Lotic Diatoms as Environmental Indicators for Modern and Paleo Studies

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Introduction

The ecological impacts of anthropogenic activities on aquatic environments have led to the development of new methods of environmental monitoring (Cohen et al 1993, Kelly and Whitton 1995). Benthic algae represent a ubiquitous group of photosynthetic organisms that play a pivotal role in stream food webs but may also be used for observing long-term trends in community changes that can occur because of non-point source pollution (Lowe and Pan 1996). Diatoms in particular are useful ecological indicators because they are abundant in most lotic systems and have been used in a number of trophic indices for water quality monitoring (USEPA report, Kelly and Whitton 1995 and authors therein). The persistence of diatom frustules in the environment enables prehistoric conditions to be reconstructed based on the narrow ecological preferences of most species (Lowe and Pan 1996).

The watershed of Lake Tanganyika represents an area under considerable strain due to population growth. Watersheds are cleared of forest cover for settlements, crops, and timber (Caruso 2002). Deforestation can severely impact aquatic communities and the diversity therein (Cohen et al 1993). Because benthic algae are attached to the bottom substrate, they must either cope with their surrounding environment or perish (Lowe and Laliberte 1996). Several studies of the littoral phytoplankton of Lake Tanganyika have been conducted in the past decade (Cocquyt 1999 and authors therein), but the benthic community of the surrounding tributaries remains little studied (Cocquyt 1999b). It is the aim of this investigation to look at benthic algal community composition in the streams along the eastern shoreline of Lake Tanganyika, Tanzania, that lies within forested and deforested watersheds. Trophic indices will be applied to the diatom species enumerated from each stream to look for differences between the streams sampled. The application of a trophic index based on the sensitivity of diatom species developed in Europe will be used in the hope of seeing parallel trends and validating the use of such indices to a wider range of systems.

Methods

Sites.

In July 2002 the watersheds along the eastern shoreline of Lake Tanganyika, Tanzania were mapped and subsequently ten of these watersheds were selected for water chemistry analysis (Caruso 2002) Five of these streams are within deforested watersheds, typically supporting settlements, and the other five are within the Gombe Stream National Park and represent little disturbed, forested watersheds (Lombardozzi, 2003). These 10 streams were sampled between July 14 and July 28, 2003 for the algal assemblages within the stream reach. During the dry season, ground water discharge maintains the flow within streams. The streams are small second or third order systems no more than 2 meters wide. At each stream two stations were chosen that had similar substrates and flow rates for more direct comparison of algal communities. Station 1 at each site represents where the stream comes out onto the sandy beach, just before entering the lake. No tree cover was present at this station at any site. Station 2 is located approximately 25m upstream. In Gombe, this site was always under canopy. At all sites small cobbles and pebbles dominated the substrate.

Algae Collection and Identification.

In each stream a 0.25 m^2 quadrat was randomly placed within the stream and all the cobbles within this area were collected. In 100 ml of distilled water, all rocks were scraped clean of the epilithic (attached) algae with a toothbrush. Care was taken to collect only those species attached and not free-floating in the stream's current. Samples were preserved in ~3% formalin and the sample volume brought to 125 ml. Samples were returned to the laboratory on ice and refrigerated until analysis.

Samples were thoroughly mixed and made into wet mounts for soft algae identification. A number of slides were made of each site and all soft algae were identified to the genus level (Prescott 1978). Organic matter was removed prior to permanent mounting of diatoms by adding 2-5 ml of H_2O_2 to a 5-10 ml sub-sample of the collected material and left in a hot water bath for ~1hr. Permanent mounts were made with Permount solution, labeled, and filed until identification. Counts of at least 400 valves were conducted at 1000 x magnification with a Leica microscope, to ensure the number of new taxa encountered was no longer increasing exponentially (Kelly and Whitton 1996, Cocquyt pers. comm.). The work of Coccquyt (1998) on the diatoms of the North Basin of Lake Tanganyika was used as a reference in addition to personal observations by C. Cocquyt and J. C Stager.

Community descriptions.

