

Characterization and comparison of benthic macroinvertebrate communities in small streams of forested and deforested catchments bordering Lake Tanganyika

Student: Matthew Fuller

Mentor: Catherine O'Reilly

Introduction

Deforestation is one of the world's greatest land-use habitat alterations (Scarsbrook and Halliday, 1999). Specifically, tropical environments, where the rate of deforestation is currently increasing and changing not only the landscape, but the quality of water draining it, are the sites for the greatest freshwater biodiversity loss and system simplification (Boyero and Bailey, 2001). For example, freshwater biodiversity loss in streams on Madagascar has been associated with poor land-use practices such as deforestation by slash-and-burn agriculture (Benstead and Pringle, 2004). Much of the same land-use practices are found in the watersheds surrounding Gombe Stream National Park (GSNP), Tanzania.

Deforestation has many implications for the streams flowing off the land. Often changes in the sediment load in streams and stream morphology are changed in such a way, that indigenous organisms can no longer inhabit their native habitat (Benstead et al., 2003). Changes in the sediment load to streams can decrease the number of habitable living spaces for algae, benthic macroinvertebrates and fish in streams, by occupying vital interstitial spaces between larger substrates in the stream (Boyero, 2003). The removal of riparian vegetation also allows increased light input to the stream, which in turn supports greater primary productivity rates in the stream, as well as increased water temperature (Snyder et al., 2003). These changes have drastic effects on the macroinvertebrate community present in the stream (Buss et al., 2002).

Macroinvertebrate community characterization has been used in North American temperate streams to effectively evaluate the water quality of streams (Klemm et al., 2002). Macroinvertebrates are good biological indicators because they are long-lived in the ecosystem and have species of varying degrees of tolerance for different sources of pollution (Linke, Bailey and Schwindt, 1999). They are also easily and economically caught, identified and evaluated (Metzeling et al., 2003). The different tolerances of individual macroinvertebrate species are what drive the community changes from one system to the next and therefore allow fast and effective evaluation of a stream (Marques and Barbosa, 2001).

Land-use is often associated with changes in the physical and chemical health of a stream (Linke et al., 1999), therefore, changes in macroinvertebrate communities are good indicators for changes on the land, making a freshwater macroinvertebrate community comparison between two streams not just a stream system comparison, but a full ecosystem evaluation of the two stream catchments. While the characterization of temperate stream macroinvertebrate communities is extensive and well documented, the tropical communities are still vaguely understood and understudied (Metzeling et al., 2003). There is a need to understand the differences between communities in the tropics to understand what implications different land-uses have for the freshwater biodiversity within the streams, wetlands and lakes of the catchment.

This study characterizes the macroinvertebrate communities of three forest catchment streams (FCS) within GSNP and three deforested catchment streams (DFCS) in adjacent catchments to GSNP. We expect to find a higher diversity of macroinvertebrates in the forested streams since they offer more diverse food sources and types than deforested streams (Benstead and Pringle, 2004). The abundance of invertebrates in forested streams should be less than deforested streams due to a decreased productivity in the water from lower light inputs and therefore a smaller quantity of basal food source (Scarsbrook and Halliday, 1999). Also, associated with a less diverse food base, a simplification (more linear) of the stream food web should be found in deforested streams (Boyero and Bailey, 2001). The individual species of macroinvertebrates found in deforested streams should be more tolerant of poor water quality (low dissolved oxygen or organic nutrient enrichment) due to the negative effects associated with deforestation (Klemm et al., 2002). This study will add to the little knowledge of tropical African stream macroinvertebrate communities, as well as show differences between the communities found in natural FCS and human-disturbed DFCS.

