

Exploring Diatom Assemblages and Depositional Patterns in Two Lake Tanganyika Watersheds

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Introduction

Due to their sensitivity to total P concentrations, pH and other variables, diatoms have become important biological indicators of present and paleo-environments for limnologists and paleoclimatologists. Diatoms' silica valves are well preserved in many sedimentary environments; thus, many have studied variations in diatom assemblages through sediment cores to describe paleo-lake environments, and how they have changed up to the present time (Battarbee 1999, Fritz 1989). In river environments, limnologists have correlated diatom assemblages with measures of pH, phosphate and nitrate, and patterns have been found between the appearance of certain taxa and relative degrees of river eutrophication (Bellinger *et al.* 2006). Past Nyanza projects have studied questions of lacustrine paleoenvironments (Meeker 2002) and river eutrophication (Bellinger 2003).

Since diatoms can be used to study paleoenvironmental questions in lakes and eutrophication in present-day river environments it might be possible to combine these applications, and use patterns of riverine diatom deposition in deltaic lake sediments to study how rivers' chemical environments have changed through time. Before trying to look for evidence of changing river diatom assemblages down a sediment core, however, one must first determine whether riverine diatoms are being deposited offshore with any regularity.

This project investigates diatom assemblages and depositional patterns in two similar watersheds in Lake Tanganyika, East Africa: those of the Mtanga and Kasekera streams. By testing for differences between the benthic diatom genera of the rivers, the genera in the rivers' deltaic sediments and the genera in nearby, off-delta lacustrine sedimentary environments, one can make preliminary conclusions about how significantly diatoms deposited in deltaic sediments reflect the diatom assemblages of their corresponding rivers. This study hypothesizes that the diatom genera in deltaic sediments will reflect the benthic diatom assemblages of the deltas' respective inflowing rivers more so than lake diatom assemblages.

Site Descriptions

Mtanga and Kasekera streams are both located on the northeast coast of Lake Tanganyika north of Kigoma, Tanzania. Mtanga stream runs through Mtanga village, a sizeable fishing community; it has an approximate watershed area of 3.76km², and its catchment is significantly deforested (Guerra 2007). The village's buildings, goat pens and storefronts encroach closely upon the river's banks. In July 2007, the stream's final 50m stretch had little tree cover and patchy vegetation along its banks, and flowed into Lake Tanganyika over a beach of mixed cobbles and sand. In contrast, Kasekera stream (watershed area 3.32km²) runs through forested Gombe National Park, with very low human populations in its catchment (Guerra 2007). Trees shade the stream for most of its final 50m, with only the stream mouth and the first few meters in direct sunlight. The stream also flows into Lake Tanganyika over a beach of mixed cobbles and sand.

The two watersheds' deltaic environments share many similarities (Figs 1, 2). Both environments featured canyons to the north of the stream mouths, and deltaic lobes that extended to approximately 40m water depths.

