An Observation on Diatom Species Composition in the Kenyan waters of Lake Victoria

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SUMMARY

Planktonic diatoms were investigated in the Kenyan waters of Lake Victoria in September 1997. A total 82 diatom taxa were recorded. Among the centrales, Aulacoseira was the most diversified genera followed by Cyclotella, and, among the pinnates, Nitzschia and Navicula were the most diversified. Diatom abundance ranged from 2.51 x 10^5 to 5.42 x 10^5 frustules l^{-1} in the Nyanza Gulf and from 1.58 x 10^5 to 8.61 x 10^5 frustules l^{-1} in the open lake. Nitzschia acicularis and N. lacustris were the most dominant in the open lake and they were prevalent in most parts of the lake. N. gracilis and Cyclotella radiosa were also important in the open lake. Aulacoseira nyassensis var. victoriae, Navicula digitoradiata, Nitzschia palea, Cyclotella ocellata and C. meneghiniana predominated in the Nyanza Gulf. The spatial patterns indicate recent changes in species composition and abundance of dominant taxa. Species richness, diversity and equitability were higher inshore than offshore. Diversity was related to Secchi transparency, conductivity and concentration of silicate.

BACKGROUND

Talling (1966, 1987) reported clear seasonal succession of phytoplankton groups in Lake Victoria in early 1960s and he observed that during periods of isothermal mixing of the water column, diatoms replaced cyanobacteria (blue-green algae) as the dominant group. Recent studies indicate that this succession has diminished and the cyanobacteria seem to persistently dominate and diatoms and other phytoplankton groups have declined (Hecky & Bugenyi, 1993; Ochumba & Kibaara, 1989; Lung'ayia, *et al.*, 2000). Besides, diatoms mainly of the genus *Aulacoseira*, formed a major source of food for detritivorous and phytoplanktivorous fish species (Greenwood, 1953; Welcomme, 1968).

Diatoms are sensitive to many environmental variables and have been considered as ecological indicators of environmental perturbations such as acidification, eutrophication and climatic changes (Dam *et al.*, 1994). The shifts in communities of diatoms in Lake Victoria are manifestations of a changing environment that has implications on water quality, biological and fish production. Studies on the distribution and composition of diatoms can be one of the first steps in providing a biological means of assessing environmental conditions as well as natural variability and production in the lake.

The objectives of this study were to describe planktonic diatom species composition, especially spatial distribution in abundance and diversity in the Kenyan waters of Lake Victoria and their relationship to some environmental factors.

MATERIALS AND METHODS

Study area

Investigations were carried out at 10 sites in the Kenya waters of Lake Victoria (Fig. 1) in September 1997. The sites were selected from among stations established by Kenya Marine and Fisheries Research Institute (KMFRI) for routine limnological sampling and were used by Lake Victoria Fisheries Research Project (LVFRP) for fish stock assessment studies. The sites represented inshore, mouths of major rivers and offshore in both the Nyanza Gulf and the open lake. The geographic, hydrological and physical characteristics of the lake, including the Nyanza Gulf have been summarized by Mavuti & Litterick (1991) and Crul (1995).

