Relationships of Age and Growth of Lake Superior Deepwater Sculpin *(Myoxocephalus thompsonii)* among Shallow and Deep Habitats

by Will Otte

Abstract:

In 2017, I collected Deepwater Sculpin at 40 sites throughout Lake Superior. Total length was recorded for all fish, and otoliths were collected from a subsample. I fit the Francis parameterization of the von Bertalanffy growth function to Deepwater Sculpin captured from sites <150 meters and >200 meters. Growth of Deepwater Sculpin at all ages differed among the two depth classes. The maximum estimated age was 17, which is older than what was previously reported for Deepwater Sculpin from Lake Superior, but not other Lakes. The growth of Deepwater Sculpin differed among the two depth classes at all lengths.

Introduction:

The Deepwater Sculpin, *Myoxocephalus thompsonii* (Girard 1851), is a benthic fish distributed sporadically in oligotrophic lakes in areas formerly occupied by glacial lakes or the Champlain Sea (Scott and Crossman 1973). The range of Deepwater Sculpin is almost entirely confined to Canadian lakes and the Laurentian Great Lakes (Sheldon et al. 2008). In Lake Superior, Deepwater Sculpin are found at depths from 15 to 407 meters and are the most abundant benthic fish (Selgeby 1988, Gorman et al. 2012). They are a major prey of Siscowet Lake Trout (*Salvelinius namaycush siscowet*) and Burbot (*Lota lota*), comprising up to 80% of the diets of these fishes (Ray et al. 2007; Sitar et al. 2008; Gamble et al. 2011a). Deepwater Sculpin are considered a signal of a healthy benthic community due to their sensitivity to contamination, eutrophication, and other habitat alterations (McPhail & Lindsey 1970; Parker 1988).

We are aware of only four studies that examined age and growth of Deepwater Sculpin. Maximum estimated ages from whole otoliths were 5 from Burchell Lake, Ontario in 1980 (Black and Lankester 1981), 9 from Lake Michigan in 1981-1986 (Bruch 1986), and 7 from the Apostle Islands region of Lake Superior in 1972-1974 (Selgeby 1988). Sheldon (2006) determined that whole otoliths were inadequate for consistently estimating the age of Deepwater Sculpin because annular rings were faint. Sheldon (2006) suggested that sectioned otoliths were more accurate and consistent and, from sectioned otoliths, reported a maximum age of 24 (one fish) for Deepwater Sculpin from 20 lakes across their range in Canada in 2004, excluding the Laurentian Great Lakes. In all previous studies, growth rates of Deepwater Sculpin were greatest to age-1 and then declined with age (Blank and Lankester 1981; Bruch 1986; Selgeby 1988; Sheldon 2006). Males showed no significant differences in mean lengths-at-age compared to females (Bruch 1986).

Lake Superior is a large, complex system. Many investigations of this system have either examined the lake as a whole or investigated specific locations or regions. Comparisons of habitats at a finer scale between regions of Lake Superior would aid in our understanding the complexities of this system to better inform its management.

The objective of this study was to more extensively survey the size and age structure of Deepwater Sculpin in Lake Superior. I specifically address the questions of how size, age, and growth differ between fish collected from relatively shallow (< 150 m) and deep (> 200 m) waters of Lake Superior. I also assess if mean lengths-at-age differed between my contemporary collections of Deepwater Sculpin in Lake Superior and the summaries provided by Black and Lankester (1981), Bruch (1986), Selgeby (1988), and Sheldon (2006).

Methods:

Deepwater Sculpin were collected from trawl tows at 40 sites from throughout Lake Superior during May-July 2017 (Figure 1). Collections were made with the U.S. Geological Survey's R/V Kiyi using Yankee bottom trawls with either a chain or rubber disk footrope towed at approximately 3.5 km/h. Trawl nets had an 11.9 m headrope and a 15.5 m footrope, and a 2.2 m wing height, with stretch meshes of 89 mm at the mouth, 64 mm for the trammel, and 13 mm at the cod end.