Methods

Study Site

This study was conducted in six streams (Mtanga, Ngelwa, Kalande, Mkenke, Rutanga and Ngonya) in Tanzania, Africa. Three streams drain forested catchments (Kalande, Mkenke and Rutanga) within Gombe Stream National Park in Tanzania and three streams drain deforested catchments (Mtanga, Ngelwa and Ngonya) bordering Gombe National Park. The three Gombe streams (forested streams) drain catchments of protected forested terrain, where active wildfire control is conducted and the vegetation is mostly native mature forest. The deforested catchment vegetation consists primarily of grasses and local agriculture. Wild vegetation growth is suppressed by fires set by locals on a regular basis in the deforested catchments. All six stream catchments drain westward into Lake Tanganyika and have comparable catchment areas. Rainfall comes on a seasonal basis, with 1321-1717 mm of rain during the wet season (November – April) and almost no rain during the dry season (May – October). All streams have primarily fast flowing riffles and few pools, with one exception: Rutanga Stream has a consistent riffle – pool pattern. All three DFCS' sample reaches were within villages and therefore are frequently disturbed by humans. The FCS' sample reaches were located just upstream from trail crossings in Gombe Stream National Park and therefore considered undisturbed by humans.

Light input to the stream is much less in forested streams than deforested streams due to a more complete canopy cover from riparian vegetation. Even during the dry season when many native trees tend to lose their leaves, there is still a mostly complete canopy. The deforested stream reaches in the villages have little to no riparian vegetation; single trees or small bushes are the only vegetation. Forested streams are mostly surrounded by large native trees on both banks as well as small bushes and other vegetation on the forest floor. Stream banks of deforested streams appear unstable and frequently trampled by local people. Forested stream banks appear mostly stable except at Mkenke, where sandy banks and sandbars looked like they were recently formed and unstable. Mkenke banks were easily disturbed during sampling just by walking them.

Sampling and Identification Methodology

Macroinvertebrates were collected in the 6 study streams for community characterization from 17 July – 1 August 2005. On each sampling date, 5 Surber samples (1 ft²) were taken in 5 different riffles at each stream along a 100 m reach and brought back to the lab for preservation in 70% ethanol. All large substrates within each sample area were scrubbed with a plastic brush and the substratum disturbed by hand about 5 cm deep. Each sample was sieved through a stacked 500 µm sieve and 1.4 mm sieve. The sample caught in the 1.4 mm was picked in the field and the 500 µm sample was washed into a container for laboratory sorting. In the lab, three of the five Surber samples were chosen randomly and sorted into morphospecies and then identified to family or the lowest taxonomic unit possible using a dissecting microscope and Thorp and Covich (1991).

Data Analysis

Invertebrate counts of each family were used to determine percent dominant RTU (Relative Taxonomic Unit) and dominant RTU for each stream. Percent Dominant RTUs for each stream catchment type were used to compare DFCS and FCS. Overall stream diversity was also used to compare forested and deforested stream communities by counting the number of RTUs in each stream. Macroinvertebrate abundance (individuals/m²) in each stream was calculated and also used to compare forested and deforested streams. Percent EPT (Ephemeroptera, Plecoptera and Tricoptera) was also used to assess differences between DFCS and FCS. Individual RTU life histories were also evaluated in each stream for general water quality assessment.

Results

A raw total of 5272 invertebrates were collected and counted for this study from six streams (DFCS – Mtanga, Ngelwa and Ngonya; FCS – Rutanga, Kalande and Mkenke). An average (of nine Surber samples; three from each stream catchment type) density of 4193 invertebrates/m² in the DFCS samples and 2120 invertebrates/m² in the FCS samples was calculated (Figure 1).

The total number of RTUs identified in both DFCS and FCS was 53. 42 RTUs were identified in DFCS and 28 RTUs in FCS. In the DFCS, the 5 dominant RTUs (5 invertebrate RTUs with the greatest total count in each stream type) in descending order of dominance were Chironomidae, Simuliidae, Ostracoda, Baetidae and Oligochaeta (Table 1). In the FCS, the 5 dominant RTUs in descending order of dominance were Simuliidae, Hydropsychidae, Baetidae, Chironomidae and Hydroptilidae (Table 1). The 5 dominant RTUs in the DFCS comprised 85 percent of the total number of invertebrates sampled in the DFCS (Table 1). The 5 dominant RTUs in the FCS comprised 89 percent of the total number of invertebrates sampled in the FCS (Table 1). Ostracoda and Hydroptilidae RTUs were each only found in one stream (Ngelwa and Rutanga, respectively) of their particular catchment types (DFCS and FCS, respectively) (Table 1).

