The Effects of Deforestation on Nutrient Concentrations in Tributaries of Lake Tanganyika

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Introduction

As the world's population increases, the demand for wood continually increases. Trees are harvested for multiple uses ranging from lumber to wood for fuel. Land is also continually cleared to provide space for settlements and agriculture. The rate of deforestation currently significantly exceeds the rate of forest renewal.

Deforestation has many significant ecological consequences. The removal of vegetation results in increased erosion of soil sediments, which are many times deposited in water bodies, consequently depositing soil particles and nutrients. A decrease in vegetation also corresponds with a decrease in nutrient uptake in the soil, resulting in an increased rate of nutrient leaching from the soil. The leached nutrients are often deposited in water bodies. Both types of nutrient inputs subsequently alter physical stream characteristics as well as rates of productivity and ecological components of water bodies affected by deforestation.

Tropical systems tend to have high rates of deforestation due to high population growth rates. The large and ever increasing populations that are typical of many tropical countries tend to rely on wood as a means of subsistence more than countries in temperate climates. Since most deforestation studies have been done in non-tropical locations, it is essential to study deforestation in tropical climates. Deforestation might have different and more severe consequences in tropical ecosystems for many reasons. For example, tropical ecosystems generally have relatively high precipitation levels. This might amplify rates of nutrient leaching and sedimentation in comparison to non-tropical ecosystems.

Tributaries of the northeast shore of Lake Tanganyika provide an ideal study site for comparison of forested and deforested watersheds in a tropical ecosystem. Lake Tanganyika is a large lake ecosystem located in a tropical climate. The climate is consistent along the shoreline of the lake, as is the amount of precipitation. Elevation, relief, and substrate all also remain relatively constant. Gombe Stream National Park provides an example of an undisturbed habitat along the shoreline. Watersheds within the park can be easily compared to deforested watersheds in villages surrounding the park. In this study, I expected to find significantly higher nutrient concentrations in deforested watersheds due to increased rates of nutrient leaching and sedimentation.

Methods

Sites
Ten tributaries on the northeastern shore of Lake Tanganyika were studied from July 14 through August 4, 2003. Five of the streams under study were located in forested watersheds within the boundaries of Gombe Stream National Park. These watersheds encompassed vast ranges of vegetation that varied with elevation, fire regime and drainage patterns. Vegetation included evergreen forest, dry forest, deciduous woodland and rift grasslands. Also, three of these streams had nearby communities of park staff (Caruso, 2002).

The remaining five streams were located in deforested watersheds both north and south of the park. All of these streams were in villages ranging in size from 456 inhabitants in Mtanga, the southern-most village to approximately 12,000 inhabitants in Kiziba, the northern-most village. The land was deforested for living space and agricultural use, and the wood was used for fuel, houses, and boats, among other things.

The sizes of the watersheds are dependent on the surrounding landscape. The ridge off the eastern shore of Lake Tanganyika increases in distance from the shoreline as it runs north. Consequently, the size of the northern-most watersheds and the component streams are larger than those in the south. Thus, the streams

in Gombe Stream National Park range in size from small to large, as do the streams in the villages. The three streams in deforested watersheds north of the park are generally larger than the two streams south of the park (Caruso, 2002).

Field Sampling
Water samples were collected and stored in acid-washed Nalgene containers from three locations within 25 meters from the mouth of the stream on each collection day. Samples were collected on two separate days (n = 6). Both filtered and unfiltered water was collected at all sample sites. Filtered water samples were filtered in the field through a pre-combusted Whatman GF/F filter for lab nutrient analyses. Unfiltered water was collected for later alkalinity analysis. Water temperature, conductivity, dissolved oxygen (mg/L and percent), pH, and turbidity data were collected at each sample collection site.

