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Detection and Identification of Potentially Harmful Microalgal Species in Doreri Bay, Manokwari, West Papua, Indonesia: A Preliminary Study

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Abstract

Harmful algal blooms (HABs) frequently exhibit recurring patterns in specific locations and are often associated with significant environmental challenges, such as eutrophication. However, HABs have also been observed in areas with lower levels of eutrophication. This study aimed to detect and identify phytoplankton species responsible for blooms in the waters of Doreri Bay, with a particular focus on potentially harmful species (HABs). It represents the first attempt in this region to identify microalgal species. Field sampling was conducted during the southeast (dry) season of 2023 at nine stations across Doreri Bay. A total of 21 phytoplankton taxa, representing three classes were identified, with 14 taxa (66.7%) being potentially harmful. Phytoplankton cell densities ranged from 2.96 × 10^4 cells L^{-1} to 1.22 × 10^5 cells L^{-1}, with an average density of 2.01 × 10^4 cells L^{-1}. The community was dominated by Diatoms, including Bacillaria *spp.,* Coscinodiscus *spp., and* Rhizosolenia *spp., and Cyanobacteria, mainly* Trichodesmium *spp. Two bloom patterns were observed: Cyanobacteria and Dinoflagellates dominated coastal areas, while Diatoms were more abundant in the outer bay. Correlation analysis revealed that temperature, salinity, and dissolved oxygen (DO) were the primary environmental factors driving phytoplankton variability and growth in the shallow coastal waters of Doreri Bay. These findings suggest that the phytoplankton community structure in this region remains stable when environmental gradients stay within the tolerance thresholds of sensitive species. Conversely, potentially harmful algal blooms are likely to develop when these environmental gradients exceed the tolerance levels of more resilient species.*

Keywords: *eutrophication, HABs, microalgal, phytoplankton, salinity, temperature*

Introduction

In recent decades, the frequency and geographical extent of harmful algal blooms (HABs) have increased globally (Hallegraeff *et al*., 2021). These blooms have garnered significant attention due to their detrimental effects on coastal ecosystems, fisheries, aquaculture industries, and human health. Notably, the prevalence of HABs dominated by toxin-producing species has risen, with the species responsible for these blooms being highly diverse (Anderson *et al*., 2021). Consequently, HABs have become a significant form of marine environmental pollution faced by coastal nations worldwide. Research on HABs has intensified due to their environmental and economic impacts, as well as the notable increase in the frequency of such events globally (Wu *et al*., 2013). HABs can proliferate rapidly under favorable climatic and aquatic conditions, with their severity and spatial distribution being highly dynamic (Zhou *et al*., 2023). These blooms are sensitive to various meteorological factors, such as temperature, precipitation, and wind direction (Díaz *et al*., 2021), complicating efforts to accurately characterize their spatial and temporal dynamics over extended periods. Furthermore, many researchers contend that HABs are driven by climate change and the rapid growth of the human population (Gobler, 2020).

Doreri Bay, situated north of the Bird's Head Seascape, is celebrated for its biodiversity. The bay's ecosystem holds significant ecological and economic value owing to its rich diversity and history. Proximity to the Pacific Ocean imparts dynamic oceanographic characteristics to Doreri Bay, including heightened temperatures and salinity levels alongside low nutrient content (Siregar and Waas, 2006; Kolibongso, 2020). Despite these natural attributes,

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the coastal habitats within Doreri Bay have faced degradation in recent decades due to rapid population growth and intensified land use practices, leading to compromised water quality (Tururaja and Mogea, 2010; Sembel and Manan, 2018; Sembel *et al*., 2021). Industrial activities, agriculture, fisheries, forestry, and urban expansion have collectively contributed to this decline (Sembel *et al*., 2022). Moreover, Doreri Bay serves as the estuarine outlet for several major rivers - such as the Andai, Wosi, Sowi, Wirsi, Maripi, and Maruni - which transport organic matter from the mainland. These materials carry varying levels of nitrogen, sulfur, and phosphate (Sembel *et al*., 2019), undergoing seasonal fluctuations influenced by weather patterns and terrestrial activities. Elevated concentrations of these nutrients in the water can lead to eutrophication, further impacting the bay's ecological balance and biodiversity (Damar *et al*., 2016).

Eutrophication refers to the process of nutrient enrichment in aquatic ecosystems, primarily driven and exacerbated by human activities, leading to excessive algal growth. This phenomenon disrupts the natural balance of ecosystems and degrades water quality (Akinnawo, 2023). Eutrophication poses a growing environmental challenge in many developing regions (Khan and Mohammad, 2014), observed in various rivers, lakes, and coastal areas worldwide (Wang *et al*., 2021; Hou *et al*., 2022). Future projections indicate that eutrophication's intensity, duration, and frequency are likely to increase in this century due to altered rainfall patterns and heightened anthropogenic pressures in both inland and coastal zones (Sinha *et al*., 2017). A significant concern associated with eutrophication is the occurrence HABs, commonly known as red tides (Anderson *et al*., 2002).

HABs refer to the rapid proliferation of microalgae (phytoplankton) populations, resulting in adverse ecological consequences. These blooms contribute to ecosystem disruption by generating harmful biotoxins, impairing aquatic organisms' gills through physical damage and blockage, and fostering anoxic or hypoxic conditions in the water column (Sellner *et al*., 2003). Such conditions can lead to significant mortality events within aquatic ecosystems (Lassus *et al*., 2016). Indeed, blooms triggered by toxin-producing phytoplankton species pose significant threats to both aquatic organisms (Likumahua *et al*., 2019) and humans. Consumption of contaminated fish or shellfish can result in severe poisoning incidents (Xu *et al*., 2021). Biotoxins tend to accumulate in the tissues or digestive tracts of these organisms, leading to various potentially fatal illnesses in humans, such as Ciguatera Fish Poisoning (CFP), Amnesic Shellfish Poisoning (ASP), and Paralytic Shellfish Poisoning (PSP) (Hallegraeff *et al*., 2004; Ettoubi *et al*., 2020). Several incidents of poisoning due to the consumption of shellfish or fish contaminated with biotoxins have been documented in various Indonesian regions, including Hurun Bay, Ambon Bay, Lampung Bay, Semarang Bay (Mizushima *et al*., 2007; A'In *et al*., 2018; Sidabutar *et al*., 2021; Samudra *et al*., 2023). HABs often exhibit a recurring pattern in specific locations, coinciding with significant environmental issues like eutrophication (Liu *et al*., 2010). However, HAB occurrences have also been observed in areas with lower levels of eutrophication, suggesting that factors other than environmental conditions may play dominant roles in their occurrence. This variability implies that HABs can manifest in diverse regions due to additional influential factors beyond environmental variables. This study aims to detect and identify potentially harmful phytoplankton species in the waters of Doreri Bay, with a focus on those capable of causing HABs. This research represents the inaugural effort in the region to pinpoint these microalgal species. The findings are expected to advance our comprehension of ecological risks and facilitate enhanced management of coastal environments.

