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The Influence of Land Based Activities on the Phytoplankton Communities of Shimoni-Vanga system, Kenya

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ABSTRACT: Phytoplankton communities play a significant role in the oceanic biological pump by forming the base of the trophic structure. Increase in nutrients loading affects spatial and temporal distribution of phytoplankton. This study examined the phytoplankton community structure and ecological indices in relation to nutrients dynamics in both estuarine and oceanic areas of Ramisi-Vanga systems along the Kenyan coast. Surface water samples were collected and analysed for nutrients (PO_4^{3-}-P, NO_3^--N and NH_4^+-N) and phytoplankton abundance and community structure. This study reported very diverse phytoplankton community structure consisting of 88 taxa that were dominated by *Chaetoceros sp.*, *Coscinodiscus sp.*, *Nitzschia sp.*, *Pseudo-nitzschia sp.*, *Alexandrium sp.*, *Protoperidium sp.* and *Prorocentrum sp* that are among the potentially harmful algae. Diatoms were the most abundant taxa in Ramisi-Vanga system. Phytoplankton abundance was found to be higher in the estuarine systems (1182.06±149.14 cells/L) as compared to the oceanic systems (551.99±166.70 cells/L) with high abundance observed in May for oceanic and estuarine systems. Shannon Weiner's species diversity index was greater than 2 in both oceanic and estuarine systems. Phytoplankton species' abundance, composition and diversity were found to be influenced by the availability of NH_4^+-N, NO_3^--N and PO_4^{3-}-P. Phytoplankton cell density was below 4000 cells/ L, thus, this study has classified Ramisi-Vanga system as an oligotrophic system implying that the current level of land based activities are not having significant impacts on the phytoplankton communities.

Key words: Phytoplankton, Ecological indices, Diatoms, Dinoflagellates, Nutrients, Flagellates

INTRODUCTION

Phytoplankton form the base of the marine food chain and as such sustains diverse assemblages of species ranging from microscopic zooplankton to large marine mammals, seabirds and fish. With just a proportion of less than 1% of the earth's photosynthetic biomass, marine phytoplankton is responsible for more than 45% of the planet's annual net primary production (Field *et al.*, 1998). Indeed, phytoplankton is the fuel on which marine ecosystems run (Falkowski, 1994; Huppert *et al.*, 2002) through conversion of inorganic compounds to high- energy rich organic compounds (Lalli and Parsons, 1993).

Coastal environments differ in their physical and hydrographic properties such as depth, tidal mixing or nutrient loadings and these differences can lead to complex phytoplankton dynamics (Cebrian and Valiela, 1999). This is further complicated by the fact that water quality in coastal areas worldwide is constantly changing in response to rapidly increasing land based activities such as fertilizer application, land clearing and waste discharge. The increasing land based activities are affecting the spatial and taxonomic distribution of this important oceanic biota as well as their photosynthetic activity. The role of land based activities is both direct, through changes in ocean chemistry and indirect through climatically induced alterations in the ocean's physical circulation (Sarmiento *et al.*, 1998).

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Plankton are relatively short lived and are known to respond quickly to environmental perturbations such as point source pollution (Osore, 2003). Zingone *et al.*, (1995) also reported that phytoplankton periodicity is affected by the different sources of land-derived nutrients and by their dilution patterns. Thus, phytoplankton communities could be considered as recurrent organized systems of organisms responding in a related way to changes in the environment (Legendre and Legendre, 1998). The factors that influence water quality of the Ramisi-Vanga systems are natural processes such as rivers' freshwater supply and land based activities related to changes in land use. In this paper, we briefly examine the controls of water chemistry on plankton community structure (mainly ecological indices) with an emphasis on the effects of nutrients dynamics.

MATERIALS & METHODS

This study was conducted in Ramisi-Vanga system located in the southern part of the Kenyan coast (Fig. 1). Sampling was carried out in the estuarine and oceanic systems. Ramisi-Vanga system is a low-lying coastal plain submergent complex (below 30m contour) dominated by an extensive cover of mangrove forest, intertidal areas covered with sea grass beds and shallow water lagoons harboring the coral reefs. These critical systems are inter-linked through exchange of water, nutrients and carbon by the tidally controlled circulation and river discharge (UNEP, 1998). In this study, rivers Umba, Ramisi and Mwena were considered as estuarine sites characterized by mangrove ecosystems with freshwater input whereas Wasini, Kima, Sii Kiromo and Shimoni were considered oceanic sites. The sampling stations were River Umba (U1, U2 and U3); R. Ramisi (R1, R2 and R3); R. Mwena (M1, M2, M3 and M4); Wasini (W1, W2 and W3); Kima (K1, K2 and K3), Sii Kiromo (Si1, Si2 and Si3) and Shimoni (S1, S2 and S3) (Fig. 1). Samples were collected from the stations in February, March, May, June and August in 2009. The choice of sampling periods was based on past study elsewhere that had shown that undisturbed successions of phytoplankton community approach competitive exclusion and ecological equilibrium after approximately 35 to 60 days (Reynolds, 1993). The mid-point of this range, 47.5 days is roughly in agreement with the sampling intervals adopted. Although phytoplankton populations are not strictly periodic and may exhibit sudden collapses that we may have sometimes missed, this analogue does at least provide a rough justification for the sampling frequency that was adopted for this study.

