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Effect of selected environmental factors on microalgae diversity and abundance in Gazi Bay, south coast Kenya

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A R T I C L E I N F O

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A B S T R A C T

Microalgal community structure of Gazi Bay, Kenya and association with environmental factors was studied between February, June 2019 and October 2020. Non-Metric Multidimensional Scaling (NMDS) and the Rarefaction curves were used for the analysis of community structure; while Principal Component Analysis (PCA) was used to determine correlation between environmental factors with abundance and species diversity of microalgae. A total of 79 microalgae species belonging to 10 classes were recorded, with diatoms dominating in all the sampling sites. The three most abundant species of microalgae observed were *Scripssiela sp*, *Peridinium quinqeucorne*, and *Striatella sp.* There was temporal and spatial distribution of microalgae in the study area. Microalgae abundance ranged from 942 cells/L to 14,990 cells/L, with the highest mean abundance recorded in February during the dry season. Western creek indicated the highest abundance and species diversity compared to other stations at the bay with a significant difference in sample compositions ($R = 0.236$, $P = 0.002$). Pearson correlation coefficient showed that the environmental parameters; Total Dissolved Substances (0.61) and salinity (0.59) had a positive correlation with microalgae abundance. This relationship was significant at $p < 0.05$ for $N = 12$. In addition, these parameters had a strong influence on microalgae composition and abundance in the Western creek at Gazi Bay. While the microalgae in Mapononi and Doa were influenced by nitrate levels and pH respectively. Gazi Bay is recognized as an important breeding site for fisheries in the south coast of Kenya. Therefore, our findings may be useful in identifying areas within the bay that may be conserved in order to sustain the coastal community livelihood, and justify effective management of hinterland activities to minimize eutrophication.

1. Introduction

Microalgae are photosynthetic microorganisms that play an important role in nutrient cycling and conversion of carbon-dioxide in the atmosphere to useful biomass (Zongo and Boussim, 2015; NOAA, 2019; Gogoi et al., 2019). In addition, the microalgae are considered as good indicators of pollution in the aquatic environment (Nassar and Gharib, 2014; Parus and Karbowska, 2020).

They are the most abundant primary producers in aquatic ecosystems. More than 90% of the total marine primary production is contributed by the microalgae (Fondriest Environmental. Inc, 2014; Kyewalyanga, 2016; Gogoi et al., 2019). In the marine environment, primary production is dependent on microalgae biomass and composition, meaning that any disturbance on microalgae biomass and composition, may lead to the disturbance of the aquatic food web and, reduction of biological productivity (Zongo and Boussim, 2015; Gogoi et al., 2019).

These primary producers play an important role in fisheries productivity as the critical source of the aquatic food chain. This means that any change in primary production may affect fish breeding, growth and reproduction (Kyewalyanga, 2016). Fisheries resources are a source of livelihood to the coastal communities (Dzoga et al., 2019), providing not only income to coastal communities, but also the main source of proteins for the coastal inhabitants (Kyewalyanga, 2016; Musembi et al., 2019).

The abundance, composition and distribution of microalgae in marine waters are controlled by factors such as physico-chemical parameters (dissolved nutrients, light, pH, turbulence, salinity and temperature), biological parameters (predators, mortalities) and the

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water cycle (Kitheka et al., 1996; Shen et al., 2010; Zongo and Boussim, 2015; Rekik et al., 2015; (Martonen, 2017)). These physico-chemical parameters are essential for the biological functions in the marine environment. Fluctuations of the levels of physico-chemical parameters in the aquatic environment are normally caused by anthropogenic activities (Okuku et al., 2011) as well as seasonal changes (Kitheka et al., 1996; Jumba and Mwashote, 2002). As a result of such fluctuations, there is need to understand the factors that may influence the abundance, composition, distribution and, diversity of microalgae within the Gazi ecosystem.

Gazi bay is a shallow coastal water system that is considered to be an uncontaminated environment due to its remote location (Mwashote, 1997; Okuku et al., 2011). It is characterized by a vast mangrove forest cover, seagrass meadows, and coral reefs. These features are important in the productivity and coastal stabilization processes of the Bay. Coral reefs are known for supporting diversity and abundance of fish and invertebrate faunas, while mangroves and seagrass beds are important nursery and feeding grounds for fishes and crustaceans (Martens, 1996; Mwashote, 1997; Gullstron et al., 2002; Githaiga et al., 2017; Musembi et al., 2019). These ecosystems have high economic value as a source of forestry and fishery products, coral blocks for building and, seagrass farming (Kitheka and Mwashote, 2001; Githaiga et al., 2017; Musembi et al., 2019).

Artisanal fisheries are dominant in Gazi Bay and are the main source of income (Musembi et al., 2019). Microalgae are not only the indicators for fisheries productivity but are also indicators of pollution such as eutrophication. The knowledge of microalgae biodiversity, abundance, and distribution may, therefore, provide justification for the management of upstream land use activity and impact on rivers draining into the ocean. It may also rationalize the conservation of fisheries breeding areas and support the livelihood of coastal communities. Within this perspective, this study investigated the effect of selected environmental factors on abundance and diversity of microalgae in Gazi Bay, south coast, Kenya.