Enumerated diatoms were subjected to a number of indices to test the biotic integrity of the system. The Shannon diversity index (H) and evenness (J) along with the Simpson-Yule Index (D) and evenness (E) were used for within and across site comparisons as well as index comparison (EPA water quality monitoring). The Shannon is the most commonly applied index despite the Simpson-Yule being more sensitive to community shifts. The Trophic Diatom Index (TDI) developed by Kelly and Whitton (1995) for temperate streams was used to determine the trophic status of the streams analyzed. Sensitivity and indicator values used in the index equation are assigned based on the orthophosphate concentrations taxa are most abundant. Sensitivity values range from 1 to 5 and indicator values from 1 to 3 based on the spread of values around the abundance peak (Kelly and Whitton 1995). The index is then calculated as:

$$\text{Index} = \frac{\sum^{n}_{j=1} a_j v_j i_j}{\sum^{n}_{j=1} a_j v_j}$$

"where a_j = abundance (proportion) of species j in sample, v_j = indicator value (1-3) and i_j = pollution sensitivity (1-5) of species j. The value of the TDI can range from 1 (very low nutrient concentrations) to 5 (very high nutrient concentrations)" (Kelly and Whitton 1995). Personal observations of the relative abundances of soft algae and their usefulness as indicators were included.

Statistics.

Student t-tests were used to look for significant differences between the forested and deforested TDI means, phosphorus (as SRP) concentrations, Simpson-Yule index and genus and species abundance. A modified t-test was used to compare the Shannon diversity index between the deforested and forested streams (Zar 1999). The TDI of the forested and deforested streams was compared to phosphorus concentration (as SRP) and compared to the theoretical TDI after Kelly and Whitton (1995). Cluster analysis was applied to look for similarities between stations using diatom species abundance and local water chemistry parameters.

Results

A significant difference was observed between the total number of genera (soft algae and diatoms) between the deforested and forested streams ($P < 0.01$) with the deforested streams having more genera present (Tables 1 and 2). There were observed differences in the soft algal composition between the forested and deforested sites. At all sites, filamentous green algae were present, typically of the genus *Cladophora*. In the streams draining deforested watersheds and harboring human settlements, a number of soft algae were present that are indicative of eutrophication and include *Lyngbya* and *Oscillatoria*. *Cosmarium, Gloeocystis* and *Lyngbya* were only observed in the impacted streams and are reported as potentially producing toxins and causing taste and odor problems (The Water Research Laboratory at NKU pers. comm.). The streams located within Gombe National Park had fewer filamentous green and blue-green (cyanobacteria) algae and none of the toxic, taste and odor causing genera.

A total of 51 diatom species representing 17 genera were observed in all streams analyzed. In all cases the observed number of diatom genera was significantly greater than that of the soft algae ($P < 0.001$) (Tables 1 and 2). Biotic integrity of diatom species as determined with the Shannon diversity (H) and Simpson-Yule (D) did not yield significant differences between forested and deforested watersheds ($P > 0.05$). Mean values for the Shannon index were 0.89 ± 0.18 in the deforested streams and 0.90 ± 0.11 in the forested streams. Simpson-Yule values were 6.59 ± 0.73 in the deforested streams and 5.93 ± 0.69 in the forested streams (Tables 1 and 2). Total diatom species present in the deforested and forested streams did not significantly differ ($P > 0.05$). Diatom species richness was 15.33 ± 1.11 in the deforested streams and 16.80 ± 1.05 in the forested streams (Tables 1 and 2).

Although diatom community diversity did not differ significantly among sites, there were strong differences in the abundance of some species. Figure 1 shows the abundance of the diatom genera for each station and stream. *Achnanthes* was the most common genera in the forested watersheds and was especially dominant at station 2 under the forest canopy (Fig 1). Two genera tolerant to eutrophication, *Amphora* and *Cymbella,* were found almost exclusively in the deforested streams (Fig 1). *Nitzschia* is also typical of p-enriched waters and were found in the greatest proportions in the deforested streams. Common in all systems were moderate indicators *Achnanthes*, *Gomphonema* and *Navicula* species. Taxa intolerant to p-enriched waters were rare or absent from all stream samples observed. Application of the TDI to the streams resulted in a significantly lower value in the forested systems ($P < 0.01$) (Fig 2). Values were 4.10 ± 0.09 in the deforested sytems and 3.62 ± 0.09 in the forested systems (Tables 1 and 2). Phosphorus values (as SRP) that the index is based on were significantly lower in reference streams compared to impacted streams ($P < 0.01$) (Lombardozzi, this volume). Observed TDI values plotted with the theoretical TDI based on the regression equation of Kelly and Whitton (1995) were greater for most sites (Fig 2).