Lab Analyses
Filtered water was used to determine reactive phosphorus (Hach PhosVer 3 Method), nitrite (Hach Diazotization Method), nitrate (Hach Cadmium Reduction Method), ammonia (Hach Nessler Method), and silica (Hach Silicomolybdate Method). These analyses were performed the day following sample collection. Unfiltered water was used to determine alkalinity (Hach Phenolphthalein and Total Using Sulfuric Acid Method) on the same day the sample was collected.

Statistical Analysis
Significant differences in nutrient concentrations and physical parameters between forested and deforested watersheds were determined using T-tests.

Results

Field Sampling
Stream temperatures ranged from 18.42 to 26.47 degrees C. Average stream temperature in the deforested watersheds was 23.17 °C, while the average stream temperature in the forested watersheds was 20.01 °C. Dissolved oxygen ranged from 8.18 to 11.01 mg/L, averaging 9.47 mg/L in deforested watersheds and 10.34 mg/L in forested watersheds. Conductivity ranged from 13 µS/cm to 153 µS/cm. Conductivity values were significantly higher in Kiziba (average 146.5) than in any other watershed. Values of pH ranged from 6.26 to 8.1. Turbidity values were not accurate due to the large number of spectators in the stream at the time of sampling, and were therefore not reported.

Nutrient Analysis
Nitrate, nitrite, silica, reactive phosphorus and alkalinity values were determined in the lab for all streams. Mean nutrient concentrations are presented in Table 1.

Site	Status	PO_4^{3-} (mg/L)	NO_2^- N (mg/L)	NO_3^- N (mg/L)	SiO_2 (mg/L)
Bugamba	Deforested	0.112	0.004	0.24	8.95
Mtanga	Deforested	0.063	0.0063	0.09	10.48
Mtanga A	Deforested	0.182	0.006	0.032	12.5
Kiziba	Deforested	0.292	0.0042	0.048	18.32
Mwamgongo	Deforested	0.123	0.0037	0.002	8.58
Rutanga	Forested	0.068	0.0033	0.032	9.58
Bwavi	Forested	0.19	0.0053	0.012	10.53
Kasekera	Forested	0.082	0.0045	0.04	9.73
Mkenke	Forested	0.07	0.003	0.033	8.77
Mitumba	Forested	0.168	0.0033	0.038	11

Table 1: All values presented are an average of 6 samples taken within 25 m from the mouth of each stream over the course of two days.

Nitrate values ranged from 0.001 to 0.24 mg/L, averaging 0.082 mg/L in deforested watersheds and 0.031 mg/L in forested watersheds. Nitrate values from Mwamgongo, a deforested watershed, were substantially lower than any other watershed. Nitrate values for Bugamba, also a deforested watershed, were much higher than any other stream. Nitrite values ranged from 0.003 to 0.006 mg/L.

Phosphate levels ranged from 0.06 to 0.28 mg/L, averaging 0.15 mg/L in deforested watersheds and 0.11 mg/L in forested watersheds. Phosphate levels in Bwavi, a forested watershed, were much higher than all other forested watersheds and many deforested watersheds. When values from Bwavi were excluded, the average phosphate load for forested watersheds decreased considerably.

Silica concentrations ranged from 5.5 to 18.8 mg/L. Average silica values for deforested watersheds were 11.76 mg/L, and 9.9 mg/L in forested watersheds. The highest silica concentrations overall were in the deforested Kiziba watershed.

Statistical Analyses
T-tests were performed to determine if nutrient concentrations and physical parameters in deforested watersheds were significantly different than forested watersheds. Silica and nitrate were both significantly different ($p = 0.0135$ and $p = 0.0023$ respectively) with 95% confidence. When Bwavi was excluded from analyses, phosphate ($p = 0.0057$) and nitrite ($p = 0.0184$) were significantly different with 95% confidence. When Bwavi was included, phosphate and nitrite were statistically significant with 90% confidence ($p = 0.0736$ and $p = 0.0618$, respectively). Temperature ($p = 0.0001$), conductivity ($p = 0.0004$), % dissolved oxygen ($p = 0.0182$) and dissolved oxygen (mg/L; $p = 0.0001$) were all statistically different at 95% confidence. Turbidity and pH were not significantly different between forested and deforested watersheds ($p = 0.729$ and $p = 0.0997$, respectively).