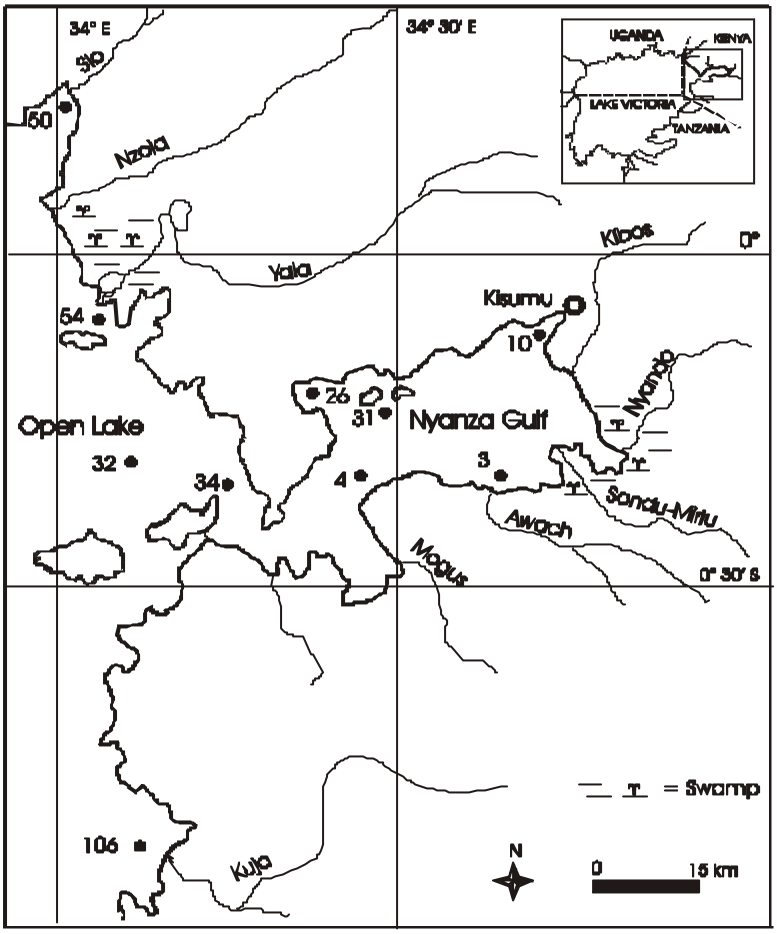

Fig. 1. Location of the sampling stations (3-106) in the Kenyan part of Lake Victoria.

Secchi transparency was estimated with a 20 cm diameter black-white sectioned Secchi disk. Turbidity was measured with a 2100 P Hach Turbidimeter. Water temperature, dissolved oxygen, pH, and conductivity were measured *in situ* with a Hydrolab Surveyor II Multi-parameter Water Quality Monitoring System. Alkalinity was determined by titration with acid as described by Heron & Talling (1978). Chlorophyll a was determined after cold (refrigerated) 90% acetone extraction followed by spectrophotometric analysis and calculated according to Strickland & Parsons (1968). Water samples for analysis of nutrients were preserved with mercuric chloride, stored in ice and transported to the laboratory. The samples were filtered through cellulose-acetate membranes (pore size 0.45 mm) and subsequently analysed for nitrate-nitrogen i.e. NO_3-N (cadmium reduction, diozoic complex), phosphate-phosphorus PO_4-P (SRP, ascorbic acid) and silicate SiO_2 (heteropoli blue) using methods based on those described by Mackereth *et al.*, (1978).

Diatom samples were collected with a 3 l Kemmerer water sampler from the surface (0-0.5 m depth). 250 ml of water were put in polyethylene bottles and preserved with Lugol's solution and 5% formalin. The samples were concentrated by settling for 48 hours to a final volume of 20-30 ml. Diatom frustles were cleaned with sulphuric and nitric acids and mounted in Styrax (Gum storax). Examinations were done on a light microscope using oil immersion lens at 1000 X magnification. Taxonomic identifications were made following Krammer and Lange-Bertalot (1986, 1988, 1991a, b). Counting 300-500 frustules in a known surface area on each permanent slide made quantitative estimates. The counts were recorded as number of frustules l-1. Species richness (d) was calculated by equation of Margalef (1951), diversity (H) by Shannon and Weaver (1963) index and species equitability (J) or evenness by the equation of Pielou (1975). Pearson correlation coefficients between diatom abundance, diversity and environmental factors were calculated using STATISTICA computer program.

