An approach to studying climate change impacts on Arctic fish: The use of $\delta^{18}O$ stable isotope analysis

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Abstract

In northern latitudes, past climate variability and exploitation have played key roles in determining the dynamics of Arctic charr (*Salvelinus alpinus*) populations. In the face of climate change, there is a requirement for clarifying interactions between environmental variables and population dynamics, particularly as they pertain to ensuring the sustainability of economic and culturally important species like Arctic charr. The use of stable isotope analysis (SIA) is a potentially useful means of describing possible climate change effects because it allows retrospective documentation of past temperature-growth relationships. Otolith oxygen ($\delta^{18}O$) SIA, in particular, permits thermal reconstructions for individual fish that may ultimately be correlated to growth chronologies to determine patterns of within- and among-population growth over a broad range of thermal and productivity conditions. Exploration of the possible implications of warming trends in Arctic ecosystems is accomplished by (1) estimation of relevant fractionation relationships that permit translation of measured $\delta^{18}O$ signatures in young-of-the-year (YOY) Arctic charr otoliths to temperature (°C), and (2) analysis of Arctic charr otoliths from across the Canadian Arctic.

Introduction

Arctic charr (*Salvelinus alpinus*) is a widely distributed species in eastern North America, with a range extending from northern New England to the northern coast of Ellesmere Island (Johnson 1980), and are arguably one of the most cold-adapted freshwater fish species. Concerns over the effects of climate warming on northern fish communities have risen in recent years and are supported by evidence of change in northern ecosystems. The Arctic Climate Impact Assessment (ACIA) report (www.acia.uaf.edu) notes that northern latitudes are likely to be significantly affected by climate change, yet few regional climate-related biological studies have been completed to date.

Otolith microchemistry, however, enables research to offset the scarce information base by facilitating the construction of historical data series for retrospective analysis of climate variation effects on fish. Otoliths are acellular and unlikely to be metabolically reworked after deposition (Campana & Neilson 1985). Therefore, otolith elemental signatures accurately represent the effects of environmental rather than physiological variation (Campana 1999, see Figure 1).

Among the environmental influences accurately recorded by the otolith is water temperature (Devereaux 1967), which may be extracted by measuring otolith $\delta^{18}O$ signatures and translating the obtained $\delta^{18}O$ value to temperature via a fractionation equation (Figure 2). To date, fractionation equations have been developed for marine fish and freshwater museum specimens from a broad range of presumed thermal habitats. However, questions remain concerning the extent to which species-specific differences in physiology ultimately influence fractionation processes and the derived fractionation equation. Accordingly, the objectives of this study are 1) to develop a genus-specific $\delta^{18}O$-fractionation equation, and 2) to apply $\delta^{18}O$ methods to the investigation of YOY Arctic charr thermal habitat utilization patterns across a latitudinal gradient from Ellesmere Island to insular Newfoundland.

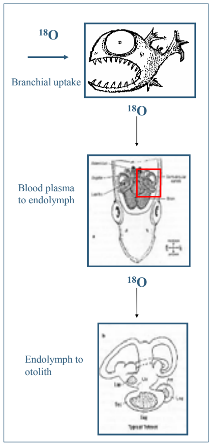
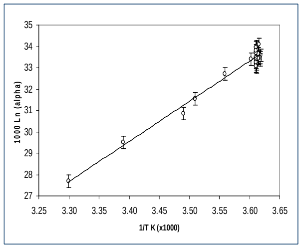


Figure 1. The path of ^{18}O isotopes from the surrounding water to the otolith (left). Water ^{18}O enters via branchial uptake where it exchanges with blood plasma. From the blood plasma, ^{18}O exchanges with endolymphic fluid of the sacculus (in red box). The endolymphic fluid precipitates aragonite forming the otolith incorporating ^{18}O and other trace elements into its crystal structure according to their concentration in the endolymphic fluid.