Discussion

Nutrient Concentrations
Deforestation has a significant impact on stream phosphorus and silica concentrations. Both of these nutrients are geologically derived and are deposited in the stream via erosion. Therefore, increases in both phosphate and silica concentrations in deforested watersheds are strong indicators of the anthropogenic impacts that deforestation causes. Phosphate is also a component of detergents and is therefore also anthropogenically emitted into stream ecosystems, potentially increasing concentrations.

High phosphate levels in Bwavi are potentially a result of the use of detergents. However, samples with high phosphate concentrations were collected during periods when there was no visible use of detergents upstream. A third set of samples analyzed ex post facto also had high phosphate concentrations, even upstream of the village. Also, benthic invertebrate samples collected during the same time period by Bob Swarthout had a high family biotic index (Swarthout, personal comm.). This indicates that Bwavi is a nutrient-enriched stream. Diatom samples collected during this period by Brent Bellinger contained high *Nitzschia* populations (Bellinger, personal comm.). *Nitzschia* typically indicates a phosphorus-enriched ecosystem. High family biotic index and large *Nitzschia* populations coupled with high phosphate concentrations found by Bethany Caruso (2002) last year suggest that phosphate enrichment has been occurring over a long period of time in the Bwavi watershed. Perhaps sampling occurred near a spring that has high phosphate concentrations. While the groundwater source for Bwavi might be the potential source of high phosphorus levels in the stream, further investigation is necessary before conclusions can be drawn.

Nitrate and nitrite concentrations also significantly increase in deforested watersheds. While nitrogen concentrations in water often increase with nitrogen deposition and fertilization, the villages surrounding the streams studied do not have large sources of nitrogen additions to the ecosystem. Thus, the increase in nitrogen concentrations in these streams is largely due to a lack of vegetation that would use the nitrogen compounds for growth and production. Consequently, more nitrogen is leached from the surrounding soil and deposited in the streams. Studies should be conducted on the microbial communities and processes in the surrounding watershed to determine if these communities alter nitrogen compounds or availability.

Changes in nitrogen compounds and availability in the surrounding soils can change how much and what types of nitrogen compounds are present in surrounding water bodies.

Nitrite concentrations are significantly higher in Bwavi than in other forested watersheds. High nitrite concentrations further support the hypothesis that sampling at Bwavi occurred near a groundwater spring. Nitrite is oxidized quickly into nitrate in the presence of oxygen and therefore is not common in aerobic soils. Nitrate from the ecosystem surrounding the watershed likely leached into the groundwater, as it is the most mobile nitrogen compound found in soils. Because groundwater is often anoxic, nitrate is reduced to nitrite. Therefore, groundwater often has higher concentrations of nitrite in comparison to stream water. Thus, if sampling at Bwavi occurred near a groundwater spring, concentrations of nitrite would most likely be higher than other streams that were not sampled near a groundwater source.

Both phosphorus and nitrogen are commonly limiting nutrients for ecosystem production. Therefore, increases in either of these nutrients, if one is limiting, can cause an increase in ecosystem productivity. In aquatic ecosystems, increases in productivity often result in a process known as eutrophication, which will be discussed in greater detail later.

Physical Parameters
Deforestation also has a significant impact on many physical parameters, including stream conductivity, which increases with an increase in ion concentration. Ions are often found in soil as micronutrients that plants use for growth and enter aquatic ecosystems via erosion and leaching. Since both of these processes increase with deforestation (also demonstrated through increased nutrient concentrations), conductivity increases in streams in deforested watersheds.

Temperature also increases significantly with deforestation. Deforestation causes a lack of trees to provide canopy cover. This results in higher levels of incident sunlight, increasing stream temperatures.