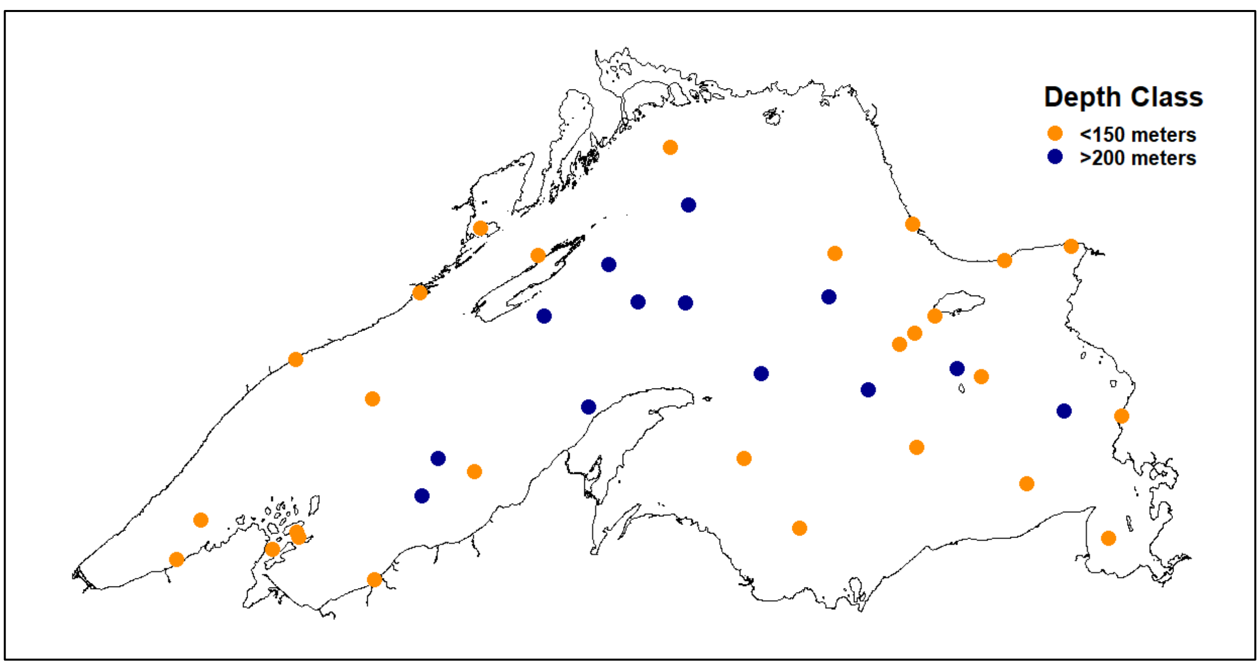

Figure 1. Locations in Lake Superior where Deepwater Sculpin were collected in 2017 for the ageing portion of the study. Of the 40 locations sampled, 27 were <150m and 13 were >200.

For each collection location, all Deepwater Sculpin were counted and as many as 50 fish were measured for total length (TL; nearest mm). The total lengths for all fish collected at each location were then estimated by assigning a TL to the unmeasured fish based on the proportions of measured fish of each TL. A maximum of 30 fish from each location were frozen and returned to the laboratory for further processing.

In the laboratory, frozen fish were thawed at room temperature. The average time frozen was 9 months. A representative sample of fish for estimating age was obtained by selecting as many as three individuals per 10-mm length bins for fish between 50 and 120 mm for each location. Fish smaller than 50 mm and larger than 120 mm were rare at many locations and were thus oversampled at some locations where they were more prevalent to ensure an adequate overall (i.e., lake-wide) sample size was obtained. Each selected fish was then measured for TL (nearest 1 mm) and the sagittal otoliths were removed using the "up through the gills method" described by Secor et al. (1992).

Otolith preparation followed the commonly used (Quist et al. 2012) "embed and polish" method described by Secor et al. (1992). Otoliths were embedded in clear epoxy (Buehler EpoKwick, 5:1 ratio of resin to hardener) before using a Beuhler IsoMet low-speed saw to cut a 0.3-millimeter section along the transverse plane through the nucleus. Otolith thin sections were then polished with 1,000-grit sandpaper before viewing them in clove oil on a dark background with reflected light under a Nikon SMZ 745T microscope at 50x magnification. A digital image of the otolith section was captured using a Nikon DS-U3 camera attached to the microscope (Figure 2). Multiple images were taken for some images when a single image was not clear or focused in all areas of the image.

