

# **Epilithic algal productivity and biomass in streams of contrasting land use patterns on the northeastern shore of Lake Tanganyika**

**Student: Liabeth Yohannes**

**Mentor: Catherine O'Reilly**

## **Introduction**

Streams are an important interface between the cumulative water bodies of catchments and the main water body of Lake Tanganyika. As such, streams can serve as a critical ecosystem unit with which to study the impact of land use change on the lake, because anthropogenic disturbance can affect these smaller bodies of water by increasing soil erosion and nutrient leaching, and thus altering productivity and other ecological parameters. The importance of benthic algae as a high turnover production base of lake food webs and main source of fixed carbon for many fish taxa is well established (Vadeboncoeur et al. 2003). Primary productivity by periphyton is a useful proxy in determining stream water quality because these organisms respond rapidly to environmental change. As sessile, short-lived organisms, algae must either tolerate environmental disturbances or die, with each species having its own specific tolerances. Thus, benthic algal communities respond rapidly to a changing environment and provide a good indication of current conditions (Lowe and LaLiberte 1996).

Studies of primary productivity in streams may provide a sensitive measure of the impact of anthropogenic land use changes on the lake. If land use along the watershed heavily impacts epilithic algae, then the amount of organic energy available to heterotrophs at higher trophic levels may be altered, since algae compose the base of the food web, providing oxygen and fixed carbon for many organisms. Vadeboncoeur et al. (2003) found eutrophication caused a shift in dominance of benthic to pelagic algae, which was transferred up food web to littoral primary consumers and invertebrate predators. Eutrophication also decreases dissolved oxygen concentrations as a consequence of increased algal productivity and thus decomposition, aided by increased nutrients and sunlight penetration to the stream.

Although productivity patterns are well established in lakes and oceans, much less is known about primary energy sources in running waters such as streams (Allan 1995), particularly along Lake Tanganyika. Does deforestation affect primary production in streams in the Kigoma region? I expect organic carbon to differ in streams within a disturbed watershed by source and by type, shifting from allochthonous to autochthonous and detrital to algal, when canopy cover is lacking. This study seeks to determine how land use change affects epilithic algal productivity and biomass in streams draining watersheds from western Tanzania into the northeastern shore of Lake Tanganyika, as well as to compare methods of measuring these parameters.

## **Methods**

### *Study Sites*

Six streams were studied along the northeastern shore of Lake Tanganyika from July 19 to August 4, 2005. Three streams drain a forested watershed in Gombe Stream National Park (Kalande, Mkenke, Rutanga) and three streams lie within a deforested watershed (Mtanga, Ngonya, Ngelwa). For further details on these watersheds see Stoll and Miller, this volume.

### *Dissolved Oxygen*

Respiration and productivity of benthic algae were determined using change in dissolved oxygen (DO) concentrations. For each stream, six cobbles were each incubated in a 1.25 liter clear plastic chamber with a rubber stopper. Oxygen concentrations were determined using a YSI Model 58 Dissolved Oxygen meter and by Winkler titration. For initial DO readings, water was renewed in each chamber and the DO probe was inserted through a hole in the lid. The chamber remained in the stream during this time to minimize air entering the chamber. After the measurement, the stopper was inserted to seal the incubator from the surrounding stream water. Final DO probe readings were taken with chambers out of the stream to avoid mixing chamber and ambient stream water. For three chambers, sixty milliliters of water were taken with a

syringe immediately after the initial and final DO probe readings. DO was immediately fixed in the syringes by injecting 0.2mL of manganous sulfate and alkali-iodide-azide using 1cc syringes. Syringes were then shaken and placed in a shaded section of the stream to keep cool using a dark-colored mesh bag.

Prior to measuring respiration, lidless chambers were put underneath a black opaque plastic bag for approximately 30 minutes in order to acclimate to dark conditions. Respiration incubation periods ranged from 20 minutes to 1.5 hours. After incubation for respiration, cobbles were acclimated in lidless chambers to sunlight and fresh stream water for approximately 15 minutes. Productivity incubations ranged from 20 minutes to 2 hours. After sampling, all 12 syringes of stream water were placed in a cooler for boat transport. All six cobbles were collected in plastic bags for chlorophyll *a*, carotenoid and algal biomass measurements. The volume of water in each chamber was also determined.