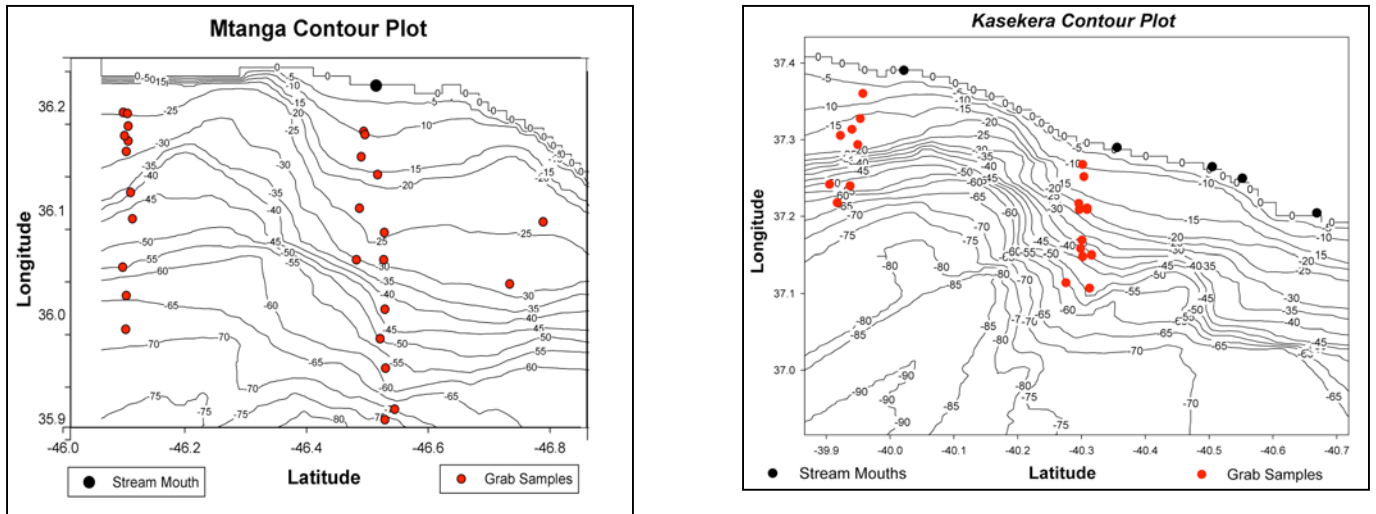
Methods

Field sampling: Offshore sampling

Offshore sampling employed grab sampling and SCUBA diver sampling methods. Grab sample-sites were chosen based on thorough bathymetric survey of the two deltas completed in summer 2007 (Guerra, this vol.). Using a winch and sampling ponar mounted aboard the *R/V Echo*, teams from the Nyanza Project Geology Team

took grab-samples along two transects at the Mtanga and Kasekera rivers: one on each of the deltas' axes and another along an off-delta transect to the north of the river deltas (Figs 1, 2). The “off-delta transects” were taken to approximate a lacustrine sedimentary environment with no direct inputs from shore. These are sometimes referred to as “lake transects” in the body of this paper.

Once the sampling ponar hit the lake bottom for each grab-sample, team members recorded position and depth measurements via handheld GPS units and the depth sounder onboard the R/V Echo. The ponar was brought back to the boat using the winch, and once within reach of crew-members on the boat, the water trapped in the ponar



Figs 1, 2. Contour Plots of Mtanga and Kasekera Stream Deltas. Numbers along the topographic lines indicate depths, and dots indicate locations of grab samples. Dots along the 0m-depth contour line mark stream mouths; the multiple stream mouths at Kasekera made determining the appropriate locations for off-delta and on-delta transects difficult (see discussion).

was drained by tilting it slightly to the side to preserve the sediment sample. Team members then placed the ponar on a clean plastic surface on the boat deck, carefully opened the ponar to preserve the sediment-water interface, and sampled the upper 1cm interval of sediment using a metal teaspoon. Samples were collected in airtight, sterile plastic bags and placed in action packers for transport back to the lab.

Dive sampling sites were also chosen based on the Guerra (2007) bathymetric survey. The dive team selected sample sites 30m to the north and south of the main deltaic grab-sample transects at 10m, 15m, 20m and 25m depths, based on the GPS positions logged during the bathymetric survey. Divers sampled the north and south sides of the grab sample transects in two dives; one dive for the north side, and one for the south. Using a compass to hold the bearing of the deltaic grab-sample transect, divers swam offshore to 25m (Kasekera) and 20m water depths (Mtanga), and using kick-cycles to estimate distance, swam 30m to the north of the main deltaic transect line. At the end of a kick-cycle, divers swam parallel to the main deltaic transect line, back towards shore, and proceeded to collect sediment samples at 15m and 10m depths. At each sampling site the upper 1cm of lake sediments were collected with a metal teaspoon and placed into sealed, sterile plastic bags before being carried to the surface.

Onshore sampling

Benthic algal samples were collected at randomly selected sites on the Mtanga and Kasekera rivers. One sample was taken at the stream mouth, and one 25m (by tape measure) upstream from the stream mouth sample. At each sample site, chosen at random, the cobbles were removed from the stream in a 0.25m² rope quadrat and scrubbed clean of algae with a toothbrush. Scrubbed algae were collected in plastic bags filled on-site to a volume of 125ml with bottled drinking water.