RESULTS

Table 1 gives the data on environmental characteristics for the 10 sites sampled. When the different parts of the lake are compared, the Nyanza gulf had lower Secchi transparencies than the open lake. Trends in turbidity were the inverse to those of transparency and turbidities were higher in the gulf than the open lake. There was little variation of water temperature whereas pH was slightly alkaline. Dissolved oxygen was generally high at all stations. On the whole, alkalinity, conductivity and algal biomass, as indicated by chlorophyll-a, were higher in the gulf than in the open lake. Concentrations of PO_4-P showed no clear variations except at Stations 34, at Rusinga Channel and 32 in offshore open lake, where the highest values were recorded. Concentrations of NO_3-N were higher in the gulf where the highest value was recorded at station 10. Slightly higher concentrations of NO_3-N were recorded in the open lake. Similarly, the gulf had higher concentrations of SiO_2 and they decreased to very low values in the open lake.

Table 1. Environmental characteristics of the 10 stations sampled. (NTU = Nephelometric Turbidity Units).

	Station									
	3	**4**	**10**	**26**	**31**	**34**	**32**	**54**	**50**	**106**
Secchi transparency	0.8	1.3	0.7	0.8	0.8	1.3	1.6	1.0	1.0	1.3
Turbidity NTU	13	9	27	12	15	8	4	11	11	8
Temperature °C	27	27	28	28	26	27	26	28	27	27
Dissolved oxygen $mgO_2 \ l^{-1}$	8.3	7.5	7.6	8.4	6.3	9.4	6.7	8.3	6.4	7.9
pH	7.8	8.3	7.8	8.3	8.1	7.5	7.9	8.7	7.7	8.1
Alkalinity mg l^{-1} as $CaCO_3$	78	76	84	80	84	72	48	42	44	42
Conductivity $\mu S \ cm^{-1}$	195	191	213	238	236	138	133	126	128	128
PO_4-P $\mu g \ l^{-1}$	36	27	31	22	28	48	47	31	29	50
NO_3-N $\mu g \ l^{-1}$	17	7	169	34	23	37	53	58	27	16
SiO_2 $\mu g \ l^{-1}$	2.6	1.6	4.1	3.5	3.9	0.3	0.3	0.7	0.7	0.2
Ch a $\mu g \ l^{-1}$	9	33	23	51	31	22	8	28	23	7

A total 82 taxa of diatoms belonging to 24 genera (from 6 orders) were recorded (Table 2). The most important order was Biraphidales, which comprised 68% of the total number of taxa, followed by Coscinodiscales (16%), Araphidales (9%) and Monoraphidales (5%). Rhizoseniales and Rhaphidioididales accounted for 1% each. Among the centric diatoms (Centrophycidae), *Aulacoseira* was the most diversified genera comprising 46% of the taxa in this group followed by *Cyclotella* (23%), and *Stephanodicus* (15%). The most diversified genera among the pinnates (Pennatophyicidae) were *Nitzschia* accounting for 22% followed by *Navicula* (20%), *Pinnularia* (13%) and *Gomphonema* (9%). Higher numbers of taxa per station were observed in the littoral and inshore shallow waters particularly in the Nyanza Gulf and they decreased offshore. Numbers of taxa varied from 12 at Station 4 in mid-gulf to a maximum 36 at Stations 3 and 54 near the mouths of Awach and Yala respectively.

Spatial abundance of diatoms ranged from 2.51×10^5 to 5.42×10^5 frustules l^{-1} in the Nyanza Gulf and from 1.58×10^5 to 8.61×10^5 frustules l^{-1} in the open lake (Fig. 2). The highest abundance was observed at Station 54 and was mainly constituted by *Nitzschia acicularis* that accounted for 36% of the total diatom population, and, *N. lacustris* 21% (Fig. 2, Table 3). A second maximum occurred at Station 34 and was dominated again by *N. acicularis* accounting for 67%. These two species, *N. acicularis* and *N. lacustris*, were among the most predominant in other parts of the open lake together with *N. gracilis* and *Cyclotella radiosa*. In the gulf, the highest abundance occurred at Station 10 and *Aulacoseira nyassensis var. victoriae* was the most important taxa, others included *Navicula digitoradiata*, *Aulacoseira nyassensis*, *Nitzschia palea*, *Cyclotella ocellata* and *C. meneghiniana*, *Nitzschia acicularis* and *N. lacustris*.

Table 2. Taxonomic list of diatoms recorded in the sampled area.

