

A comparison of streambed composition within forested and deforested watersheds of Lake Tanganyika, Tanzania

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Introduction

The resources of Lake Tanganyika, like those of the other African Rift Lakes, are central to the viability of East Africa. As reported by O'Reilly et al. (2003), the pelagic fishery of Lake Tanganyika alone supplies 20-40% of the animal protein consumed by the people of its bordering countries. This statistic not only reflects the high productivity of the lake, but also serves as a clear indication of the immense pressure that local communities place on the lake's resources. The extent of the anthropogenic impact on the region, however, extends beyond the resources of the lake itself. As regional populations continue to expand, at an annual rate of 1.9-3.0%, demand for arable land, building material, and fuel wood continue to increase, causing dramatic changes to the terrestrial landscape (O'Reilly et al. submitted). In western Tanzania, like much of the area surrounding the lake, native vegetation has been largely replaced with crops of maize, sorghum, cassava, and bananas. Today, in central regions of the lake, deforestation rates exceed 40% and are as high as 100% along the northern end of the lake (Cohen et al. 2005).

The deforestation of Lake Tanganyika's eastern shoreline has not only redefined the terrestrial landscape, but has also had a significant bearing on the structure and function of the fluvial ecosystems within the lake's surrounding watersheds (Cohen et al. 2005). Although the impact of these changes is widely recognized, the lasting affects of prolonged deforestation on stream dynamics and the extent to which human impacted watersheds alter streambed habitat and nutrient availability are not fully understood in this region. Here we examine the interrelationship between watershed disturbance and stream habitat viability by comparing streambed composition in highly disturbed watersheds with those in the unaltered forests of Gombe Stream National Park, Tanzania. Although multiple factors influence stream habitat, the relative abundance of total organic and inorganic matter and the composition of the streambed are used as indicators of viability because they are closely linked to nutrient and habitat availability for micro-invertebrates and fish. In this study, these factors were determined by measuring total organic and inorganic matter within the substrate and suspended sediments. In addition, substrate size, distribution, and sortedness were also examined as a means of determining habitat suitability for micro-invertebrates and fish.

The physical characteristics of these streams also hold important implications for the Lake Tanganyika ecosystem as a whole. Although anthropogenic activity does not directly influence the water quality of the lake, suspended sediments pose a tangible threat to the viability of the ecosystem (Nkotagu & Mbwambo 2000). In areas of high impact, soil erosion rates are as high as 28-100 metric tons per year (O'Reilly et al. 2005). When these sediments are discharged on the rocky lake substrate they limit algal growth and decrease lake productivity. Increases in inorganic sediment flux through fluvial systems and an associated decrease in organic sediment flux therefore could have negative implications for the viability of littoral habitats in the lake.


The Gombe Stream National Park and the surrounding watersheds provide an ideal setting for comparing the viability of stream habitats and examining the relationship between deforestation and streambed composition. In this study, six streams along the eastern shore of Lake Tanganyika were selected; three within Gombe National Park and three within nearby villages. The region is composed of a number of physically similar watersheds with land use histories that are vastly different from one another (Table 1). In contrast to the undisturbed watersheds of Gombe, the watersheds adjacent to the park's boundaries have been heavily altered by human activity since the late 19th century (Cohen et al. 2005).

Hypothesis: We predict that the streams within deforested watersheds will have a greater abundance of fine grain particulate matter than those in undisturbed streams during the dry season (June-September) as a result of lower stream flow. We also predict that the ratio of inorganic to organic matter will be significantly higher in deforested streams as a result of increased soil erosion.

Such findings could potentially have negative implications for benthic invertebrates because particle size of organic and inorganic sediments is of major importance to the distribution and viability of many benthic invertebrates.

Study Sites

Region of Study



<i>Stream Name</i>	<i>Site Location</i>	GPS coordinates	<i>Status of Watershed</i>	<i>Watershed Size (sq km)</i>
Ngelwa	Mtanga-B	S 04° 46.461 ' E 029° 36.377'	Deforested	1.6
Ngonya	Mwangongo	S 04° 45.448 ' E 029° 36.344'	Deforested	8.5
Mtanga	Mtanga	S 04° 37.390 ' E 029° 38.337'	Deforested	5.2
Rutanga	Gombe Stream National Park	S 04° 39.117 ' E 029° 37.687'	Forested	3.8
Mkenke	Gombe Stream National Park	S 04° 40.658' E 029° 36.275'	Forested	2.7
Kalande	Gombe Stream National Park	S 04° 42.266 ' E 029° 36.801'	Forested	1.7

Table 1: Map of study region and study site locations along the eastern shore of Lake Tanganyika, Tanzania.