2. Materials and methods

2.1. Study area

Gazi Bay is found in the southern coast of Kenya about 50 km from Mombasa town (Fig. 1). It is located in the equatorial zone between 4°25′S and 39°30′E. It has a surface area of approximately 17 km^2. The bay waters are recharged by two rivers (Kidogoweni River on the north-west and Mkurumudzi River on the south-west of the bay). The rivers are seasonal and flow into the bay between October and December in the North-East Monsoon (NEM), and between March and July in the South-East Monsoon (SEM) (Mwashote, 1997; Githaiga et al., 2017; Jumba and Mwashote, 2002).

Gazi Bay is characterized by two creeks, a western and eastern creek. The western creek extends to the freshwater River Kidogoweni on the northwestern side of the bay, while on the southeastern side the eastern creek extends to R. Mkurumudzi. The climatic conditions in Gazi are influenced by the SEM and NEM winds, which blow from May to September and November to March respectively (Githaiga et al., 2017).

2.2. Sampling and analysis

The study was conducted in February and July 2019, and October

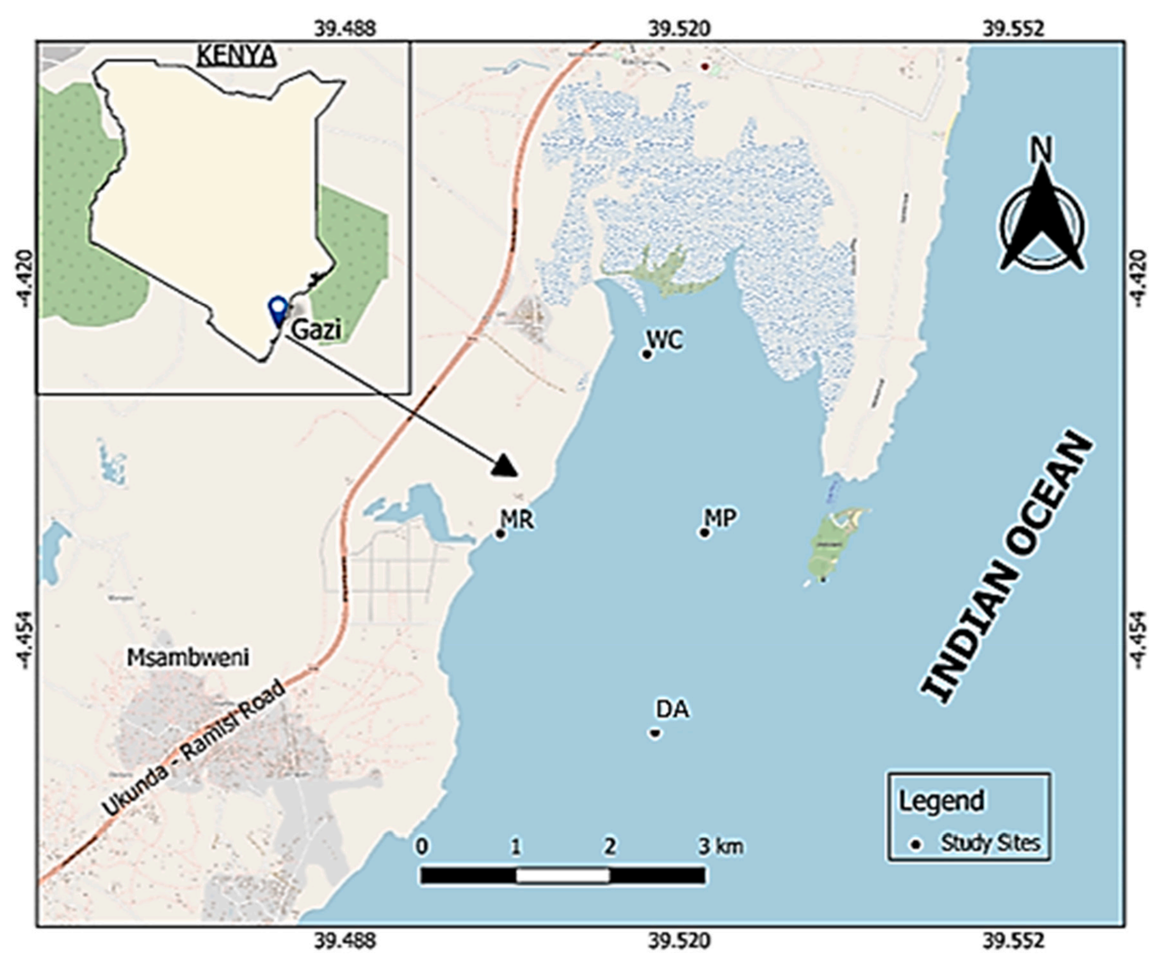

Fig. 1. Map of Gazi Bay showing sampling Sites.

2020. A total of four sites (Fig. 1) were sampled during the study which included Western creek (WC), Mapononi (MP), Doa (DA) and Mkurumudzi (MR).