Centrophycidae

Coscinodiscales
Aulacoseira agassizii (Ostenf.) Sim.
A. ambigua (Grun.) Sim.
A. granulata (Ehr.) Sim.
A. italica (Ehr.) Sim.
A. nyassensis (O. Müll.) Sim.
A. nyassensis O. Müll. var. *victoriae* O. Müll.
Caloneis bacillum (Grun.) Cl.
Cyclotella meneghiniana Kütz.
C. radiosa (Grun.) Lemm.
C. ocellata Pantocksek
Stephanodiscus astraea (Ehr.) Grun. var *astraea*
Stephanodiscus sp.
Thalassiosira weissflogii Grun.
Rhizosoleniales
Rhizosolenia victoriae Schröd.

Pennatophycidae

Araphidales
Asterionela formosa Hassall.
Diatoma elongatum (Lyngb.) Argardh.
Fragilaria construens (Ehr.) Grun. var. *construens*
F. construens (Ehr.) Grun. var. *exigua* (W. Smith) Schulz.
F. construens (Ehr.) Grun. var. *subsalina* Hust.
F. capucina var. *capucina* Desmaz.
F. intermedia (Grun.) Grun.
Raphidioididales
Eunotia pectinalis Rabh.

Monaraphidales
Achnanthes hungarica (Grun.) Grun.
A. clevei Grun. in Cl. & Grun.
A. ploenensis Hust.
Cocconeis Ehr. var. *placentula*

Biraphidales
Amphora commutata Grun.
A ovalis (Kutz.) Kütz. var. *ovalis*
A. pediculus (Kütz.) Grun.
A. veneta Kütz.
Anomoeoneis follis (Ehr.) Cl.

Cymatopleura solea Bréb. W. Smith var. *solea*
Cymbella sesatii (Rabh.) Grun.
C. turgida (Greg.) Cl.
C. ventricosa Kütz.
Gomphonema acuminatum Ehr. var. *turris*
G. angustatum (Kütz.) Rabh.
G. clavatum Ehr.
G. clevei Frieke
G. gracile Ehr.
G. oliveceum (Hornemann) Bréb.
Gyrosigma acuminatum (Kütz.) Rabh.
Hantzchia amphioxys (Ehr.) Grun. var. *amphioxys*.
Mastogloia smithii Twaites
Navicula clementis Grun.
N. cuspidata Kütz.
N. cryptocephala Kütz.
N. digitoradiata Greg.
N. gastrum Ehr.
N. gottlandica Grun.
N. gracilis Ehr.
N. oblonga Kütz.
N. pupula Kütz.
N. rynchocephala Kütz..
N. viridula Kütz.
N. variostriata Krasske
N. vulpina Kütz.
Navicula sp.
Nitzschia acicularis W. Smith
N. amphibia Grun.
N. dissipata (Kütz.) Grun.
N. gracilis Hantsch.
N. hantzschiana Rabh.
N. intermedia Hantsch.
N. lacustris Hust.
N. linearis W. Smith
N. microcephala Grun.
N. nyassensis O. Müll.
N. palea (Kutz.) W. Smith
N. paleaceae Grun.
N. pusila Grun.
N. vermicularis (Kütz.) Grun.
Nitzschia sp.
Pinnularia alpina W. Smith
P. cardinalis (Ehr.) W. Smith
P. divergens W. Smith
P. leptosoma Grun.
P. subcapitata Greg. var. *subcapitata*

P. viridis (Nitzsch.) Ehr.
Rhopalodia gibberula (Ehr.) O. Müll. var. *heurckii* O. Mull.
Stauroneis anceps Ehr.
S. obtusa Lgst.