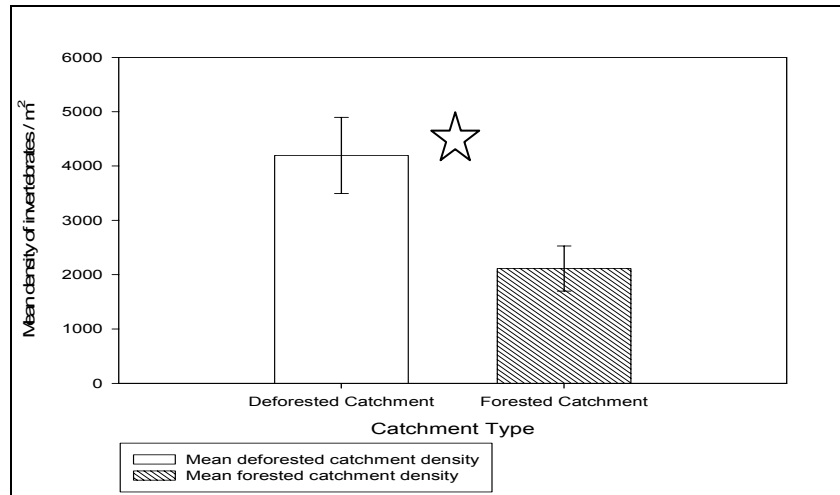


Figure 1. Mean invertebrate density per meter squared (± 1 SE) for DFCS ($n = 9$), and FCS ($n = 9$) streams. “Star” indicates a significant difference between invertebrate densities in DFCS and FCS (ANOVA, $P = 0.0386$, $R^2 = 0.59$).

Table 2. Five dominant RTUs in DFCS and FCS. Total counts are sums of five dominant RTU counts. Percent of total deforested is the percent the 5 dominant RTUs in the DFCS comprise of all deforested invertebrates sampled. Percent of total forested is the percent the 5 dominant RTUs in the FCS comprise of all forested invertebrates sampled. “▲” indicates RTU was only found in samples of one stream (Appendices).

Deforested		Forested	
1783	Chironomidae	805	Simuliidae
420	Simuliidae	274	Hydropsychidae
332	Ostracoda ▲	238	Baetidae
311	Baetidae	198	Chironomidae
130	Oligochaeta	50	Hydroptilidae ▲
2976	Total Dominant RTUs Count	1565	Total Dominant RTUs Count
84.85885	% of total deforested	88.66856	% of total forested

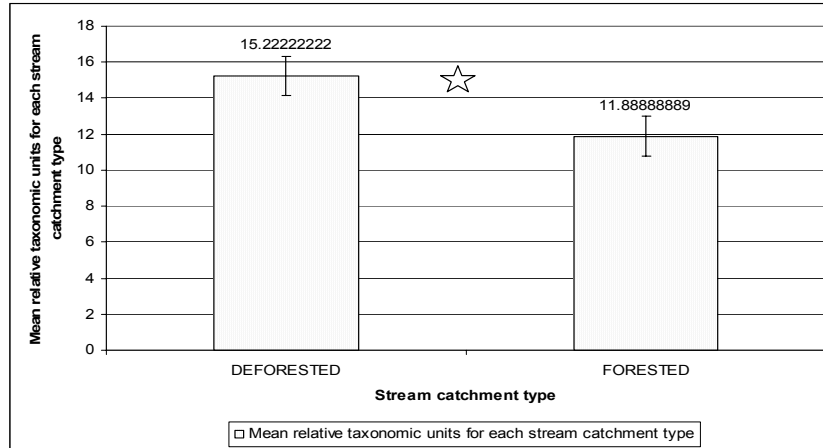


Figure 2. Mean number of RTUs (± 1 SE) in each catchment type stream ($n = 9$ for each catchment type). Star indicates significant difference between stream catchment types and RTU number (ANOVA, $P = .0022$, $R^2 = 0.76$).