Materials and Methods

Doreri Bay, an open bay adjoining the Pacific Ocean, is utilized by local communities for fishing (both fish and shellfish), aquaculture (fish farming), and tourism. The coastal area surrounding Doreri Bay faces significant anthropogenic pressures, notably from the Semen plant to the south, Manokwari Airport to the east, and Wosi and Sanggeng Markets to the northeast. Moreover, the bay accommodates a harbor handling passengers, goods, and fish to the north. Studies have detected contamination of surface water, sediments, and seagrasses in Doreri Bay with heavy metals, particularly Pb (Sembel *et al*., 2022). Additionally, the bay exhibits the presence of coliform bacteria, which are pathogenic and indicate environmental contamination or inadequate sanitation practices (Tururaja and Mogea, 2010). Sedimentation processes and concentrations of suspended matter in the coastal areas of Doreri Bay are notably high (Sembel *et al*., 2019; Kolibongso *et al*., 2024). The bay encompasses a large sea area along the continental shelf, characterized by gently sloping coastal areas that transition to steeper depths towards the open sea. The seabed composition predominantly comprises sand in the central region and mud near the mouths of the surrounding rivers that empty into Doreri Bay.

Field sampling was conducted during the southeast monsoon (dry season) of 2023 at nine stations across three bay zones: the inner bay near the river mouth (stations 1, 5, 6, and 7), the middle bay as a transitional area (stations 2, 8, and 9), and the outer bay (stations 3 and 4) (Figure 1). Sampling occurred twice between 08:30 and 13:30, during high tide, which coincides with semidiurnal tides-tidal range 0.8 m (Suhaemi *et al*., 2018). Tides were selected to optimize plankton sampling because tidal currents bring offshore waters, rich in plankton, organic particles, and nutrients, to the surface and coastal areas. The energy at high tide in shallow waters causes full homogenization of the water column, which initiates the formation of blooms (Hallegraeff *et al*., 2004).

Environmental parameters, including salinity, temperature, pH, and dissolved oxygen (DO), were measured on-site. Salinity was determined using a Hand Refractometer (ATAGO), while a Water Quality Analyzer (HORIBA PD220-K) was used to measure DO, temperature, and pH. Water samples of approximately 1 liter were collected using a 3.2-liter horizontal water sampler for nitrate and dissolved phosphate analysis. The samples were then filtered through Whatman filter paper (47 mm diameter, 0.45 µm pore size) in accordance with the Indonesian National Standard (SNI 6964.8:2015).

Table 1. Environmental parameters in Doreri Bay

Environmental Parameters	Minimum	Maximum	Average	Standard Deviation
Temperature (^{o}C)	30.0	31.20	30.60	0.44
Salinity (ppm)	31.68	33.45	32.9	0.61
pH	7.58	8.19	8.04	0.19
DO (mg L^{-1})	6.35	7.13	6.70	0.22
Nitrate (mg L^{-1})	0.33	0.51	0.39	0.05
Phosphate (mg L^{-1})	0.07	0.08	0.07	0.001

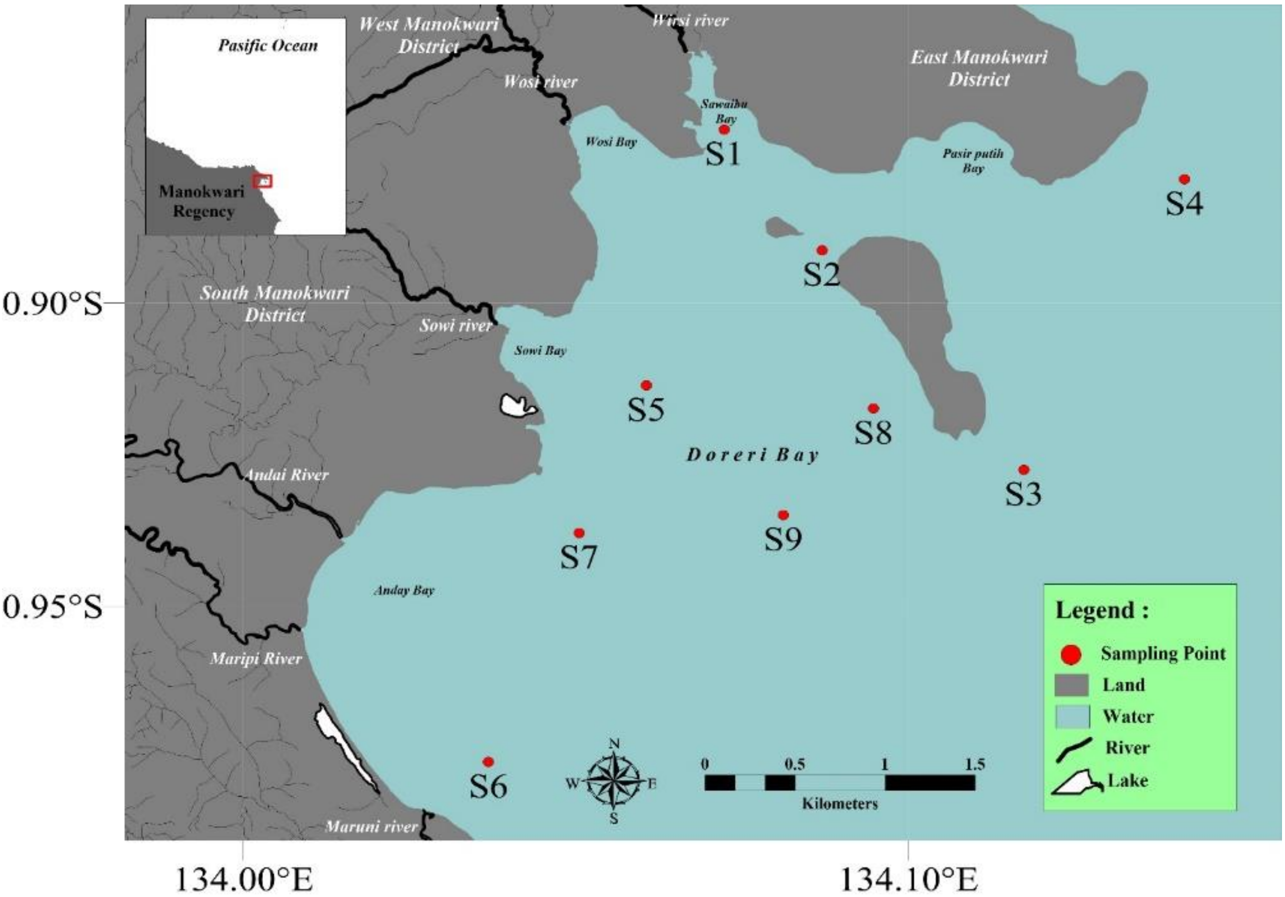

Figure 1. Sampling locations in Doreri Bay.