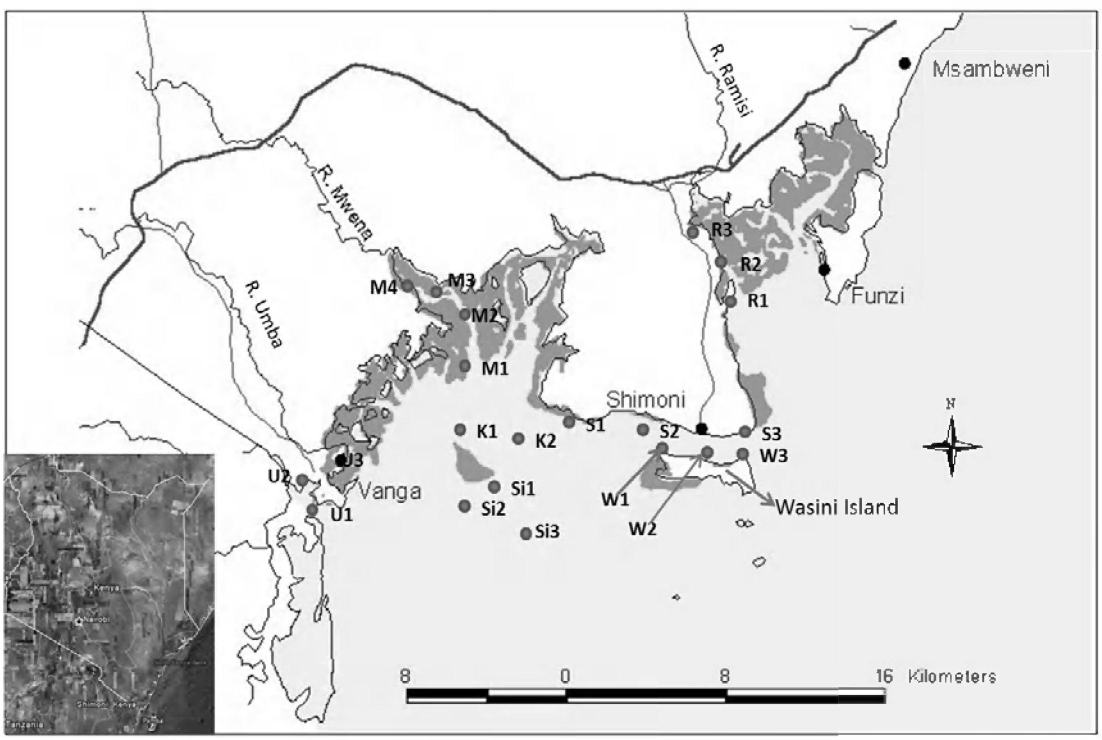

Fig. 1. Map showing the sampling stations

Qualitative concentrated samples were collected by filtering 20 liters of water (collected from just below the water surface) through a 20 μm phytoplankton net. For numerical analysis and species identification, 250 ml of water samples were fixed in 5% Lugol's solution and kept undisturbed for three to four days till complete sedimentation was achieved. The samples were further concentrated to a volume of 50 ml and 1 ml (in triplicate) of the concentrated sample transferred into a Sedgewick Rafter counting cell mounted on an inverted compound microscope (Leica DMIL) and counting of phytoplankton cells carried out in 100 squares of the cell chosen randomly. The results were expressed as the number of cells per litre. The cell counts were used to compute the cell density using the Striling, (1985) formula where the plankton density was estimated by:

$$N = (A * 1000 * C) / (V * F * L)$$

Where N = No of plankton cell per litre of original water,
A = Total No. of plankton counted,
C = Volume of final concentrate of the sample in ml;
V = Volume of a field in mm^3
F = No. of fields counted
L = Volume of original water in litre.

Estimation of the phytoplankton abundance was carried out by sedimentation method (Utermöhl, 1958). Phytoplankton were identified using identification keys by Carmelo, (1997) and Botes, (2003). Whenever possible, identification was carried out to the species level, although in some cases identification was only possible to genus level.

Nutrients samples were collected in acid prewashed polyethylene bottles from the surface and stored frozen prior to analysis. The methods described by Parsons *et al.*, (1984) and APHA, (1998) were used to analyze ammonium (NH_4^+-N), Nitrate + Nitrite {(NO_3^- + NO_2^-)-N} and orthophosphate (PO_4^{3-}-P) in the water samples. All the chemicals used for analysis were of analytical grade and all the glassware were pre-washed in acid before use. PO_4^{3-}-P was determined using the ascorbic acid method at 885 nm. NH_4^+-N was determined using the indophenol method at 630 nm after at least six hours. Dissolved (NO_3^- + NO_2^-)-N was determined using cadmium reduction method and measured colorimetrically at 543 nm. Analytical quality check was carried out by running procedural blanks alongside the samples as well as through the use of a check standard.

Phytoplankton data were expressed as ecological indices to describe the phytoplankton community structure, eutrophication and water quality. The indices used were species richness, abundance (cell density), Shannon Wiener's diversity indices and Pielou's evenness indices.

Species richness was taken as the total number of taxa found in a sample. Shannon Wiener's species diversity index (Shannon, 1948) was calculated from the taxa and abundance (cells L^{-1}) data for each site on each sampling occasion. Shannon-Wiener's species diversity index formula used is described below

$$H = -\Sigma \, ni/N \log2 \, ni/N;$$

Where: n*i* is the number of individuals of the *i*th species
N is the total number of individuals.
Pielou evenness index was calculated as follows;

$$E = H/\ln S;$$

Where: H is the Shannon Wiener's species diversity index and S is the species richness (number of species).

Phytoplankton and nutrients data were categorized as estuarine and oceanic and subjected to Shapiro Wilk normality test and Levene's homogeneity of variance test. Phytoplankton data that were not normally distributed were log transformed to improve the normality of the data. Kolmongorov-Smirnov goodness of fit test for normality was not significant in both the estuarine and oceanic systems ($p>0.05$). This validated the phytoplankton data for parametric analysis using one way ANOVA. Species abundance, diversity, richness and evenness indices that showed significant difference among sites and months were further subjected to post hoc comparisons using Turkey Honest Significant Difference test. Pearson's correlation coefficient was used to test for any relationships between nutrients and phytoplankton indices.

RESULTS & DISCUSSION

A total of 88 taxa were encountered in this study. 79 taxa were recorded in the estuaries whereas 75 taxa were present in the oceanic systems. Phytoplankton were grouped either as diatoms, dinoflagellates, flagellates or 'others' group (to include all the other groups rather than the three major groups). Generally, the diatoms were the most diverse group with a total of 45 taxa, followed by the dinoflagellates, 'others' groups and flagellates with 20, 17 and 6 taxa respectively (Table 1). Temporally, the abundance of diatoms dominated the rest of the phytoplankton groups throughout the study.

