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Potentially Harmful Algae along the Kenyan Coast: A Norm or Threat.

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Abstract
Harmful algal blooms are known to cause mortalities of aquatic organisms when in high biomass through formation of anoxic conditions or production of marine biotoxins (that ultimately reach humans through food web transfer). Only a few studies of phytoplankton communities have been carried out along the Kenyan coast. Of these studies, very few have focused on potentially harmful algae. Due to the increasing economic importance of harmful algal blooms, there is need to carry out an inventory of potentially harmful algal species that are present in the Kenyan coastal waters. Phytoplankton samples were collected along the Kenya Coast from 2009-2010 and analyzed for species abundance. A total of 39 taxa of potentially harmful algae were encountered over the study period. Potentially harmful algal taxa with high abundance were *Chaetoceros sp.*, *Nitzschia sp.*, *Coscinodiscus sp.*, *Pseudo-nitzschia sp.*, *Rhizosolenia sp.*, *Anabaena sp.*, *Protoperidinium sp.*, *Oscillatoria sp.* and *Trichodesnium sp.* whereas the taxa with lowest abundances were *Fibrocapsa sp.*, *Chrysochromulina sp.*, *Umezakia sp.*, *Dinophysis sp.* and *Aphanizomenom sp.* Taxa such as *Dinophysis sp.* that is generally known to be toxic at low cell densities occurred in most sampling stations. Highest cell densities of potentially harmful algae ($39.51x10^2$cells/L) were recorded in the estuarine systems as compared to the creeks ($22.83x10^2$cells/L) and near-shore ($2.86x10^2$cells/L) ecosystems. Compared to previous studies, this study registered increased number of potentially harmful algae species, an indication of potential threat of future bloom occurrences with the risks of phycotoxins contamination in the expected scenarios of increased eutrophication and climate change.
Keywords: Phycotoxins, Abundances, Oceanic, Estuarine, Phytoplankton.

INTRODUCTION:

Phytoplankton form the food base of most aquatic organisms both in the wild and cultured areas. Proliferation of phytoplankton therefore is beneficial for aquaculture and wild fisheries. However, proliferation of some phytoplankton species (commonly referred to as Harmful Algal Blooms - HABs) have been detrimental to aquatic organism and higher animals Fish kills are usually the first direct effect with most deleterious impacts that occur when HABs affect entire ecosystems, causing death of phytoplankton, zooplankton, seaweeds, and shellfish.

HABs have increased worldwide in waters ranging from fresh to coastal estuarine and marine waters (Anderson, 1989; Hallegraeff, 1993; Smayda, 1990; Van Dolah, 2000), causing enormous impacts in such aquatic ecosystems (Granéli and Hansen, 2006) resulting into severe economic losses to aquaculture, fisheries and tourism operations as well as major environmental and human health impacts. These harmful algae species are known to cause mortalities of aquatic organisms when in high biomass through development of anoxic conditions or production of toxins (phycotoxins). Marine phycotoxins or biotoxins are responsible for more than 60,000 intoxication annually, with an overall mortality of about 1.5% (van Dolah, 2000). Human intoxications are due to consumption of seafood and respiratory exposure to aerosolized phycotoxins. Phycotoxins are also responsible for extensive die-offs of fish and shellfish, as well as mortality in seabirds, marine mammals and other animals depending on marine food web(van Dolah, 2000).These phycotoxins are produced by two major phytoplankton groups namely dinoflagellates and diatoms, that represent about 2% of known phytoplankton species (60-80 out of 3400-4000 species) and can reach humans directly (via consumption of shellfish) or through food web transfer to higher trophic levels (zooplankton and herbivorous fish).The fact that some species are highly toxic to humans and some other animals has extensively been reported, though most accounts relate to bloom-forming species in freshwaters and shallow coastal waters (Codd *et al.*, 2005).

Harmful algae species are greatly influenced by local and regional environmental changes by inducing harmful algae proliferation, thus increasing toxins concentrations (van Dolah, 2000). For instance, the magnitude and the timing of inflows influence the physicochemical environment and bring about variations in salinity, nutrient availability, stratification and hydraulic flushing. In turn, these affect plankton community composition and productivity (Buyukates and Roelke, 2005; Miller *et al*., 2008). In bays and estuaries, inflows from rivers and tidal waters can stimulate system-level productivity and alter community composition by influencing essential nutrients, hypersaline conditions and connectivity between habitats (Cloern, 2001; Fejes *et al*., 2005; Heinsch *et al*., 2004; Miller *et al*., 2009). This has affected the incidence of HABs observed over a wide range of taxa that include cyanobacteria, dinoflagellates, diatoms and prymnesiophytes (Jacoby *et* al., 2000; Roelke *et al.*, 2010; Spatharis *et al*., 2007).