Cluster analysis of the stations sampled was based on diatom species relative abundance and water chemistry parameters (PO_4^{3-}, NO_3^-, NO_2^-, SiO_2) observed at each station (for a complete review of the water chemistry data from the streams see Lombardozzi, this volume). Streams matched up according to being forested or deforested and within the forested streams, those stations under the forest canopy (station 2) and on the exposed beaches (station 1) aligned accordingly (Fig 3). A number of outliers occurred for Mtanga (station 2), Bwavi (station 1), and Mkenke (station 2).

Discussion

From this survey of the algal communities in the tributaries to Lake Tanganyika, it appears that species presence/abundance can be a valid tool for inferring local water quality conditions. Observations of cyanobacteria and green algae typical of disturbed, eutrophic systems only in the deforested and populated watersheds help implicate anthropogenic influences as negatively affecting the stream ecosystem. The alga observed could be potentially toxic to livestock and be the source of taste and odor problems for humans consuming the water. River catchments with little forest cover will typically see a downstream increase in nutrient loading (especially with higher intensity land use), shifting the stream community from diatoms to filamentous, nutrient-demanding taxa (eg. *Cladophora*) (Biggs 1996). The effects of light limitation on the benthic algal community were evident in the streams analyzed. Under the forest canopy in Gombe Stream National Park, the diatoms dominated the algal community. This is consistent with previous predictions that in lower light intensities, diatoms plus some cyanobacteria will flourish (Hill 1996 and authors therein). On the exposed beaches (station 1) and throughout the stream reaches of the deforested watersheds, light is not limiting, allowing the green algae to better compete with the diatoms and cyanobacteria. Seasonal succession of the algal community from a diatom dominated system to one dominated by cyanobacteria and other filamentous algae are common in enriched, spring-fed tropical systems (Biggs 1996) however this succession was only marginally evident in the reference watersheds and the affects of deforestation and human settlements may confound this process in the impacted streams.

The diatom communities of the streams analyzed were dynamic, but trends and patterns were observed. Metrics of biotic integrity applied to the systems did not yield significant differences and species richness in the undisturbed systems was not significantly greater than that of the disturbed watersheds. A number of critisims have been leveled against both indices used. The Shannon diversity index, though commonly used, may be a distraction and can be strongly influenced by species number (Southwood and Henderson 2000). The Simpson-Yule index suffers due to the influence a dominant species can bear on the derived value (Southwood and Henderson 2000). Species richness is predicted to be greater in undisturbed systems, but it has been shown that minor disturbances may increase diversity (Lowe and Pan 1996). However, presence of specific indicator species in the impacted streams does reflect the perturbations occurring throughout the watershed. *Amphora*, *Cymbella* and *Nitzschia* represent taxa more tolerant of eutrophication (Kelly and Whitton 1995, Water Research Laboratory at NKU pers. comm.) and were either exclusively found in the disturbed streams, or in greater abundances when compared to the reference stations. The nutrient typically associated with eutrophication of fresh water systems is phosphorus. Streams draining forested watersheds had significantly less phosphorus in solution; however it does not appear to be a limiting nutrient. This is consistent with Lake Tanganyika as a whole, where nitrogen tends to be limiting (O'Reilly pers. comm.). The relatively high pH of the streams (range 6.61-8.05) can leach more phosphorus from the soils making it readily available for uptake (Wetzel 2001). Application of the Trophic Diatom Index (TDI) appears to be valid in tropical systems. Sensitivity values used in the index are based on abundances of certain taxa within a narrow range of phosphorus values. As phosphorus values increase, the TDI value is expected to be greater. This trend held true for the streams analyzed, with the impacted streams having a significantly higher TDI value compared with reference streams. Observed TDI values were greater then the theoretical TDI values based on the phosphorus concentrations. Forested watersheds were generally closer to the predicted values compared to the impacted stream communities, possibly due to additional organic inputs enriching the system (Kelly and Whitton 1995).