Methods

Six streams from Mtanga to Mwangongo were sampled between July 16th, 2005 and July 31st, 2005. Within each stream study site, a 100 m reach was established upstream of the sandy shoreline. Each reach was subsequently divided into ten primary transects and eleven secondary transects at 5 m intervals, as outlined in the EPA's Wadeable Stream Manual (USEPA 2004). At primary transects, a known volume of water was filtered through precombusted 0.7 µm pore size Fisher filters. Ten 5cc fine-grained substrate samples were also collected along the reach using syringes. All samples were subsequently dried (60 °C) and combusted (500 °C) to calculate the percentage of organic and inorganic material within each sample.

Streambed composition was analyzed along the primary and secondary transects. Characterization of these streams was conducted using the Wolman pebble count (USEPA 2004) and a photographic technique described by Whitman et al. (2002). For the Wolman Pebble count, primary and secondary transects were divided into quintiles. At each quintile, a pebble was haphazardly chosen from the substrate, and the pebble's intermediate axis was measured using a gravelometer (Potyondy & Bunte 2002). Streambed width and depth were also measured at each transect. The results from the Wolman Pebble count were used to calculate the substrate size distribution and sorting for each stream. The mean of the pebble count data was used to characterize average pebble size for each stream and the coefficient of variation was used as a measure of sorting. In conjunction with this method, substrate size and sorting were also characterized using a photographic technique described by Whitman et al. (2002). Using this method, the substrate in the thalweg at each transect was photographed using a digital camera mounted on a Plexiglas-bottomed bucket. To avoid blurred or distorted images, several photos were taken at each transect and the clearest image was then analyzed using Arcview GIS 3.2. In Arcview, a polygon was drawn around each clast and any fine grain sediments were outlined. The intermediate axes of all clasts entirely visible in the images were

subsequently drawn. The axis of a scale was also drawn to use as a reference. The amount of sand and fine sediment in each photo was used as a measure of embeddedness. This data was then used to create a substrate size distribution for each stream and to determine both sortedness and average embeddedness. For statistical analyses, the pebble size data from both the Wolman and GIS counts were normalized by taking the natural log of all intermediate axis data. One-way and nested ANOVAs were used to examine differences between forested and deforested sites. Data was analyzed using SAS JMP.

Results

The results from the Wolman pebble count are summarized in the Table 2 below. The one-way ANOVA revealed that the differences in substrate pebble size between forested and deforested streams were not significant (Figure 1). Although deforestation did not affect substrate size, Forest cover does affect sorting of the streambed substrate. Sorting did not vary significantly within individual streams, but the substrate was significantly less sorted in streams within forested areas ($p < 0.0091$) (Figure 2).

The amount of fine sediment substrate in streams also shows large differences between forested and deforested streams. The streambeds of deforested streams contained much more fine sediments than did the streambeds of forested streams. The results are detailed in the table and graph below (Table 3a & Figure 3b).

The filter samples of suspended matter did not reveal any differences in the amount of organic and inorganic matter suspended in the water column of fluvial systems along the lake ($P = 0.247$ when comparing suspended organic matter concentrations by status and $P = 0.421$ when comparing suspended inorganic matter). Unlike the suspended matter samples, the substrate sediment samples yielded unexpected results. Organic matter concentrations were higher in the fine sediments of deforested streams than in forested streams (Figure 4).

Comparison of Methods

The Arcview GIS pebble size analysis method developed by Whitman et al. (2003) yielded much smaller averages than the Wolman pebble count. Mean pebble size remained statistically similar among forested and deforested streams regardless of the method used. Differences in sortedness that are obvious in the Wolman pebble count disappear with the GIS analysis method. Mtanga and Kalande showed the highest differences in sorting of any of the streams when surveyed with the Wolman pebble count. When analyzed with Arcview GIS, the two streams show no difference in sorting.

Discussion

The primary purpose of this paper is to provide insight into the interrelationship between watershed disturbance and streambed viability. The methodology used to collect our data also provides an opportunity to critically assess the effectiveness of a new technique of photographically characterizing streambed compositions.

Challenges of photographic streambed characterization:

The photographic analysis of streambed composition offers advantages and disadvantages over the standard method of streambed characterization. Although the Wolman pebble count provides a simple, low-tech method of collecting data, the subjective nature of the technique diminishes the method's accuracy and replication potential. As a result of these shortcomings, efforts have been put forth by the USGS to establish a technique that minimizes these biases. A photographic technique developed by Whitman et al. (2003) provides a method by which selection bias and qualitative estimates of particle embeddedness can potentially be reduced.