Phytoplankton studies along the Kenya Coast have received minimal attention in the past. Even though a number of fish deaths in Kenya (in Kiunga and Shimoni) have been attributed to HABs incidences, there have been no dedicated studies on potential harmful algae species occurrences. This study was therefore, undertaken so as to come up with an inventory of potential harmful algal species along the Kenya Coast on a spatial scale.

MATERIALS AND METHODS

Study Sites

The Kenyan coast runs in a southwesterly direction from the Somalia border in the north, at 1^o 41'S to 4^o 40'S at the border with Tanzania. Kenya has about 574-km coastline running from Kiunga in the North to Vanga in the south. It is influenced by the northeast monsoon and southeast monsoon winds of the Indian Ocean. The Kenyan coast experiences semi-diurnal tides. River systems create conditions of low salinity and high turbidity in estuaries and deltas that are characterized by extensive mangrove forests in some areas.

The study was carried out in estuarine systems of rivers Sabaki (S1, S2 and S3), Ramisi (R1, R2 R3 and R4), Mwena (M1, M2, M3 and M4) and Umba (U1, U2, U3, U4 and U5) that play key ecological function in the nearshore areas along the Kenya coast in terms of river flow discharge and water quality. The nearshore areas in this study in the southern part of the coast were Wasini (WN, WI, WJ, WCM), Kibuyuni (KBI, KBL, KBM and KIMA), Shimoni (SJ and MW), and Sii Kiromo (SK) areas whereas in the northern part were Malindi (MDJ, MDP, MDN and MAM). The creeks of interest were Mtwapa (MTM, MTB, MTP and MTF), Tudor (FJ, NB, KMC, MIK, MAD and CG) and Makupa (MKC, MKM, MKB and MKD) respectively that are influenced by anthropogenic activities due to urban growth. The creeks and nearshore areas are mainly influenced by tidal movement and wave actions whereas the estuarine systems are influenced by both tidal movement and river flow discharge. The rivers that form part of the estuarine systems are greatly influenced by upland anthropogenic activities such as agricultural practices and human settlement that greatly impact on the natural ecosystem downstream that is characterized by mangrove forests.

Sample collection and analysis

Phytoplankton samples were collected by filtering 20 litres of water (surface water) 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 (Utermöhl, 1958). The samples were further concentrated to a volume of about 100 ml after which one ml (in triplicate) of the concentrated sample used to determine Cell density using an inverted microscope(Leica DMIL) and a Sedgewick Rafter Chamber. The results were expressed as '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:

$$\mathbf{N = (A \times 1000 \times C) / (V \times F \times L)}$$

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 water filtered in litre.

Phytoplankton cells were identified using identification keys by Botes, (2003) and Carmelo, (1997). Whenever possible, identification was carried out to the species level, although in some cases identification was only possible to genus level.

Data analysis and reporting

Phytoplankton data was analyzed for mean cell densities and abundance. The identified harmful algae species were reported in three groups depending on the effect of bloom formed (more or less dangerous to humans and /or animals, Andersen, 1996); i) Blooms of species that produce basically harmless water discolorations resulting in decreasing recreational value and eventually, under exceptionally weather conditions in sheltered bays, the blooms grow so dense that they cause escape reactions and indiscriminate benthic invertebrates and fish kills due

to oxygen depletion, ii) Blooms of species that produce potent toxins which accumulate in food chains and cause a variety ofl illnesses in humans and other higher animals; iii) Blooms of species that are non-toxic to humans but harmful to fish and invertebrates (especially in intensive aquaculture systems) through intoxication, damaging or clogging of the gills or other means.