2.2.1. Microalgae

Samples were collected by filtering 20 l of surface water through a 2 μm phytoplankton net. The 20 l was collected in replicates (twice) for each sampling site for each sampling month in February, July and October. The samples were preserved in acidic Lugol's solution (0.15 ml/50 ml water sample) and transported to the laboratory for analyses. 50 ml of the water sample was kept in the dark for at least 4 days for sedimentation (Soumia, 1978; Karlson et al., 2010). A sub-sample (1 ml) was placed in a Sedgewick rafter cell chamber and counted under an inverted microscope of brand Euromex model Oxion Inverso. Microalgae identification was done using the books by: Tomas (1997), Botes (2001), Hallegraeff et al. (2004) and Hoppenrath et al. (2014).

2.2.2. Water samples

The pH, salinity and temperature, were measured *in situ* using a YSI Professional multi probe meter. Water samples for nutrients (phosphates, nitrates and ammonium) analysis were collected at 0.5 m below the surface in pre-cleaned polypropylene bottles and preserved in the field with concentrated sulphuric acid (1 ml/100 ml of water) in cooler boxes at 4 °C. Nutrient analysis was done using the classical analytical methods by Parsons et al. (1984). Orthophosphate was determined using ascorbic acid method and measured calorimetrically at a wavelength of 885 nm. Ammonium-N was determined using indophenol method and absorbance read at 630 nm after at least 6 h. Dissolved (nitrate and nitrite)-N was determined using cadmium reduction method and determined calorimetrically at a wavelength of 543 nm.

2.3. Data analysis

The number of phytoplankton counted in each site was calculated using the formula below, adapted from Eaton et al., 1995

$$\text{Number of phytoplankton}\Big/\text{ml} = \frac{\text{C} \times 1000\ \text{mm}^3}{\text{A} \times \text{D} \times \text{F}}$$

where:

C = number of organisms counted per field
A = Counted area of counting chamber (Field)
D = depth of field, in mm
F = number of fields counted on the slide.

Non-Metric Multidimensional Scaling (NMDS) in Primer 7 software was used to determine microalgae composition; 1-way ANOSIM and one-way SIMPER analysis were used to show the difference in microalgae composition and determining the type of genus that contributed most to dissimilarity. The diversity of microalgae in the 4 selected study stations was determined by rarefaction curves. Principal Component Analysis (PCA) was used to determine correlation between environmental factors with abundance and species diversity of microalgae.

3. Results

3.1. Microalgae abundance and distribution in Gazi Bay

A total of 79 microalgae species that belong to 10 microalgae classes (Table 2) were observed during the study period. The microalgae abundance ranged from 942 cells/L to 14,990 cells/L (Table 1). February 2019 recorded the highest abundance of microalgae genus across all the study areas compared to July 2019 and October 2020 (Table 1). The Western Creek indicated the highest level of abundance (11,406 cells/l) than Mapononi, Doa, and Mkurumudzi (Table 1).

Table 1
Abundance (cells/l) of microalgae genus in Gazi Bay, Kwale County, Kenya.

	Mapononi	Doa	Mkurumudzi	Western Creek	Total
February 2019	14,990	3448	3917	11,406	33,761
July 2019	2365	3427	1198	5156	12,146
October 2020	4133	942	3908	4108	13,091

The class Bacillariophyceae and Dinophyceae indicated the greatest number of species observed at 43 and18 respectively (Table 2). In the class Bacillariophyceae, the most abundant species observed in Western Creek were *Navicula sp., Nitzschia sp.,* and *striatella sp.* In Mkurumudzi, *Chaetoceros sp.* was the most abundant while in Mapononi *Chaetoceros sp.* and *Nitzschia sp.* were the most abundant. In class Dinophyceae, *Protoperidinium sp.,* and Scripsiella *sp.* were abundant in Mapononi and Doa, while *Peridinium quinquecorne,* was abundant in Mapononi and Mkurumudzi (Table 2). The images of the most abundant species in Gazi bay are shown in Fig. 2.

3.2. Composition and diversity of microalgae in Gazi Bay

The richness of the genus of microalgae varied in the study areas. The Western Creek indicated the highest diversity of microalgae genus compared to Doa, Mapononi, and Mkurumidzi (Fig. 3).

Non-Metric Multidimensional (NMDS) plots showed distinct separation of Western Creek samples of microalgae collected in February, July 2020, and October 2021 in Gazi Bay (Fig. 4). 1-way ANOSIM showed significant difference in sample compositions in Western Creek station ($R = 0.236, P = 0.002$). These results were confirmed by pairwise comparison that showed a significant difference between Western Creek with Doa, Mopononi, and Mkurumidzi stations where $P < 0.05$ in all cases.

Results of SIMPER analysis (Table 3) showed that the most abundant genus contributing to the dissimilarity (54.1%) of genus composition between Mapononi and Western Creek stations were *Nitzschia, Peridinium, Leptocylindricus, camylodicus* and *cocconeis.*

3.3. Influence of environmental factors on microalgae abundance and diversity

In comparison with other stations, the Western Creek depicted the highest levels of conductivity, TDS, salinity and temperature. While the levels of phosphate, pH and nitrates were highest in Doa (Fig. 5).