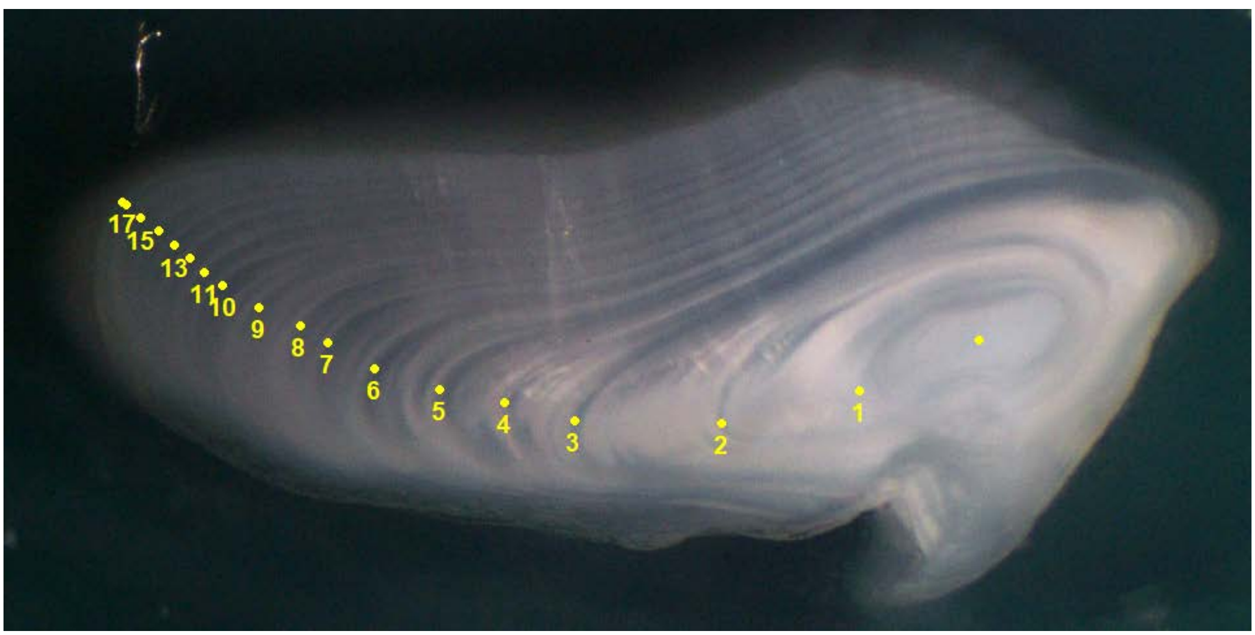

Figure 2. Sectioned otolith from a 122mm Deepwater Sculpin captured at a depth of 64m from a nearshore site in the Eastern Michigan region on June 6, 2017. This individual was estimated to be 17 years old.

Age was determined for each fish from the digital images without any biological or sampling information about the individual. Annuli were identified by Annuli were identified as the distal edge of dark bands that were seen in most fields of the otolith and were generally associated with discontinuities at the otolith margin (Figure 2). Annuli were recorded on the image using the RFishBC package v0.1.1 (Ogle 2018) in the R statistical environment v3.5.1 (R Development Core Team 2018) (Figure 2). I conducted two readings for each fish approximately 2 days apart.

Bias in otolith ages among readings was assessed visually with age-difference plots from the FSA package v0.8.20 (Ogle 2015) in the R statistical environment. If no significant bias was present, the precision of age estimates was summarized as the percentage of fish for which the estimated ages differed by zero to three or more years and the average coefficient of variation (ACV; Chang 1982; Kimura and Lyons 1991) as computed with agePrecision() from the FSA package.

A consensus reading was conducted for all individuals with estimated ages that disagreed between both initial readings. Assigning consensus ages was aided by viewing records of both interpretations overlaid on the structure image.

Estimated ages could not be validated because known-age Deepwater Sculpin were not available. However, to potentially corroborate the age estimates of fish collected in 2017, I examined TL data for Deepwater Sculpins collected from 2011 to 2017 to determine if distinct age-classes were evident in the length frequency histograms. These data were from Deepwater Sculpins collected with the R/V Kiyi at 57 sites during the summers of 2011-2017 (Figure 3).

