Dynamics of two clupeid species and *L. stappersii* in Lake Tanganyika: Use of trace elements and rare earth element chemistry of otoliths

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**Introduction**

Fish stock levels in Lake Tanganyika are subject to various pressure and fluctuations such as climatic change and land-use patterns (e.g., deforestation, urbanization and sedimentation) (Mölsä et al., 1999). To meet the increasing demand for fish products by the four riparian countries, fish habitats must be delineated and protected. However, it would be very expensive and impractical to protect all fish habitats in this large freshwater body (50 km width, 673 km long and 1470 m maximum depth) rather than identifying those habitats that contribute disproportionately to future generation and protect them (i.e., source vs. sink habitats).

The conventional method used to assess fish population dynamics and richness is large-scale physical tagging. Although the method can provide information about the survival rates of juvenile fish and their subsequent recruitment to stocks, it suffers from some inherent limitations such as tag-induced mortality, low recapture rates and high cost of the operation. Genetic studies are another assessment method that has attracted fisheries scientists. The technique can be used successfully to identify different species within a given habitat. Like physical tagging, the method has two major limitations. Firstly, it cannot classify fish to their natal habitats. Secondly, it fails to differentiate between juvenile and adult fish within a population (Markwitz et al., 1999).

A relatively new technique based on geochemical signatures in fish earstones (otoliths) may be a more effective for estimating past and present habitat use by juvenile and adult fish. Additionally, the chemical composition of otolith can be used to discriminate between different stocks in a given waterbody (e.g., Lake Tanganyika).

In addition to using the whole otolith geochemistry to investigate population dynamics of the target species the technique of otolith aging is also useful. Scales, traditionally used for aging, can be difficult to age fish in water that retains a constant temperature (e.g., Lake Tanganyika), because annuli deposition will stay similar year round. In contrast to scales, otoliths are not affected by constant temperature. They are therefore a better record of fish growth, since they are internal and not exposed to weathering factors and regeneration. Consequently, otolith aging is more accurate than scale aging and it provides detailed information on the history of individual fish such as age at maturation, evidence of growth problems, etc. Furthermore, otolith aging can be used to validate scale aging as scale aging becomes increasingly less accurate with fish age, and when fish are unhealthy the quality of the scale record diminishes, while the integrity of the otolith record remains intact.

Data concerning the species richness of the sites within each sub-basin, relative abundances, age structure and growth (length, width and age) will be combined to initially identify regions within Lake Tanganyika that have higher numbers of juveniles, mature members and their movement.

**Objectives**

The overall objectives of the present study are:

1. To examine differences in lake and river (Malagarasi, Luiche, Lufubu and Rusizi rivers) water chemistry.
2. To investigate the existence of possible relationships between otolith geochemistry of target species and surrounding water and sediment samples.
3. Assess growth and age of fish by studying length, weight, scale and daily and annuli increment of otoliths.
Hypothesis

Differences in the environments (e.g., bedrock geology, flow regimes, etc) to which each fish population was exposed will affect the chemistry of their otoliths (otolith chemistry is specific to the environment) (Thorrold et al., 1997).

Background and Rational

Three pairs of otoliths are found in fish: The largest ones, commonly referred to as otoliths, are called Sagitta (a mechanical transducer), and are composed of calcium carbonate (i.e., aragonite). The other two pairs are lapillus and asteriscus (Bell, 2001). Otoliths are acellular (unlike bones they are not metabolically resorbed or reworked) and their growth continues throughout the fish life. Consequently, they are permanent records of the influence of internal and external factors. The shape of an otolith depends on the size of the fish, age and species. Otoliths grow (about 1-5µm per day) in the fluids of the endolymph in fish inner earstones (Markwitz et al., 2000). In natural waters, Ca\(^{2+}\) is substituted in otolith matrix by other bivalent cations such as Sr\(^{2+}\), Ba\(^{2+}\), Mag\(^{2+}\), Mn\(^{2+}\), etc. Thus, the ratios of Sr/Ca, Ba/Ca, Mg/Ca, Mn/Ca, \(^{13}\)C and \(^{18}\)O in otoliths correspond to their concentrations in the surrounding water. The uptake of these bivalent cations by otoliths depends on several factors such as temperature (particularly for Sr), salinity and primary productivity. Because of low salinity and constant temperature of Lake Tanganyika, impacts of temperature and salinity can be initially ignored.

In addition to bivalent species that substitute for calcium in the aragonite structure, rare earth elements (REEs) (from La to Lu), trivalent species can be biogenically incorporated into carbonate structure forming Me(CaCO\(_3\))\(_2\) and MeCO\(_3\)\(^+\) complexes, and therefore their elemental compositions in otolith are directly related to dissolved composition found in water column (Barrat et al., 1999). The chemistry of the surface water of the lake is influenced by the composition of sediments and debris originated from weathering and erosion of geological formations of its catchments. There are three main catchments: Rusizi, Malagarasi and Lufubu catchments. The bedrock of these catchments is primarily composed of granites, gneisses, amphibolites and quartzites. However, there are some compositional differences between the catchments. For example, the Rusizi River drains more Mg\(^{2+}\) and Ca\(^{2+}\) to the lake than the two other major rivers (Cohen et al. 1997). Similarly, cores studies in the Mpolungu sub-basin indicated high content of vivanite, dissolved iron and phosphate. Edmond et al., (1993) also suggested that the high phosphorus content found in Kigoma sub-basin is supplied by the Malagarasi catchment bedrock, which is rich in ferric-phosphate complex. Despite these differences in geological composition of bedrock of the three main catchments (Rusizi, Malagarasi and Lufubu) that feed the lake, there may not be a difference in major element compositions (Barrat et al. 1999). This homogeneity is mainly due to the well mixing events that occur in surface water of the Lake. However, Barrat et al (1999) found a significant heterogeneity in REEs composition in various sites within the lake. Because of the similarity of their ionic radii (they are mainly in trivalent Oxidation State), REEs can be used as a natural tracer to identify the source reservoir of water and sediments (Sholkovitz et al., 1989).