Comparing the results from the two techniques illustrates the inconsistency between methods, but does not definitively illustrate which is more reliable. Whitman et al. (2003) speculated that the discrepancy between the mean particle sizes of the two methods is a reflection of preferential selection of larger particles during the Wolman pebble count. Although this explanation is compelling, we believe the photographic technique

may also be biased, disproportionately favoring smaller particles. As acknowledged by Whitman et al. (2003), the photographic images do not necessarily reflect the true size or shape of the particles because often their intermediate axes are not visible due to their orientation and/or embeddedness within the streambed. The mean particle size may also be underestimated because large clasts often extend beyond the view of image and therefore their axes cannot be measured. Additionally, large clasts often extend above the surface of the water; the photographic technique cannot account for these clasts and hence excludes an entire class of pebble size. Despite these problems, we believe the photographic method serves as a useful method of quantitatively determining sand coverage since no other method presently exists.

Streambed composition and the effects of Deforestation

Although not all the parameters measured in this study provide statistical correlations between deforestation and streambed composition, our results demonstrate that deforestation influences stream habitat viability.

Mean particle size and sand cover – The mean particle size within forested and deforested watersheds showed no significant variation. The lack of variation between mean particle size may reflect the geophysical homogeneity of the watersheds, which is composed primarily of coarse grain sand and angular to sub-angular *Kigoma Quartzite* cobbles. One would expect that during the wet season more fine sediment erosion would occur in deforested watersheds. More fine sediment accumulation would obscure the existing pebbles in the stream and account for the higher fine sediment cover found in deforested streams.

Sorting – The average clast size appears to correlate with the geologic similarity of the watersheds. However, differences in sorting may be best explained not by geophysical differences in the watersheds but by direct anthropogenic causes. Villagers use larger clasts to build small dams and pools for the water. Villagers could also remove the larger clasts to make the stream more convenient for bathing and laundry.

Organic & Inorganic Matter – Counter to our prediction, no significant correlations between the ratio of organic and inorganic matter and deforestation were found in either the substrate or suspended matter. The absence of a clear link between these factors may be explained by the seasonal conditions during which this study was conducted. During the dry season (June-September) the region receives very little of its 1200 mm of annual rainfall (Nkotagu & Mbwambo 2000). The low rainfall dictates stream discharge and limits velocity (0.39-1.46 m/s). The low rainfall also diminishes runoff and limits the influx of inorganic matter.

Organic Content of Sediments – One might expect that because forested watersheds contain more detritus, sediments in forested fluvial systems would contain higher organic matter. The opposite is true, at least during the dry season. Nutrients on the forest floor are more likely to be reabsorbed by trees and other plants whereas with higher sediment flux, deforested watersheds show higher potential to wash nutrients into the streams themselves. Because deforested streams receive more light and nutrients, they show higher primary productivity and biomass (Yohannes 2005). One would then expect to find more living and decaying organic matter in the sediments of deforested streams.

Predictions for the Wet Season

During the wet season, one would expect higher inorganic sediment flux and turbidity in streams. However, it is unclear how suspended organic matter would change during the wet season. Since forested watersheds contain much more detritus, forested streams could show much more suspended organic matter during the wet season as organic matter decomposes and is washed into the stream. However, deforested streams would have higher overall sediment flux during the wet season and could have an associated increase in organic matter suspended in the water column. It appears unlikely that pebble size or sorting would vary significantly between seasons because both appear to be factors of geophysical homogeneity and anthropogenic intervention, respectively. Fine sediment cover in deforested streams could increase as sediment flux increases during the wet season.

Conclusions

Our comparison of the Wolman pebble count to the Whitman photographic technique illustrates the relationships between these methodologies. Although we cannot definitively conclude which technique

provides more accurate data, we believe the photographic technique doesn't adequately measure particle size or sorting. Despite these findings, we believe that this technique can serve as a useful tool for determining the percentage of fine-grained sediment.

Physical differences between forested and deforested streams hold important implications for the habitat viability of streams with altered watersheds. Increased sorting in deforested streams means that these ecosystems are less complex and provide less diversity of habitats for fish and macroinvertebrates. Deforested streambeds contain much more fine sediments and create an entirely different habitat than forested streams. One would expect to see markedly different species of fish and macroinvertebrates in deforested streams. However, higher organic matter content of deforested stream sediments suggest that deforested streams may be more productive and/or contain more biomass. Aside from turbidity, one would not expect to find significant changes in these findings during the wet season.

