## A comparison of nutrient concentrations and suspended matter along two stream reaches, forested and deforested, in northwestern Tanzania.

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### Introduction

Streams provide valuable functions as material transporters and transformers from terrestrial riparian areas to areas further downstream or into lakes. This exchange of material provides an input of organic matter and other materials such as nutrients and minerals into the stream and can pass them further along the continuum. When compared to inputs from in-stream primary production, the main source of organic matter input to streams is from allochthonous material (Allen 1995). Erosion and rock-weathering provide the main source of nutrients to streams; however anthropogenic sources such as detergent and fertilizer have been documented as having added large amounts of nitrogen and phosphorus to adjacent freshwater systems in recent decades. The movement, transformation, and relative ratios of carbon and various nutrients have important effects upon ecosystem function, for example carbon compounds are an integral part of photosynthesis and nutrients are often limiting to plant growth (Dodson 2005).

This study examined the influence of deforestation on dissolved nutrient concentrations and suspended matter along two stream reaches flowing into the northeastern shore of Lake Tanganyika, Tanzania. Kalande Stream flows through Gombe Stream National Park and is located within a densely forested watershed. Nearby Ngelwa Stream flows through a village and is located within a predominantly deforested watershed with various land uses including agricultural plantations, housing, and domestic animal grazing. Stream maps and detailed geographical information are provided by Mike Strickler and Aaron Palke (see Stricker, Palke, this volume). These two streams were selected based upon their striking difference in relative watershed forest cover, and because they have similar underlying bedrock geology and watershed area. Dissolved nutrient concentrations were expected to be significantly higher in Ngelwa Stream, due to anthropogenic sources and increased erosion. Suspended organic matter concentrations were expected to be higher along Kalande Stream since there tends to be more coarse woody debris found along a vegetated stream bank while inorganic matter concentrations were expected to be higher in Ngelwa Stream due to increased erosion and inputs of sediment into the water column.

### Methods

Along both streams, water samples were collected in 1-liter polyethylene bottles at 10-meter intervals moving from 0 meters at the mouth to 200 meters upstream. Along Kalande Stream, velocity was measured in the field at each sampling station by recording the time required for a small stick to travel two meters downstream. Ngelwa Stream did not permit this velocity measure due to a much shallower stream depth, slower speed, and the frequent presence of thick algal mats. Additional field measures such as latitude, longitude, elevation, wet width and depth were recorded at each sampling station by Mike Strickler and Aaron Palke, along with streambed particle size information gathered with a gravelometer (see Stricker, Palke, this volume).

In the laboratory, water samples were measured for turbidity using a Hach turbidometer and then vacuum-filtered through precombusted glass fiber filters. Approximately 20 ml of unfiltered water were kept aside for laser particle size analyses of suspended matter conducted by Mike Strickler (see Strickler, this volume). Filtered water was stored in acid-washed bottles and kept chilled on ice until. Samples were analyzed for silica ($SiO_2$) and orthophosphate ($PO_4^{3-}$) using the Hach silicomolybdate method for high range silica and PhosVer3 method for soluble reactive phosphate. Silica samples were prepared in dilution (2.5 ml sample, diluted to 10 ml, multiplication factor 4) since they were out of range when measuring a 10 ml undiluted sample. Percent organic and inorganic suspended matter was determined using the loss on ignition method (500° C; 2 hours).

### Results and Discussion

Nutrient concentrations of silica and phosphorus were significantly higher in the deforested stream of Ngelwa than in the forested watershed of Kalande ($p < 0.0001$ for both $SiO_2$ and $PO_4^{3-}$). Average $SiO_2$ concentration was 1.83 mg/l in Ngelwa versus 0.87 mg/l in Kalande, while average $PO_4^{3-}$ concentration was 0.05 mg/l in Ngelwa versus 0.03 mg/l in Kalande. The greater difference between the two streams observed in silica concentration is likely due to the fact that phosphorus is generally a more limiting nutrient to plant growth and thus any input is likely taken up by biotic processes very quickly (O'Reilly, pers. comm.). Qualitatively, I noted a much higher prevalence of algae and macrophytes in deforested Ngelwa, reflecting this increased availability and uptake of phosphorus. This is further demonstrated as silica decreased significantly with distance downstream in both streams ($p = 0.0003$, Figure 1); however phosphorus did not ($p = 0.4889$, Figure 2), perhaps indicating greater nutrient uptake along the reach. For both silica and phosphorus, Ngelwa showed a greater range of difference between the highest and lowest nutrient concentrations indicating more variation in amount and source of nutrient input or less efficient nutrient processing occurring within the stream.