#### *Winkler titration*

Titration were performed using 0.025 M sodium thiosulfate and a 25mL Brand Digital Burette following the Winkler method described in Hauer and Hill (1996).

#### *Chlorophyll a*

Rocks were removed from the freezer and scrubbed using a small steel brush to remove and collect algae in a plastic tray. Latex gloves were used to prevent contamination when handling cobbles. Rock scrubbing samples were then diluted to 250 mL and shaken well before each filtration. The volume of sample filtered ranged between 5 and 25 mL. Two replicates for each sample were filtered for chlorophyll *a* and carotenoid pigment analyses and placed in 15 mL centrifuge tubes and frozen. Ten milliliters of 90% ethanol solution were added to the tubes 24 hours prior to measurement. Immediately before analysis, filters were discarded and samples centrifuged for 15 minutes. Using a Genesys 20 Thermospectronic, four milliliters of sample were placed in a 1 cm glass tube cuvette and absorbance read at 665 nm and 480 nm pre- and post-acidification with 2 mL of 0.1N HCl to account for pheopigments. Chlorophyll and carotenoid concentrations were determined by methods described by Steinman and Lamberti (1996).

#### *Algal biomass*

To determine ash free dry weight 25 milliliters of the scrubbed sample was filtered onto pre-weighed Fisher or GF/F filters and stored in foil envelopes to dry. Samples were then placed in a drying oven at 60 °C for four hours and weighed to obtain dry mass. Samples were then combusted in a furnace at 500 °C for four hours and reweighed to obtain ash free dry mass. DM and AFDM were calculated following methods described by Steinman and Lamberti (1996).

#### *Cobble surface area and volume*

To determine surface area cobbles were dried, labeled, and wrapped with aluminum foil. Foil was then cut to remove the bottom area of the rock (assumed to be uncolonizable by algae) and weighed. Both colonizable and uncolonizable areas of foil were weighed. A square piece of foil of known area was also weighed, and surface area was calculated following the method described by Hauer and Lamberti (1996).

#### *Statistical Analysis*

One-way analysis of variance (ANOVA) was used to determine differences in productivity (GPP and NPP) per exposed rock area ( $\text{mgO}_2 \text{ hr}^{-1} \text{cm}^{-2}$ ) and in productivity per chlorophyll *a* concentration ( $\text{mg O}_2 \text{ hr}^{-1} \text{cm}^{-2}$ ), between watershed status and streams. ANOVA was also employed in testing for differences in chlorophyll *a* and carotenoid concentrations ( $\text{mg cm}^{-2}$ ) between watershed types and streams. Tukey-Kramer HSD was used to compare means among significant pairs. A two-way ANOVA was used to determine the combined effect of chlorophyll *a* concentration and stream type on GPP. A student's T-test was performed to determine differences between means of matched pairs for DO, NPP, and GPP obtained by the Winkler titration and DO probe methods.

## Results

### *Gross and Net Primary Productivity*

GPP/cm<sup>2</sup> and NPP/cm<sup>2</sup> were significantly higher in disturbed versus undisturbed watersheds ( $p < 0.0001$ ,  $R^2 = 0.3897$ ;  $p < 0.0001$ ,  $R^2 = 0.542$ ). There were significant differences in GPP cm<sup>-2</sup> and NPP cm<sup>-2</sup> by stream ( $p < 0.0001$ ,  $R^2 = 0.814$ ;  $p < 0.0001$ ,  $R^2 = 0.686$ ). Analysis of GPP cm<sup>-2</sup> by stream determined Kalande to have significantly lower GPP than all other streams and Mtanga to have significantly higher GPP than Mkenke and Kalande. However, analysis of NPP cm<sup>-2</sup> differences between streams showed Mtanga to have significantly higher NPP than all other streams.

