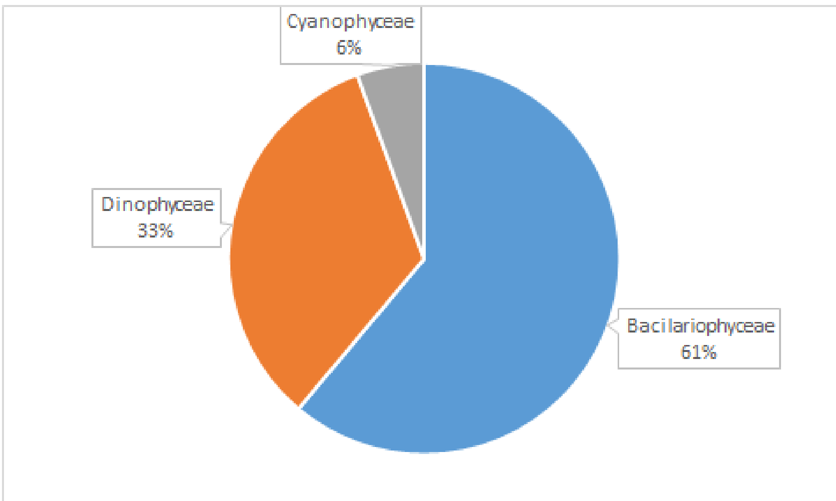

Fig. 3. Phytoplankton composition (%) based on abundance of each class

This percentage is also consistent with previous studies in other tropical waters, where diatoms tend to dominate in nutrient-rich conditions with significant upwelling. For instance, a study in the Mediterranean Sea by **Ignatiades *et al.* (2009)** and **Mena *et al.* (2019)** reported Bacillariophyceae dominance under stratified conditions influenced by nutrient dynamics, with significant contributions from Dinophyceae and Cyanophyceae. Thus, the composition observed in the Banda Sea is not an anomaly but follows the general pattern of tropical marine ecosystems with high primary productivity.

Overall, this distribution confirms that the Banda Sea is a productive water body, with diatoms serving as the primary producers that support the marine trophic network. Dinophyceae play a crucial role in ecosystem stability, but their presence should be monitored, as some species can contribute to harmful algal blooms (HABs). Meanwhile, although Cyanophyceae are present in small quantities, they still contribute to biogeochemical cycles, particularly nitrogen fixation. Therefore, regular monitoring of the phytoplankton community is essential for gaining a deeper understanding of the Banda Sea ecosystem dynamics.

2. Phytoplankton abundance

The phytoplankton abundance in the Banda Sea exhibited significant spatial variation during the observation period. Based on the analysis, phytoplankton abundance ranged from 220 to 3,540 cells per liter, with an average of 1,990 cells per liter (Fig. 3). This fluctuation is likely influenced by environmental factors such as nutrient availability, temperature, and ocean currents, which play a role in the distribution and growth of phytoplankton **(Reynolds, 2006)**. Notably, Station 15 recorded the highest abundance, while Stations 1 and 2 had the lowest. These differences can be attributed to variations in oceanographic conditions at each site, such as water column stratification and sunlight intensity **(Parsons *et al.*, 1984)**.

The phytoplankton community in this area was dominated by diatoms, particularly *Chaetoceros*, which had the highest average abundance of 978 cells per liter. The dominance of *Chaetoceros* may be due to its tolerance to environmental variations and its ability to reproduce rapidly under favorable conditions **(Tomas, 1997)**. In addition to *Chaetoceros*, other genera with relatively high abundance included *Bacteriastrum* (260 cells per liter), *Rhizosolenia* (221 cells per liter), *Trichodesmium* (136 cells per liter), and *Nitzschia* (142 cells per liter) (Fig. 4). The presence of *Trichodesmium*, a cyanobacterium, indicates potential nitrogen fixation in the region, which can enhance nitrogen availability in the marine ecosystem **(Capone *et al.*, 1997)**.

Several phytoplankton genera, including *Coscinodiscus*, *Rhizosolenia*, and *Trichodesmium*, were found across all sampling locations. Their widespread distribution suggests a high adaptability to diverse environmental conditions **(Margalef, 1978)**. *Coscinodiscus*, a centric diatom, is often found in waters with high silicate concentrations and plays a crucial role in marine food webs **(Round *et al.*, 1990)**. Meanwhile, *Rhizosolenia* is known for its ability to thrive in oligotrophic conditions and is commonly found in tropical waters with stable water column conditions **(Chen *et al.*, 1996)**.