In the estuarine system, the diatoms were the most abundant group with a mean ± SE of 1858.65±367.61

Table 1. Phytoplankton genera for the phytoplankton groups

Groups	Phytoplankton Taxa	
	Estuarine	Oceanic
Diatoms	Guirnadiasp, G. delicatula, Licmophoraehrenbergii, Asterionellopsisgracilus, Thalassionemasp, T. nitzschioides, Dactyliosolenphuketensis, Dactyliosolensp, Melosirasphaerica, Melosirasp, Actinoptychussplendens, Fragilariastriatula, Astrerionellasp, A.bleakeleyi, Asteriomphalussp, Bacillariapaxilifera, Bacteriastrumsp, Bleakleleyanotata, Ceratualinasp, Chaetocerossp, Coscinodiscussp, Cyclotellasp, Cylindrothecaclosterium, Cymatosirasp, Ditylumbrytwelli, Eucampiasp, E. zoodiacus, Fragilariopsissp, Hasleasp, Hemidiscuscornifermis, , Lauderiasp, Leptocylindrussp, , Naviculasp, Nitzschiasp, N. sigma, N. closterium, N. longisima, Odontellasp, Pleurosigmasp, P. directum,Planktoniellasp, Pseudo-nitzschiasp, Rhizosoleniasp, Stephanopyxisturris, Skeletonemasp, Striatellaunpunctata, , Thalassiosirasp, andThalassiothrix sp.	Guirnadiasp, G.delicatula,Licmophoraehrenbergii, Asterionellopsisgracilus, Thalassionemasp, T. nitzschioides, Dactyliosolenphuketensis, Dactyliosolensp, Melosirasphaerica, Melosirasp, Actinoptychussplendens, Astrerionellasp, A.bleakeleyi, Asteriomphalussp, Bacillariapaxilifera, Bacteriastrumsp, Bacteriosirasp, Bellerocheasp, Bleakleleyanotata, Ceratualinasp, Chaetocerossp, Corethronsp, Climocodiumsp, Coscinodiscussp, Cyclotellasp, Cylindrothecaclosterium, Cymatosirasp, Ditylumbrytwelli, Eucampiasp, E. zoodiacus, Fragilariopsissp, Hasleasp, Hemidiscuscornifermis, Hemiaulussp, Lauderiasp, Leptocylindrussp, Lithodesmiumsp, Nitzschiasp, N. sigma, N. closterium, N. longisima,Naviculasp, Odontellasp, Pleurosigmasp, P. directum, Pseudo-nitzschiasp, Striatellaunpunctata,Rhizosoleniasp, Skeletonemasp, Synedropsissp, Thalassiosira sp. andThalassiothrix sp.
Dinoflagellates	Gonyaulaxsp,G. cysts, Ceratiumsp, C. furca, C. fusus, C. trichoceros, Pyrocystisnoctiluca, Noctilucascintillans, Scripsiellatrochoidea,Gambierdiscustoxicus, Alexandriumsp, Amphisoleniasp, Azpeitiasp, Dinophysissp, Gyrodiniumsp, Gymnodiniumsp, Ostreopsissp, Oxytoxumsp, Peridiniumsp, Polykrikossp, Preperidiniumsp, ProrocentrumspandProtoperidinium sp.	Gonyaulaxsp,G. cysts, Ceratiumsp, C. furca, C. fusus, C. trichoceros, Pyrocystisnoctiluca, Noctilucascintillans, Gambierdiscustoxicus, Scripsiellatrochoidea, Alexandriumsp, Amphisoleniasp, Dinophysissp, Goniodomasp, Gymnodiniumsp, Gyrodiniumsp, Ostreopsissp, Oxytoxumsp, Peridiniumsp, Polykrikossp, Preperidiniumsp, ProrocentrumspandProtoperidinium sp
Flagellates	Chaonoflagellideasp, Euglena sp, E. volvox, Eutreptiellagymnastica, Fabricapsasp, Phacuscontortus, Trachelomonasbacilifera, T. cylindriicaand T. grandis.	Chaonoflagellideasp, Eutreptiellagymnastica, Trachelomonascylindriicaand T. grandis.
'Others' group	Anabaena sp, Chattonellasp, Chlorococcales-order, Chlorophyceasp, Chrysophyceasp, Coccolithophorids, Cornutasp, Cosmariumcontractum, Cyanobacteria sp, Dictyochaoctonaria, Lyngbyasp, Oscillatoriasp, Pediastrumsp, Prymnesiumsp, ScenedesmusspandVolvocale sp.	Chlorophyceasp, Chrysophyceasp, Coccolithophorids , Cornutasp, Cynobacteriasp, Dictyochaoctonaria, Oscillatoriasp, Osmothescussp, Prymnesiumsp, ScenedesmusspandVolvocalesp

cells/L. Diatoms showed a declining trend from February to March and an increase in cell density in May (Fig. 2). The months of June and August had the highest cell density of diatoms (>3000 cells/L). In general, the most abundant diatom taxa in the estuarine systems were *Coscinodiscus sp* (149.95±24.07 cells/L) and *Nitzschia sp* (116.42 ± 83.155 cells/L). The month of February had the highest cell densities of (*Coscinodiscus sp*, *Thalassiosira sp* and *Actinoptychus sp.*). *Coscinodiscus sp.* was the most abundant in May, June and August.

Generally, *Coscinodiscus sp* had the highest cell density (145.19±43.73 cells/L) in R. Umba. *Pseudo-nitzschia sp.* was the most abundant taxa in March. On the spatial scale, *Pseudo-nitzschia sp.* dominated in rivers Ramisi and Mwena whereas *Nitzchia sp.* dominated in rivers Mwena and Umba. Diatoms dominance was observed over the studied period with peak abundances in June and August and the lowest abundance in March (Fig. 2). The diatoms abundances significantly differed (F=11.85; p<0.01) between the months with low precipitation (February and March) and high precipitation (May, June) as shown in Fig. 5.