Dissolved oxygen percentages and concentrations are both higher in forested streams. This can be attributed to two different ecosystem functions. First, oxygen dissolves more easily in cold water. Therefore, as temperature increases as a result of deforestation, dissolved oxygen concentrations and percentages will decrease. Secondly, the process of eutrophication decreases dissolved oxygen concentrations and percentages. As more sunlight penetrates the stream, algal productivity can increase if the algal community is not limited by nutrients. Since deforestation tends to increase nutrient concentrations (see above), algal productivity is likely to increase. Eventually, the algae die, and oxygen-consuming decomposers decompose the algae, decreasing dissolved oxygen content in the stream. Decreases in dissolved oxygen are detrimental to many aquatic organisms. Because sunlight increases due to deforestation, decreased dissolved oxygen concentrations and percentages as a function of both increasing temperature and eutrophication are indirect consequences of deforestation. Lower levels of dissolved oxygen in the deforested streams may also indicate increased inputs of allochthonous organic matter such as detritus or sewage. Because allocthonous organic matter adds nutrients to these ecosystems, eutrophication again becomes a prominent process.

Conclusions

In conclusion, deforestation has a significant impact on tropical stream ecology. Significant differences in phosphate and silica are strong indicators of erosional inputs to streams in deforested watersheds. Increases in nitrate and nitrite concentrations are indicators of leaching inputs to streams in deforested watersheds. Changes in concentration of all of these nutrients change stream ecology in that they are often limiting and can cause severe ecological consequences, such as eutrophication. Deforestation also significantly increases conductivity, temperature, and decreases dissolved oxygen. Many aquatic organisms are sensitive to these parameters, either directly or indirectly. Therefore, changes result in alterations of the biotic community.

The consequences of deforestation on tropical stream ecology create other large and widespread effects. Deforestation alters the aquatic biotic community, often leading to the endangering or the potential extinction of native or endemic species. The changes caused by deforestation can also be harmful to

humans. For example, high nitrate concentrations can cause "blue-baby syndrome," which is fatal to infants. Thus, deforestation also has economic and political consequences when trying to resolve the problems that it creates.

Acknowledgements

References

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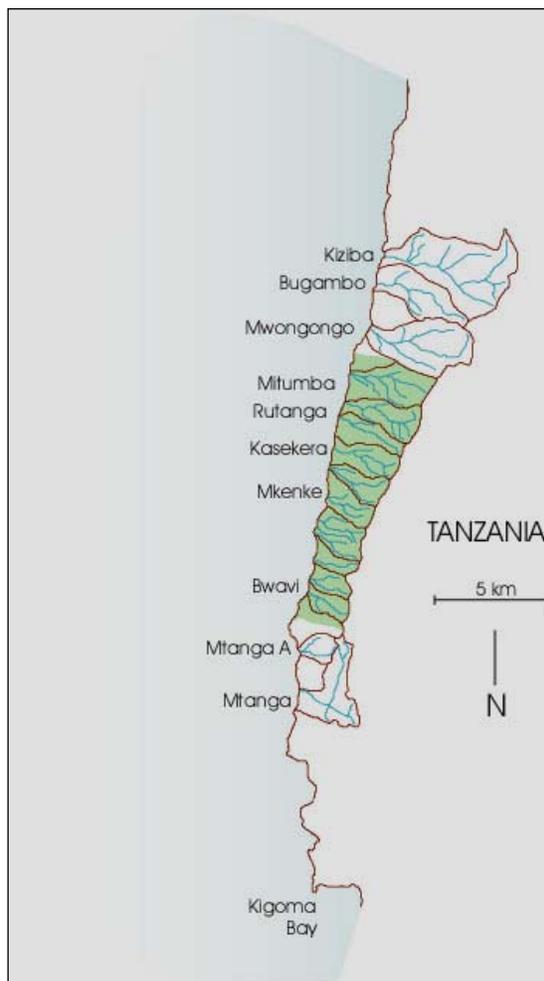
Figure 1: Map of watershed locations along Kigoma Bay