It is worth noting that silica concentrations appear highly variable when examining previous studies on similar streams in the area using the same method. Concentrations measured during the same months of the dry season in deforested streams were found to be on average 3.93 mg/l, 11.76 mg/l , and 27.25 mg/l (Caruso 2002, Lombardozzi 2003, and Shineni 2005, respectively). In forested streams, concentrations were found to be on average 3.17 mg/l, 9.9 mg/l, and 10.33 mg/l (Caruso 2002, Lombardozzi 2003, and Shineni 2005, respectively). Silica concentrations reflected in this report are comparatively low, possibly due to the laboratory dilution. It may be worth examining silica concentrations further in future studies or exploring other reagents or analyses to measure high-ranging silica.

Neither turbidity nor concentration of inorganic suspended matter showed a significant relationship to watershed type ($p = 0.0177$, $p = 0.0477$, respectively). Along Kalande however, turbidity showed an increasing trend with distance downstream ($p = 0.0033$, Figure 3) while along Ngelwa, turbidity was more variable and showed a decreasing trend with distance downstream ($p = 0.4014$, Figure 4) perhaps due to the presence of thick algal mats trapping and collecting particles that would otherwise be suspended. The lack of significant difference between streams when examining concentrations of inorganic suspended matter could provide insight into the importance of season when examining impacts of deforestation in the tropics. Suspended sediment in the water column is likely to be most apparent through runoff during the heavy and persistent rains of the wet season. These samples were taken during the dry season when there is very little, if any, rain for several months.

Concentration of suspended organic matter was significantly higher in the forested stream of Kalande ($p < 0.0001$). Inputs of organic matter are also highly influenced by seasonal factors, as rain provides the primary mechanism of bringing terrestrial material into the water. A higher water column during the rainy season also tends to bring in more vegetation and detrital matter from the stream banks (Allen 1995). However, storms during the rainy season manage concentrations of suspended organic matter not through their inputs, but through their exports. Storms serve frequently to flush the majority of the suspended organic matter out, resulting in generally lower concentrations of suspended organics in the rainy season than in the dry season (Allen 1995). This highlights the importance of internal biological processes in carbon cycling in the absence of rain (Allen 1995). Some of the organic material can be retained in the stream over time by physical impediments such as detrital dams or fallen logs. When retained, carbon can be consumed and converted to carbon dioxide in respiration or used as a substrate for microbial growth. These internal stream processes of carbon cycling appear to be more important in Kalande than in Ngelwa.

When examining characteristics along the length of the stream reach, Kalande Stream shows a significant increase in concentration of suspended inorganic matter ($p < 0.0001$, Figure 5) and concentration of suspended organic matter ($p = 0.0006$, Figure 5) with direction downstream. These relationships moving downstream are expected as overall watershed size and drainage area increases as the stream opens into Lake Tanganyika, materials upstream are flushed downstream by stream flow, and lack of rain diminishes the inputs of allochthonous material. Although Ngelwa has a similar watershed size, these relationships were not significant with direction downstream ($p = 0.0561$, $p = 0.0175$, respectively, Figure 6). The inconsistency of these characteristics along Ngelwa's reach likely indicates a broader scale and intensity of direct anthropogenic inputs, due to the various land uses occurring immediately adjacent to the stream and across the watershed. Livestock grazing and human use of the stream will erode the stream bank and input riparian sediment and detergents directly into the stream without the presence of rainfall. Not only are there more numerous types and frequency of disturbances but these disturbances are not moderated by filtration through surrounding riparian vegetation. These observances could again highlight instream biological and physical processes that are magnified under the dry season and predictable in Kalande, yet not in Ngelwa.