The microalgae species of *Striatella sp., Nitzschia sp., Navicula sp., Thalassiosira sp.,* and *Peridinium sp.* from Western Creek were influenced by Total Dissolved Substances (TDS), Temperature and salinity (Fig. 6). While the species (*Nitzschia sp., Peridinium quinquecorne* and *Chaetoceros sp.*) from Mkurumudzi were strongly influenced by the phosphate levels in Gazi Bay. Subsequently, the most abundant microalgae species (*Perinidium quinquecorne*e, *Protoperidinium sp., Scripsiella sp., and Chaetoceros sp.)* from Doa and Mapononi were strongly influenced by pH and nitrates (Fig. 6).

Pearson correlation analysis showed that the TDS and salinity had a strong positive correlation with each other ($r = 0.98$) and a positive correlation with abundance at $r = 0.61$ and $r = 0.59$ respectively. The correlation for the TDS and salinity with abundance is significant and shows a linear relationship because the $r_{crit} = 0.576$ is less than the calculated r, at $p < 0.05$ where $N = 12$. Nitrates, phosphates and ammonium had a negative correlation with abundance. The month of February was affected by Temperature, TDS and salinity and this was noticed in all the stations except for Doa (Fig. 7).

4. Discussion

The microalgae community structure and abundance at Gazi bay demonstrated spatial and temporal variations. This is because Gazi bay is characterized by a vast mangrove forest cover, seagrass meadows and coral reefs. While these ecosystems may play a critical role in provision

Table 2
List of Microalgae species in Gazi Bay. -, + and +++ representing absent, present and abundant, respectively.

Class Microalgae	Microalgae species	Sampling Station			
		Western Creek	Mapononi	Doa	Mkurumudzi
Bacillariophyceae					
	1. Achnanthes sp	+	−	−	−
	2. Actinoptychus sp	+	+	−	−
	3. Amphora sp	+	−	+	−
	4. Asterionellopsis sp	−	−	−	+
	5. Bacillaria sp	+	+	+	+
	6. Bacteriastrum sp	−	+	+	+
	7. Biddulphia sp	+	−	+	+
	8. Bleakeleya sp	+	+	+	−
	9. Campylodiscus sp	+	−	+	−
	10. Chaetoceros sp	+	+ ++	+	+ ++
	11. Cocconeis sp	+	+	+	−
	12. Cyclotella sp	−	+	+	+
	13. Cymatopleura sp	+	−	−	−
	14. Dactyliosolen sp	−	−	+	+
	15. Diploneis sp	+	+	+	+
	16. Entomoneis sp	+	+	+	+
	17. Guinardia sp	−	−	+	+
	18. Guinardia striata	−	−	+	−
	19. Gyrosigma sp	+	+	−	−
	20. Haslea sp	+	+	+	+
	21. Hemiaulus sp	−	−	+	−
	22. Lauderia sp	−	−	+	−
	23. Licmophora sp	+	+	−	+
	24. Lyrella sp	+	−	−	−
	25. Melosira sp	+	−	+	+
	26. Meuniera sp	+	−	−	−
	27. Navicula sp	+++	+	+	+
	28. Nitzschia sp	+++	+ ++	+	+
	29. Nitzschia closterium	+++	+	+	+
	30. Nitzschia longissima	+	−	+	−
	31. Nitzschia reversa	+	+	+	−
	32. Nitzschia sigma	+	+	+	+
	33. Plagiodiscus sp	+	−	−	−
	34. Pleurosigma sp	+	+	+	+
	35. Pseudo-nitzschia	+	+	+	−
	36. Rhizosolenia sp	−	+	+	+
	37. Skeletonema sp	−	−	+	+
	38. Streptotheca sp	+	−	+	−
	39. Striatella sp	+++	−	+	−
	40. Striatella unipuncta	−	−	+	−
	41. Surirella sp	+	+	+	−
	42. Thalassionema sp	+	+	−	+
	43. Thalassionema nitzschioides	−	−	−	+
	44. Triceratium sp	+	−	−	−
Dinophyceae					
	1. Alexandrium sp	+	+	+	−
	2. Amphidinium sp	+	−	−	−
	3. Ceratium furca	−	+	+	+
	4. Ceratium fusus	−	+	+	−
	5. Gambierdiscus sp	−	+	+	−
	6. Goniodoma sp	−	+	+	+
	7. Gonyaulax sp	+	+	+	+
	8. Gymnodinium sp	−	+	−	−
	9. Ostereopsis sp	+	−	+	+
	10. Peridinium sp	+	+	+	+
	11. Prorocentrum lima	+	+	+	+
	12. Prorocentrum micans	−	+	+	+
	13. Protoperidinium	+	+++	+++	+
	14. Peridinium quinquecorne	+	+ ++	+	+ ++
	15. Pyrocystis sp	+	−	−	−
	16. Pyrocystis noctiluca	+	−	−	−
	17. Pyrophacus sp	−	+	+	+
	18. Scrippsiella sp	+	+ ++	+ ++	+
Coscinodiscophyceae					
	1. Cerataulina sp	−	−	+	−
	2. Corethron sp	−	−	+	+
	3. Coscinodiscus sp	+	−	+	+
	4. Thalassiosira sp	+++	+	+	+
Mediophyceae					
	1. Leptocylindrus sp	−	+	+	+
Cyanophyceae					
	1. Anabeana sp	+	−	−	−