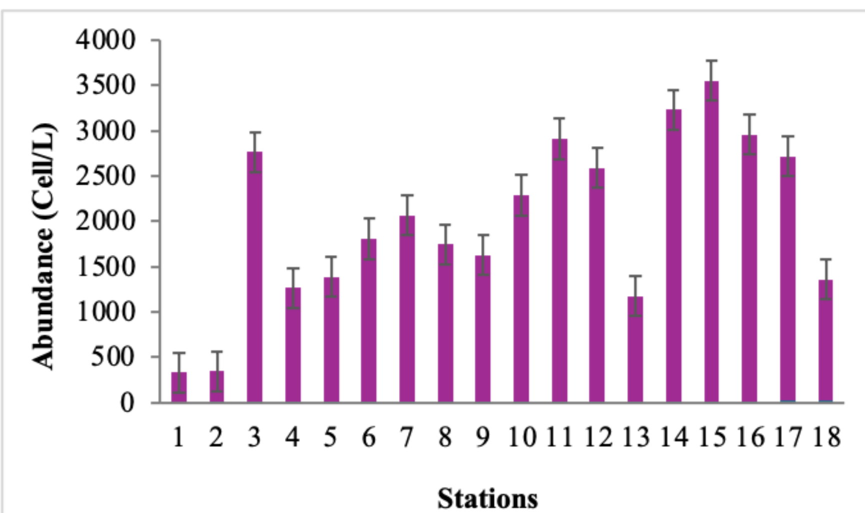

Fig. 4. Phytoplankton abundance between stations in the Banda Sea

The dynamics of phytoplankton abundance in the Banda Sea can be influenced by environmental factors such as upwelling, current patterns, and monsoon seasons. This region experiences oceanographic changes that affect nutrient availability, which is essential for phytoplankton growth **(Gordon *et al*., 2003)**. During upwelling periods, for instance, increased nitrate and phosphate concentrations support phytoplankton growth, particularly diatoms **(Small & Menzies, 1981; Brandt *et al.*, 2023)**. Conversely, during periods of strong water stratification, phytoplankton abundance may decline due to the limited nutrient supply from deeper layers to the surface.

Considering the patterns of phytoplankton abundance and community composition in the Banda Sea, it can be concluded that diatoms dominate the phytoplankton community in this region, with *Chaetoceros* being the most abundant genus. The variation in abundance among stations suggests the influence of environmental factors such as nutrient distribution, current patterns, and other oceanographic conditions. The presence of widely distributed genera across all sampling sites indicates the adaptability of certain species to diverse environmental conditions. Further studies on phytoplankton dynamics in this region will enhance our understanding of their role in primary productivity and marine food webs.

3. Bray-Curtis similarity index

Cluster analysis using the Bray-Curtis similarity index revealed that phytoplankton in the Banda Sea can be classified into five groups based on their abundance (Fig. 5), described as follows:

a) **Group 1:** Represents Station 1, dominated by *Coscinodiscus*, *Rhizosolenia*, and *Trichodesmium*. *Coscinodiscus* is a diatom commonly found in tropical waters and plays a crucial role in the marine carbon cycle **(Round *et al*., 1990; Pello *et al*., 2016; 2024)**. *Trichodesmium*, a cyanobacterium, has nitrogen-fixing capabilities that contribute to primary productivity in oligotrophic waters such as the Banda Sea **(Capone *et al*., 1997)**.

b) **Group 2:** Represents Station 2, dominated by *Rhizosolenia*, a planktonic diatom typically found in waters with complex nutrient dynamics. The presence of *Rhizosolenia* is often associated with upwelling and increased primary productivity.

c) **Group 3:** Represents Station 4, with dominant species including *Bacteriastrum*, *Rhizosolenia*, and *Ceratium*. *Bacteriastrum* is a chain-forming diatom commonly found in silicate-rich waters **(Hasle & Syvertsen, 1997)**. Meanwhile, *Ceratium*, a dinoflagellate, plays a vital role in marine ecosystem productivity and has the ability to migrate vertically to acquire nutrients from deeper layers **(Smayda, 2010)**.

d) **Group 4:** Represents Stations 6, 7, 8, 9, 11, 12, 14, 15, 16, 17, and 18, with *Chaetoceros* as the dominant species. *Chaetoceros* is a rapidly growing diatom that often dominates phytoplankton communities in highly productive waters **(Rines & Theriot, 2003)**.

e) **Group 5:** Represents Stations 3, 5, 10, and 13, dominated by *Nitzschia* and *Rhizosolenia*. *Nitzschia* is a highly adaptive diatom genus that can thrive in various environmental conditions, including waters experiencing significant nutrient fluctuations **(Lundholm *et al*., 2002)**.