Additionally, water samples were taken for phytoplankton assessment at all stations. Plankton sampling was conducted using a plankton net (mesh size 20 μm, diameter 0.5 m, net length 1.5 m), following established procedures (Suteja *et al.*, 2021). The net was towed horizontally by the boat for approximately 5 minutes at a speed of about 3 knots, with the GPS coordinates of the start and finish points recorded to accurately define the tow distance. Horizontal towing captures plankton from across the water column, including the surface, where densities are highest. This method samples a larger water volume, offering a more accurate estimate of plankton density. It is especially effective as plankton often migrate vertically or respond to factors like light and temperature, ensuring they are collected in their natural state. This approach may therefore reflect the true community structure at that time and location (Castellani, 2010). After capture, plankton collected in the cod-end were transferred to sterile HDPE bottles and preserved with 4% formalin and 1.5% Lugol's solution (Syakti *et al.*, 2019). All water and plankton samples were stored separately and transported to the University of Papua Analytical Laboratory for further analysis.

Nitrate and phosphate concentrations were measured using the spectrophotometer method in accordance with Indonesian National Standards SNI-06-2480-1991 and SNI-06-6989-31-2005 for nitrate and phosphate, respectively. Concentrations are expressed in mg.L^{-1}. Phytoplankton identification followed established procedures (Suteja *et al.*, 2021). Prior to identification, the plankton sample was homogenized by stirring in a bottle. A 1 mL aliquot of the sample was then transferred to a Sedgwick-Rafter counting cell, which was carefully sealed to prevent the introduction of air bubbles. Identification and counting of phytoplankton were performed using an Olympus binocular microscope (model CX23) at magnifications of x100 and x400. Taxonomic identification relied on cell morphology descriptions from references such as (Tomas, 1997) and online databases (www.marinespecies.org and www.algae base.org). Specifically, potentially harmful microalgae were classified according to previous descriptions (Hallegraeff *et al.*, 2004; Lassus *et al.*, 2016; Furuya *et al.*, 2018).

The total volume of water analyzed in each area was calculated by multiplying the length of the examined surface (the distance between the start and end GPS coordinates of the net) by the mouth area of the plankton net. The resulting volume was expressed in cubic meters (m^3) (Eriksen *et al.*, 2018). Phytoplankton density in the waters of Doreri Bay was quantified according to APHA standards (APHA, 1998), and expressed as cells per liter (cells L^{-1}). A list of dominant species was compiled using the dominance index (D), and both diversity and evenness were calculated using the Shannon-Wiener Index (H') and the evenness index (J) (Wang *et al.*, 2022). Statistical analyses were performed using PAST software, beginning with a normality test for the data set. If the data met the criteria for normal distribution ($p < 0.05$), a t-test was conducted; otherwise, the non-parametric Wilcoxon test was applied. One-way analysis of variance (ANOVA) was used to assess differences between phytoplankton groups, while Spearman correlation analysis was employed to examine the relationship between environmental parameters and plankton density. Additionally, Canonical Correspondence Analysis (CCA) was used to evaluate the relationship between environmental factors and phytoplankton communities, thereby elucidating the impact of environmental conditions on biological parameters.

Result and Discussion

Environmental factors

Table 1 presents measurements of environmental parameters in surface waters. In Doreri Bay, temperatures ranged from 30 to 31.20 °C, with the highest recorded at station 9 and the lowest at station 2. Temperature near the coast was generally lower than offshore, likely influenced by coastal runoff. Sembel *et al.* (2021) reported that the average water temperature in Doreri Bay during the dry season was 30.73 °C. Salinity exhibited a gradient from low near the coast to higher offshore, possibly due to freshwater inputs from land. Similarly, dissolved oxygen (DO) levels ranged from 6.35 to 7.13 mg L^{-1}, showing lower values near the coast compared to offshore waters. Low dissolved oxygen (DO) levels in aquatic environments can lead to increased ammonia concentrations, resulting from the decomposition of organic matter by bacteria under hypoxic conditions (Suteja *et al.*, 2021). pH values ranged from 7.58 to 8.19, with the highest at station 4 and the lowest at station 1. Nitrate and phosphate concentrations varied across sampling stations, with higher levels observed nearshore and lower levels offshore. Similar conditions were reported in a previous study by Alianto *et al.*, (2016) in Doreri Bay. Remineralization processes, along with river effluents and runoff, are considered the primary sources of nutrients in nearshore areas. During the dry season, the nutrient concentrations in Doreri Bay observed in this study were generally lower than those reported in earlier research (Sembel *et al.*, 2019). Phosphate was identified as a nutrient with limited availability for most of the year, while nitrogen was typically scarce during the dry season but more abundant during the wet season. Nitrate concentrations in coastal and estuarine waters are generally higher than phosphate levels, primarily due to the influx of organic matter from human activities. These inputs often originate from rivers and land runoff, contributing to nutrient enrichment in these aquatic environments (Tong *et al*., 2015).

Distribution, abundance, and diversity

The distribution of phytoplankton cell density in Doreri Bay exhibited significant variability across stations (Figure 3), although differences among stations were not statistically significant ($p > 0.05$). Total phytoplankton cell density ranged from 2.96 x 10^4 cells L^{-1} to 1.22 x 10^5 cells L^{-1}, with an average density of 2.01 x 10^4 cells L^{-1}. Phytoplankton densities exceeding 12,500 cells L^{-1} are considered high (Pratiwi *et al*., 2018) placing Doreri Bay in this category. However, this density does not exceed the World Health Organization's recommended limit of 2 x 10^6 cells L^{-1} for water bodies (Chorus and Bartram, 1999). The highest phytoplankton density was recorded at station 3 (2.96 x 10^4 cells L^{-1}), while the lowest was observed at station 9 (1.22 x 10^4 cells L^{-1}) (Figure 2). The distribution pattern suggests lower abundance in the central bay area, with higher densities observed inland and towards the cape areas by the sea. This distribution pattern may be influenced by the bay's topography, where the central trench with strong currents and nutrient-poor conditions contrasts with nutrient-rich inputs near the mainland. Additionally, headland areas like Manggewa and Arowi, influenced by transitional continental shelf dynamics and higher salinity, also exhibited elevated phytoplankton densities. Salinity likely plays a crucial role in shaping phytoplankton abundance in Doreri Bay, as observed in similar estuarine studies where planktonic diatoms distribution correlated strongly with salinity gradients (Zong *et al*., 2010). Salinity acts as a barrier affecting species dispersal patterns. Furthermore, the varying