Dinoflagellates were the second most abundant group with a mean of 395.21 ± 53.04 cells/L. The two most abundant taxa in this group were *Protoperidinium sp* (113.42±13.52 cells/L) and *Prorocentrum sp* (88.73 ± 13.57 cells/L). *Protoperidinium sp.* was most abundant in February, March, May and June. It also had the highest cell densities in R. Umba (118.37 ±19.73 cells/L). *Prorocentrum sp.* was the second dominant taxa in March, May and June. The temporal differences in dinoflagellates abundance was found to be significant (F= 2.91; p<0.05).

The others' group, with a mean of 126.04±29.65 cells/L had high abundance in comparison to the flagellates with a mean of 54.45±22.40 cells/L (Fig. 2). Cyanobacteria (116.19±58.55 cells/L) and *Oscillatoria sp.* (64.59±15.87 cells/L) were the most abundant taxa in this group. Cyanobacteria were only abundant in February and March in both rivers Ramisi and Mwena

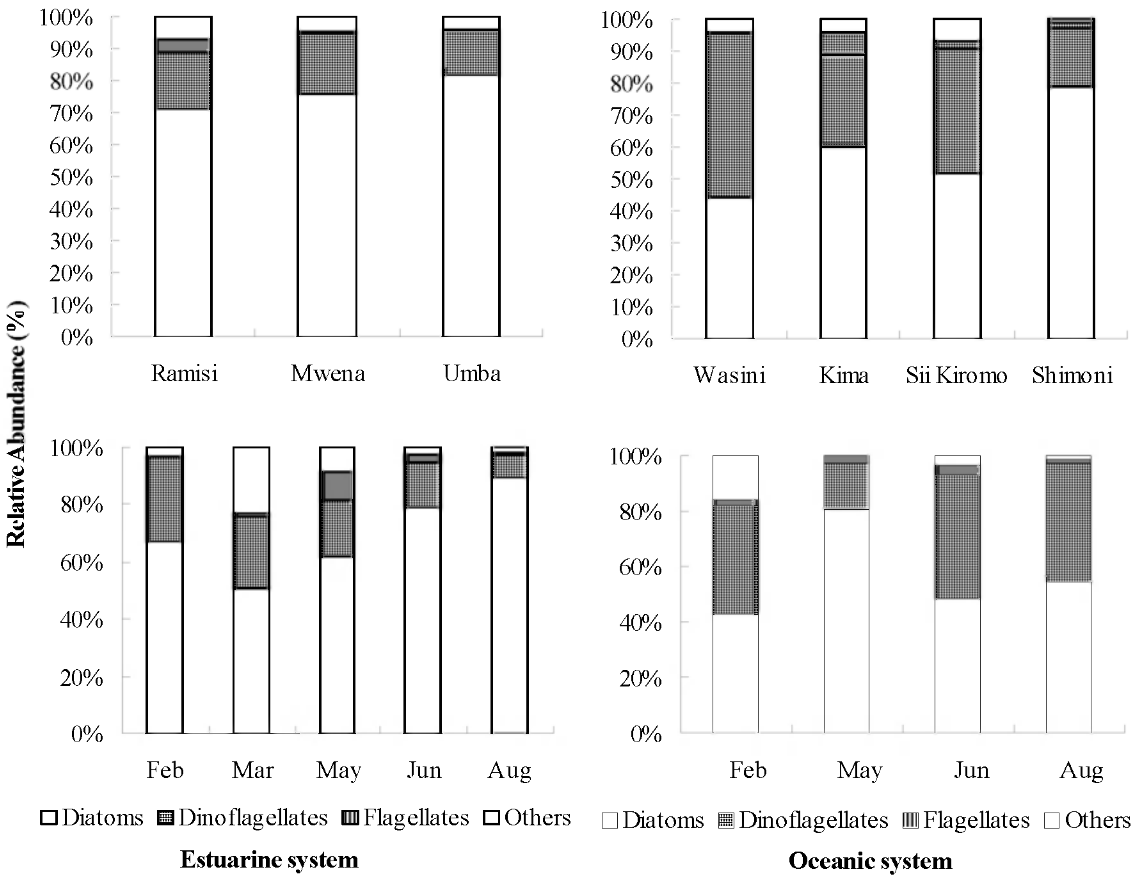

Fig. 2. Temporal and spatial distribution of phytoplankton groups within the estuarine and oceanic system of RamisiVanga

while *Oscillatoria sp.* was most abundant in May, June and August. In general *Oscillatoria sp.* was also the most abundant taxa in river Umba (103.25 +34.35 SE cells/L). The abundance of 'others' in the estuarine system increased in May and June (Fig. 2). The flagellates with the least species richness in this study were the least in abundance in both estuarine and oceanic systems.

Generally, the oceanic system abundances were lower than in the estuarine system (Fig. 3). Leading in abundance in the oceanic system were *Alexandrium sp* (110.97±16.34 cells/L), *Chaetoceros sp* (102.34±28.63 cells/L) and *Protoperidinium sp* (65.40±8.75 cells/L). Diatoms were still the most abundant group in the oceanic systems (Fig. 2) with *Chaetoceros sp* (102.34±28.63 cells/L), *Pseudo-nitzchia sp* (59.03±17.74 cells/L) and *Rhizosolenia sp* (59.93±13.17 cells/L) dominating. *Rhizosolenia sp* were most abundant in Sii Kiromo (66.08±10.59 cells/L) and Kima (53.65±22.11 cells/L) whereas *Chaetoceros sp* dominated in Wasini (78.19±22.03 cells/L). *Rhizosolenia sp.* had highest cell densities in June (55.02±6.36 cells/L). Generally, *Chaetoceros sp* dominance was also observed in August (194.85±33.85 cells/L) and May (905.11±161.97 cells/L) whereas *Pseudo-niztschia sp* dominated in February (17.67±3.37 cells/L) and May (874.62±32.39 cells/L).

The dinoflagellates abundance was lowest in February (Fig. 2). *Protoperidinium sp.* was the most abundant taxa among the dinoflagellates in Sii Kiromo (58.47±8.24 cells/L) and Shimoni (148.25±69.90 cells/L). In general, *Protoperidinium sp.* also dominated in February (14.93±3.74 cells/L) and May (407.77±87.65 cells/L). Spatially, Wasini area had high abundance of *Alexandrium sp.* (194.87±24.76 cells/L). Generally, *Alexandrium sp* also dominated in June (117.11±20.23 cells/L) and August (131.61±23.83 cells/L). The temporal variation of dinoflagellates abundance were significant ($F=23.01$; $p<0.01$).