The two most dominant RTUs in both catchment types consisted of three RTUs (Chironomidae, Simuliidae, and Hydropsychidae) (Table 1). There were significant differences in percent Chironomidae, percent Simuliidae and percent Hydropsychidae between DFCS and FCS. There was also a significant difference between percent EPT for each catchment type. The mean number of RTUs in DFCS was significantly higher than the mean number of RTUs in FCS (ANOVA, $P = 0.0022$, $R^2 = 0.76$) (Figure 2). Significant differences were also found between repetitions within one stream (ANOVA, $P = 0.008$).

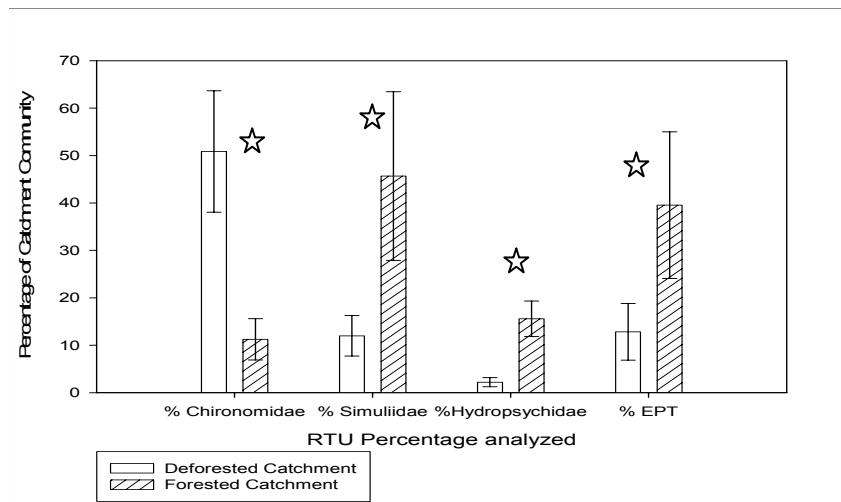


Figure 3. Percent of two most dominant RTUs in DFCS (Chironomidae and Simuliidae) and FCS (Simuliidae and Hydropsychidae). Percent EPT is the percentage of each catchment type's percent composition of the orders of insects Ephemeroptera, Plecoptera and Trichoptera. A star indicates a significant difference between DFCS and FCS.

Discussion

Sampling different catchment types has allowed for the characterization of the benthic macroinvertebrate communities in DFCS and FCS. Significant differences were found in invertebrate densities between the two catchment types (Figure 1). DFCS commonly will have a greater abundance of invertebrates in a given area due to the much greater productivity in a DFCS (Benstead and Pringle, 2004). This greater abundance is due to a much larger primary producer trophic level food base, which cascades up through trophic levels in a bottom-up trophic cascade. The higher levels of primary productivity come as a result of high light inputs since DFCS lack a forest canopy to shade the stream (Scarsbrook and Halliday, 1999). The higher abundance of algae can support a greater number of invertebrates and if the algae does not consist of a

single dominant species, then the abundance of a diverse basal food source will allow a high diversity of invertebrates as well (Benstead et al. 2003). In temperate systems, it often is observed to see more diverse communities in FCS because the diversity of food sources is greater than in DFCS (Benstead and Pringle, 2004). The greater diversity of food in FCS comes mainly as a result of allochthonous materials entering the streams, such as leaves and woody debris, that are lacking in DFCS because there is little to no canopy cover there (Magana, 2001). Community structure diversity at the family level in DFCS was significantly higher than FCS in our samples (Figure 2). However, there was also a significant difference between sample repetitions within a stream, which suggests we did not analyze enough samples from a single stream to make any substantial conclusions about taxonomic richness in DFCS and FCS of the area.