RESULTS AND DISCUSSION

Potentially harmful algae

A total of 39 taxa of potentially harmful algae species were identified along the Kenya coast during the study period (Table 1).The taxa with high cell densities were *Chaetoceros sp, Nitzschia sp, Coscinodiscus sp, Pseudo-nitzschia sp, Rhizosolenia sp, Anabaena sp, Protoperidinium sp. Oscillatoria sp.* and *Trichodesmium sp.* while *Fibrocapsa sp. Chrysochromulina sp. Umezakia natana watanabe*, and *Aphanizomenom flos-aquae* had the least cell densities. Some of the potentially harmful algae recorded during this study such as *Dinophysis sp.* are usually toxic at low cell densities (<3 x 10^2 cells/L) whereas the bloom forming species are only toxic during bloom occurrences as they cause discoloration and anoxic conditions in the aquatic system resulting into fish die offs (Table 1).

During this study, higher numbers of potentially harmful cell densities (39.25 x 10^2 cells/L) were recorded in the estuarine systems (rivers Ramisi, Mwena, Umba and Sabaki) compared to numbers recorded in the creeks (22.95 x 10^2 cells/L) and nearshore areas (2.86 x 10^2 cells/L) as seen in Table 2.

Table 1a: Potentially harmful Diatoms species and their harmful effect (Modified from LIFEHAB Report, 2001)

Taxa	Toxicity status	Harmful Effect
Chaetoceros sp.	Toxic as Blooms	Fish Kills
Corethron sp.	Toxic as Blooms	Fish Kills
Corethron criopilum	Toxic as Blooms	Fish Kills
Corethron cenofemus	Toxic as Blooms	Fish Kills
Coscinodiscus sp.	Toxic as Blooms	Bird mortality, mucilage
Rhizosolenia sp.	Toxic as Blooms	Shellfish kills; gives bitter taste
Thalassiosira sp.	Toxic as Blooms	Mucilage on gills kills shellfish
Cerataulina sp.	Toxic	Shellfish and finfish kills
Nitzschia closterium	Toxic as blooms	Shellfish and finfish kills
Nitzschia sp.	Toxic	Shellfish and finfish kills; Domoic acid
Nitzschia sigma	Toxic as blooms	Shellfish and finfish kills
Nitzschia longisigma	Toxic as blooms	Shellfish and finfish kills
Pseudo-nitzschia sp.	Toxic	Domoic acid
Guinardia sp.	Toxic as Blooms	Mucilage clogs fish nets
Guinardia striata	Toxic as Blooms	
Guinardia delicatula	Toxic as Blooms	Mucilage clogs fish nets
Leptocylindrus sp.	Toxic as Blooms	Fish Kills
Skeletonema sp.	Toxic as Blooms	High biomass

Table 1b: Potentially harmful Dinoflagellates species and their harmful effect (Modified from LIFEHAB Report, 2001)

Taxa	Toxicity status	Harmful Effect
Alexandrium sp.	Toxic	PSP, Ichthyotoxic, Spirolide, discoloration.
Dinophysis sp.	Toxic	DSP
Dinophysis caudata	Toxic	DSP
Gambierdiscus toxicus	Toxic	Ciguatera,
Gambierdiscus sp.	Toxic	Ciguatoxin-/maititoxin- like toxins
Gonyaulax sp.	Toxic	Saxitoxin
Gonyaulax sp. cysts	Toxic	
Gymnodinium sp.	Toxic	PSP, Ichthyotoxic
Gyrodinium sp.	Toxic	Ichthyotoxic
Ostreopsis sp.	Toxic	Ovatoxin, ostreotoxin, ostreocine/palytoxin
Peridinium sp.	Toxic	Ichthyotoxin
Prorocentrum sp.	Toxic	DSP, Ichthyotoxic
Ceratium fusus	Toxic as Blooms	Discolouration, anoxia
Ceratium furca	Toxic as Blooms	Discolouration, anoxia
Ceratium sp.	Toxic as Blooms	Discolouration, anoxia
Noctiluca sp.	Toxic as Blooms	Discolouration, anoxia
Noctiluca scintillans	Toxic as Blooms	Discolouration, anoxia
Protoperidinium sp.	Toxic as Blooms	Azaspiracid
Scrippsiella sp.	Toxic as Blooms	Discolouration, anoxia
Scrippsiella trochoidea	Toxic as Blooms	Discolouration, anoxia

Table 1c: The other potentially harmful algae species and their harmful effect (Modified from LIFEHAB Report, 2001)