The flagellates were mostly dominated by the *Choanoflagellidea sp.* both on spatial and temporal scales. In this group, *Coccolithophorids* had high abundance in Wasini and Shimoni areas (6.83±1.96 cells/L and 24.44±7.06 cells/L respectively).

Nutrients concentrations were variable in both the estuarine and oceanic system. February had the highest concentrations of PO_4^{3-}-P in the estuarine system followed by the month of June (Table 2a). NO_3^--N concentrations were highest in February with the lowest concentrations in June. NH_4^+-N concentrations were highest in June in this study. On a spatial scale, PO_4^{3-}-P concentrations were highest in R. Mwena whereas highest NO_3^--N concentrations were observed in R. Umba. NH_4^+-N concentrations were highest in R. Ramisi and least in R. Mwena (Table 2b). In the oceanic system, PO_4^{3-}-P and NH_4^+-N concentrations had highest concentrations in June whereas NO_3^--N concentrations were highest in Feb and least in June (Table 2a). The oceanic station with high PO_4^{3-}-P concentrations was Shimoni while Sii Kiromo had the highest NO_3^--N concentration whereas Wasini had the highest NH_4^+-N concentration (Table 2b).

Table 2a. Monthly nutrients concentrations (Mean±SE mg/L) in the oceanic and estuarine systems of Ramisi-Vangasystem

Month	Estuarine system			Oceanic system		
	PO_4^{3-}-P	NO_3^--N	NH_4^+-N	PO_4^{3-}-P	NO_3^--N	NH_4^+-N
February	0.054±0.012	0.146±0.027	0.016±0.005	0.006±0.000	0.054±0.006	0.005±0.001
June	0.034±0.016	0.003±0.001	0.040±0.009	0.036±0.002	0.004±0.000	0.031±0.003
August	0.020±0.004	0.046±0.001	0.016±0.002	0.008±0.001	0.031±0.001	0.016±0.004
Mean	***0.037±0.007***	***0.077±0.017***	***0.022±0.004***	***0.015±0 002***	***0.036±0.004***	***0.014±0 002***

Table 2b. Nutrients concentrations (Mean±SE mg/L) in the oceanic and estuarine systems of Ramisi-Vangasystem

	ESTUARINE				OCEANIC		
SITE	PO_4^{3-}-P	NO_3^--N	NH_4^+-N	SITE	PO_4^{3-}-P	NO_3^--N	NH_4^+-N
Ramisi	0.026±0.004	0.044±0.005	0.028±0.004	Wasini	0.010±0.002	0.028±0.006	0.018±0.004
Mwena	0.051±0.008	0.096±0.016	0.017±0.002	Kima	0.005±0.003	0.024±0.017	0.014±0.003
Umba	0.042±0.007	0.141±0.021	0.018±0.003	Sii -Kir	0.007±0.001	0.053±0.015	0.009±0.004
				Shimoni	0.014±0.004	0.021±0.009	0.007±0.002

The correlation matrix between PO_4^{3-}-P concentrations and most phytoplankton groups (Table 3) showed a negative correlation. A similar negative significant correlations were observed for NO_3^--N concentrations and the four phytoplankton groups with significant correlations observed for dinoflagellates in river Umba ($r=-0.72$; $p<0.05$) and diatoms and 'others' group in River Mwena ($r=-0.95$; $p<0.05$ and $r=-0.85$; $p<0.05$ respectively). River Mwena had the lowest abundance of diatoms which negatively correlated with PO_4^{3-}-P and NO_3^--N with $r=-0.51$; $p>0.05$ and $r=-0.95$; $p<0.05$ respectively. Significant positive correlations were observed between NH_4^+-N concentrations and the flagellates and 'others' group (Table 3) in River Ramisi ($r=0.89$; $p<0.05$ and $r=0.85$; $p<0.05$) as well as with diatoms and others in River Mwena ($r=0.76$; $p<0.05$ and $r=0.95$; $p<0.05$ respectively).

In the oceanic system, PO_4^{3-}-P and NH_4^+-N concentrations correlated positively with the major phytoplankton group abundances (Table 3) except for 'others' group in Wasini ($r=-0.24$; $p>0.05$ and $r=-0.19$; $p>0.05$). Diatoms in Kima and Sii Kiromo significantly correlated with PO_4^{3-}-P concentration ($r=0.97$; $p<0.05$ and $r=0.88$; $p<0.05$). A significant correlation was observed between dinoflagellates and PO_4^{3-}-P concentrations in Kima ($r=0.91$; $p<0.05$). There were negative correlations observed between NO_3^--N concentrations and dinoflagellates in Kima ($r=-0.92$; $p<0.05$). Diatoms, dinoflagellates and 'others' group in Sii Kiromo showed a positive correlation with NO_3^--N concentrations (Table 3) whereas NH_4^+-N showed a positive correlation with dinoflagellates ($r=0.95$; $p<0.05$). The four ecological indices in the estuarine system showed no significant spatial variations ($p>0.05$). The highest abundance was recorded in May whereas the lowest abundance was observed in February (Fig s 3). There was no significant variation observed in estuarine phytoplankton abundance between Umba, Ramisi and Mwena ($p>0.05$). Species diversity index was highest in June (Fig. 4). There existed a temporal significant difference in diversity index ($F=7.37$; $p<0.01$) and species richness ($F=3.93$; $p<0.05$) observed in this study. There were further significant temporal differences in evenness index ($F_{4, 39}=4.75$; $p<0.01$) and post hoc comparisons revealed significant differences between February and May ($p<0.05$) and a further difference between February and June ($p<0.01$).