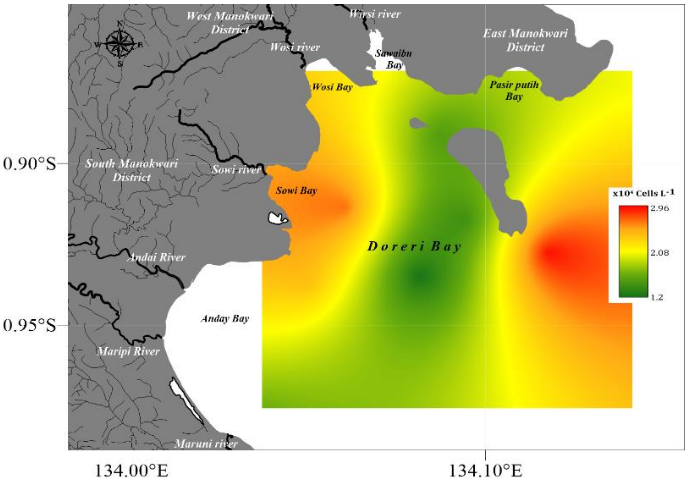

Figure 2. Total abundance of phytoplankton in Doreri Bay

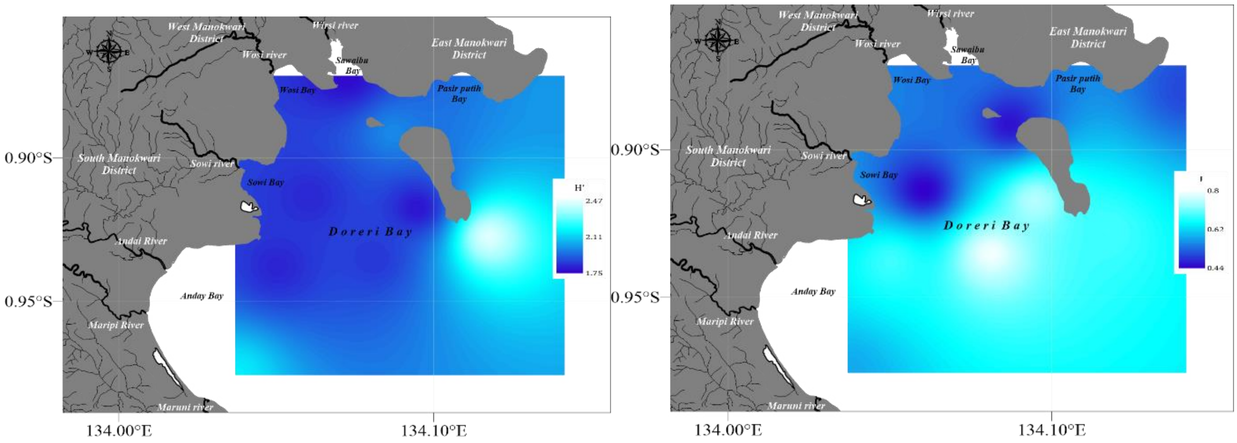

Figure 3. The magnitude of the diversity index (H') and the evenness index (J) for phytoplankton species is represented by a color gradient that transitions from dark blue to light blue.

Table 2. Comparison of phytoplankton abundance and dominant species

Survey time	Sampling method	Number of species	Average Abundance (cells L^{-1})	Dominant species	Survey area	Reference
2024	Net sample	21	2.01 x 10^4	*Trichodesmium* spp, *Rhizosolenia* spp, *Coscinodiscus* spp, *Baccilaria* spp	Doreri bay, West Papua	This study
2023	Net sample	17	5.4 x 10^3	*Pseudonitzchia* spp, *Ceratium* spp, *Anabaena* spp, *Oscillatoria* spp	Manokwari, West Papua	(Badila *et al.*, 2023)
2021	Net sampel	29	2.17 x 10^6	*Skeletonema* spp, *Nitzchia* spp, *Ceratium* spp, *Dinophysis* spp, *Protoperidinium* spp, *Alexandrium* spp, *Pyrophacus* spp	Pangkep, South Sulawesi	(Thoha *et al.*, 2021)
2021	Net sampel	66	3.03 x 10^5	*Guinardia flacida, Thalassionema nitzschioides, Skeletonema costatum, Thalassiosira gravida, Chaetoceros curvicetus*	Oma waters, Maluku	(Haumahu *et al.*, 2021)
2020	Net sampel	27	5.2 x 10^3	*Chaetoceros* spp., *Nitzchia* spp., *Bacteriastrum* spp., *Prorocentrum* spp	Hurun Bay, Lampung	(Pawhestri *et al.*, 2020)
2021	Net sampel	29	2.43 x 10^3	*Pseudo-nitzchia* spp, *Coscinodiscuss* spp, Skeletonema spp, *Chaetoceros* spp, *Rhizosolenia* spp.	Benoa Bay, Bali	(Suteja *et al.*, 2021)
2021	Net sampel	18	1.02 x 10^7	*Trichodesmium* spp.	Ambon Bay	(Mahmudi *et al.*, 2020)

dominance of specific phytoplankton taxa at each location contributes to the distinct density distributions observed across stations in Doreri Bay.

The average phytoplankton abundance observed in Doreri Bay waters (2.01 x 10^4 cells L^{-1}) was compared with studies from various locations in Papua and Indonesian waters (Table 2). Phytoplankton densities in Doreri Bay were higher than those reported in Manokwari (5.4 x 10^3 cells L^{-1} (Badila *et al.*, 2023); Hurun Bay, Lampung (5.2 x 10^3 cells L^{-1}) (Pawhestri *et al.*, 2020); and Benoa Bay (2.4 x 10^3 cells L^{-1}) (Suteja *et al.*, 2021). However, they were lower than densities observed in Ambon Bay (1.02 x 10^7 cells L^{-1}) (Mahmudi *et al.*, 2020), Pangkep (2.17 x 10^6 cells L^{-1}) (Thoha *et al.*, 2021), and Oma waters, Maluku (3.03 x 10^5 cells L^{-1}) (Haumahu *et al.*, 2021). The variation in phytoplankton abundance across these locations reflects differences in environmental factors such as nutrient inputs (nitrate, phosphate, silicate), rainfall, seasonality, sunlight penetration, water residence time, suspended solids, and flooding (Sidharta, 2005; Samudra *et al.*, 2023). These factors influence the dynamics of phytoplankton communities, with certain species dominating under specific ecological conditions, which can lead to significant shifts in the ecological community structure. It's important to note that there is no universally defined threshold for phytoplankton abundance that triggers a bloom. However, blooms typically occur when phytoplankton densities exceed average monthly levels, indicating a departure from normal ecological conditions.

The H' (Shannon-Wiener diversity index) and J (Pielou's evenness index) indices were employed to assess the complexity and stability of the phytoplankton community structure in Doreri Bay waters (Figure 3). The analysis indicated that lower diversity values were predominantly observed in nearshore areas, whereas higher diversity values were found in offshore waters. This pattern suggests that coastal areas exhibit lower species diversity and more uneven distribution patterns compared to offshore regions. Conversely, higher seas display the opposite trend. This finding supports previous observations attributing salinity as a key factor influencing both diversity and distribution patterns, with higher phytoplankton densities typically observed in offshore areas. Salinity serves as a significant barrier to phytoplankton distribution by affecting their osmoregulation. In communities dominated by diatoms, salinity often plays a pivotal role in shaping community structure (Suteja *et al.*, 2021). Diatoms and Cyanobacteria, for instance, exhibit optimal growth conditions at salinities around 35 and 25 ppm, respectively. These results align findings from the South China Sea (SCS) where coastal waters generally exhibit lower phytoplankton diversity compared to offshore waters (Wang *et al*., 2022). Similarly, research in Benoa Bay by Suteja *et al*., (2021) identified salinity as a primary factor influencing community structure and phytoplankton density. Moreover, several diatoms and dinoflagellates identified in this study were notably abundant in areas characterized by higher salinity levels. Certain potentially harmful species are known to thrive and proliferate under conditions of elevated salinity (Sparrow *et al*., 2017; Pal *et al*., 2020).

