Nutrient response to dry season upwelling in the pelagic zone of Lake Tanganyika

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Introduction

Lake Tanganyika, located between 3°20’-8°45’ South and 29°05’-31°15’ East (Adams and Charles, 2000) in Western Tanzania, has long been of interest because of its remarkable depth (maximum 1470 meters) and age, formed through rifting processes 12 – 15 million years ago. For a lake that is unusually productive, Tanganyika has remarkably clear waters, low nutrient levels and a relatively low algal biomass (Coulter 1991, Hecky 1984 in O’Reilly 2003). As Tanganyika is a tropical lake, algal growth is not limited by temperature or solar radiation, but rather nutrient availability (Coulter 1991). Considering Tanganyika’s long water residence time and the large mass of nutrients in the deeper lake waters, achieving these high levels of productivity is reliant upon internal nutrient loading (Coulter 1991). The lake is permanently stratified, with an upper layer, or mixolimnion, that experiences seasonal temperature variations extending to an average depth of 200 meters (Coulter 1991). During the months of June through October the lake is cooled and the thermocline thins. Strong monsoon winds from the south drive water northward disrupting this weakened thermocline and creating seiche activity with a period of 28-36 days during which vertical mixing of deeper water into the upper lake levels occurs (Plisnier et al. 1999 in O’Reilly 2002). This cooler anoxic water displaces warmer oxygenated waters and boosts the nutrient availability to the entire biotic community of the mixolimnion. This phenomenon is observable both through shifting nutrient levels and through changing isotopic frequencies, with effects that resonate throughout the pelagic food chain. By studying the effects of upwelling on bioavailable nutrients, as well as their incorporation into phytoplankton and the fish in subsequent trophic levels, a better understanding of nutrient use and cycling within the lake may be achieved.

Objectives

The purpose of this study is to determine the nutrient changes in the pelagic resultant of an upwelling event by examining the chemical and physical parameters of the water column at a variety of depths, and additionally by examining the isotopic frequencies and nutrient ratios (C:N:P) of the phyto- and zooplankton. Plankton are a good indicator of how the upwelling events alter food quality as they respond quickly to changes in nutrient availability. Summer work focused on the accumulation of samples with rapid chemical and physical analyses in order to understand the natural cycling of nutrients within the lake, particularly in response to dry season upwelling events. Isotopic analyses and related fish tissue %RNA calculations are to follow and will lend insight into the effects of these cycles and the nutrient dynamics within the lake as a whole.

Methods

The water column of a pelagic site (GPS: S: 04°51.260’ E: 029°35.540’) was sampled on 15, 18, 21, 24, 28, and 31 July and 4 August between 9 and 12 am. For clarity a Julian dating system is used, with 15 July being sample day one, 18 July being sample day four, etc., through to sample day 22 on 4 August. During each sampling period, Secchi depth was determined, and filtrate from zooplankton tows of 48µm and 100µm mesh were collected three times each. Six liters and 250 ml of water at depths of 0, 20, 40, 60, 80 and 100 meters were collected. Zooplankton samples were suspended in distilled water, divided into two aliquots, each representing half of the water column. Samples of zooplankton from the 48µm tow were filtered through a 100µm mesh to isolate only those zooplankton between 48 and 100 µm in diameter. Each sample was filtered on Watson GF/C or GF/F paper. All filter papers from zooplankton were dried for at least three hours and stored for later isotopic and nutrient analyses. Three liters of sample water from each depth were filtered on Watson GF/C or GF/F paper, with the filter placed in 10 mL of 90% ethanol and refrigerated overnight for later chlorophyll a analysis. The remaining three liters were filtered with filter papers dried and stored for later isotopic analysis. Unfiltered water was tested for total phosphorus using HACH Permachem® reagents. Filtered water was tested for N-NH₃, NO₃⁻, NO₂⁻, SiO₂ and PO₄³⁻ using HACH Permachem® reagents.
Results

Each nutrient had distinct patterns of availability as can be seen in Figures 1-6. Lines between points are merely to aid the eye and are not indicative of intermediate data points. Nitrate (Fig. 1) was consistently in its highest concentrations below 80 meters with a total range of 0-0.14 mg/L. Nitrite concentration (Fig. 2) was much lower than that of nitrate, with a range of 0-8 E-3 mg/L, and was highest on days 1 and 4, being found in the upper 60 meters. On days 7 through 17, nitrite was found in increasingly lower depths. Ammonia concentrations (Fig. 3) were usually close to zero, with small concentrations detected on the 24th and 31st of July and a total range of 0 – 0.02 mg/L. Total phosphorous (Fig. 4) was quite variable in terms of both depth and concentration with a range of 0 – 0.21 mg/L. Reactive phosphate (Fig. 5) was highest on the first day, at 0-20 meters and again at 80 m, and had a total range of 0-2.84 mg/L. In subsequent days the phosphate concentrations seemed to decrease in peak depth occurrence, with days 10 – 17 finding the highest concentration at 100 m. Silicates (Fig. 6) were consistently highest in concentration below 60 meters, with the peak concentration on day 14 and a total range of 1.1 – 3.0 mg/L. Chlorophyll a (Fig. 7) was found highest on day 21 at 60 meters, and then between 0 and 60 meters on days 10 through 17 and had a total range of 0 –0.651 mg/L.