There was a significant spatial difference in abundances between the oceanic stations ($F=3.50$; $p<0.05$) with Shimoni having the highest abundance (Fig. 3). The species richness, species diversity index and evenness did not vary significantly among the oceanic sites. There was a significant temporal difference in abundance ($F_{3, 31}=51.34$; $p<0.01$) with the lowest abundance occurring in February (Fig. 3). The species evenness was least in May whereas June had the highest diversity and evenness index (Fig. 4). In general, abundance was highest in May in both the estuarine and oceanic systems with oceanic system having the highest abundances (Fig. 3).

The evenness index in estuarine system showed a negative significant correlation with PO_4^{3-}-P concentrations in River Mwena ($r=-0.80$; $p<0.05$). NO_3^--N concentrations correlated negatively with most ecological indices. There were positive significant spatial correlations of the diversity, evenness and richness indices with NH_4^+-N concentrations.

Most ecological indices showed no significant correlation with the nutrients concentrations (Table 4) in the oceanic system stations. There were significant spatial correlation between PO_4^{3-}-P concentrations and species richness in Kima ($r=0.96$; $p<0.05$) and phytoplankton abundance in Sii Kiromo ($r=0.80$; $p<0.05$). There was a significant negative correlation between species richness and NO_3^--N concentrations in Kima whereas a negative significant correlation existed between NH_4^+-N concentrations and evenness indices.

The estuarine and oceanic systems had a diversified phytoplankton community. The diatoms were the most diversified taxa followed by dinoflagellates, 'others' group and flagellates. The diatoms high diversity has been observed elsewhere (Wang *et al.*, 2006). The high abundance of diatoms could be attributed to re-suspension of benthic diatoms especially in the estuarine systems. Sediments in estuaries and shallow coastal areas are continuously re-suspended and as a result, sediment particles with or without diatoms and unattached diatoms cells re-enter the water column (Trobajon and Sullivan, 2010) during tidal movement, wave action or incoming upstream waters. In this study, the benthic diatoms present were *Navicula sp*, *Nitzchia sp*, *Pleurosigma sp*, *Cymatosira sp* and *Cylindrotheca sp* which were also reported elsewhere by Underwood *et al.*, (1998). The high abundance of *Pseudo-nitzchia sp*, *Rhizosolenia sp*, *Prorocentrum sp*, *Eutreptiela sp*, *Thalassiosira sp*, *Peridinium sp*, *Ceratium sp*, cyanobacteria and *Gymnodinium sp* in this study could be attributed to their bloom causative nature. Some of these blooms causing taxa are among the harmful algal blooms (HABs) that have the ability to cause adverse toxicity to other marine life and humans either directly or indirectly. The Harmful algal species encountered in this study were *Alexandrium sp.*, *Chatonella sp.*, *Dinophysis sp.*, *Gymnodinium sp.*, *Gyrodinium sp.*, *Noctiluca scintillans*, *Peridinium sp.*, *Prorocentrum sp. Gonyaulax sp.*, *Gambierdiscus sp.*, *Ostreopsis sp.*,

Table 3. Pearson's correlation between log transformed nutrients concentrations and the phytoplankton groups in estuarine and oceanic systems

Phytoplankton Group		PO_4^{3-}-P	NO_3^--N	NH_4^+-N
	Diatoms	-0.27	-0.65**	0.36
Estuarine	Dinoflagellates	-0.19	-0.49*	0.28
	Flagellates	-0.01	-0.71*	0.63*
	Others	0.08	-0.63**	0.62**
	Diatoms	0.64**	-0.48*	0.62**
Oceanic	Dinoflagellates	0.53*	-0.60**	0.59**
	Flagellates	0.61*	-0.62*	0.82**
	Others	0.36	-0.52*	0.18

* Significant (pÂ0.05)
** Significant (pÂ0.01)

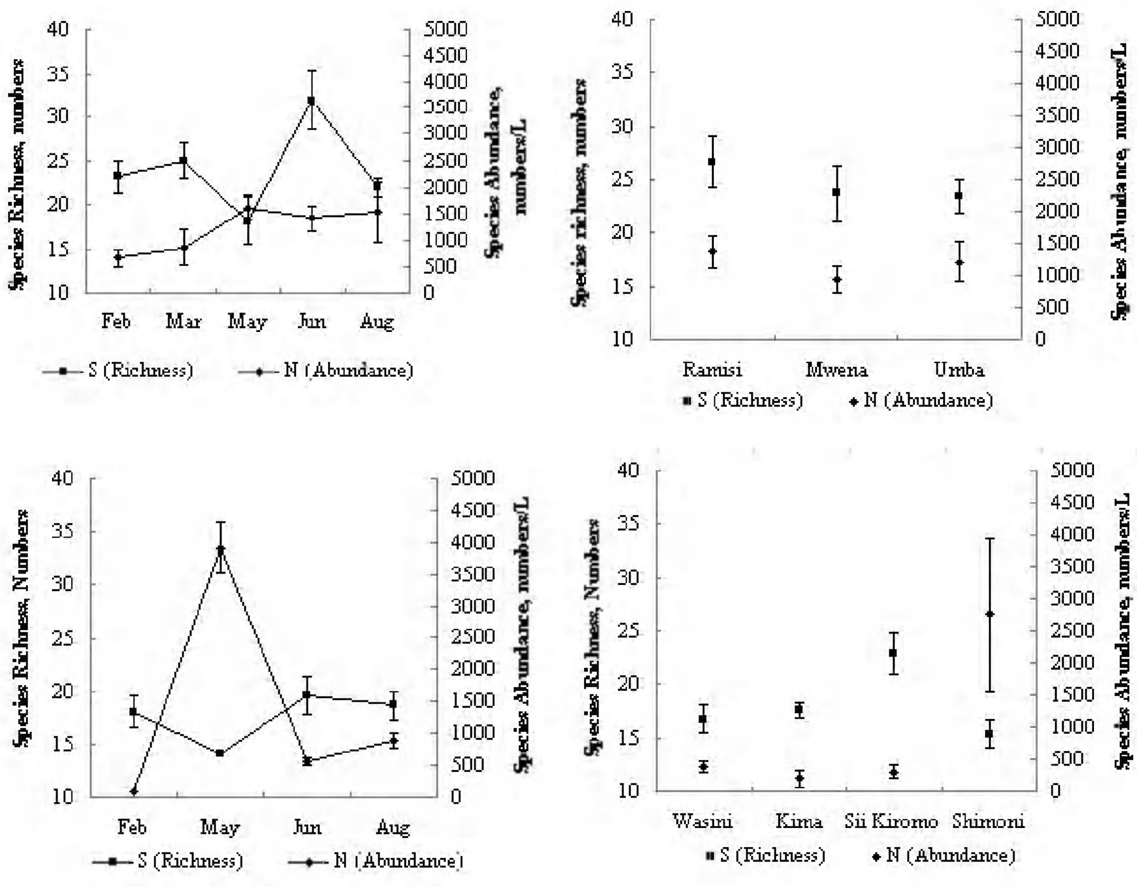

Fig. 3. Phytoplankton groups, species abundance and richness numbers in both the estuarine and oceanic system of the Ramisi-Vanga area