Lab procedures

All samples were treated with a combination of 50% hydrogen peroxide, 0.02N sulfuric acid and 10% hydrochloric acid to oxidize organic matter, dissolve carbonate and prevent diatom valves from clumping together via electrostatic attractions. Sediment samples were thoroughly mixed before being subsampled. The offshore sediment samples were mixed with a metal spatula before being weighed out for analyses; for the onshore samples, the benthic algae in suspension were mixed by withdrawing and expelling the algae/drinking water solution with a plastic transfer pipette. For the offshore sediments, 0.1-0.5g were placed into clean, dry, previously tared test tubes with the same metal spatula with which they were mixed. Masses were recorded to 4 decimal places. 12 ml of 50% H₂O₂, measured out with a graduated cylinder, was then added to each test tube. Samples sat for 1 hour at room temperature in the H₂O₂ solution. Afterwards, test tubes were placed into a beaker on a hot plate which contained boiling water, and the sediment-H₂O₂ solutions were allowed to boil at ~100 °C for 1 hour. Periodically, the test tubes were removed from the hot water baths and placed in cold water to prevent the H₂O₂ from boiling above their lips. After one hour, 2-3ml of 0.02N H₂SO₄ was added to each sediment-H₂O₂ solution with a 3ml plastic transfer pipette, and the mixture boiled for another 10-15 minutes. The reactions were ended by filling the test tubes with bottled drinking water; drinking water was poured directly into the test tubes from sealed drinking water bottles. Samples were subsequently allowed to cool, and were allowed to stand for at least three 6-hour resting periods. Between resting periods, 8-10 ml of the drinking water was pipetted out and replaced with 8-10 ml of fresh bottled drinking water.

Finally, after a minimum of three 6-hour resting periods, 2-3 ml of the rinsed sediment solution was placed onto a glass cover slip with a plastic transfer pipette and allowed to dry for 12-14 hours under a dust cover. Smear slides were made by placing two to three drops of Permount ® mounting resin onto glass microscope slides, placing the diatom-laden glass cover slips “diatom-side down” into the resin, and placing the slide onto a hot-plate set on its highest heat setting. The resin was allowed to boil for 1 min. Slides were subsequently removed, and pressed firmly with the back end of a forceps to remove air bubbles. Slides were allowed to rest for 30 mins until the Permount fully hardened.

For the onshore samples of algae scrubbed from the river rocks, processing closely followed the above procedures and procedures described in Bellinger *et al.* (2006), except formalin and refrigeration were not available. 2-5 ml of the mixed algae-drinking water solution was placed into test tubes with 6 ml of H₂O₂ with a plastic transfer pipette, and then allowed to rest for 1 hour. Afterwards, the onshore samples received the exact same treatment as the offshore sediment samples: boiling in H₂O₂ for 1 hour, H₂SO₄ application at the end of the boiling period, three 6-hour (minimum) resting periods with drinking water rinses, and slide-making using Permount resin.

Counting Diatom Valves

At least 300 intact diatom valves were identified per slide to generic level using a Leica CME microscope at x1000 magnification. Broken valves were not counted. Some samples had fewer than 300 diatom valves present; for these samples' slides, all intact diatom valves were counted on the slide. For each grab sample or dive sample from the on-delta and river transects, three slides were prepared and counted unless fewer than 300 whole diatom valves could be counted on a single slide. If fewer than 300 valves were identifiable on one slide, then only one slide was counted for that grab sample. For the grab samples along the off-delta transect, only one slide was prepared and counted for valves. Reference sources used for generic identifications were Gasse (1986), Cocquyt (1998) and Russell (2000).