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Results

Table 2: Mean Pebble Size in Forested and Deforested Streams		
Status	Ln Mean Size (mm)	Anova P Value
Forested	2.94	0.5076
Deforested	3.01	

Table 2b: Sortedness by Stream Status	
Status	Mean C.V. (%)
Forested	32.01
Deforested	26.21

Table 3a: Percent Fine Substrate Cover by Status	
Status	% Fine Substrate Cover
Forested	40.57%
Deforested	18.60%

Table 4a: Suspended Matter Analysis		
Status	Suspended Organic Matter (g/L)	Suspended Inorganic Matter (g/L)
Forested	0.00343	0.0120
Deforested	0.00284	0.0149

Table 5: Mean Pebble Size By Method		
Stream	Method	Mean Size (mm)
Mtanga	Wolman	37.65
	Arcview GIS	16.67
Kalande	Wolman	41.83
	Arcview GIS	15.33

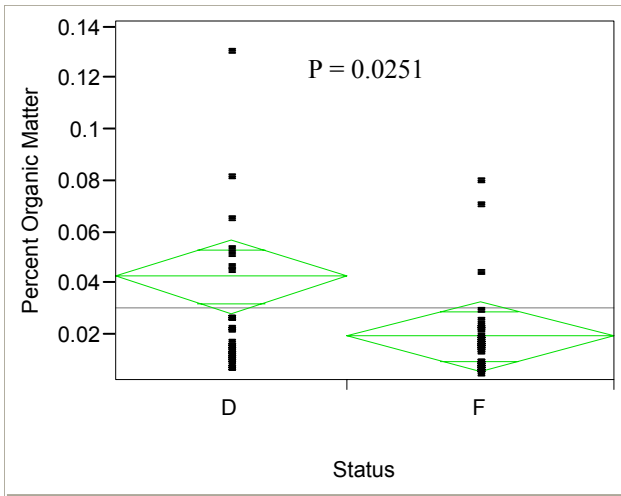


Figure 4b: Oneway Anova Analysis of Organic Matter in Fine Sediment Substrate Samples

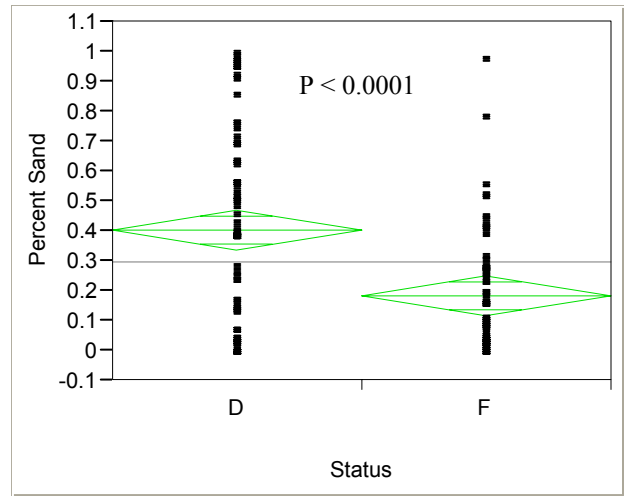


Figure 3b: Oneway Anova of Percent Fine Substrate Cover by Status

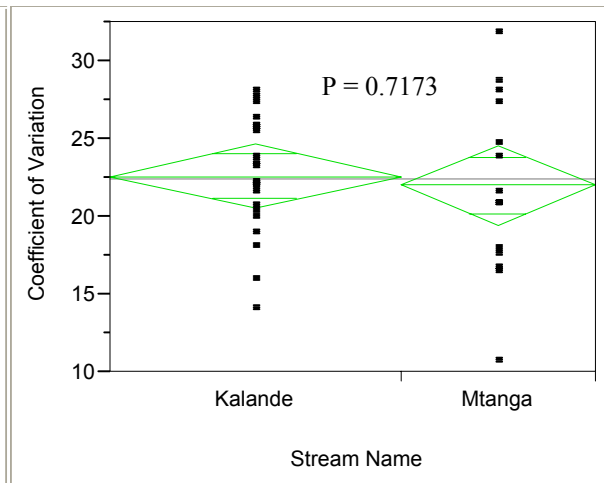
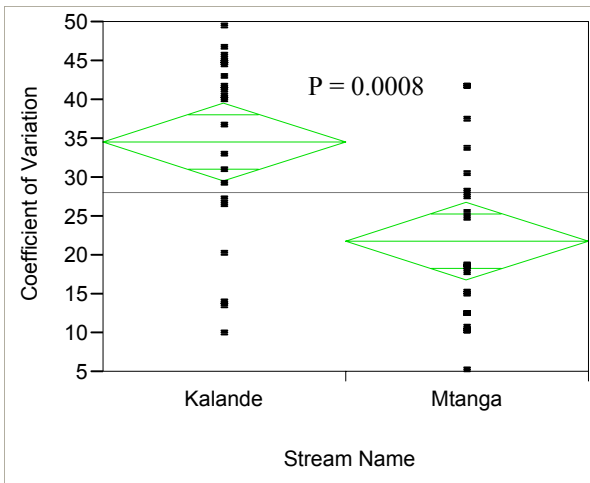


Figure 2a: Sorting Between Streams Using a) the Wolman Method and b) GIS Analysis