Taxa	Toxicity status	Harmful Effect
Cyanobacteria		
Lyngbya sp.	Toxic	Lyngbyatoxin-A,Debromoaplysiatoxin, aplysiatoxins
Oscillatoria sp	Toxic	Debromoaplysiatoxin
Fischerella epiphytica	Toxic as Blooms	
Anabaena sp.	Toxic	Anatoxin-A, Homo Anatoxin-a, Anatoxin-a(s), Neurotoxin
Nodularia spumigena	Toxic	Nodularians
Umezakia natans	Toxic	Cylindrospermopsin
Aphanizomenon flos-aquae	Toxic as Blooms	Cylindrospermopsin
Microcystis aeruginosa	Toxic as Blooms	Microcystins
Trichodesmium sp	Toxic as Blooms	Saxitoxin
Flagellates		
Dictyocha sp.	Toxic as Blooms	
Eutreptiella gymnastica	Toxic as Blooms	Discolouration, anoxia
Haptophytes		
Chrysochromulina sp	Toxic	Ichthyotoxic
Prymnesium sp	Toxic as Blooms	Toxic to Artemia, Ichthyotoxic, haemolytic
Raphidophytes		
Chattonella sp	Toxic	Ichthyotoxic
Fibrocapsa japonica	Toxic	Ichthyotoxic

In the estuarine system, River Ramisi had the highest number of potentially harmful algal cell densities (>70 x 10^2 cells/L) characterized by high cell densities of *Nitzschia sp.* (61.39 x 10^2 cells/L), *Coscinodiscus sp.* (49.5 x

10^2 cells/L) and *Anabaena sp*. (49.62 x 10^2 cells/L) as shown in Table 3. River Umba had cell densities of 16.85 x 10^2 cells/L with high harmful algal densities in U5 sampling site (>100 x 10^2 cells/L). *Nitzschia sp.* was the most abundant taxa in R. Umba (9.34 x 10^2 cells/L). Cyanobacteria such as *Trichodesmium sp.*, *Microcystis sp.* and *Lyngbya sp.* were the least encountered in river Umba (Table 3). *Alexandrium sp.* that is usually toxic at low cell densities was present in U5 sampling site.

Table 2a: Harmful algae species abundances (cells/L) in the estuarine systems

Estuarine systems							
Ramisi	***Abundance***	***Mwena***	***Abundance***	***Umba***	***Abundance***	***Sabaki***	***Abundance***
R1	8589.01	M1	547.55	U1	521.47	S1	85.14
R2	6067.95	M2	607.71	U2	1276.71	S2	146.67
R3	3246.28	M3	905.15	U3	1604.98	S3	177.50
R4	15084.25	M4	1525.42	U4	752.30		
				U5	4782.52		
Mean	**7631.67**		**820.51**		**1685.92**		**136.44**

Table 2b: Harmful algae species abundances (cells/L) in the Creeks

Creek systems					
Makupa	***Abundance***	***Tudor***	***Abundance***	***Mtwapa***	***Abundance***
MKT	2615.56	NB	2238.58	MTM	1890.69
MKC	392.83	CG	925.15	MTP	4870.71
MKD	960.67	FJ	1036.88	MTB	3802.37
MKB	604.44	MAD	997.78	MTF	5474.55
MKM	666.94	KMC	771.89	MTJ	641.39
		MIK	662.08	MTM	493.83
		NP	341.67		
Mean	**1074.61**		**1020.14**		**3510.63**

Table 2c: Harmful algae species abundances (cells/L) in the Nearshore system

Nearshore systems									
Kibuyuni	***Abundance***	***Sii Kiromo***	***Abundance***	***Wasini***	***Abundance***	***Shimoni***	***Abundance***	***Malindi***	***Abundance***
KBL	364.05	SK1	189.50	WJ	288.21	MW	1920.73	MDJ	86.25
KBM	22.50	SK2	17.50	WCM	265.98	SJ	528.26	MDP	162.92
KBI	20.00	SK3	256.35	WN	201.86			MDN	154.58
KIMA	220.94	SK4	278.68	WI	52.50			MAM	74.17
		SK5	60.00						
		SK6	33.75						
Mean	**242.57**		**213.37**		**265.75**		**713.92**		**119.48**