The predominant phytoplankton species observed in Doreri Bay were *Trichodesmium* spp., *Bacillaria* spp., *Coscinodiscus* spp., and *Rhizosolenia* spp. Notably, the phytoplankton community was primarily composed of potentially harmful species (Table 3). The frequency of occurrence for certain dominant species was notably high, exceeding 80% for *Trichodesmium* spp., *Coscinodiscus* spp., and *Rhizosolenia* spp. This observation warrants significant attention, given the harmful potential of these three species. Among them, *Trichodesmium* spp. emerged as the most dominant species, exhibiting the highest frequency of presence in the study. *Trichodesmium* spp. is a group of phytoplankton belonging to the class Cyanophyceae, recognized for its dual role as both an oxygen producer and a contributor to harmful algal blooms. This genus is capable of fixing nitrogen directly, leading to the formation of extensive blooms at the ocean's surface when environmental conditions, such as temperature and salinity, are optimal for growth. *Trichodesmium* spp. exhibits a broad distribution across subtropical and tropical marine waters (Huisman *et al*., 2018).

Table 3. Dominant phytoplankton taxa in Doreri bay

Species	Average cell abundance (cells L^{-1})	Relative cell abundance (%)	Occurrence frequency (%)	Dominance
Trichodesmium spp.	6000	29.80	100	0.298
Bacillaria spp.	1666.7	8.28	66.7	0.124
Coscinodiscus spp.	1653.3	8.21	100	0.082
Rhizosolenia spp.	2040	10.13	88.9	0.114

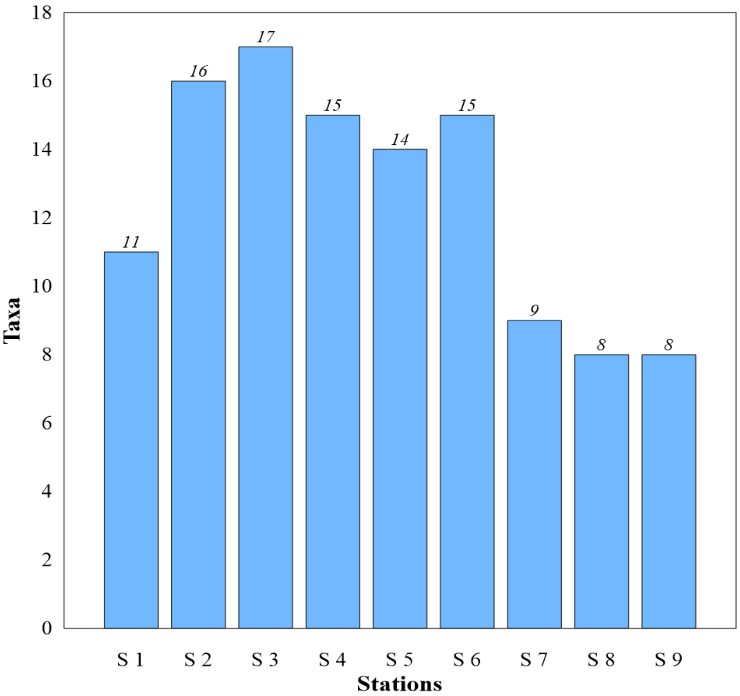

Figure 4. Number of phytoplankton taxa on each location

The environmental conditions associated with *Trichodesmium* spp. blooms in coastal waters include low temperatures, stable salinity levels (approximately 33 psu), and low nitrate concentrations (Yap-Dejeto and Batula, 2016). In Ambon Bay, *Trichodesmium* spp. blooms were observed at temperatures ranging from 26 to 27°C. Doreri Bay, located adjacent to the western Pacific Ocean, is characterized by high temperatures, elevated salinity, and low nutrient availability (oligotrophic conditions) (Siregar and Waas, 2006), creating an ideal environment for the extensive growth of *Trichodesmium* spp. This assertion is supported by the species' presence, which was recorded at a frequency of 100% across all sampling locations in Doreri Bay. The proliferation of *Trichodesmium* spp. can lead to detrimental effects, such as clogging fish gills and causing mortality. Previous reports of blooms of this species in Indonesia have been documented in areas such as the Java Sea, Lampung Bay (Puspasari *et al*., 2018), and Ambon Bay (Mahmudi *et al*., 2020).

The dominance of *Coscinodiscus* spp. in aquatic environments can be attributed, in part, to its capacity for adaptation and growth across a broad spectrum of salinity, temperature, and nutrient levels. This species typically exhibits higher densities in estuarine areas characterized by low light conditions, along with substantial inputs of freshwater and nutrients. Doreri Bay serves as the estuary for six rivers, resulting in fluctuating nutrient concentrations within the water column (Sembel *et al*., 2021). These conditions are conducive to the growth of various diatoms, including *Coscinodiscus* spp., which has demonstrated a remarkable ability to adapt, as evidenced by its presence at all sampling stations. Several studies in Indonesia have reported the occurrence of *Coscinodiscus* spp. in abundant and potentially harmful quantities, notably in locations such as Benoa Bay (Suteja *et al*., 2021), Ambon Bay (Mahmudi *et al*., 2020), and Banyuasin, South Sumatera (Aryawati *et al*., 2016).

Rhizosolenia spp. is a key species within the Diatom class and typically constitutes a dominant component of phytoplankton biomass in highly productive marine environments. While *Rhizosolenia* spp. generally exists as solitary cells, instances of blooming can lead to the formation of large, dominant aggregates. Gárate-Lizárraga *et al*., (2003) blooms of the species *Rhizosolenia debeynai* have been documented at ambient temperatures of 26°C, with recorded nutrient concentrations of 0.44 μM for nitrate plus nitrite, 0.71 μM for phosphate, and 4.71 μM for silicate in the Gulf of Mexico. Several studies in Indonesia have documented the presence of *Rhizosolenia* spp. in substantial and potentially harmful quantities, particularly in areas such as Benoa Bay (Suteja *et al*., 2021), Ambon Bay (Mahmudi *et al*., 2020), Pangkep, South Sulawesi (Thoha *et al*., 2021).

Bacillaria spp. are diatom species commonly found in habitats characterized by fluctuating salinity and elevated nutrient concentrations (Schmid, 2007). In Doreri Bay, the presence of six large rivers significantly influences fluctuations in salinity and nutrient concentrations, creating an ideal habitat for *Bacillaria* spp. This observation aligns with findings indicating lower densities of this species in locations closer to the open sea, where salinity levels are higher. Research conducted in Jiaozhou Bay, China, identified *Bacillaria paxillifer* as abundant in areas characterized by fluctuating salinity and elevated nutrient concentrations (Guo *et al*., 2019). Additionally, several studies in Indonesia have reported the presence of *Bacillaria* spp. in low-salinity environments near estuaries, notably in Benoa Bay (Suteja *et al*., 2021) and Banyuasin waters in South Sumatra (Aryawati *et al*., 2016).