Table 3. Percentage contribution of the most quantitatively important (≥5%) diatom taxa to the total count in the various stations

Taxa	Station									
	3	4	10	26	31	34	32	54	50	106
A. granulata					26					
Aulacoseira nyassensis var. victoriae			38							5
Cyclostephanos dubius				7		5				7
Cyclotella meneghiniana	16									
C. ocellata	7			7						
Navicula digitoradiata	12		12	48	23				67	
N. oblonga					5					
Nitzschia acicularis	11	46	7			67	67	36		71
N. gracilis				5	5			11		
N. lacustris	14	36	6	5		19	24	21	7	8
N. microcephala					7					
N. palea	18		25	10	7			11	8	

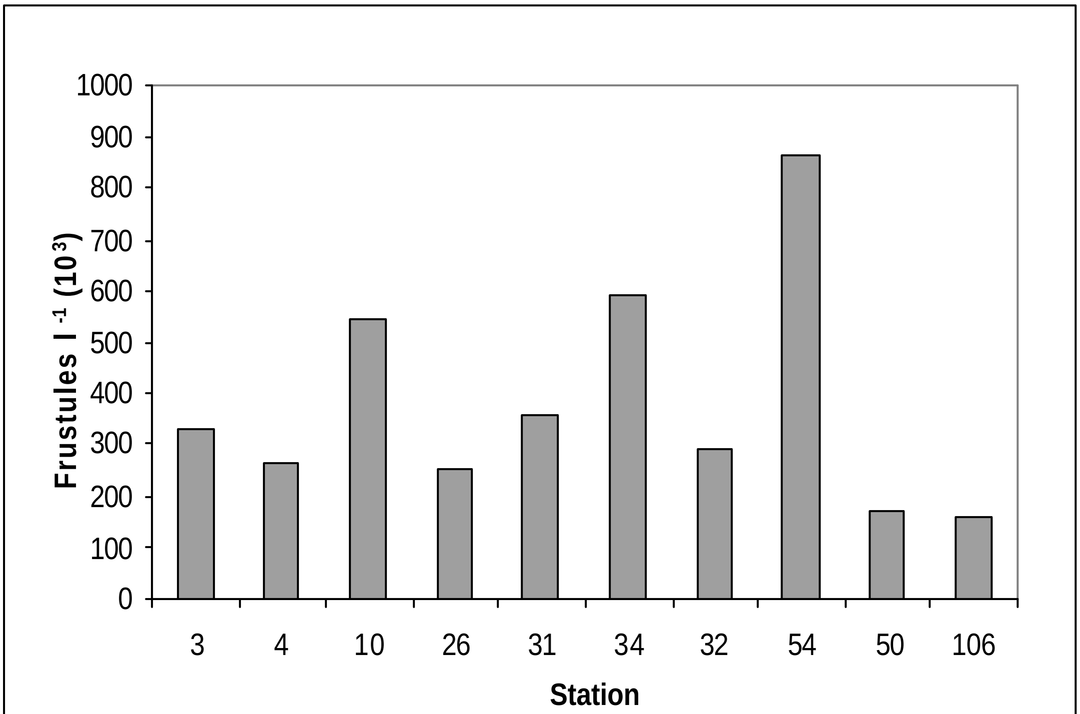

Fig. 2. Variations in diatoms abundance

Higher species richness were observed in the inshore shallow waters of the Nyanza Gulf (Fig. 3) whereas, maximum densities but lower numbers of species occurred offshore and in the open lake. The highest species richness in the gulf 2.8 was recorded at Station 3 and the lowest 0.9 was at Station 4 in mid-gulf. A minor peak of species richness occurred at Station 54 in the open lake. Spatial variations in species diversity index (H) followed similar patterns to those of species richness. The highest diversity was observed at Station 3, owing to presence of a large number of species with higher equitability (J) contributing to the total abundance (Table 3). A minor peak in diversity was observed at Station 54 while the lowest diversity at Station 4 was due to a few dominant species with a high percentage contribution to the total diatom population. Diversity was significantly correlated to Secchi transparency, conductivity and silicate ($p<0.05$) (Table 4). There was no significant correlation between abundance and any of the measured environmental factors.