For the Mtanga and Kasekera watersheds, valve counts were completed for two samples in the river environment (one sample at the stream mouth and one sample 25m upstream) and two samples in the off-delta environment (samples collected from 15.5m and 41.8m depths for Mtanga and from 9.9m and 41.2m depths for Kasekera). At Mtanga, counts were completed for six samples from the on-delta transects (from 3m, 5m, 9m, 19.3m, 28m and 42.2m depths), and at Kasekera counts from three on-delta samples were completed (5.5m, 16m, 28.3m).

Results

Common Diatom Genera--Mtanga Region (Lake + River)

Navicula
Nitzschia
Gomphonema
Amphora
Rhopalodia
Achnanthes
Stephanodiscus

33%
 28%
 13%
 6%
 6%
 2%
 1%

Common Diatom Genera--Kasekera Region (Lake + River)

Nitzschia
Navicula
Rhopalodia
Gomphonema
Amphora
Cocconeis
Stephanodiscus
Achnanthes

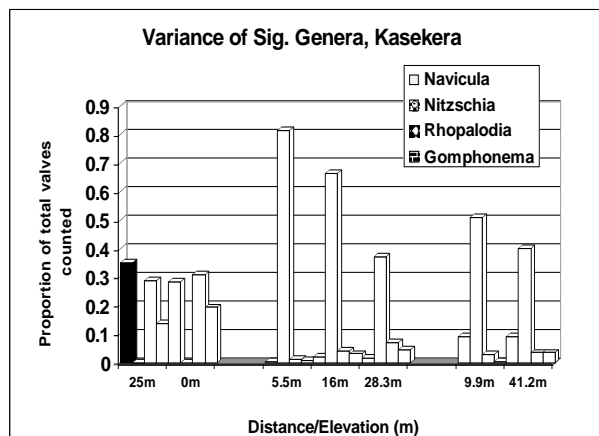
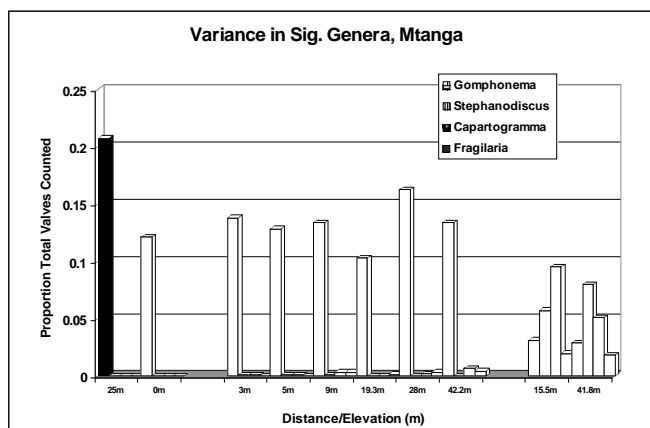
33%
 16%
 16%
 9%
 6%
 6%
 4%
 3%

Other observed diatom genera:

Anomoeoneis, *Aulocaseira*, *Caloneis*, *Capartogramma*,
Cymbella, *Cyclotella*, *Diploneis*, *Encyonema*, *Epithemia*,
Fragilaria, *Neidium*, *Pinnularia*, *Surirella*, *Synedra*

Figure 3. Summaries of Diatom Genera Observed in Mtanga and Kasekera Regions. Figure 3 lists all 22 of the diatom genera found between both watersheds. Important contributors by percent of total valves counted are listed separately for Mtanga and Kasekera. In both watersheds *Navicula* and *Nitzschia* genera dominated the counts. In Mtanga, *Gomphonema* was the third-most-abundant genus while in Kasekera *Rhopalodia* was the third-most-abundant genus.

Samples yielded 22 different diatom genera between Mtanga and Kasekera watersheds (Figs 3, 4). All 22 genera were observed at Mtanga, and 19 were present at Kasekera. By proportion of total valves counted, the two watersheds shared the same four dominant genera: *Navicula*, *Nitzschia*, *Gomphonema* and *Rhopalodia*.



Figs 4, 5. Variance of Significant Genera at Mtanga (Fig. 4) and Kasekera (Fig. 5) watersheds. River diatom assemblages (25m and 0m intervals) are to the far left; delta diatom assemblages are in the middle; off-delta assemblages are on the far right.