The three creeks sampled in this study recorded the second highest harmful algae abundance with 35.1 x 10^2 cells/L recorded in Mtwapa, 10.7 x 10^2 cells/L in Makupa and 10.2 x 10^2 cells/L in Tudor (Table 2). Within Makupa creek, MKT had the highest densities (26.16 x 10^2 cells/L) (Table 2).The dominant taxa in Makupa creek were *Leptocylindricus sp.* (2.13 x 10^2 cells/L and *Pseudo-nitzschia sp.* (2.03 x 10^2 cells/L) as shown in Table 3. Tudor creek had the lowest harmful algae densities and was dominated by *Trichodesmium sp.* (7.71 x 10^2 cells/L) and *Oscillatoria sp.* (4.31 x 10^2 cells/L). High cell densities of *Oscillatoria sp.* (26.77 x 10^2 cells/L) in Tudor creek were encountered at NB whereas high cell densities of *Trichodesmium sp.* were encountered at FJ (16.91 x 10^2 cells/L) and CG (10.96 x 10^2 cells/L). Mtwapa creek was dominated by *Chaetoceros sp.* (24.67 x 10^2 cells/L) and *Pseudo-nitzschia sp.* (8.29 x 10^2 cells/L).

Table 3: Harmful algae taxa cell densities (means, cells/L) recorded in different systems along the Kenya Coast

	Ramisi	Mwena	Umba	Sabaki	Makupa	Tudor	Mtwapa	Kibuyuni	Sii Kiromo	Wasini	Shimoni	Malindi
Nitzschia sp	1203.18	65.88	933.73		58.89	78.92	25.61	6.47	14.99	12.81	17.65	4.44
Coscinodiscus sp	1870.81	70.00	173.17	15.28	189.94	91.93	50.78	27.05	23.67	24.11	36.24	16.15
Peridinium sp	147.49	41.42	26.46	11.78	39.32	20.61	24.03	5.86	24.76	29.27	22.04	12.50
Protoperidinium sp	1242.51	126.08	172.48	13.11	147.79	103.62	71.31	32.10	66.82	67.53	116.78	7.92
Anabaena sp	3799.74		219.00	10.00		37.50	6.90	60.00				5.28
Prorocentrum sp	98.24	111.32	91.47	16.89	66.39	63.60	45.31	39.65	35.59	44.57	66.80	14.08
Ostreopsis sp	53.34	56.53	38.43	9.17	31.72	37.49	45.31	54.78	41.77	46.45	31.53	10.00
Gonyaulax sp	50.12	8.96	19.07	11.46	35.71	22.60	23.27		7.43	9.83	15.00	
Scrippsiella trochoidea	53.97	18.13	42.21	11.46	48.94	44.90	34.28	2.08	4.45	8.45	15.00	5.83
Prymnesium sp	123.30	14.03	62.89		30.56	22.86	26.99	63.33	1.25	2.50	5.00	
Oscillatoria sp	230.56	53.29	58.03	14.50	59.00	431.42	30.42	18.33	26.15	14.58		10.83
Gyrodinium sp	41.07		13.98	15.37	31.67	37.34	18.36		8.13	8.62	30.67	8.13
Dinophysis sp	27.23	67.58	22.34	10.00	27.29	17.67	26.14	8.54	13.45	12.43	36.05	6.25
Leptocylindrus sp	18.67	23.01	35.86	10.56	213.46	18.17	19.95	10.57	21.16	16.41	45.47	
Corethron sp	112.62		13.89		16.67	29.69	12.46		5.28	2.71		4.92
Eutreptiella sp	33.33	1.25	23.42	10.00	25.35	19.81	9.64	2.50	2.50	13.02	7.92	7.08
Rhizosolenia sp	237.78	59.74	75.18	18.50	126.46	37.30	277.31	54.45	76.51	35.71	306.55	6.77
Alexandrium sp	45.13	52.90	53.81	14.58	21.83	20.50	29.34	38.88	32.98	194.87	23.38	11.50
Chaetoceros sp	1777.62	89.24	281.40		176.96	58.78	2467.96	155.50	50.35	78.19	296.36	7.19
Thalassiosira sp	78.55	41.73	57.50	7.92	33.89	34.10	17.25	26.57	20.48	18.21	118.74	6.15
Pseudo-nitzschia sp	397.96	64.19	63.06		203.51	55.69	829.48	25.39	33.74	42.13	222.10	5.00
Gambierdiscus sp	77.10	23.33	7.50			18.96	25.36	11.33	6.17	9.75		5.00
Guinardia sp	21.52	29.61	87.63		26.07	25.28	26.29	12.92	16.11	13.00	25.30	10.00
Fibrocapsa sp	3.13											
Lyngbya sp	21.10	7.08	13.44			5.83	4.17					
Noctiluca sp	43.15	9.29	14.54		26.78	25.00	18.28	1.67		10.60		3.33
Chattonella sp	3.13		32.44									
Skeletonema sp	24.91	21.48	25.52		20.00	10.83	94.21	2.50	3.65	9.58		
Gymnodinium sp	14.17	7.50			5.00	10.42	25.00		1.25	1.25		
Ceratium	64.01	63.04	53.44	10.00	170.14	19.91	21.71	30.44	20.15	21.95	23.5	4.69
Dictyocha sp	7.50	1.25	10.63	11.85	41.67	7.50	25.00			9.17	16.83	5.00
Trichodesmium sp	280.00		25.00			771.11	167.73					
Microcystis sp	106.82		15.00		8.42	30.56	85.83				5.00	
Chrysochromulina sp	8.33											4.17
Cerataulina sp		29.81	5.25			77.22	3.75		1.25	12.17	5.00	
Nodularia sp					16.00	5.00						
Fischerella sp				14.31		8.89	8.33				5.00	
Umezakia sp												10.00
Aphanizomenon sp												5.00