**Conclusion**

Streams and other freshwater resources are vital connectors across not only a terrestrial-aquatic landscape but also across a human landscape, with great dependencies existing upon them for consumption and overall human health. This is particularly true in small villages in tropical regions of the world where long dry periods alternate with seasonal rains and where direct dependency upon the freshwater resource is high. Understanding instream biological processes and carbon and nutrient cycles is fundamental to the understanding of how a stream functions as a part of a larger ecosystem. Understanding the impacts of deforestation to streams is imperative to the ability to prevent or mitigate them and to the assurance of a healthy and functioning ecosystem into the future.

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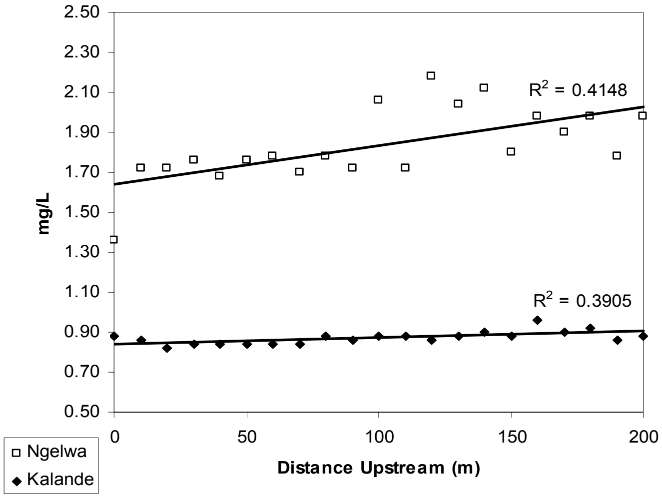


Figure 1. Average silica ($SiO_2$) concentrations along Ngelwa Stream and Kalande Stream.

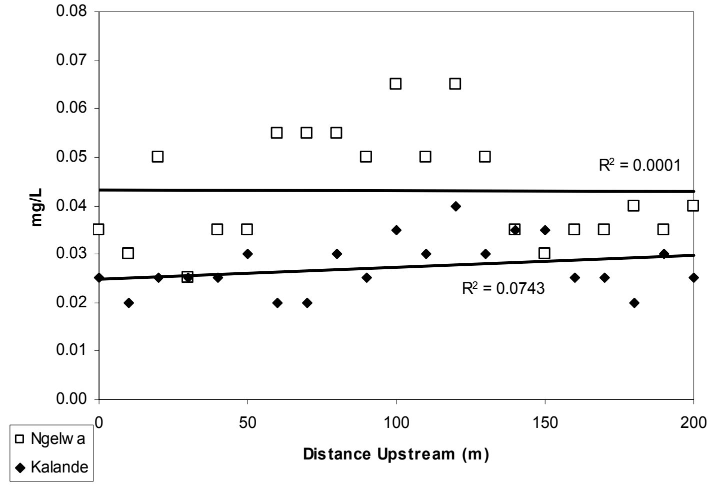


Figure 2. Average phosphorus ($PO_4^{3-}$) concentrations along Ngelwa Stream and Kalande Stream.

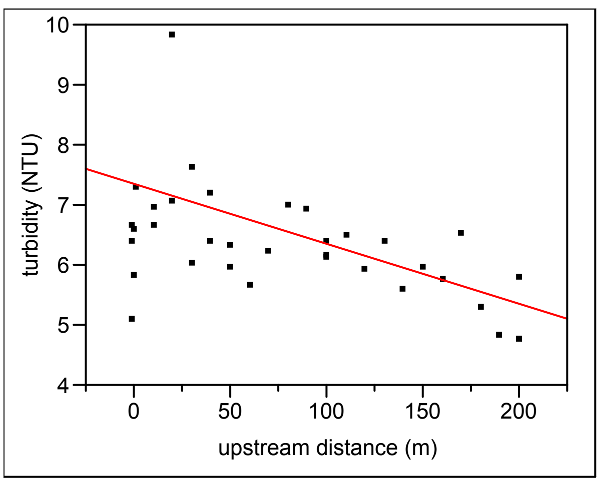


Figure 3. Turbidity along Kalande Stream ($R^2$ = 0.3729).