(*continued on next page*)

Table 2 (*continued*)

Class Microalgae	Microalgae species	Sampling Station			
		Western Creek	Mapononi	Doa	Mkurumudzi
	2. Lyngbya sp	+	–	–	+
	3. Oscillatoria sp	+	+ ++	+	+
	4. Phormidium sp	–	–	–	+
	5. Spirulina sp	–	–	–	+
	6. Trichodesmium sp	+	+	+	+
Fragilariophyceae					
	1. Fagilaria sp	+	–	+	+
	2. Tabellaria sp	+	–	+	+
Euglenophyceae					
	1. Eutreptiella sp	–	+	–	+
Chlorophyceae					
	1. Pediastrum sp	+	+	+	+
Dictochophyceae					
	1. Dictyocha sp	–	+	–	–
Zygnematophyceae					
	1. Mougeotia sp	–	+	–	+

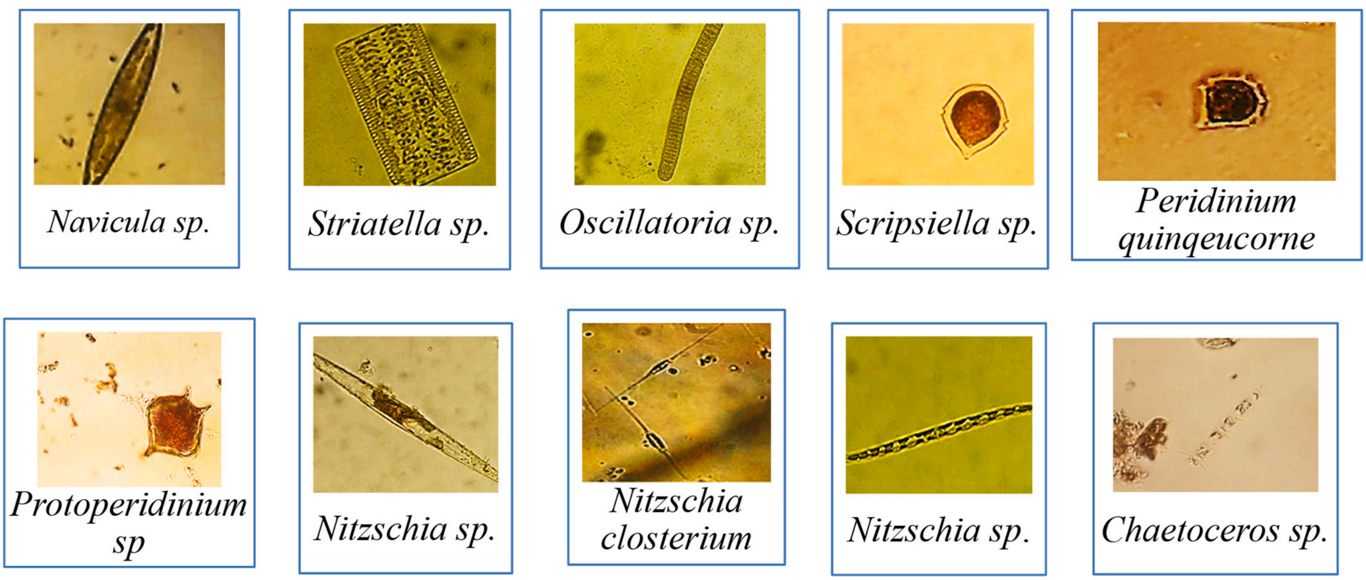

Fig. 2. Images of the most abundant microalgae species from Gazi bay as viewed under microscope at 40× magnification.
(Source: Pictures shot from an inverted microscope of brand Euromex model Oxion Inverso at the Kenya Marine and Fisheries Research Institute.)

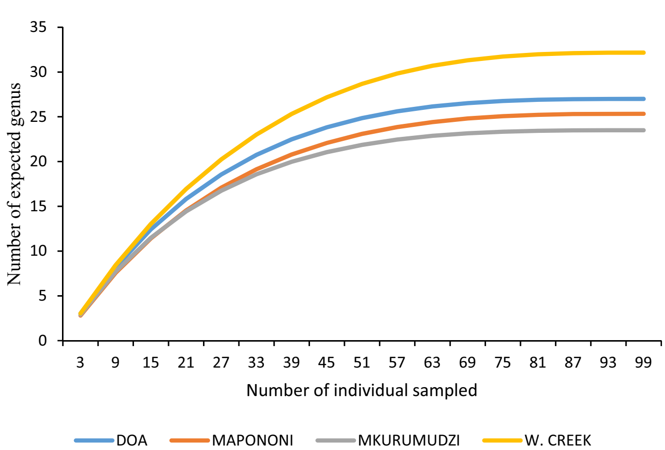

Fig. 3. Rarefaction curves showing the total number of genus collected in different stations with the increase of sample size of micro algae in Gazi, south coast Kenya.

of particulate organic matter and nutrients, the abundance, spatial and temporal distribution of microalgae in the bay may also be influenced by seasonal rivers. Gazi Bay is characterized by freshwater discharge from R. Mkurumudzi and R. Kidogoweni which has an impact on the biological, physical and chemical parameters (Kitheka, 1996; Mwashote, 1997). Furthermore, Saifullah et al. (2016) observed that mangrove ecosystems are important medium for phytoplankton succession. The latter study also linked the abundance and diversity of microalgae with the presence of nutrients and physicochemical parameters provided by coastal ecosystems such as mangroves.