Composition and potential harmful phytoplankton

In this study, a total of 21 phytoplankton taxa representing three different classes were identified. Bacillariophyceae dominated the phytoplankton community with 12 taxa (59.1%), followed by Dinophyceae with 7 taxa (31.8%), and Cyanophyceae with 2 taxa (9.1%) of the total abundance. Algal blooms, predominantly caused by dinoflagellates, diatoms, and cyanobacteria, significantly influence biodiversity changes (Wells *et al*., 2020; Hallegraeff *et al*., 2021). In Indonesian waters, these groups are the primary drivers of blooms (Sidabutar *et al*., 2024). Diatoms (Bacillariophyceae) were the most abundant group throughout Doreri Bay. Phytoplankton composition varied among stations, with taxa counts ranging from 8 to 17 per station and an average of 12 taxa per station (Figure 4). Station 3 had the highest diversity with 17 taxa, while stations 8 and 9 had the lowest with 8 taxa each. Previous studies in similar regions have also highlighted the dominance of Bacillariophyceae. Badila *et al*., (2023) and Ayu *et al*., (2023) found Bacillariophyceae to be the predominant phytoplankton group in Manokwari waters. This class is known for its cosmopolitan distribution and ecological importance, particularly in nutrient-rich coastal ecosystems, although its abundance may decrease in nutrient-poor open ocean environments (Malviya *et al*., 2016).

Dinophyceae, the second most abundant class in this study after Bacillariophyceae, includes species known to form HABs. These blooms can degrade water quality, harm aquatic organisms, and reduce oxygen levels, particularly in eutrophic environments (Hallegraeff *et al*., 2004; Lassus *et al*., 2016).

Dinophyceae have the ability to form resting cysts, allowing them to survive adverse environmental conditions until conditions improve (Bravo and Figueroa, 2014). Cyanobacteria, another phytoplankton group identified in this study, utilize sunlight to convert CO_2 into biomass and have played a significant role in the evolution of Earth's atmosphere through photosynthetic activity (Schirrmeister *et al*., 2015). However, in eutrophic waters, exacerbated by climate change, harmful cyanobacterial blooms are increasing, posing threats due to the production of toxins (cyanotoxins) that can endanger human and ecosystem health (Griffith and Gobler, 2020). These blooms can create hypoxic or anoxic conditions in aquatic environments, further exacerbating their impact. Overall, the composition and dynamics of phytoplankton communities, dominated by Bacillariophyceae in Doreri Bay, reflect the complex interplay between environmental factors and biological responses, particularly in nutrient-rich coastal waters susceptible to phytoplankton blooms.

Among the 21 phytoplankton taxa identified in this study, 14 taxa (66.7%) were classified as potentially harmful, toxic, or bloom-forming (Table 4). Key species include, *Pseudo-nitzschia* spp. and *Nitzschia* spp., members of the diatom group, are known producers of domoic acid (DA) and isodomoic acid B toxins, which cause amnesic shellfish poisoning syndrome (ASP) in humans. This species frequently blooms in nutrient-rich coastal waters, with occurrences reported in various Indonesian locations, including Segara Anakan in Central Java (Dewi *et al*., 2018), Ambon Bay (Likumahua *et al*., 2019), Hurun Bay (Pawhestri *et al*., 2020), Benoa Bay (Suteja *et al*., 2021), and Jakarta Bay (Sidabutar *et al*., 2021). *Dinophysis* spp., member of the Dinophyceae class, produce diarrhetic toxins such as okadaid acid (OA), dinophysistoxins (DTXs) and pectenotoxin as secondary metabolites. These toxins cause gastrointestinal illnesses and lead to diarrhetic shellfish poisoning (DSP) (Reguera *et al*., 2014). A blooming event of this species was recorded in Ambon Bay (Likumahua *et al*., 2020). *Gymnodinium* spp., produce saxitoxin, decarbamoyl saxitoxin, N-sulfocarbamoyl gonyautoxins, which cause paralytic shellfish poisoning (PSP) in humans (Liu *et al*., 2020). These species have been identified in several Indonesian waters, such as Ambon Bay (Likumahua *et al*., 2022), Jakarta Bay (Nasution *et al*., 2021), and Lampung Bay (Sidabutar *et al*., 2021). Other taxa identified (*Trichodesmium* spp., *Coscinodiscus* spp., *Rhizosolenia* spp., *Protoperidinium* spp., *Chaetoceros curvisetus, Chaetoceros didymus, Ceratium fusus, and Noctiluca scintillans*) are known to form blooms, commonly referred to as red tides, which can discolor water and lead to oxygen depletion, thereby posing risks to ecosystems, fisheries, and aquaculture when their densities become excessive (Hallegraeff *et al*., 2004; Lassus *et al*., 2016).

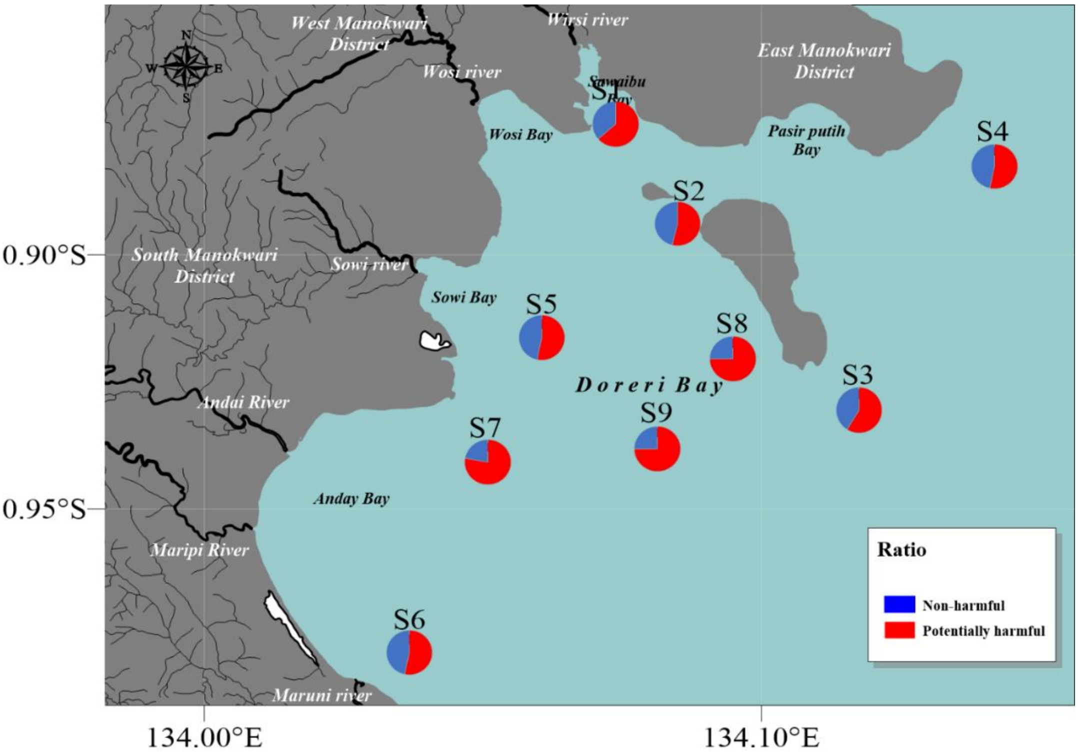

Figure 5. Ratio of potentially harmful vs non-harmful phytoplankton in Doreri Bay

Table 4. Checklist and Presence Code of Phytoplankton Species in Doreri Bay, Indonesia. The cell density coding system is as follows: (++++) indicates a cell density greater than 10,000 cells.L^{-1}; (+++) indicates 1,000 to 10,000 cells.L^{-1}; (++) indicates 100 to 1,000 cells.L^{-1}; (+) indicates 1 to 100 cells.L^{-1}; and (-) indicates absence.