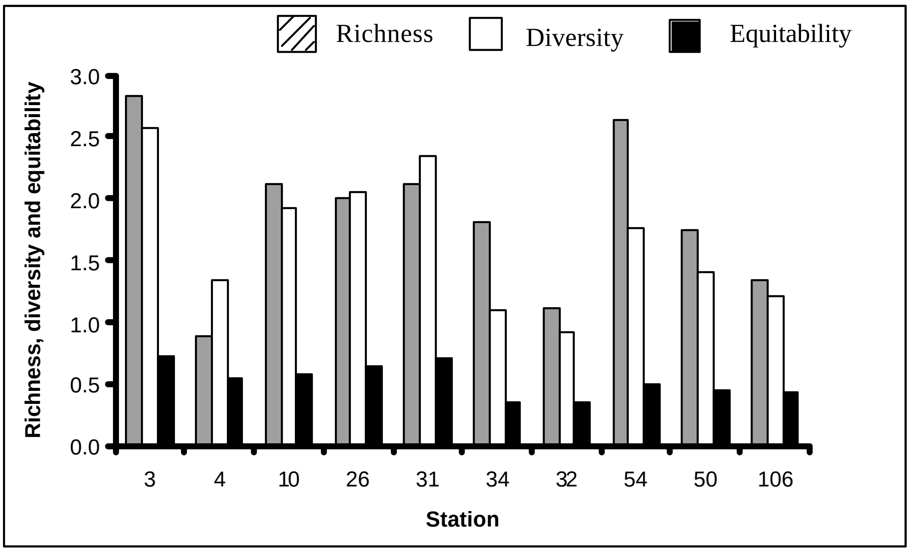

Fig. 3. Variations in diatom species richness (D), diversity (H) and equitability (J)

Table 4. Correlation coefficient 'r' and significant 'p' values calculated between diatom abundance and diversity, and environmental factors (* Significant at 5% level).

Environmental factor	Abundance		Diversity	
	r-value	p-value	r-value	p-value
Secchi transparency	- 0.164	0.651	- 0.892	0.001 *
SiO_2	- 0.016	0.964	0.806	0.005 *
Conductivity	- 0.149	0.681	0.732	0.016 *
PO_4-P	0.009	0.098	- 0.577	0.069
Turbidity	0.253	0.480	0.595	0.070
Alkalinity	0.005	0.990	0.592	0.071
pH	0.399	0.254	0.316	0.374
Chlorophyll a	0.106	0.771	0.304	0.393
Temperature	0.424	0.222	0.228	0.527
NO_3-N	0.451	0.191	0.083	0.819
Dissolved oxygen	0.451	0.191	- 0.003	0.996

DISCUSSION

In Lake Victoria, diatoms were quite diverse and quantitatively important in the phytoplankton in early 1960s (Talling, 1966, 1987). Unpredictable weather changes in the lake's basin is causing variations in thermal structure of the water column and according to Hecky, *et al.*, (1994), there is an increase in stability that has reduced mixing of the water column. Consequently, this has reduced redistribution of nutrients, accumulated in bottom sediments, particularly silicate required for structural growth of diatoms. The decrease in silicate in the epilimnion (Hecky & Bugenyi, 1993) may have lead to a decline in diatoms and in addition, increased their photosynthetic activity as reported by Mugidde (1993). Higher rates of photosynthesis may partly explain the higher concentrations of dissolved oxygen at stations with large populations of diatoms.

In our study, concentration of silicate remained low except in shallower waters in the Nyanza Gulf, particularly near mouths of rivers where higher concentrations were recorded. These areas were also characterized by lower transparency (except at mouth of Yala) mainly due to suspended sediments, and, they had higher ionic content (higher conductivity). Most of the diatom species that were dominant in the shallower waters, such as *Aulacoseira nyassensis, Navicula digitoradiata*, *Nitzschia palea,* and *Cyclotella meneghiniana*, are tolerant to low light conditions and that is why they contributed greatly to the higher diversities seen, for example at Station 3. This could also be why diversity was significantly correlated to secchi transparency, conductivity and silicate. Our findings agree with those of Lung'ayia *et al*., (2000) who report that silicate and turbidity influenced significantly the distribution of phytoplankton, in general, in Lake Victoria. Elsewhere, in the gulf, lower transparency could be attributed to high algal biomass mainly contributed by other algal groups as shown by higher concentration of chlorophyll a but lower abundance of diatoms, for example at Stations 26 in Asembo Bay, 4 and 31 in mid-gulf.