Analytical methods

Water, fish and sediment samples were collected in the following sites: The Malagarasi, Luiche, Rusizi and Lufubu Rivers, the Kigoma sub-basin, the Moba sub-basin, the Mpolungu sub-basin and the Bujumbura sub-basin (Figure 1). A set of unfiltered water samples from upstream, downstream and off Malagarasi and Luiche and Kigoma Bays was analyzed for total phosphorus contents and alkalinity (CaCO\(_3\)). NO\(_3\), SiO\(_2\), Cl, SO\(_4\)\(^{-2}\) contents were directly measured on filtered samples. Another set of water samples was filtered and acidified with H\(_2\)SO (pH<2) for a subsequent major (Mg, Ca and K), minor ion analysis (Ba, Mn, Sr, U, Li and B) and rare earth elements (REEs) at Water-Rock-Life lab (Arkansas State University). Flame Atomic Absorption (AA) for major elements and Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) for both minor and REEs content. After aging, otoliths will be digested in nitric acid under clean lab conditions and run on ICP-MS for trace elements and REEs.
A duplicated sediment samples was also collected from the Rusizi, Malagarasi and Lufubu Rivers. Five grams will be accurately weighed from each sample and digested for major, minor and REEs analysis at Water-Rock-Life lab (Arkansas State University).

It was not possible to get *Lates stappersii* in the southern part of the lake at this time. This low catch of *L. stappersii* is probably due to high turbidity caused by upwelling (April to September), since the movement of this species it believed to be limited by turbidity.

**Figure 1: Sampling sites of water, sediment and fish**

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**Preliminary results & discussion:**

1. Low nitrogen species composition (ammonia was under detection limit) in surface water of the lake indicate that the photic zone is sink source for this species The low ammonia content is primary due to the alkalinity of the lake (pH~9.1) under which condition NH$_3$ is evaporated in the atmosphere (Edmond et al., 1993).
2. Contrary to nitrate, total phosphorus content was relatively high in the lake (Table 1).
3. The concentration of total phosphorus can be attributed to seasonal nutrient regeneration, resuspension from sediment due to vertical mixing and a probably release from fluvial sediments following dissolution of ferric iron, for example the river Malagarasi (Edmond et al. 1993).
4. Nutrient contents were higher in rivers than in the lake (Figure 2). This was in agreement with a previous work on the Ruzizi River (Vandelannoote et al., 1999).
5. Mass-length regression analysis of the three species showed a high correlation between weight and length ($R^2 > 80\%$) (Figure 3). Further analysis of daily increment of otoliths and scales will be used as a tool to determine the growth rate of the fish.
6. Analysis of major elements such as Mg, Ca, K etc. in surface water of the lake the main rivers (the Ruzizi, Malagarasi, and Lufubu river), will provide a better understanding of the extent of mixing and water movement between different basins.

Table 1. Physicochemical compositions of Lake Tanganyika and the River Malagarasi and Luiche

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Malagarasi</th>
<th>Luiche</th>
<th>Lake</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Upstream</td>
<td>River mouth</td>
<td>Upstream</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>0</td>
<td>4</td>
<td>0</td>
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<tr>
<td>T (°C)</td>
<td>23.3</td>
<td>22.8</td>
<td>26.3</td>
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<tr>
<td>pH</td>
<td>8.14</td>
<td>8.15</td>
<td>9.03</td>
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<tr>
<td>DO (mg/L)</td>
<td>7.5</td>
<td>7.43</td>
<td>7.4</td>
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<tr>
<td>Total P (mg/L)</td>
<td>0.12</td>
<td>0.21</td>
<td>0.094</td>
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<tr>
<td>Nitrate (mg/L)</td>
<td>0.01</td>
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<td>0</td>
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<tr>
<td>Silica (mg/L)</td>
<td>1.8</td>
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<td>CaCO3 (mg/L)</td>
<td>74.9</td>
<td>66.8</td>
<td>187.8</td>
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<tr>
<td>Chloride (mg/L)</td>
<td>23.5</td>
<td>14.1</td>
<td>22</td>
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<tr>
<td>Conduc. (µMHOs)</td>
<td>192</td>
<td>200</td>
<td>430</td>
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<tr>
<td>Chla (µg/L)</td>
<td>0.00192</td>
<td>0.001</td>
<td>0</td>
</tr>
<tr>
<td>Secchi disk (m)</td>
<td>1.5</td>
<td>1.5</td>
<td>2</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
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<td>*</td>
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<tr>
<td>Sulfate (mg/L)</td>
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<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 2: Chemical composition of rivers and lake water.
L. stappersii, Kigoma basin

\[
y = 0.0391x + 22.51 \\
R^2 = 0.8972
\]

L. stappersii, Bujumbura basin

\[
y = 0.1174x + 10.285 \\
R^2 = 0.9765
\]

L. tanganicae, Mpalungu basin

\[
y = 0.3047x + 7.6306 \\
R^2 = 0.9141
\]

Figure 3: Mass-Length regression analysis of the target fish species

References