The nearshore systems recorded the least mean abundance of harmful alga taxa (<3 x 10^2 cells/L) as compared to the other systems (estuarine and creeks). Of this system, Shimoni sampling station had the highest mean densities of potentially harmful algae (7.13 x 10^2 cells/L) with *Rhizosolenia sp*. (3.06 x 10^2 cells/L) and *Chaetoceros sp.* (2.96 x 10^2 cells/L) leading in abundance (Table 3). *Alexandrium sp*. dominated in Wasini station (1.95 x 10^2 cells/L) whereas *Rhizosolenia sp* dominated in Sii Kiromo (6.61 x 10 cells/L) while *Chaetoceros sp.* dominated in Kibuyuni (1.55 x 10^2 cells/L).

Dinophysis sp. were encountered in most sampling sites in this study at low cell densities (<70 cells/L). R. Mwena recorded the highest cell densities of this species (67.57 cells/L). *Trichodesmium sp*. being an oceanic cyanobacterium was found in Mtwapa and Tudor creeks at high cell densities compared to rivers Ramisi and Umba that are continually influenced by freshwater input via river discharge (Table 3).

Most of the potential harmful algal taxa encountered in this study have the potential to form blooms while in high densities (i.e. only toxic when in high cell densities even though threshold of toxicity effect is specific for each taxon in relation to other physicochemical characteristic of the aquatic system they proliferate). For example, *Gyrodinium sp*, is known to kill fish and benthic fauna at cell densities higher than 10^7 cells/L (Andersen, 1996). On the contrary, *Dinophysis sp.* that was among harmful algal taxa with low cell densities in this study is capable of causing harm at low cell densities, with no visible discoloration in the water. The low *Dinophysis sp*. counts encountered in this particular study are similar to those reported elsewhere (Maestrin, 1998; Okaichi *et al.*, 2003).

Harmful algae species known to cause water discoloration and anoxic conditions when found in high cell densities (such as *Eutreptiella sp., Ceratium sp., Noctiluca scintillans*, and *Skeletonema sp.* recorded in this study) were found to be present at low cell densities in the three studied systems. In the estuarine system, the low cell densities could be attributed to the high turbidity levels due to river inflow and tidal movement resulting in sediments flocculation and sinking (with the attached algal cells) thus altering photochemistry (Meyer, 1979; Pierce *et al.*, 2004; Seitzinger *et al.*, 1991; Shirota, 1989). For the creeks and nearshore stations, the low cell densities of this group of harmful algae may have been due to the flushing out of the cells during tidal movement.

Apart from causing discoloration and anoxic conditions in aquatic systems, some of the potential harmful algal taxa produce toxins that can accumulate in the food chain causing toxicity to humans and other higher animals. In this study, such taxa included *Alexandrium sp*., *Gymnodinium sp*., *Dinophysis sp*., *Pseudo-nitzschia sp*., *Gamberidiscus toxicus*, *Anabaena sp.* and *Nodularia spumigena* (Table 1). *Anabaena sp* proliferation in R4 and U5 stations depicts their freshwater nature and this explains their low cell densities in the sampling stations that are influenced by oceanic waters. The wide distribution (but in low cell densities) of *Alexandrium sp*. and *Dinophysis sp.* observed in this study could be explained by the fact that these taxa are less affected by coastal nutrient enrichments (UNESCO, 2004).