The diatoms were the most abundant group of microalgae in Gazi Bay and they were represented by class Bacillariopheae, Coscinidiscophyceae, Fragillariophyceae and Mediophyceae, which could be attributed to the fact that they can endure highly changing hydrographical conditions (Gowda et al., 2001; Yusuf, 2020). The Western Creek was dominated by species *Navicula sp., Nitzschia sp.,* and *striatella sp* forming the most diversified microalgae genus in the bay. The high abundance of *Navicula sp.* and *Nitzschia sp* in this area indicated that the area was rich in nutrients and organic matter. This observation agreed with the findings by Yusuf (2020) who showed that species *Nitzchia sp.* and *Navicula sp* are usually present in eutrophic environments. High diversity in the Western Creek may be due to the presence of seagrass meadows and the

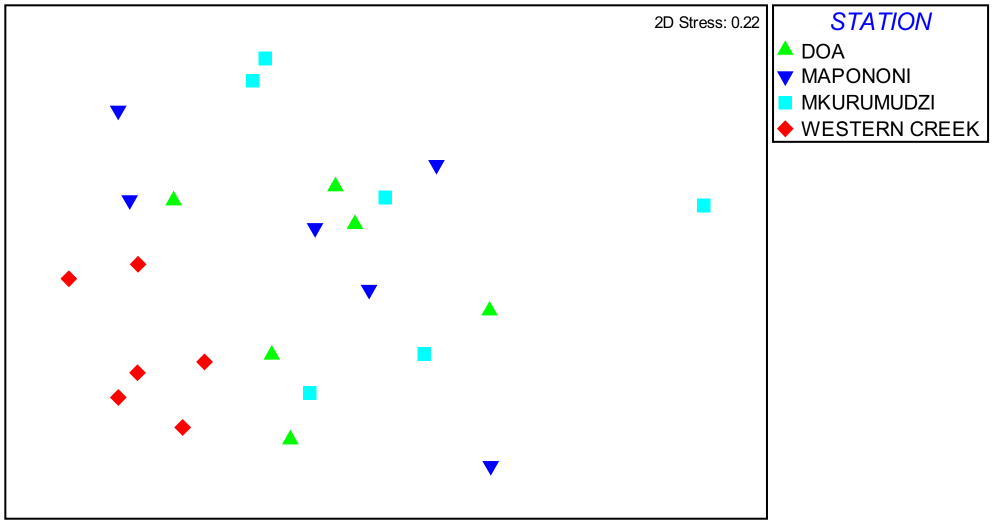

Fig. 4. Plots for Non-Metric Multidimensional Scaling (NMDS) showing distinct separation of Western Creek station for sampled of microalgae collected in February, July, and October in Gazi, South coast Kenya.

Table 3
SIMPER results indicating the most abundant genus contributing to the dissimilarity (54.1%) of genus composition between Mapononi and Western Creek stations.

	Mapononi	Western Creek		
Genus	Average Abundance	Average Abundance	Average Dissimilarity	Contribution (%)
Nitzschia	8.94	7.45	2.56	4.54
Nitzschia	3.09	2.29	1.74	3.09
Peridinium	5.56	2.46	1.57	2.79
Leptocylindrus	3.11	0	1.55	2.76
Campylodiscus	0	2.89	1.45	2.57
Cocconeis	0.54	2.89	1.24	2.2

mangrove forest. Indeed, studies have shown that seagrass meadows support a high biodiversity in marine ecosystems (Githaiga et al., 2017; Short et al., 2007; Reynolds, 2018). They are considered to be highly productive areas and are important in nutrients cycling.

The most abundant species in class Dinophyceae were the *Pererinidium sp., Protoperidinium sp., Peridinium quinqucorne and Scripsiella sp.* This was evident across all the study areas. Dinophyceae class has been associated with toxic algal blooms in many countries (López-Flores et al., 2006*;* Ogongo et al., 2015; Alkawri et al., 2016). *Peridinium quinquecorne* has been previously associated with death of fish in Yemen (Alkawri et al., 2016). However, their concentration in Gazi bay was low and could not be a threat to the environment. This is due to the fact that the bay is considered to be a clean and healthy environment with little contamination (Okuku et al., 2011).