### *Algal Biomass and Productivity*

Streams in the deforested watershed had significantly higher chlorophyll *a* concentrations (mg cm<sup>-2</sup>) than forested streams ( $p = 0.0067$ ,  $R^2 = 0.149$ ) with significant variation among sites ( $p < 0.0001$ ,  $R^2 = 0.633$ ). Ngelwa had significantly higher chlorophyll concentrations than all streams except Rutanga, and Mkenke had significantly lower concentrations from all sites but Mtanga. GPP mg<sup>-1</sup> Chl *a* was found to be significantly higher in deforested streams ( $p = 0.0161$ ,  $R^2 = 0.119$ ), but was not significantly different between sites ( $p = 0.516$ ,  $R^2 = 0.223$ ). NPP mg<sup>-1</sup> Chl *a* was significantly higher in streams draining the deforested catchment ( $p < 0.0001$ ,  $R^2 = 0.303$ ), and was also shown to differ between streams ( $p < 0.0001$ ,  $R^2 = 0.659$ ) with Mtanga significantly higher than all sites. A significant correlation was found when stream and chlorophyll concentration were combined to determine their contribution to GPP cm<sup>-2</sup> ( $p < 0.0001$ ,  $R^2 = 80.4$ ). However, although the additive effect of stream was shown to be significant to the correlation ( $p < 0.0001$ ), mgChl *a* cm<sup>-2</sup> was not ( $p = 0.398$ ).

### *Carotenoid Concentration*

Carotenoid concentrations (mg cm<sup>-2</sup>) were found to be significantly higher in the deforested watershed ( $p = 0.0189$ ,  $R^2 = 0.114$ ) and differ among streams ( $p < 0.0001$ ,  $R^2 = 0.655$ ). Ngelwa had significantly higher concentrations than all streams but Rutanga, and Mkenke had significantly lower concentrations than all sites but Mtanga.

### *Comparing Measurements of Productivity*

Comparison of Winkler titration and DO probe methods determined there to be no significant difference between matched pairs of dissolved oxygen. In fact, DO measurements between methods are significantly correlated ( $R^2 = 0.9752$ ). GPP and NPP measurements obtained by both methods, although not significantly different were not as strongly correlated ( $R^2 = 0.1087$ ) and ( $R^2 = 0.0368$ ) (See Figures).

## Discussion

Results demonstrate that anthropogenic disturbances do increase benthic algal biomass and primary productivity in streams in the Kigoma region. However, differences in productivity are better explained by the additive effect of streams than by chlorophyll *a* concentration (mgChl *a*/cm<sup>2</sup>). This suggests that differences in nutrient concentrations and light penetration between streams are more important factors than algal biomass in determining primary productivity, and periphyton in forested streams is more nutrient and light limited than in deforested streams. Shineni found reactive phosphorous to be significantly higher in deforested versus forested streams (this volume) which may explain the difference in productivity between watersheds. Although Shineni found no significant difference for nitrate, Lombardozzi (2003) found significantly higher nitrate and nitrite concentrations in deforested watersheds, which may also explain higher productivity and biomass in the streams.

Shineni also determined stream temperature to be significantly lower in forested streams, with Rutanga and Mkenke being the coldest. Several studies have found algal cells to acclimate light-harvesting efficiency by increasing chlorophyll *a* concentrations at higher temperatures to compensate for increased CO<sub>2</sub> fixation, since photosynthetic dark reactions are influenced by temperature (DeNicola 1996). This adaptation to higher temperature may explain increased chlorophyll *a* concentrations in deforested streams. Research has also shown that environmental conditions that limit cellular energetics, such as low light, can also limit

nutrient uptake (Borchardt 1996). High forest canopy cover of streams within the Gombe watershed may inhibit algal nutrient cycling and consequently, productivity.

Carotenoid concentrations have been observed to be higher in nutrient-limited algal communities, however, carotenoids were demonstrated to be higher in deforested streams unlimited by reactive phosphorous or silica. Average nitrate concentration was lower for the impacted watershed than for the unimpacted watershed, although the difference was not significant (Shineni, this volume). This variation in nitrate may explain the high concentration of carotenoids in the deforested streams. It is also possible that algal production of carotenoid pigment is a result of lower ambient stream dissolved oxygen concentrations in deforested versus forested streams. Lombardozzi found significantly lower DO in deforested streams, although the difference between stream DO measured in 2005 was not significant (Nyanza Report 2003).

Although Winkler and probe readings were highly correlated, NPP and GPP as determined by each method were not strongly related. This indicates that the additive effect of the slight error between initial and final DO measurements causes different productivity estimates by both methods. Consequently, this study demonstrates that choice of methodology should take into account the parameter to be measured, and that despite strong correlation between Winkler and DO probe methods for dissolved oxygen measurements, the Winkler method gives a more accurate measurement of productivity.