The two most dominant RTUs for DFCS were Chironomidae and Simuliidae, which in many biological indices, is scored as a poor water quality invertebrate (Thorp and Covich, 1991). Chironomidae and Simuliidae are also found as dominant RTUs in FCS, but not as the two most dominant RTUs (Table 1). The Hydropsychidae family is a net-spinning caddisfly family and therefore a filter feeder much like the Simuliidae family (Georgian and Thorp, 1992). Hydropsychidae and Simuliidae were the two most dominant families in FCS (Table 1). The presence of two filter feeding families as the two most dominant RTUs suggests there is a lot of suspended particulate organic matter (POM) available to support these macroinvertebrates. FCS have generally been associated with higher levels of suspended POM due to a greater presence of shredders (Graca et al., 2001). The shredders occur more in FCS because of the abundant supply of allochthonous organic material entering the stream habitat (Magana, 2001). The shredders present in FCS break down a lot of leaves and woody debris (course particulate organic matter) and therefore increase the suspended particulate organic matter available in streams (Graca et al., 2001).

Chironomids are generally a family associated with poor water quality (low dissolved oxygen (DO) linked to eutrophication of the aquatic habitat). Some species within the family are red due to a hemoglobin molecule which helps them absorb and retain oxygen in near anoxic environments (Thorp and Covich, 1991). Red Chironomids were noted in the field during sampling at all DFCS, but absent from all FCS. Unfortunately red chironomids lose their color when preserved in 70% ethanol and therefore counts of red chironomids could not be made. Chironomids comprised approximately 50 percent of the community in DFCS sampled suggesting that DO was low in the streams.

DFCS had a significantly lower percent EPT index (only used at the Family level rather than genera) (Figure 3). The EPT index is a good indicator of DO content in North American streams. The higher the percent EPT usually the more oxygenated the water (Lillie et al., 2003). The orders Ephemeroptera, Plecoptera and Trichoptera are characterized as orders with a poor tolerance for low DO and therefore, the greater their presence in the overall community the more oxygenated the water must be (Lillie et al., 2003).

Another taxonomic anomaly in the samples was the complete lack of the order Odonata in the FCS. Globally, this order is ubiquitous in streams as a predator of other macroinvertebrates in streams (Thorp and Covich, 1991). Odonates were found in high abundances in the DFCS (sixth most dominant RTU). The family Perlidae is a dominant predator in most streams (Thorp and Covich, 1991) they inhabit and they were found in all FCS sampled. It is possible the perlids are out-competing the odonates in the FCS where the perlids could survive. In the DFCS, the perlids were probably oxygen limited, therefore allowing the odonates to colonize and thrive in the DFCS as the dominant predator. Another possible indicator of the lowered DO in DFCS is the presence of Coenagrionidae in only DFCS. This RTU is a family within Odonata and has been found in waters with very low DO. The dominant DFCS RTUs Oligochaeta and Ostracoda are also RTUs tolerant of low DO. One RTU found associated with organic pollution was Psychodidae (Thorp and Covich, 1991). Psychodids were found only in DFCS indicating a potential organic pollution input to DFCS that might not be present in FCS.

Baetidae was another dominant RTU in both catchment types (Table 1). Baetids are a family of swimmers and therefore have been associated with fast recolonization of stream habitats after physical disturbances in the stream (Bradt et al., 1999). Baetids are also known to actively search for the best food sources and therefore are often found drifting in streams (McIntosh et al., 2002). The drifting effect could cause a high number of baetids in samples because we collected not just the baetids in the Surber sampler area, but also the baetids that are drifting from up stream. The drifting baetids would be in even greater numbers in

streams that are physically disturbed upstream of the sample site during sampling. This was a common problem in sample stretches of DFCS since they were in villages and people were often walking through the stream.

The communities of the DFCS sampled indicate deforestation is causing a slight decrease of DO in streams. DFCS invertebrate communities are also showing signs of greater primary productivity and if studies were done on the taxonomic make up of the primary producers, it would be interesting to compare their diversity with FCS. Diversity of primary producers might be one of the variables allowing the high diversity of invertebrates in the DFCS. It would also be interesting to look at the invertebrates at the genus and species levels where possible to see if diversity of invertebrates is still greater in DFCS than FCS. Some families such as Baetidae and Hydropsychidae were observed in the lab to be quite diverse, but no means of identification were available.

Acknowledgements

I would like to specially thank my mentor Catherine O'Reilly for her constant advice, help, support and candy treats throughout the entirety of the project. I would also like to thank the rest of the Nyanza 2005 stream team for their help in the field and lab with the collection and processing of my samples. The other Nyanza professors, TAs and students also helped make this project run smoothly and gave tremendous advice for the project. All of the TAFIRI staff was also of great assistance in preparing field and lab supplies for our use. Funding for this project came from NSF (DBI-0353765).