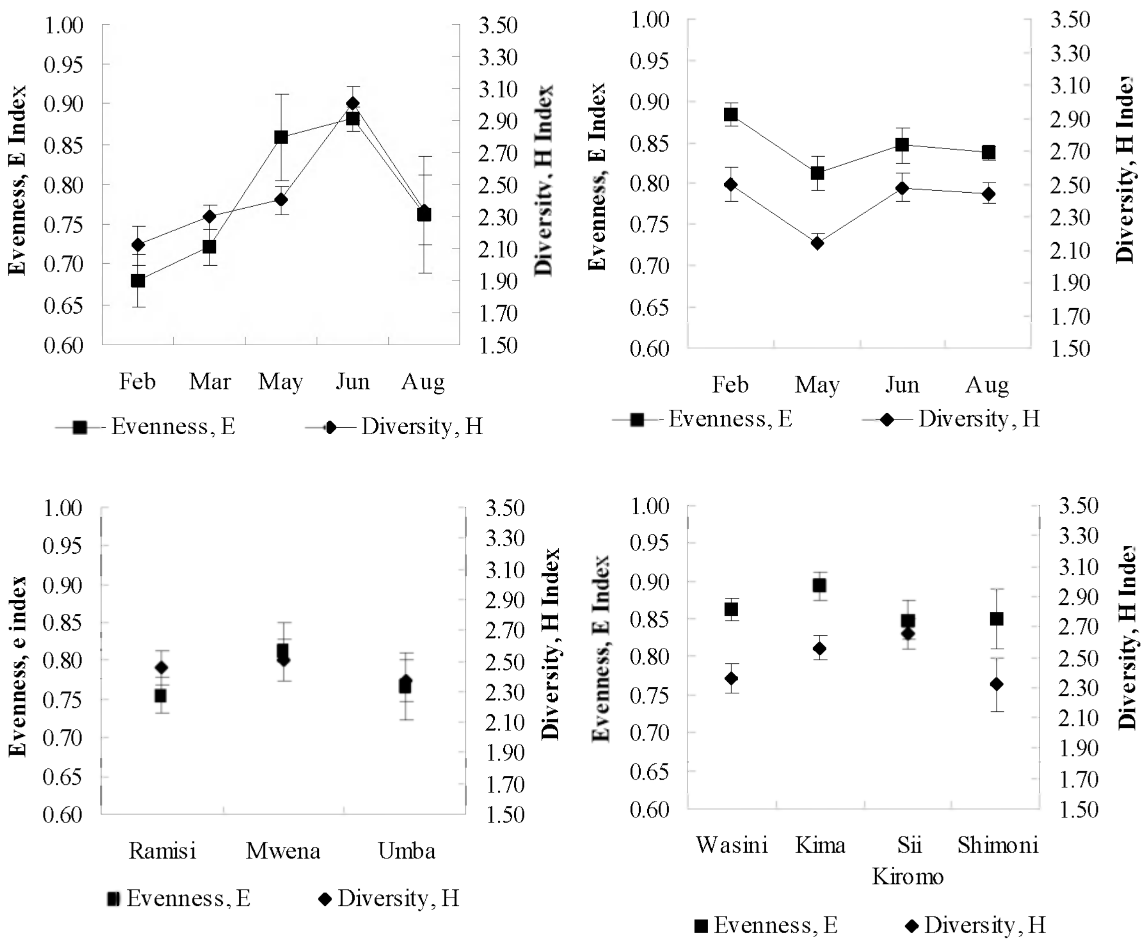

Fig. 4. Phytoplankton evenness E, and Shannon H, diversity indices in the Ramisi-Vanga system

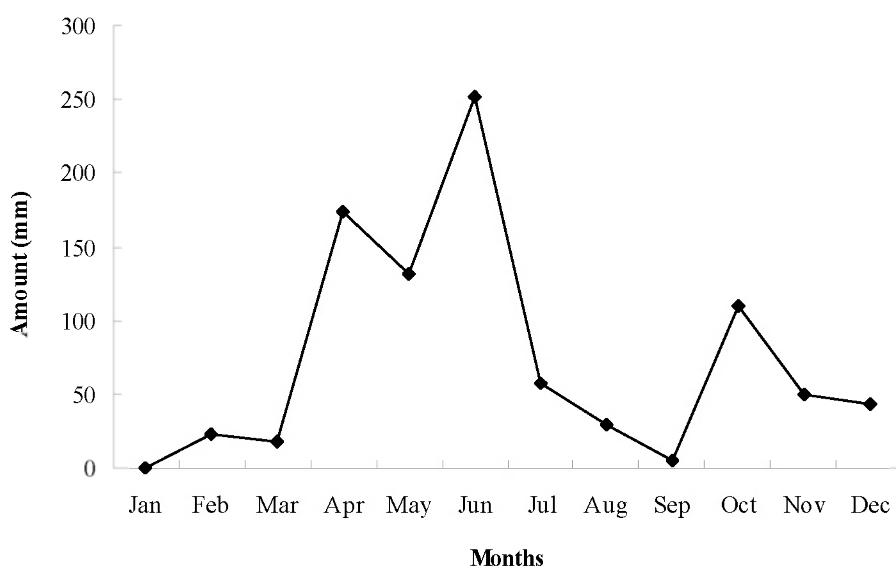

Fig. 5. Rainfall pattern in Msambweni District (source:District Crop Report December 2010)