Species	Potentially	Impact	Stations								
			S1	S2	S3	S4	S5	S6	S7	S8	S9
Baccilariophyta											
Cerataulina spp.			+++	++	+++	++	+++	++	-	-	-
Chaetoceros curvisetus Cleve	Toxin	Damaging or clogging to fish and invetebrates	++	++	++	++	++	++	-	-	-
Chaetoceros didymus Ehrenberg	Toxin	Damaging or clogging to fish and invetebrates	++	++	+++	++	++	++	-	-	-
Coscinodiscus spp.	Toxin	Damaging or clogging to fish and invetebrates	++	++	+++	+++	+++	+++	+++	++	+++
Climacosphenia spp.			-	-	-	-	-	-	+++	+++	+++
Bacillaria spp.			+++	+++	+++	++	+++	+++	-	-	-
Guinardia spp.			-	++	+++	+++	++	++	-	-	-
Isthmia spp.			+++	+++	+++	+++	++	++	-	-	-
Nitzchia spp.	Biotoxin	Amnesic shellfish poisoning (ASP)	-	-	-	-	-	-	+++	+++	+++
Proboscia spp.			-	-	++	++	++	++	-	-	-
Pseudo-nitzchia spp.	Biotoxin	Amnesic shellfish poisoning (ASP)	++	++	++	++	-	++	-	-	-
Rhizosolenia spp.	Toxin	Water discolorations, kill of fish	-	++	+++	+++	+++	+++	+++	+++	+++
Dynophyta											
Ceratium fusus (Ehrenberg) Dujardin	Toxin	Oxygen depletions	++	++	++	++	++	++	++	++	++
Ceratium lineatum (Ehrenberg) Cleve	Toxin	Oxygen depletions	++	+++	++	+++	+++	++	-	-	-
Ceratium declinatum (Karsten) Jorgensen	Toxin	Oxygen depletions	-	-	++	++	-	++	++	++	++
Dynophysis spp.	Biotoxin	Diarrhetic shellfish poisoning (DSP)	++	++	+++	++	++	++	-	-	-
Gymnodinium spp.	Biotoxin	Paralytic shellfish poisoning (PSP)	-	++	-	-	-	-	++	-	-
Noctiluca spp.	Toxin	Oxygen depletions	-	-	++	-	-	-	-	-	-
Protoperidinium spp.	Toxin	Water discolorations, kills of fish	-	++	++	-	-	-	+++	++	+++
Cyanophyta											
Anabaena spp.			-	++	-	-	-	-	++	-	-
Trichodesmium spp.	Toxin	Oxygen depletions, kills of fish	+++	+++	+++	+++	++++	+++	+++	+++	+++

The composition of phytoplankton species in Doreri Bay revealed a dominance of potentially harmful microalgal species (Figure 5). The proportion of these harmful species was particularly high in several nearshore and offshore locations. Two distinct patterns of potentially harmful phytoplankton blooms were identified, likely influenced by different environmental factors. Numerous studies have demonstrated that spatial and temporal variations in phytoplankton blooms are primarily driven by environmental factors, including nutrients, temperature, salinity, and light availability (Sha *et al*., 2021; Li *et al*., 2022; Wang *et al*., 2022). The first pattern, observed in coastal areas, is primarily associated with high concentrations of nitrate and phosphate, calm water conditions, and low salinity. These factors were the main contributors to harmful phytoplankton blooms in this region, with Cyanobacteria and Dinoflagellates being the dominant groups. In contrast, the second pattern, occurring in the outer bay, appears to be driven by low nitrate and phosphate concentrations, variable salinity, and mixed water conditions, with Diatoms serving as the primary contributors. According to (Pal *et al*., 2020), harmful algal blooms can develop rapidly under specific environmental conditions. Intense blooms are typically associated with high nitrate and phosphate levels, calm waters, warm temperatures, and low salinity, whereas less intense blooms occur in environments with low nitrate and phosphate levels, mixed waters, low temperatures, and high salinity. A detailed statistical analysis examining the influence of environmental factors on phytoplankton abundance is presented in the following section.

Relationship between phytoplankton abundance and environmental factors

The correlation analysis between phytoplankton cell density and environmental factors in Doreri Bay is presented in Table 5. The results indicate that temperature, salinity, and dissolved oxygen are key factors driving phytoplankton abundance and distribution. Conversely, no correlation was observed between phytoplankton abundance and the nitrogen-to-phosphorus (N:P) ratio in these waters. Many studies have suggested a relationship between algal blooms and increased nutrient concentrations in water (Wells *et al*., 2020; Díaz *et al*., 2021). Doreri Bay's open and dynamic characteristics create challenges for nutrient enrichment, as hydrodynamic processes dilute and disperse nutrients. Consequently, nutrients are not a limiting factor for phytoplankton blooms in this bay. Furthermore, data collection occurred during the southeast monsoon (dry season), a period with minimal nutrient input from rivers and runoff. As a result, no significant relationship was observed between phytoplankton abundance and nutrient levels. In contrast, temperature plays a critical role in phytoplankton physiology and metabolic processes. Under light-saturated conditions, elevated temperatures enhance productivity by influencing photosynthetic carbon assimilation (Lewandowska *et al*., 2012; Righetti *et al*., 2019). Additionally, increased temperatures can boost nutrient uptake, as studies have shown that warming stimulates growth rates and metabolic activity in phytoplankton (Trombetta *et al*., 2019).

Salinity plays a crucial role in shaping phytoplankton density and distribution in Doreri Bay with significant correlations, as evidenced by the composition and structure of the phytoplankton communities. Nearshore areas with lower salinity concentrations tend to be dominated by Cyanobacteria and Dinoflagellates, while offshore regions with variable salinity are characterized by a diverse and abundant presence of Diatoms. Diatoms exhibited a strong response to the salinity gradient, with a preference for high salinity. Typically, diatoms thrive in high-salinity zones and are more abundant in summer when salinity and temperature high (Tarafdar *et al*., 2021). In contrast, Cyanobacteria favored low salinity in Doreri Bay, consistent with others research (Bharathi *et al*., 2018). Their abundance during the study may be attributed to longer water residence times and low flow rates, conditions that support their slow growth. Additionally, nitrogen (N) limitation suppressed diatoms while promoting the growth of N-fixing Cyanobacteria, such as *Trichodesmium spp*., leading to harmful blooms. Dinoflagellates also preferred lower salinities, consistent with prior studies showing their prevalence in brackish and marine environments. In tropical systems, salinity is a key factor influencing the distribution of dinoflagellates (Mukherjee *et al*., 2018). However, it is important to note that this study did not reveal any significant changes in phytoplankton composition across different seasons of the year.