Grouping of stations based on the algal assemblage and water chemistry parameters generally produced predictable pairs. Forested and deforested stations were more closely aligned and within the forested basin, stations under canopy cover typically paired up. For the outliers observed, dominance by one species is the most likely cause. An important variable not included in the analysis but evident in a few of the pairings is watershed area. In the absence of disturbance and anthropogenic inputs, topography and geology of the watershed will have broadscale impacts on the benthic algal community (Biggs 1996). The diatom genera present also reflect the hydrodynamics of the stream basin. In the riffles of enriched streams, low growing diatoms (e.g., *Cocconeis*, *Navicula*, *Nitzschia*) will typically dominate the diatom community (Biggs 1996). These genera were most common in the river delta valley stations where slope (and therefore current), were reduced. For a better understanding of how proximate (nutrients) and ultimate factors (human inputs, geology) may be controlling the algal communities observed, more detailed multivariate approaches (e.g. PCA) should be applied (Lowe and Pan 1996).

Conclusions and Recommendations

From this investigation, the benthic algal community observed reflected watershed manipulations by human activity. Presence of indicator organisms primarily in impacted streams implicates anthropogenic activities as being detrimental and also strengthens the usefulness of biological organisms as ecological indicators. For a more direct comparison of the streams in question, only one habitat type was sampled at two stations. To get a better grasp of the entire algal assemblage present in the stream system, multiple habitats (sand, mud, tree roots, etc.) throughout the stream reach need to be sampled. Presence of more indicator species may be identified, reinforcing the relationships observed here. It appears from this study that the application of temperate derived indices is valid for tropical systems. Only small modifications would be needed to account for local conditions and variations. More robust data sets on the autecology of organisms will make an index like the TDI a more powerful tool in monitoring eutrophication and recognizing disturbed systems.

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Table 1: Summary of algal communities from impacted streams along the north east coast of Lake Tanganyika sampled in July 2003.

	Stream								
	Mtanga sta 1	Mtanga sta 2	Mtanga "A" sta 1	Mwongongo sta. 1	Mwongongo sta. 2	Bugambo sta. 1	Bugambo sta. 2	Kiziba sta 1	Kiziba sta 2
soft algae genera	8	7	5	3	4	6	5	4	7
diatom genera	8	8	7	7	9	11	11	7	10
diatom species	10	10	12	12	17	20	19	17	21
total genera	16	15	12	10	13	17	16	11	17
Diatoms									
Shannon (H)	0.61	0.64	0.94	0.81	0.90	0.97	1.02	1.03	1.13
Shannon Evenness (J)	0.61	0.64	0.87	0.75	0.73	0.75	0.80	0.84	0.85
Simpson-Yule (D)	3.34	3.63	7.26	4.82	6.19	6.76	7.76	8.57	10.99
Simpson-Yule Evenness (E)	0.33	0.36	0.61	0.40	0.36	0.34	0.41	0.50	0.52
TDI	4.022	4.551	4.149	3.911	3.829	4.201	4.329	4.004	3.936

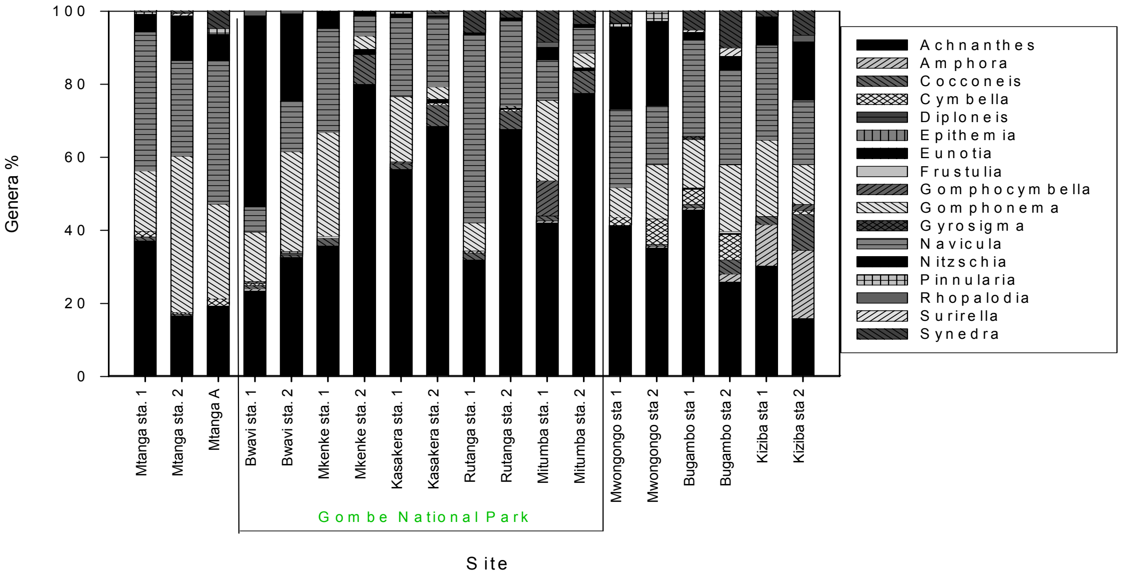
Table 2 Summary of algal communities from reference streams within Gombe National Park, Tanzania in July 2003.