It has been observed that very low *Dinophysis sp.* concentrations (~ 50 cells/L) could lead to mussels' contamination and toxicity (Kat, 1983; Marcello-Le Abut *et al*., 2001). Some stations in this study reported mean cell densities of *Dinophysis sp.* that were above this threshold implying that some sort of contamination may be present in seafood. The wide spatial distribution of *Pseudo-nitzschia sp.*(described elsewhere as cryptic bloomers, Trainer *et al.*, 2009) could be attributed to its ability to grow over a wide range of salinities (Thessen *et al.*, 2005) and the ability of its blooms to arise from shifts in population rather than the appearance of a fundamentally different assemblage.

The high cell densities of toxic benthic *Gambierdiscus toxicus* observed in the shallow estuarine system in comparison to the creek and nearshore systems could be attributed to the resuspension of benthic matter in the water column through tidal and river inflow (see Trobajon and Sullivan, 2010). The presence of *Nodularia spumigena* only in Makupa and Tudor creeks could be attributed to the ability of these taxa to utilize dissolved organic matter as a nutrient source (Panosso and Granéli, 2000; Põder *et al.*, 2003) and their tolerance to wide ranges in salinity levels (0-35 PSU) (Lehtimäki *et al.*, 1997; Mazur-Marzec *et al*., 2005). These two creeks are characterized by high organic matter inputs from both, human, garbage and slaughterhouse wastes as detailed in findings by Okuku *et al.*, (2011).

Some of the HABs known to be directly toxic to fish but not necessarily to human were *Chaetoceros sp., Gyrodinium sp., Prymnesium sp., Chattonella sp., Leptocylindricus sp. Rhizosolenia sp.* (Table 1). The inverse relationship observed between *Leptocylindricus sp* and *Gymnodinium sp.* in this study could be attributed to allelopathic exudates produced by *Gymnodinium sp* as reported elsewhere by Chan *et al*., (1980) and Gentien and Arzul, (1990) thus totally inhibiting *Leptocylindrus sp.* growth (Clément *et al.*, 2002) in most stations in this study.

Tropical waters are generally oligotrophic and blooms which develop are usually reduced in frequency as seen in this study having low cell densities of harmful algal species and their extent may have only localized impacts. These blooms can form a mosaic in close areas in which some zones are toxic while some are not. In such ecosystems, organisms feeding on algae are responsible for toxins transfer (Bourdeau *et al*., 2001).

Potential Phycotoxin effects

The bloom causative taxa harmful effect is most commonly seen with the massive die off of fish. The anoxic conditions result from the high cell densities of *Skeletonema sp., Noctiluca scintillans, Eutraptiella sp.* and *Ceratium sp.* although this study recorded low cell densities of these taxa. The chain forming *Chaetoceros sp.* which was abundant in most of the stations is known to cause mucus production in the gill tissue. Other taxa