The potentially harmful species, *Rhizosolenia* spp. showed significant positive correlations with temperature and salinity, thus warming and increasing salinity in the ocean will support high populations of this phytoplankton. Next, *Ceratium declinatum* and *Nitzchia* spp. showed a significant correlation with salinity and temperature, respectively. While other potentially harmful species, such as *Trichodesmium* spp., *Ceratium fusus*, *Pseudo-nitzschia* spp., and *Chaetoceros didymus* were found to have a negative correlation with temperature. The density of these species will increase when the water temperature is low and decrease when the water temperature is high. The relatively consistent and high average temperature of

Doreri Bay during the study period suggests that temperature may not be a primary factor influencing the distribution of species responsible for harmful algal blooms. *Dinophysis* spp., showed a negative correlation with temperature and DO, where higher temperature will affect the density of this species which will then decrease the DO concentration in the water. The density of *Dinophysis caudata* typically increases at the onset of the rainy season, when water temperatures tend to be lower (Drakulović *et al*., 2017).

Table 5. Spearman correlation analysis of physic-chemical and biological parameters during investigation period in Doreri Bay.

Species	Temp	Sal	DO	pH	NO_3^-	PO_4^{3-}
Isthmia spp	-0.762*	-0.612	-0.365	-0.322	-0.474	-0.389
Trichodesmium spp.	-0.683*	-0.493	-0.200	-0.116	0.033	0.066
Rhizosolenia spp.	0.733*	0.769**	0.284	0.300	0.600	0.450
Coscinodiscus spp.	0.333	-0.279	-0.125	0.350	0.600	0.300
Bacillaria spp.	-0.644	-0.800**	-0.578	-0.322	-0.186	-0.084
Dinophysis spp.	-0.741*	-0.407	-0.744*	-0.379	-0.224	-0.207
Ceratium fusus	-0.778*	-0.531	-0.447	-0.306	0.052	0.148
Ceratium lineatum	-0.646	-0.401	-0.447	0.136	0.042	0.144
Ceratium declinatum	0.441	0.861**	0.104	0.294	0.086	0.147
Cerataulina spp.	-0.759*	-0.441	-0.528	-0.345	-0.345	-0.310
Pseudo-nitszchia spp.	-0.778*	-0.223	-0.535	-0.306	-0.375	-0.358
Chaetoceros curvisetus	-0.589	-0.150	-0.570	0.094	-0.008	0.059
Chaetoceros didymus	-0.692*	-0.279	-0.596	-0.188	-0.265	-0.222
Nitszchia spp.	0.782*	0.611	0.382	0.099	0.336	0.188
Guinardia spp.	-0.489	0.017	-0.482	0.227	0.096	0.157
Proboscia spp.	-0.321	0.069	-0.322	0.311	0.330	0.366
Noctiluca scintilans	-0.410	0.412	-0.550	-0.273	0.000	-0.136
Protoperidinium spp.	0.522	0.642	0.205	-0.078	0.139	-0.104
Anabaena spp.	-0.479	-0.389	0.114	-0.159	0.159	0.159
Gymnodinium spp.	-0.182	-0.160	-0.137	-0.433	0.136	-0.136
Clymacosphenia spp.	0.782*	0.611	0.382	0.099	0.336	0.188

Temp: Temperature; Sal: Salinity; DO: Oxygen concentration; pH: potential of Hydrogen; NO_3^-: nitrate concentration; PO_4^{3-}: phosphate concentration. **significant correlation at the level $p<0.01$; *significant correlation at the level $p<0.05$.

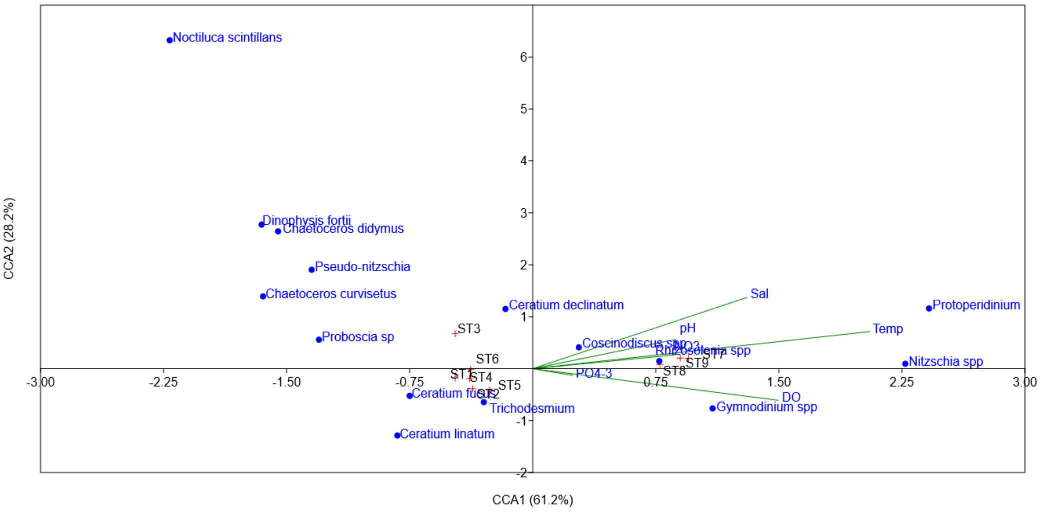

Figure 6. The Canonical Correspondence Analysis (CCA) ordination biplots of phytoplankton abundance and environmental factors in Doreri Bay

The results of the CCA ordination indicate that temperature, salinity, and dissolved oxygen are the most significant environmental factors influencing phytoplankton variability in this study (Figure 6). These findings align with those of (Carstensen *et al*., 2015), who reported that phytoplankton, particularly the diatom group, exhibit strong adaptability to environmental changes. Certain species within this group can tolerate a wide range of temperatures, salinities, and dissolved oxygen levels, enabling them to thrive in high densities and dominate estuarine and coastal waters. In Doreri Bay, *Rhizosolenia* spp. and *Coscinodiscus* spp. are the two dominant diatom species (Table 3). *Rhizosolenia* spp. is considered a key diatom species and often dominates phytoplankton biomass in productive marine environments (Tuo *et al*., 2014). Meanwhile, *Coscinodiscus* spp., a diatom species known for its large cell size, frequently forms blooms. This species exhibits a strong correlation with water temperature, salinity, and nutrient levels (Dienye and Sikoki, 2023).

Conclusion

The detection and identification results revealed a total of 16 microalgal species associated with blooms, 14 of which were classified as potentially harmful in Doreri Bay. The highest phytoplankton abundance (2.64 × 10^4 cells L^{-1}) was observed in the offshore area, influenced by high salinity. *Trichodesmium* spp. and *Coscinodiscus* spp. were present at nearly all sampling stations. *Trichodesmium spp.* are notable for their nitrogen-fixing ability, which supports bloom formation under low temperatures and stable salinity conditions, whereas *Coscinodiscus* spp. exhibit adaptability to a wide range of salinity, temperature, and nutrient levels. Potentially harmful microalgae accounted for 66.7% of the total phytoplankton. Statistical analyses identified temperature, salinity, and dissolved oxygen as the primary environmental factors driving phytoplankton variability. This preliminary assessment provides a foundation for future research exploring broader spatial and temporal dynamics in phytoplankton communities.

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