The abundance of microalgae in the bay was found to be highly influenced by seasonal changes, which was attributed to the discharge of freshwater by seasonal rivers, similar observations was made by Kitheka et al. (1996) and Mwashote (1997). During the dry season (February), microalgae abundance was high and this could be attributed to high microalgae productivity as a result of intense sunlight and high temperature (Yusuf, 2020). Moreover, the concentration of nutrients in water increases with decrease in water level due to the increase in temperature, and enhanced evaporation during the dry season. On the contrary, during the wet season (October), the bay experienced dilution of essential nutrients especially from surface water runoff and increased inflow of water from River Kidogoweni near the Western Creek and River Mkurumudzi (Kitheka, 1996; Mwashote, 1997; Ohowa et al., 1997; Kitheka and Mwashote, 2001). Consequently, this would contribute to turbidity and reduce the availability of sunlight, resulting in low abundance in microalgae population (Yusuf, 2020). There is need to note that, however, phytoplankton abundance in Gazi bay was considerably lower compared to other areas in the coastal region of Kenya, such as Tudor Creek (5.23×10^4 cells/L) and Mtwapa Creek (6.04×10^4 cells/L) (Kiteresi et al., 2019). This makes Gazi Bay to be less productive when compared to Mtwapa and Tudor Creeks (Veronica et al., 2014).

It was previously reported that the inputs from the two seasonal rivers R. Kidogoweni and Mkurumudzi at Gazi Bay affect nutrient input and changes in the salinity (Ohowa et al., 1997; Jumba and Mwashote, 2002; Githaiga et al., 2017). The drainage basin of the two seasonal rivers, extends into the coastal ranges of the Shimba Hills, where the major economic activity is farming with intensive fertilizer application. In addition, there is a lot of usage of river water by the community and titanium mining activities along R. Mkurumudzi (Mwashote, 1997; Kitheka and Mwashote, 2001; Mwashinga et al., 2019). The river discharge results in the input of considerable amount of nutrients, derived from decayed vegetation, animal waste and runoff from farmland, into the Bay. However, lower levels of nutrients and microalgae abundance were recorded in Gazi Bay compared to other areas in the coast region (Okuku et al., 2011; Pole et al., 2015). This was suggested to be the result of the high exchange rate between offshore and inshore waters and the short residence time of the water in the bay. In addition, it was further noted that mangrove forest, seagrass meadows and coral reefs could act as sources and sink of most nutrients (Mwashote, 1997; Ohowa et al., 1997). Therefore, despite the high level of nutrients discharge from the rivers, no eutrophic conditions prevailed in the bay. These factors thus made Gazi Bay to be considered an unpolluted environment (Mwashote, 1997; Okuku et al., 2011).

There was a positive correlation between TDS, Temperature and salinity in Gazi bay. The TDS, Temperature and salinity had a strong influence on species from the Western Creek. In addition, high water temperature enhances the rate of photosynthesis and increases microalgae reproduction (Saravanakumar et al., 2008; Nyakeya *et al* Reynolds, 2018; Gogoi et al., 2019). The microalgae species from Mkurumudzi were also strongly influenced by the phosphate levels in Gazi Bay. The inputs of phosphates in Mkurumudzi are through discharge by the seasonal rivers (Mwashote, 1997; Kitheka and Mwashote, 2001).