Ceratium fusus, Prymnesium sp., Coscinodiscus sp., Thalassiosira sp., Ceratualina sp., Rhizosolenia sp., Chaetoceros sp., Pseudo-nitzschia sp., Cylindrotheca sp., Guinardia sp., Nitzschia sp., Amphora sp., and *Fibrocapsa sp. Lyngbya sp.* and *Oscillatoria sp.*

The diatoms dominance in abundance observed in this study could be supported by previous findings of Zingone *et al.*, (1995) that singled out diatoms as the abundant taxa in nutrient rich coastal waters. Worth noting is the high abundances that were observed in May and June that is characterized by increased precipitation which corresponded to increased nutrients levels caused by increase in surface runoff. The dominance of diatoms in the two systems was also observed in February and March (that had low precipitation hence reduced nutrient influx) could be attributed to their ability to withstand a wide range of nutrient concentrations. In contrast, dinoflagellates had lower abundance than the diatoms as they are known to have unimpressive nutrient-dependent uptake and growth that result in poor competitive abilities for inorganic macronutrients (Falkowski and Knoll, 2007) as compared to diatoms and other functional phytoplankton groups. This also explains the temporal significant difference in abundance within this group in relation to nutrients loading concentrations.

The high abundance of cyanobacteria in the 'other' phytoplankton group in February and March (that are characterized by low precipitation and low nutrients levels) could be attributed to their nitrogen fixing ability during N-limiting situations (Sumich and Morrissey, 2004). Cyanobacteria with their characteristic small sized cells have a competitive advantage under nutrient-limited conditions (Falkowski and Knoll, 2007) due to their high surface to volume ratio; they are also able to use organic forms of phosphorus (Labry *et al.*, 2002) and can as such may flourish to form blooms. This further explains why high abundances of cyanobacteria were observed in Ramisi and Mwena rivers that are known to have low influx of nutrients in comparison to Umba River. It can also be noted that the cyanobacteria proliferation was minimal in oceanic areas except in February as most marine cyanobacteria are especially abundant in intertidal and estuarine areas with a smaller role in oceanic waters (Sumich and Morrissey, 2004). *Oscillatoria sp* abundance during the months of high precipitation in Umba River and Sii Kiromo could be attributed to their tolerance to increased nutrients concentrations. The flagellates' low abundance in the two systems could be attributed to their motile nature and the ability to move to areas with favourable conditions.

In general, the increase in phytoplankton groups' abundance corresponded to a decrease in the NO_3^--N concentrations in Ramisi-Vanga system. Findings by Yajnik and Sharada, (2003) showed that NO_3^--N uptake by phytoplankton is severely reduced by the presence of NH_4^+-N. The month of May being the onset of the rainy season, the high abundance in oceanic phytoplankton as compared to estuarine systems was attributed to increased influx of nutrients and could also be attributed to river inputs that create a thin haline stratification which is favourable for phytoplankton production (Chapelle, 1990). The early rains carry loads of loose particulate matter which reduces the photic zone in the water column hence the slight reduction phytoplankton abundance in the estuarine system.

The species abundance, composition and diversity of phytoplankton communities in this study corresponded to nutrients levels although the biogeochemical functioning of this area is largely unknown. Nutrient influx during the early rains in May led to increase in phytoplankton abundance in the oceanic systems which later reduced in June. The decrease in abundance in June was accompanied by an increase in diversity index, species richness and evenness index due to favourable conditions for proliferation of diverse phytoplankton taxa. The low species richness in the oceanic system in comparison to the estuarine system both temporally and spatially may have been controlled by abiotic and biotic factors providing equilibrium between accumulation and loss of species over time (Fischer, 1960). Species evenness was lowest in River Ramisi which on the other hand had the highest species richness and abundance. This meant that a few taxa dominated the phytoplankton community in this estuarine system. The contrary was observed in River Mwena that could be an indication of favorable environmental condition encouraging fair competition among the phytoplankton communities leading to overlapping niches and efficient resource utilization. In general, the species diversity index revealed good species equitability in Ramisi - Vanga system that ranged from 2 to 3. Shimoni village which is adjacent to ocean, receives runoffs and leachate from land based activities thus increased nutrients concentrations unlike the other sites which are within Wasini channel that experience frequent dilution/mixing with the nutrient depleted oceanic water. In the oceanic system, phytoplankton periodicity is affected by the different sources of land-derived nutrients and by their dilution patterns (Zingone *et al.*, 1995). This enabled the more tolerant species to highly proliferate in Shimoni area as it has been reported elsewhere that phytoplankton composition generally change with nutrient loadings and in response to pollutant levels because of different nutrient needs and sensitivities to contaminants (U.S. EPA, 2000). High disturbances can suppress or eliminate many members of the community which in turn lowers the species richness index. The few species that will be favoured in such species shift always thrive in high numbers and this could be the possible explanation for the observed high abundance that corresponded to low species richness in this study.

According to the classification scheme proposed by Siokou-Frangou and Pagou, (2000); Pagou, (2000), the Ramisi-Vanga system with phytoplankton cell densities ranging only from 194.96 to 3919.6 cells/L could be classified as oligotrophic. Oligotrophic systems are defined by this scheme to be systems with phytoplankton cell densities less than 6000 cell/L.

CONCLUSION

In conclusion, diatoms dominance was observed in Ramisi-Vanga system. The wide distribution and high abundance of diatoms reported in this study is indicative of a conducive environment for active growth and survival of other forms of lives. The clear dominance of diatoms in the study areas, both in abundance and diversity also suggests the presence of a clean environment. On the other hand, the presence of bloom causative taxa in high abundance is a signal of potential blooms within the Ramisi- Vanga system even during periods of reduced nutrients input. These potential HABs species serves in this study as an early warning on possible toxins contamination of seafood for human use. Ramisi-Vanga system has been classified in this study as an oligotrophic system and as such this study concludes that the currently level of land based activities are not having adverse effects on the phytoplankton communities of this system.

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