Variations in the relative counts of other genera differ between the two watersheds' river, lake and delta environments. At Mtanga, counts of *Gomphonema* in the river and delta environments both range between 10-21% of the valves counted (Fig. 5). In the off-delta transect, *Gomphonema* constituted <5% of the valves counted. Contrastingly, *Stephanodiscus*, *Capartogramma* and *Fragilaria* made up <1% of the valve counts in the delta and river, but all contributed to >2% of the valves counted in the off-delta transect (Fig. 5). *Capartogramma* and *Stephanodiscus* each made up less than 1% of the valve counts in river and deltaic environments, and more than 5% of the counted valves in the off-delta transects.

At Kasekera, counts of *Nitzschia* were > 30% of the total valves counted in the delta and lake environments, and <1% of the total valves counted in the rivers (Fig. 6). A foil to the pattern in the *Nitzschia*, the *Rhopalodia*, *Gomphonema* and *Navicula* all constitute >10% of the total counted valves in Kasekera stream and <10% of the total counted valves in the delta and off-delta transects.

Tukey-Kramer tests of multiple means for significant differences using JMP IN (2001) statistical software were applied to all counts of the diatom genera in the two watersheds' delta, river and off-delta diatom assemblages to test for significant differences (Fig. 6).

Fig. 6: Tukey-Kramer test results for Mtanga and Kasekera diatom assemblages

MTANGA

GENERA	TK result
<i>Pinnularia</i>	Delta unlike River, Lake
<i>Gomphonema</i>	Delta like River
<i>Stephanodiscus</i>	Delta like River
<i>Capartogramma</i>	Delta like River
<i>Fragilaria</i>	Delta like River
<i>Caloneis</i>	Delta like River
<i>Diploneis</i>	Delta like River
<i>Navicula</i>	Delta like Lake
<i>Achnanthes</i> , <i>Amphora</i> , <i>Encyonema</i> , <i>Synedra</i> , <i>Aulocaseira</i> , <i>Surrirella</i> , <i>Rhopalodia</i> , <i>Nitzschia</i> , <i>Cymbella</i> , <i>Anomoeoneis</i> , <i>Neidium</i> , <i>Cocconeis</i> , <i>Epithemia</i> , <i>Cyclotella</i>	No statistical trends (63.6%)

KASEKERA

GENERA	TK result
<i>Navicula</i>	Delta like Lake
<i>Nitzschia</i>	Delta like Lake
<i>Rhopalodia</i>	Delta like Lake
<i>Gomphonema</i>	Delta like Lake
<i>Achnanthes</i> , <i>Amphora</i> , <i>Encyonema</i> , <i>Synedra</i> , <i>Aulocaseira</i> , <i>Surrirella</i> , <i>Stephanodiscus</i> , <i>Cyclotella</i> , <i>Capartogramma</i> , <i>Fragilaria</i> , <i>Epithemia</i> , <i>Caloneis</i> , <i>Diploneis</i> , <i>Neidium</i> , <i>Cocconeis</i>	No statistical trends (78.9%)

Fig. 6. 36.4% of Mtanga stream's diatom assemblages and 21.1% of Kasekera stream's assemblages show statistically significant trends.

Discussion

Between the two watersheds, the results show that the Mtanga delta's diatom assemblage reflects the Mtanga river assemblage more so than the off-delta lacustrine assemblage, and that Kasekera delta's diatoms resemble the off-delta lacustrine assemblage more closely than the Kasekera river's assemblage. Mtanga's river and delta assemblages are similar to each other, and different from the lake assemblage; the opposite visual pattern holds for Kasekera (Figs 5, 6). The statistical signals also were stronger at Mtanga than Kasekera. Out of 22 diatom genera found at Mtanga, 7 showed significant variations between river, delta and off-delta sites, and 6 of those genera's counts were statistically different between delta and off-delta sites. At Kasekera, counts of 4 of the 19 observed diatom genera were statistically different between delta and river sites.