Minor peak diatom abundance in the Nyanza Gulf at Station 10 in Kisumu Bay, was accompanied by relatively high NO_3-N. On the other hand, the peak of diatom abundance in the open lake coincided with higher transparency and a fairly rich nutrient environment (higher PO_4-P and NO_3-N). Lower SiO_2 in the same areas could be due to exhaustion by the large populations of diatoms. Talling, op cit. reported low concentrations of silicate during and after periods of diatom abundance and associated this to depletion of silicate by the diatoms. As a whole, concentration of PO_4-P and NO_3-N remained higher than the 10 µg l^{-1} reported by Talling (1966) confirming the increasingly eutrophic nature of Lake Victoria. Long-term trends of major nutrients in the lake indicate that, while concentrations of phosphates have not changed significantly since 1960s, nitrates have increased and silicates have reduced. According to Hecky (1993), the N: P ratio has reduced and this has favoured cyanobacteria that are now persistently dominating the phytoplankton.

In the inshore shallow waters, the diversity of littoral habitats and high amounts of nutrients seem to encourage the floristic richness and growth of different species. This is in agreement with Rao, *et al.*, (1988) who related higher diversity of plankton in general in Lake Rangasagar, India, to high temperature and nutrients. On the other hand, lower concentration of silicate in offshore Lake Victoria results in a decrease in diversity, although also, the concentration of silicate seems to be sufficient enough to support large numbers of *Nitzschia acicularis* and *N. lacustris*. The coupling between diatoms, and phytoplankton in general, and herbivorous zooplankton and fish in Lake Victoria is not known and needs to be studied. Although the decline of detritivorous / phytoplanktivorous fish species in the lake is blamed on the introduced predatory Nile perch *Lates niloticus* (L.) (Ligtvoet & Witte, 1991), it appears that the changes in phytoplankton composition where cyanobacteria are persistently dominating and other groups are becoming lesser could also have contributed to the decline of the fish species. This is probably due to reduction in availability of certain food items including species of diatoms. According to Greenwood (1953) and Welcome (1968), many detritivorous and phytoplanktivorous fish species fed mainly on diatoms, particularly Aulacoseira that used to be among the most dominant genera.

The abundance of diatom species reported by Talling (1966) as dominant appears to have changed. These included *Aulacoseira nyassensis* (1011 cells l^{-1}), *A. agassizzi* (10^4), *Nitzschia acicularis* (10^5) *Surirella nyassae* (10^3) and *Stephanodiscus astraea* (10^4). The maximum that we recorded for some of these species were: *A. nyassensis* (2.1 x 10^5 *frustules* l^{-1}), *A. agassizzi* (4.7 x10^2), *Nitzschia acicularis* (4 x10^5) and *S. astraea* (1.4 x 10^4). If we compare our data with those of Talling *op cit*., it is possible that *Nitzcschia* may have replaced *Aulacoseira* as the most important diatom particularly in the open lake.

CONCLUSIONS AND RECOMMENDATIONS

From 1997 up to 2000, more data have been collected but it is still predominantly an irregular sampling stream and most of the data is yet to be examined. Until there is complete data collection at regular intervals and covering different seasons, clear relationships, more than the type demonstrated here will be inconclusive and will remain descriptive. However, our data are still sufficiently inclusive to reveal spatial distribution that is governed by environmental factors, since the samples were taken from areas representing different habitats of the lake.

Water quality monitoring programs on Lake Victoria are mostly based on environmental variables. Considering that there is growing interest worldwide on assessment methods on water quality, based on biological organisms such as diatoms, our data may provide baseline and useful information to examine the controlling processes as well as the potential of ecosystem production. Research on diatoms and other organisms as biological indicators of the state of the aquatic environment should be pursued further.

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