References

- Benstead, J.P. and Pringle, C.M., 2004. Deforestation alters the resource base and biomass of endemic stream insects in eastern Madagascar. *Freshwater Biology*. 49:409-501
- Benstead, J.P., Douglas, M.M., Pringle, C.M., 2003. Relationships of stream invertebrate communities to deforestation in Eastern Madagascar. *Ecological Applications*. 13(5): 1473-1490
- Boyer, L. and Bailey, R.C., 2001. Organization of macroinvertebrate communities at a hierarchy of spatial scales in a tropical stream. *Hydrobiologia*. 464:219-225
- Boyer, L., 2003. The quantification of local substrate heterogeneity in streams and its significance for macroinvertebrate assemblages. *Hydrobiologia*. 499:161-168
- Bradt, P., Urban, M., Goodman, N., Bissell, S. and Spiegel, I., 1999. Stability and resilience in benthic macroinvertebrate assemblages. *Hydrobiologia*. 403:123-133
- Buss, D.F., Baptista, D.F., Silveira, M.P., Nessimian, J.L. and Dorville, L.F.M., 2002. Influence of water chemistry and environmental degradation on macroinvertebrate assemblages in a river in south-east Brazil. *Hydrobiologia*. 481:125-136
- Georgian, T. and Thorp, J.H., 1992. Effects of microhabitat selection on feeding rates of net-spinning caddisfly larvae. *Ecology*. 73(1): 229-240
- Graca, M.A.S., Cressa, C., Gessner, M.O., Feio, M.J., Callies, K.A. and Barrios, C., 2001. Food quality, feeding preferences, survival and growth of shredders from temperate and tropical streams. *Freshwater Biology*. 46:947-957
- Klem, D.J., Blocksom, K.A.; Thoeny, W.T.; Fulk, F.A.; Herlihy, A.T.; Kaufman, P.R. and Cormier, S.M. 2001 Methods development and use of macroinvertebrates as indicators of ecological conditions for streams in the Mid-Atlantic Highlands Region. *Environmental Monitoring and Assessment* 78:169-212
- Lillie, R.A., Szczytko, S.W. and Miller, M.A., 2003. Macroinvertebrate Data Interpretation Guidance Manual. Wisconsin Dept. of Natural Resources.
- Linke, S., Bailey, R.C., and Schwindt, J., 1999. Temporal variability of stream bioassessments using benthic macroinvertebrates. *Freshwater Biology*. 42:575-584
- Magana, A.E.M., 2001. Litter input from riparian vegetation to streams: a case study of the Njoro River, Kenya. *Hydrobiologia*. 458:141-149
- Marques, M.M. and Barbosa, F., 2001. Biological quality of waters from an impacted tropical watershed (middle Rio Doce basin, southeast Brazil), using benthic macroinvertebrate communities as an indicator. *Hydrobiologia*. 457:69-76
- McIntosh, A.R., Peckarsky, B.L. and Taylor, B.W., 2002. The influence of predatory fish on mayfly drift: extrapolating from experiments to nature. *Freshwater Biology*. 47:1497-1513
- Metzeling, L., Chessman, B., Hardwick, R. and Wong, V., 2003. Rapid assessment of rivers using macroinvertebrates: the role of experience, and comparisons with quantitative methods
- Scarsbrook, M.R. and Halliday, J. 1999 Transition from pasture to native forest land-use along stream continua: effects on stream ecosystems and implications for restoration. *New Zealand Journal of Marine and Freshwater Research*. 33:293-310
- Snyder, C.D., Young, J.A., Villella, R. and Lemarie, D.P., 2003. Influences of upland and riparian land use patterns on stream biotic integrity. *Landscape Ecology*. 18:647-664
- Thorp, J.H. and Covich, A.P., 1991. Ecology and Classification of North American Freshwater Invertebrates. Academic Press, Inc. Ch: 10, 12, 13, 17-19