Chemical and physical differences between the Kasekera and Mtanga's watershed environments may account for the statistical trends in diatom deposition. Mtanga stream likely receives more nutrients than Kasekera because of the differences in land use between the two catchments. At Mtanga, cassava farming on steep hillsides (causing enhanced erosion) and direct release of fecal matter from humans and livestock into the river were both observed first-hand during sampling in July 2007; at Kasekera, which was within the Gombe Stream National Park, the catchment was forested and fires are actively suppressed. The diatom floras reflect these differences in land use and nutrient input. High nutrient concentration-tolerant diatom genera such as *Gomphonema* were found either exclusively at Mtanga, or in much higher relative abundances at Mtanga than Kasekera. Low nutrient concentration-tolerant diatom genera, such as *Rhopalodia*, were found in higher relative abundances at Kasekera than Mtanga (Figs 3, 4).

Similar genus-level signals of water chemistry have been found in previous studies (Bellinger *et al.*, 2006). Occurrence patterns of these indicator genera suggest that a more productive algal community exists at Mtanga. The latter could cause the total abundance of benthic river diatoms to be greater at Mtanga than Kasekera, and consequently, greater abundances of benthic river diatoms to wash into deltaic sediments at Mtanga than Kasekera. However, to test the above notion directly, one would have to study total abundances of river diatoms in deltaic sediments between the two streams. This study, based on relative counts of diatom genera, simply shows that the differences in diatom sedimentation patterns offshore coincide with chemical differences between the streams.

In addition to chemical differences, differences in physical sedimentation processes between the deltas may be causing larger numbers of benthic river diatoms to be ripped or eroded from their habitats and deposited offshore at Mtanga.

Finally, uncertainty about sampling sites and the number of samples processed for this study may be exerting a strong influence on the results. The complexity of the Kasekera stream, which had multiple stream mouths but only one active stream channel during July 2007, made it difficult to be certain which sediments were deltaic and which were "off-delta." Guerra (2007) concluded that Kasekera's "on-delta" grab samples, from which the "deltaic" diatom assemblage was sampled for this study, were not definitively from Kasekera's main delta. Thus, the comparisons between river, deltaic and off-delta diatom assemblages for Kasekera must be considered rough at best.

Future studies on diatoms in this region should concentrate both on more accurately sampling the on-delta environment at Kasekera, and on counting diatoms from more Kasekera samples. It is possible that sampling from locations more definitely on and off the main Kasekera delta would show different, and stronger statistical trends between the river, delta and off-delta diatom flora than the data in this study illustrate.

Conclusion

Preliminarily, this study shows that it is possible to read a benthic river diatom signal in offshore, deltaic lake sediments. The results from Mtanga stream demonstrate that diatom assemblages in deltaic sediments can reflect river assemblages more than lacustrine signals. However, factors such as catchment forestation, stream nutrient concentrations and sampling strategies all introduce noise to a potential riverine diatom signal in lake sediments.

It is difficult to say whether Kasekera's deltaic diatom assemblages reflected the lake due to differences in its catchment, stream chemistry or the sampling treatments in this study. Further research is needed to determine whether sampling deltaic sediments to study river diatom communities could become a reliable tool for studying paleo- river environments.

Acknowledgements

I would firstly like to thank my Nyanza project mentor, Dr. Jon Todd, and my research advisor at Brown University, Dr. James Russell, for their guidance in developing this project's conceptual framework and in helping me interpret my data. I also owe acknowledgements to Drs Kiram Lezzar, Andrew Cohen and Catherine O'Reilly for aiding me in carrying out the project's sampling and labwork in Kigoma. Special thanks also go to Justin Meyer for advice on statistical tests; to Willie Guerra, Jon Husson, Anthony Romano, Sara Collins and Katie Holzer for

recording diatom counts; and to the crew of the R/V Echo, TAFIRI, and the U.S. National Science Foundation. This project was funded by the Nyanza Project, NSF grant #ATM 0223920 and #DBI-0608774.

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