Discussion

Many nutrients have increased concentration with depth due to the combined effects of decreased algal consumption and increased bacterial decomposition with subsequent re-release, particularly as the hypolimnion is approached and the penetration of solar radiation decreases. Oxygen is consumed as organic matter sinks through the lake and decomposes, and when combined with the lack of photosynthesis there is a decrease in oxygen positively correlated with depth. The large break in dissolved oxygen found between 80 and 100 meters (Athuman 2003) would limit animal life while providing sufficient oxygen for decomposition and redox reactions. With secchi depth consistently higher than 12 meters, it is to be expected that phytoplankton would not subsist at the lowest sampling depths, where light availability limits growth. Compounded with the abundance of nutrients in lower depths as compared to higher, it is evident that at depth light availability limits chlorophyll growth more than any other parameter. Additionally, with Tanganyika’s high water clarity, there is little organic material to absorb UV radiation. Therefore, in the upper 20 meters of the lake the photo-inhibition effect (the prohibition of growth due to UV radiation) may limit chlorophyll growth, explaining the persistence of chlorophyll at depths lower than surface. This finding is consistent with the results found by Kimirei and Nahimana, 2000. The boost in productivity indicated by increased chlorophyll a values on 21 July may be attributed to the increased availability of nutrients, particularly nitrate. While many systems are limited by phosphorus, Lake Tanganyika has been shown to be nitrogen limited (Coulter 1991), and a resurgence of nitrate allows biomass growth.

While the overall concentration of nutrients is often highest at the lower depths, days 17 and 21 show a substantial increase of nitrate concentrations in the higher water levels, indicative of an upwelling event. The absence of a similar peak in phosphate is not entirely unexpected as nitrate peaks higher in the water column than phosphate (Adams and Charles 2000, McAndrews 2002). This difference in peaks is to be expected, as nitrate may only be formed above the oxic zone through a bacteria mediated conversion of ammonium to NO\textsubscript{3} (nitrification). Therefore, and upwelling event is observed first as a change of nitrate concentrations, particularly if the seiche activity is not yet strong enough to bring water from 200 meters, where phosphate concentrations peak (McAndrews 2002). Ammonia is the intermediate in nitrification reactions. These occur in anoxic conditions, and ammonia is rare in oxic zones because it is rapidly converted to nitrate. Its presence on the 17th further supports upwelling as the ammonia may have originated from the deeper anoxic waters.

Silica levels were boosted, by contrast, on the 14th day of sampling, with overall values quite variable with depth. Silica is released by weathering of alumino silicate minerals and dissolves more rapidly at higher pH (Wetzel 1975) and also by the decomposition of diatoms (Van Meel, 1987 in Kimirei and Nahimana, 2000). Silica is therefore expected to be relatively low with regard to the first 100 meters of the water column and oscillations between 0 and 3 mg/L as seen here are in accord to other investigations of SiO\textsubscript{2}
concentrations (Kimirei and Nahimana, 2000). Nitrite values are typically quite low in the upper levels of the lake as this bacteria mediated reaction occurs under low oxygen and in anoxic conditions denitrification continues with an end product of $\text{N}_2\text{(g)}$, removing nitrogen from the system.

Total Phosphorus, which includes the forms of phosphorus with are not bioavailable and may be found bound to sediment particles or other immobile forms, was quite variable with depth and sample date. Reactive phosphorus is often removed from a system as it binds to particulate matter while sinking through the water column and is eventually buried in the sediment, not to be re-released until mineral weathering.

**Conclusions**

Continuation of this research in the direction of isotopic and somatic RNA analyses is planned. The isotopic data will elucidate the conservation of nutrients through the pelagic food web of various sized plankton and the two pelagic fish *Lates stappersi* and *Stolothrissa tanganicae* Analysis of water in which fish have been allowed to excrete for one hour will provide information on the effects fish have on the nutrients in their immediate vicinity, and how other organisms may benefit from this form of internal cycling. Analysis of the % RNA of various sized *Lates stappersi* and *Stolothrissa tanganicae*, when related to the available phosphate will provide information of nutrient demand at varied growth stages in the fish cycle, as phosphorus limits the production of RNA and subsequently protein.

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**References**


Figure 1. Nitrate Concentrations (mg/L) shown across a variety of depths (m) and Sampling Days.

Figure 2. Nitrite Concentrations (mg/L) shown across a variety of depths (m) and Sampling Days.

Figure 3. Ammonia Concentrations (mg/L) shown across a variety of depths (m) and Sampling Days.
Figure 4. Total P Concentrations (mg/L) shown across a variety of depths (m) and Sampling Days.

Figure 5. Phosphate Concentrations (mg/L) shown across a variety of depths (m) and Sampling Days.

Figure 6. Silicate Concentrations (mg/L) shown across a variety of depths (m) and Sampling Days.

Figure 7. Chlorophyll a Concentrations (mg/L) shown across a variety of depths (m) and Sampling Days.