	stream									
	Bwavi sta 1	Bwavi sta 2	Mkenke sta 1	Mkenke sta 2	Kasakera sta 1	Kasakera sta 2	Rutanga sta. 1	Rutanga sta. 2	Mitumba sta. 1	Mitumba sta. 2
soft algae genera	5	3	1	1	3	1	3	1	2	2
diatom genera	9	8	6	6	8	9	7	8	9	7
diatom species	13	17	17	14	19	19	18	16	18	17
total genera	14	11	7	7	11	10	10	9	11	9
Diatoms										
Shannon (H)	0.65	1.03	1.02	0.94	0.85	0.88	0.80	0.93	0.95	0.97
Shannon Evenness (J)	0.59	0.83	0.83	0.82	0.67	0.69	0.64	0.77	0.76	0.79
Simpson-Yule (D)	3.00	9.13	8.11	7.17	4.76	4.31	4.02	6.34	5.87	6.58
Simpson-Yule Evenness (E)	0.23	0.54	0.48	0.51	0.25	0.23	0.22	0.40	0.33	0.39
TDI	3.81	3.85	4.24	3.42	3.54	3.57	3.86	3.37	3.35	3.23

Figure 1: Generic distribution of diatoms from streams sampled along the northeast coast of Lake Tanganyika in July 2003.

Figure 2: Relationship between trophic diatom index (TDI) and phosphorus (as SRP) for deforested sites (open circles) and forested sites (closed circles). Linear line represents the theoretical TDI based on the regression equation of Kelly and Whitton (1995).

Figure 3: Cluster diagram of all sites sampled from streams along the northeast shore of Lake Tanganyika in July 2003.



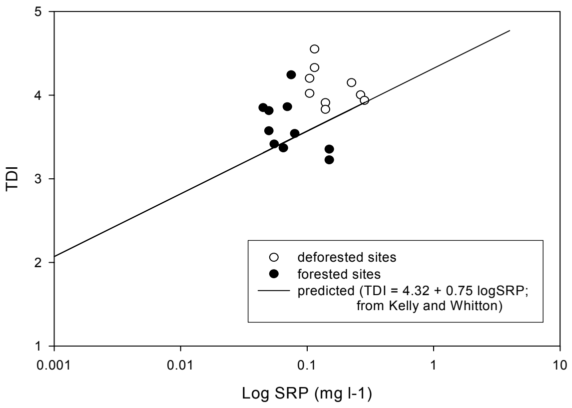


Figure 2

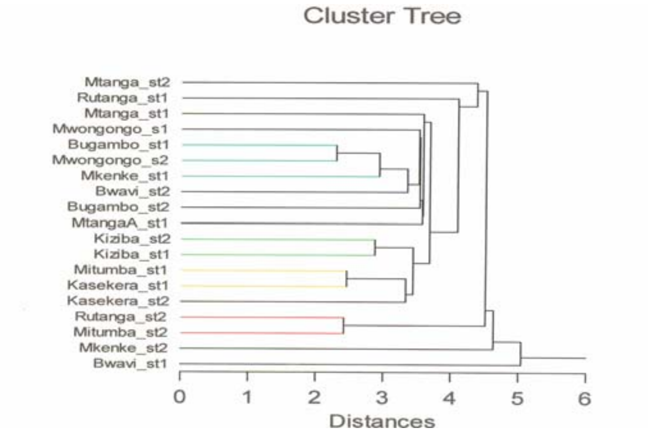


Figure 3