such as *Thalassiosira sp., Skeletonema sp.* and *Dictyocha sp.,* which were recorded at low cell densities in this study, are equally effective in stimulating excess mucus production in fish gills when present in dense concentrations and may lead to fish deaths (UNESCO, 2004). Harmful algal species (such as *Nitzschia sp., Alexandrium sp., Dinophysis sp., Gambierdiscus toxicus, Ostreopsis sp., Prorocentrum sp.* and *Protoperidinium sp.*) produce different categories of toxins which accumulate in the food chain leading to specific syndromes in the predators. were also encountered in this study. For instance, Paralytic Shellfish Poisoning (PSP) causative organism are dinoflagellates (*Alexandrium sp., Gymnodinium sp.*,) that produce saxitoxins and is characterized by gastrointestinal and neurological symptoms, with nausea, vomiting, diarrhea, tingling or numbness around lips with gradual and more severe paralysis, respiratory difficulty, death through respiratory paralysis. Potentially toxic *Dinophysis sp.* and *Prorocentrum sp.* presence in this study is indicative of the potential of a possible Diarrhetic Shellfish Poisoning (DSP) with consumption of contaminated seafood by this taxa. This poisoning is caused by a group of toxins, represented by okadaic acid, and is characterized by gastrointestinal symptoms (nausea, diarrhea, vomiting, abdominal pain) which follow chronic exposure that may evolve into digestive system tumors. Amnesic Shellfish Poisoning (ASP) is caused by domoic acid and main sign of this syndrome is loss of short term memory, accompanied by gastrointestinal and neurological symptoms. The commonly known causative taxon is the *Pseudo-nitzschia sp.* whereas the benthic *Gambierdiscus toxicus* and *Ostreopsis sp.* are known to cause Ciguatera Fish Poisoning (CFP). This syndrome is due to ciguatoxin. Together with tetrodotoxin, this is the only toxin transmitted by fish and not by shellfish. Typical symptoms are diarrhea, abdominal pain, nausea, vomiting, and lots of neurological signs. *Anabaena sp.* and *Nodularia spumigena* are known to produce microcystin and nodularin, respectively, and the discrepancy in hepatotoxin concentrations (Pattanaik *et al*., 2010). *N. spumigena* is capable of producing significant amounts of nodularin, a pentapeptide hepatotoxin that acts as a tumour promoter and have been reported to harm wild and domestic animals (Nehring, 1993).The cyanobacteria *Oscillatoria sp.* are known to produce debromoaplysiatoxin (Mynderse *et al*., 1977). These toxins are highly inflammatory and are potent skin tumour promoting compounds.

Economic impact

Local communities living along Kenya coast depend on coastal fisheries as source of livelihood through mariculture, artisanal fishing and offshore fishing. Increase in occurrence of potential harmful algae is expected to lead to fish die offs destroying most fishing grounds. This may also result into closures of fishing areas with harmful algae occurrence to allow for fish to depurate. It is also a requirement in some export destination countries that fish toxin levels in fish products be reported, in such cases, Kenya as a country is bound to suffer losses resulting from rejection of fish by the international market. Complementing the coastal fisheries is mariculture/aquaculture that has been on the rise for the last two decades in Kenya. Aquaculture can greatly be impacted by harmful algae through massive fish deaths. This can lead to serious economic losses.

Phycotoxins are capable of accumulating in shellfish and finfish causing great concern on seafood safety. Consumption of contaminated seafood put at risk the human consumers of shellfish and fish through a number of illnesses and in extreme cases leading to death.

Though this has not be reported in Kenya, harmful algal blooms are known to reduce the aesthetic nature of areas of economic values (frequently visited by tourist) such as beaches, sport fishing, snorkeling and diving. Blooms that cause water discoloration reduce the visibility of these areas rendering snorkeling and diving activities impossible. Beaches can be rendered inhabitable from foul smell of hydrogen sulphide from bacteria acting on dead organism due to anoxic condition of harmful algal blooms. This may lead to reduced influx of tourist visit to these areas thus reduced economic activities (revenue generation).

CONCLUSION AND RECOMMENDATION

There is a significant increase (nearly twofold) in the number of potential harmful algal species recorded along the Kenya coast in the last decade. A total of twenty four species of potentially harmful microalgae were recorded along the Kenyan coast in 2001(UNESCO, 2001).These included four serious species of *Alexandrium (A. affine, A. leei, A. tamarense and A. tamiavanichii*) known to cause Paralytic Shellfish Poisoning (PSP). Some fish kills have been reported in Kiunga and Shimoni areas. Such fish kills were attributed to toxic algae in Kiunga (UNESCO, 2001) and Shimoni (KMFRI SEED report 2008). The observed increase in number of species and cell densities serves as an early warning of future bloom occurrences with subsequent potential impacts.

Continuous increase in toxic algae species as well as their cell densities, as observed and reported in this study underlines the urgent need to:

1. put in place a monitoring programme and management strategies for harmful algal species at a local and regional levels to compliment the international efforts already in place,
2. conduct further studies on toxins profiles both in phytoplankton and shell fish to assess their potential

toxicity

3. determine the environmental drivers that trigger the development of potential harmful algae blooms and their toxin in order to inform future development of shell fish aquaculture
4. Create public awareness on seafood safety (in relation to harmful algal toxins) as well as on early warning signs with an aim of developing strategies of avoiding contamination related deaths and illnesses.

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