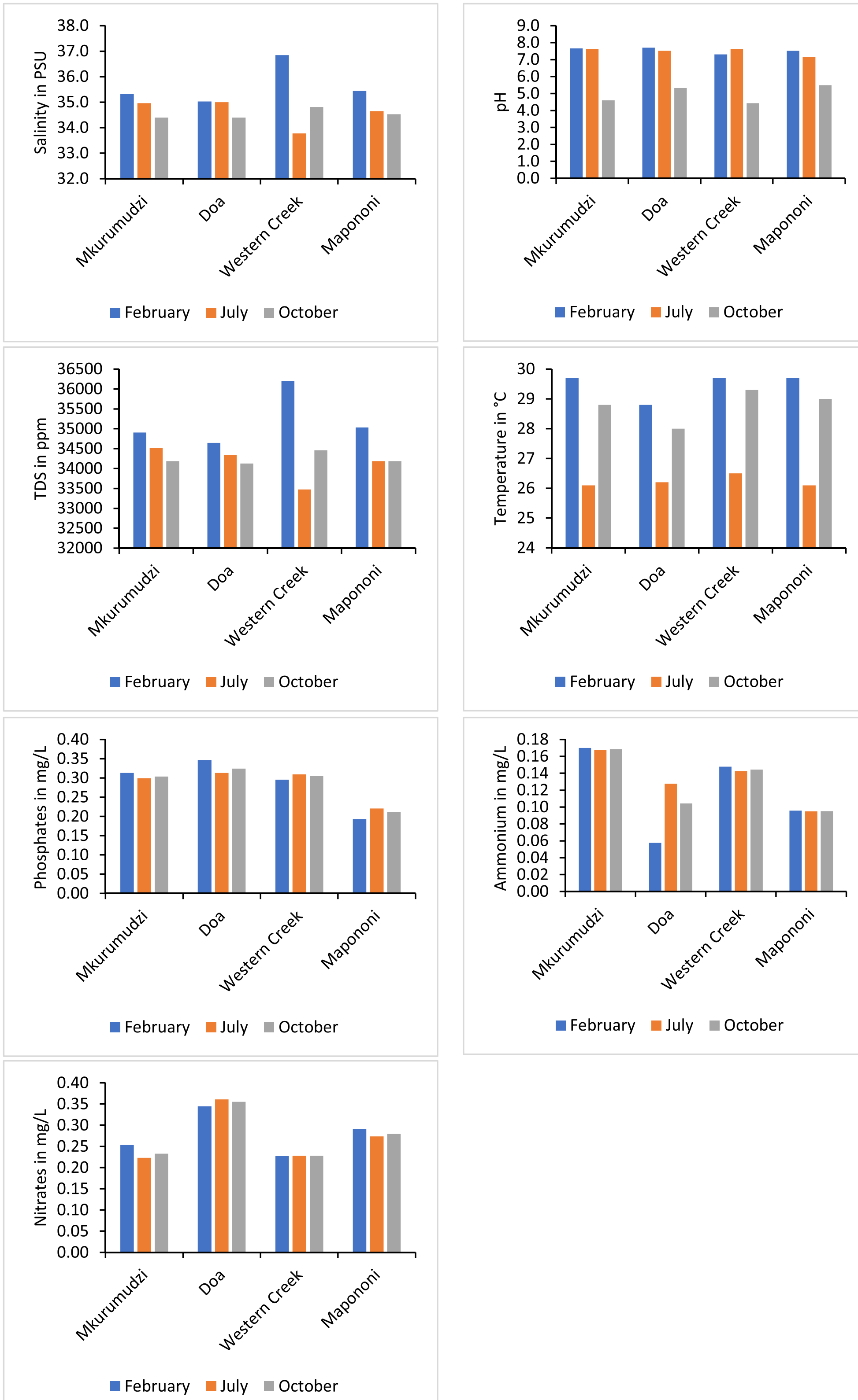

Fig. 5. Influence of environmental parameters on abundance and diversity of microalgae in Gazi Bay, Kenya.

5. Conclusion

Gazi Bay in the south coast of Kenya hosts a variety of microalgae species that are significant to the productivity of the area. The abundance, distribution, and composition of the micro algae in the bay are strongly influenced by physio-chemical parameters such as Total Dissolved Substances (TDS), temperature, and salinity. As a result, some areas in the bay are richer in microalgae species than others. The Western Creek of Gazi Bay has the most diversity of microalgae species, thus, making it the most favorable area for fisheries conservation as a

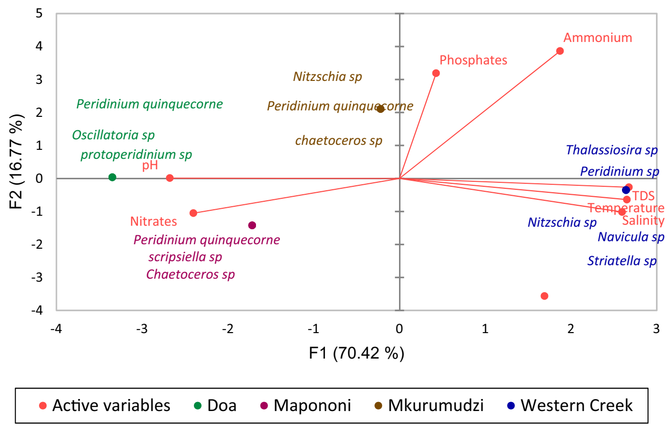

Fig. 6. Principal Component Analysis showing the effect of physicochemical parameters on microalgae species in Gazi Bay.

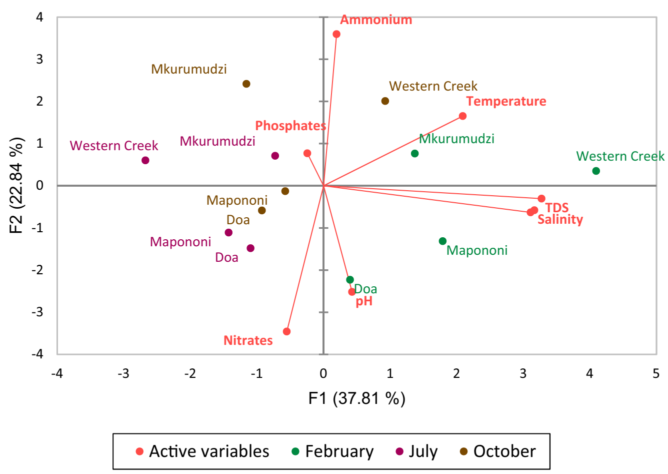

Fig. 7. Principal Component Analysis showing physicochemical parameters distribution in Gazi Bay.

breeding area. Changes of physio-chemical parameters which in turn affect the microalgae species, are influenced by anthropogenic activities, inland. River Mkurumudzi and R. Kidogoweni could be associated with the transportation of nutrients from the hinterland into the bay. The catchment areas of the rivers are characterized by extensive mining and agricultural activities. This calls for urgent conservation of the Western Creek area of the Gazi Bay, concomitant with proper management of the inland activities. Such interventions could minimize eutrophication, and enhance fisheries productivity.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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