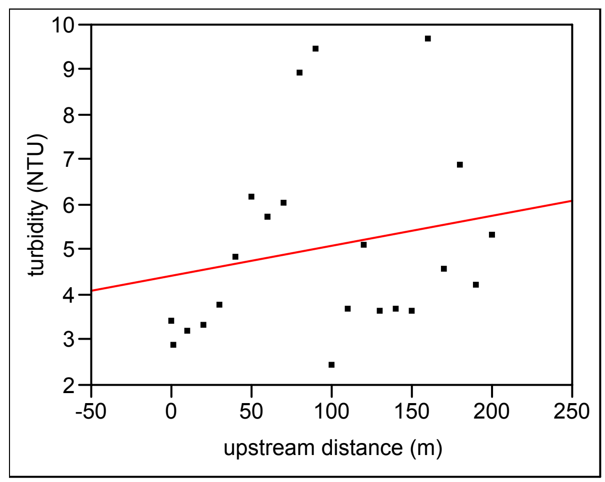


Figure 4. Turbidity along Ngelwa Stream ($R^2$ = 0. 0373).

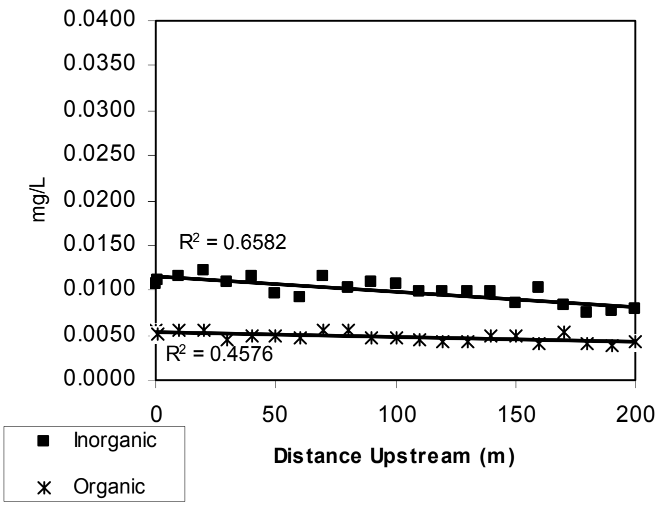


Figure 5. Average concentrations of inorganic and organic suspended matter along Kalande Stream.

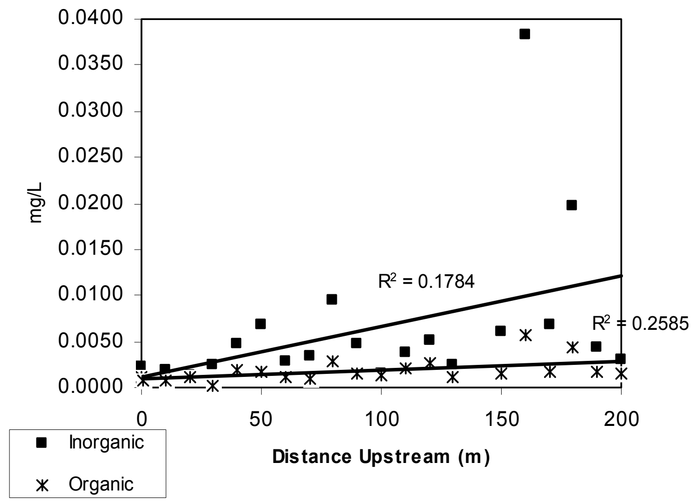


Figure 6. Average concentrations of inorganic and organic suspended matter along Ngelwa Stream.