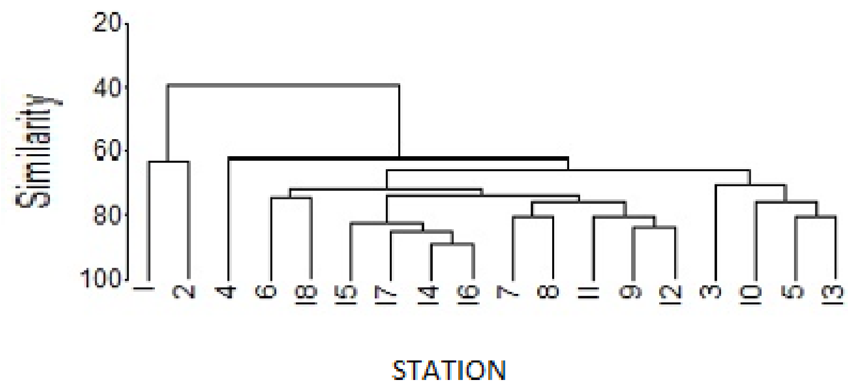

Fig. 5. Dendogram of station grouping based on the similarity of phytoplankton abundance in the waters of the Banda Sea

4. Implications of phytoplankton abundance on aquatic productivity

The high abundance of phytoplankton in the Banda Sea, particularly at stations where cell concentrations reach 3,540 cells per liter, indicates significant primary productivity in this region. Phytoplankton serve as the primary producers in marine ecosystems, playing a crucial role in supporting the food chain by transferring energy to zooplankton and higher trophic levels, including small pelagic fish such as anchovis (*Engraulidae*) and mackerel (*Rastrelliger* spp.) **(Miller & Wheeler, 2010)**. The dominance of diatoms, particularly *Chaetoceros*, which exhibit rapid growth and high efficiency in nutrient utilization, further suggests that these waters receive an adequate nutrient supply, likely from upwelling or vertical mixing processes that transport nutrients from deeper layers to the surface **(Longhurst, 2007)**.

The implications of this high water productivity include increased food availability for zooplankton, which in turn sustains the biomass of commercial pelagic fish in the Banda Sea. Previous studies have shown that regions with high diatom abundance are often associated with productive fishing grounds, as observed in other upwelling areas such as the waters off Peru and West Africa **(Pauly & Christensen, 1995)**. In the Banda Sea, this productivity also supports tuna (*Thunnus* spp.) and skipjack **(***Katsuwonus pelamis***)** fisheries, which rely on the abundance of small fish as their primary food source **(Waileruny *et al*., 2014; Satrioajie *et al*., 2018; Usemahu *et al*., 2022)**. Therefore, fluctuations in phytoplankton abundance can directly impact fishery yields in this region, making it a key factor in sustainable fisheries management.

In addition to supporting the fisheries ecosystem, high phytoplankton productivity also plays a crucial role in the global carbon cycle through photosynthesis and the absorption of atmospheric carbon dioxide **(Falkowski *et al*., 1998)**. Phytoplankton-rich waters, particularly those dominated by diatoms, can contribute to increased organic carbon export to the seafloor via the "biological carbon pump" mechanism, which is essential for climate change mitigation **(Boyd *et al*., 2019)**. Therefore, monitoring phytoplankton dynamics in the Banda Sea is not only relevant for sustaining the fisheries sector but also for understanding the role of this ecosystem in global carbon regulation and marine environmental stability.

CONCLUSION

The research findings indicate that phytoplankton in the Banda Sea are dominated by *Bacillariophyceae*, with *Chaetoceros* and *Rhizosolenia* as the predominant genera. Variations in abundance across stations reflect the influence of environmental factors such as temperature, salinity, and current dynamics, particularly upwelling, which enhances nutrient availability. The high phytoplankton abundance supports marine productivity by sustaining zooplankton populations and small pelagic fish, which are crucial for local fisheries. However, the potential presence of toxic *Dinophyceae* necessitates continuous monitoring to prevent negative impacts such as harmful algal blooms (HABs).

Further research should include long-term monitoring using satellite technology and eco-hydrodynamic models. Additionally, more studies on the interactions between phytoplankton, zooplankton, and fish are needed. From a policy perspective, protecting upwelling ecosystems, managing water quality, and implementing regular phytoplankton monitoring are essential to ensuring sustainable fisheries and maintaining the ecological balance of the Banda Sea.

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