Higher epilithic algal productivity in deforested streams locally affects primary consumers by supporting a higher abundance of insects, particularly chironomids (Fuller, this volume). Does increased algal productivity in streams ultimately affect the productivity and the carbon transfer efficiency of Lake Tanganyika? Among the many studies of primary production most have underestimated periphyton contributions to conceptual and qualitative models of lake metabolism and food webs (Vadeboncoeur et al. 2003). Models of primary productivity for Lake Tanganyika also seem to be lacking comprehensive accounts of benthic algal productivity. Compared to other tropical lakes, primary productivity ( $0.8 \text{ gC m}^{-2} \text{ day}^{-1}$ ) is not high, and yet the lake's fisheries yield 125 kg/hectare annually (Hecky et al. 1981). Thus, either the efficiency of carbon transfer from primary production to fishery is comparable to those of the most productive marine fisheries in the world, or annual primary productivity is vastly underestimated or else other sources of fixed carbon are important (Hecky and Fee 1981). Littoral periphyton is among the alternative sources, although data to support this hypothesis is lacking and would probably not account for all carbon sources. Hecky et al. (1981) did conclude that in order to maintain the lake's highly efficient trophic structure algal growth rates must be high, algal biomass accumulation low, and nutrient regeneration rapid. This study demonstrated deforestation to increase stream algal productivity, but data for biomass accumulation and nutrient cycling within the stream and the immediate Tanganyika water body are lacking. What affects do these ecological changes in streams have on Lake Tanganyika? Could increased stream algal productivity negatively affect the highly efficient carbon transfer within Lake Tanganyika's fisheries? It would be worthwhile to compare lotic and lentic nutrient concentrations and cycling, algal productivity, and biomass changes especially at the interface between streams and the lake to determine and compare how land use change affects both ecosystems.