Figure 2. Mean fractionation factors (1000Lnα) ± standard error values for numerous museum specimens from a broad range of thermal habitats. $1000\ln\alpha = 18.56 \cdot 1000T^{-1}K - 33.49$ $r=0.99$ *Patterson et al. (1993)* (below)



Methods

Sample Collection

YOY Arctic charr and brook charr were collected for years ranging from 1975-2005 between May and October from locations plotted on the map (left).

Isotope Methods

Step 1 ⟶ Ground otoliths roasted at 350°C for 1 hour under helium

Step 2 ⟶ Otoliths treated with 100% H_3PO_4 under helium

Step 3 ⟶ Acidified samples heated at 40°C for 2-3 hours and analyzed in a Micromass IsoPrime (IRMS) isotope mass spectrometer (accuracy ± 0.2‰)

Genus specific $\delta^{18}O$-fractionation equation estimation methods

$\delta^{18}O$ Otolith + $\delta^{18}O$ Water ⟶ 1000Lnα ⟶ Fractionation Equation ⟶ Temperature°C

Planned Zoogeographic Analysis

- To study variation in temperatures used by YOY Arctic charr, samples will be collected across the latitudinal range and the inferred water temperatures estimated by the genus-specific fractionation equation will be correlated with local air temperature measures to determine differences.

Preliminary Results

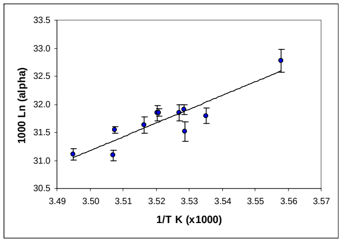


Figure 3. Mean fractionation factors (1000Lnα) ± standard error values for Arctic charr and brook charr sampled to date from field collection sites. Horizontal axis gives mean monitored water temperature in degrees Kelvin. Vertical axis gives mean fractionation factors. A regression line through the data yields the equation:

$1000\ln\alpha = 24.56 \cdot 1000T^{-1}K - 54.77$ $r=0.90$

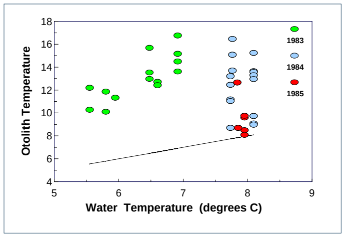


Figure 4. Predicted $\delta^{18}O$-otolith temperatures plotted against mean measured water temperature for YOY Arctic charr from Ikarut River, Labrador for the years of 1983-1985. Individual temperatures are plotted as round circles. The one-to-one line is plotted as a solid black line. *Power et al. (2004)*

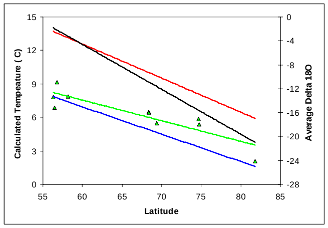


Figure 5. Average otolith-$\delta^{18}O$ signatures of Arctic charr (green triangles, green regression line) and residency waters (blue line) plotted against latitude for sites sampled to date and calculated $\delta^{18}O$-temperatures using the fraction equations estimated in this study (red line) and Patterson *et al.* (1993) (black line).

$\delta^{18}O$ latitude Regressions:

$\delta^{18}O$ Otolith = -0.35•Latitude + 6.84 $r^2=0.79$
$\delta^{18}O$ water = -0.46•Latitude + 12.36 $r^2=0.90$

Fractionation Equations:

This study T°C = -0.31•Latitude + 30.90 $r^2=0.64$
Patterson T°C = -0.40•Latitude + 36.66 $r^2=0.64$

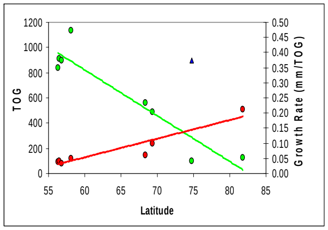


Figure 6. Thermal opportunity for growth (TOG) (green circles) as defined by the cumulative degree-day > 0°C plotted against latitude for sites sampled to date and growth rate (mm/TOG) (red circles). The blue triangle indicates an anthropogenically disturbed site not included in the regression analysis. A regression line through each dataset yields the following equations:

TOG= -36.32• Latitude +3000.9 $r^2=0.87$

GR= 0.0062• Latitude – 0.32 $r^2=0.88$

Key Findings

- No significant differences were found between the slopes of the otolith or water average $\delta^{18}O$-latitude regression lines ($t = 0.52$, $P>0.05$)
- No significant differences were found between the slopes of the fractionation equations for Patterson *et al.* (1993) or the current study ($t = -0.99$, $P>0.05$) or Thorrold *et al.* (1997) and the current study ($t = -1.09$, $P>0.05$)

Discussion

The preliminary *Salvelinus*-specific fractionation equation (Figure 3) does not differ significantly from equations estimated for mixed assemblages of freshwater (Patterson *et al.* 1993) (t-test $P>0.05$) or marine (Thorrold *et al.* 1997) fish (t-test $P>0.05$). Average $\delta^{18}O$ otolith values differ predictably from $\delta^{18}O$ water values along the considered latitudinal gradient and, therefore, may be used to characterize YOY thermal habitat use.

For example, detailed comparisons of $\delta^{18}O$ otolith derived and monitored water temperatures from the Ikarut River (Power *et al.* 2004) suggest behavioral thermoregulation in Arctic charr (Figure 4), with YOY seeking the warmest available waters. Along the latitudinal gradient, calculated temperatures decline as a result of climatic limitations (e.g. declining TOG) (Figure 5). However, growth rate (mm/TOG) increases along the latitudinal gradient, suggesting adaptation for quicker growth rates at higher latitudes (Figure 6). This result tentatively confirms the counter gradient variation hypothesis as stated by Conover & Present (1990), but contrasts for similar studies in European brown trout (e.g. Jensen *et al.* 2000) and suggests responses to climate change will be evidenced in northern fishes by increased growth rates.

Future Directions

- Use of final genus-specific $\delta^{18}O$-fractionation to the study of young-of-the-year Arctic charr along a latitudinal gradient in eastern North America to determine differences in thermal habitat use and correlations between thermal habitat use, air temperature, and growth.
- Expand method to the study of inter-annual variation in thermal habitat use as it is connected to growth among adult otoliths.

References

ACIA (Arctic Climate Impact Assessment) 2004. ACIA, Impacts of a warming climate: Arctic Climate Impact Assessment. Cambridge: Cambridge University Press.
Campana, SE. & Neilson JD. 1985 *Can. J. Fish. Aquat. Sci.* **42**, 1014-1030.
Campana, S.E. 1999 *Marine Ecology Press Series* **188**, 263-297.
Conover, D.O. & Present, M.C. 1990 *Oecologia* **83**, 316-324.
Devereaux, I. 1967 *Science* **155**, 1684-1685.
Johnson, L. 1980. The arctic charr, *Salvelinus alpinus*. In: Balon, E.K. (Editor), Volume 1: Perspectives in Vertebrate Science. Kluwer Boston, Inc., Hingham, MA, pp. 15-32.
Jensen, A.J., Forseth, T., & Johnsen, B.O. *J. Anim. Ecol.* **69**, 1010-1020.
Patterson, W.P., Smith, G. R. & Lohmann, K. C. 1993 In *Continental Climate Change from Isotopic Indicators*. (Swart, P. A. Lohmann, K. C.,McKenzie, J. & Savin, S., eds.) *American Geophysical Union Monograph* **78**, 191-202.
Power, M., Storm-Suke, A., and Dempson, B. 2004 Proceedings of the 10th and 11th ISACF workshops on Arctic char, 2002 and 2004. Institute of Freshwater Research, Drottingholm, Sweden.
Thorrold, S.R., Campana, S.E., Jones, C.M., & Swart, P.K. *Geochim Cosmochim Ac* **61**, 2909-2119