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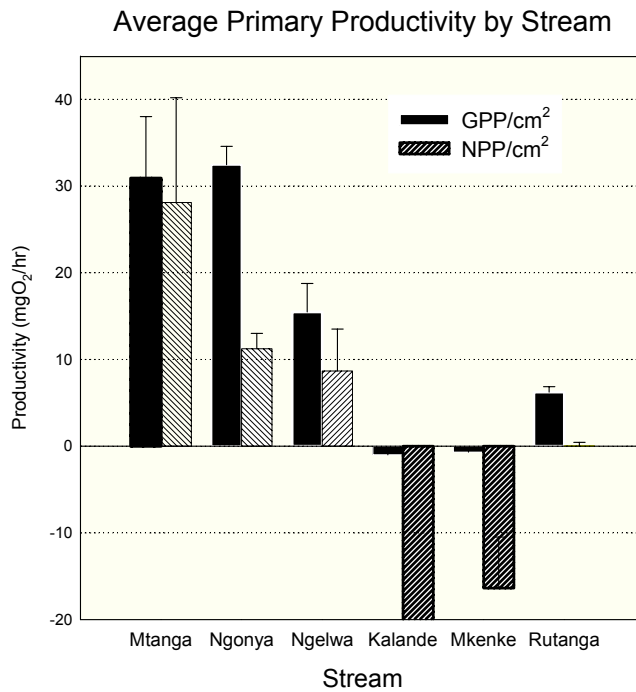
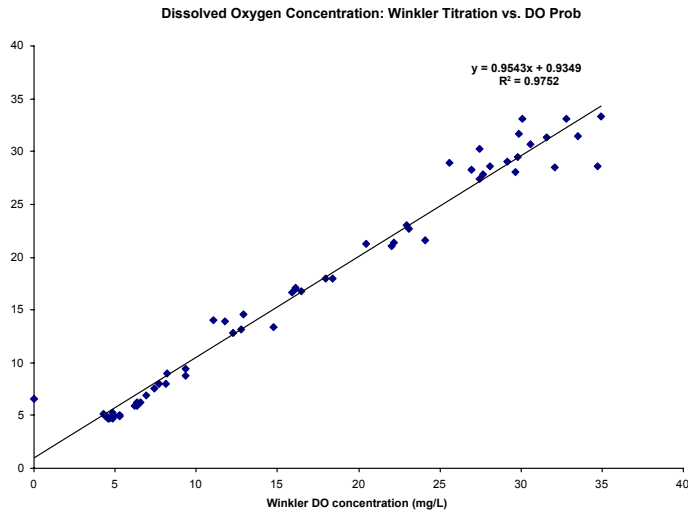
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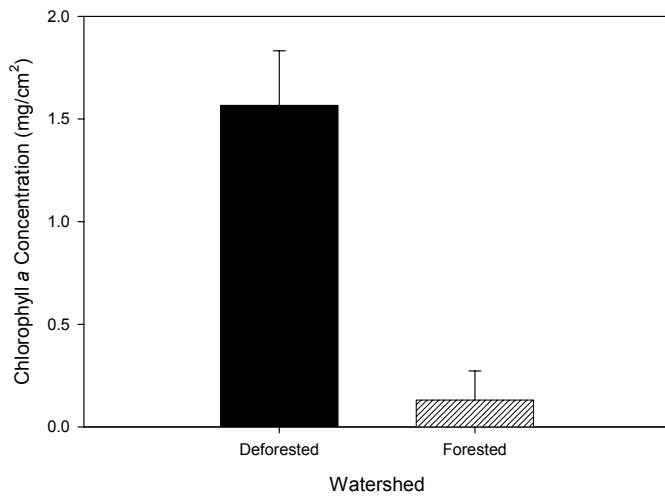
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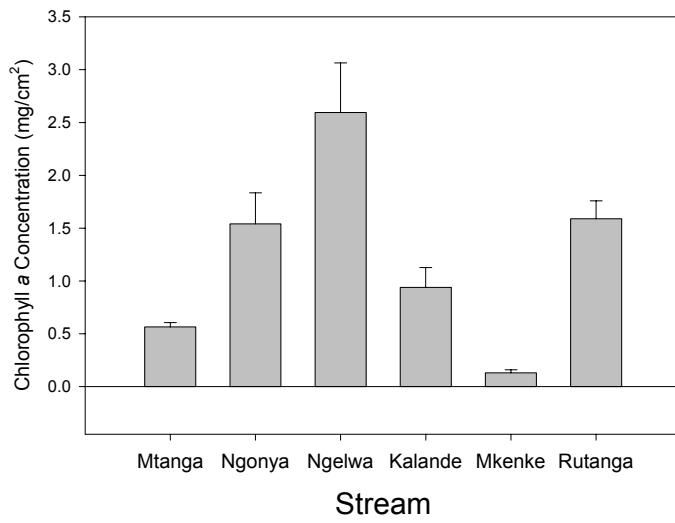
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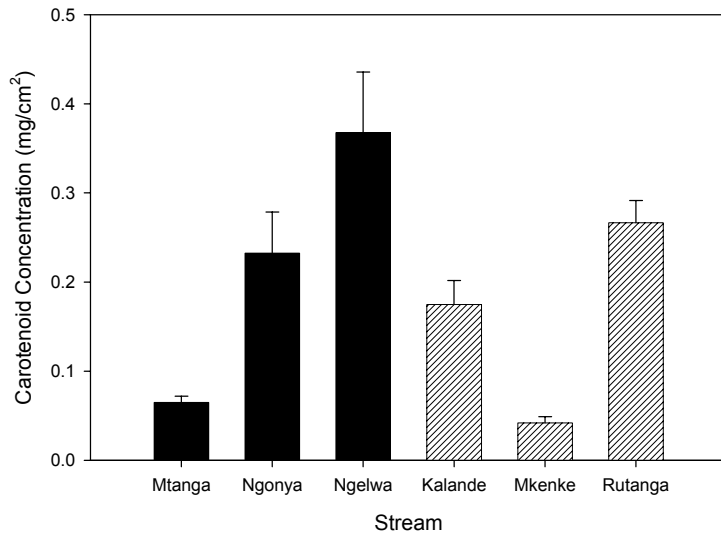
Chlorophyll a Concentration by Watershed



Average Chlorophyll a Concentration by Stream



Average Carotenoid Concentration by Stream



Average Carotenoid Concentration by Stream