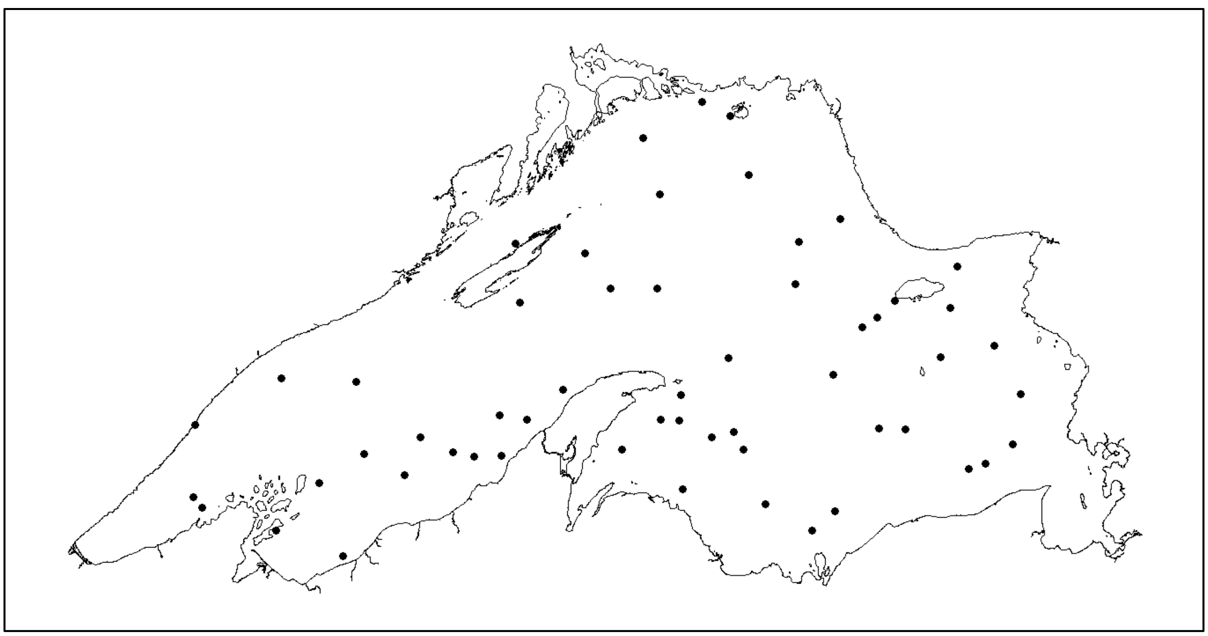

Figure 3. Locations in Lake Superior where Deepwater Sculpin were collected in 2011-2017 for the supplemental length frequency analysis

Once consensus ages were determined, they were used to construct age length keys for each depth category. These age-length keys were then applied to all Deepwater Sculpin captured in 2017 from their respective depth categories.

I used the Francis (1988) parameterizations of the von Bertalanffy growth function to model growth of Deepwater Sculpin. The Francis parameterization was used to correct for data dependent issues with the meanings of L_∞ and K in the traditional parameterization of the von Bertalanffy growth function (Ogle et al. 2017). The Francis parameterization is defined as

$$E[L|t] = L_1 + (L_3 - L_1)\frac{1 - r^{2\frac{t - t_1}{t_3 - t_1}}}{1 - r^2} \quad \text{where } r = \frac{L_3 - L_2}{L_2 - L_1}$$

where L_1, L_2, and L_3 are the mean lengths at ages t_1, t_2, and t_3, respectively. The values of t_1 and t_3 are chosen reference ages and t_2 is half-way between each. Due to limited numbers of older fish from shallow habitats (<150m) I selected ages 1 and 11 to represent t_1 and t_3, respectively, which results in t_2 being equivalent to age 6. Thus, my parameters for the eight Francis VGBFs are the mean total lengths of Lake Superior Deepwater Sculpin at ages 1, 6, and 11.

To statistically assess differences in growth among the two depth categories, I followed the "Nested Family of Models" method described by Ogle (2016). Specifically, I fit and compared eight versions of Francis parameterizations of the von Bertalanffy growth function to all Deepwater Sculpin captured in 2017 that were assigned ages from the age-length keys. The function vbStarts() from the FSA package was used to identify starting values for the Francis VGBFs. The nested relationships among these models were compared with an extra sum-of-squares test to identify differences among the L_1, L_2, and L_3 parameters (Ogle 2016). In all analyses I used $\alpha = 0.05$ to determine significance.

Results:

Deepwater Sculpin ages were estimated from otoliths for 174 individuals. Although visually, the age-difference plot suggests that my estimates may have been biased, particularly at older ages, the Bowker Test for Symmetry found no systematic bias (p-value = 0.7071). The within-reader ACV was 2.403 with perfect agreement for 85.6% and agreement within 1 y for 94.8% of individuals. Estimated ages differed among readings by no more than 2 years.

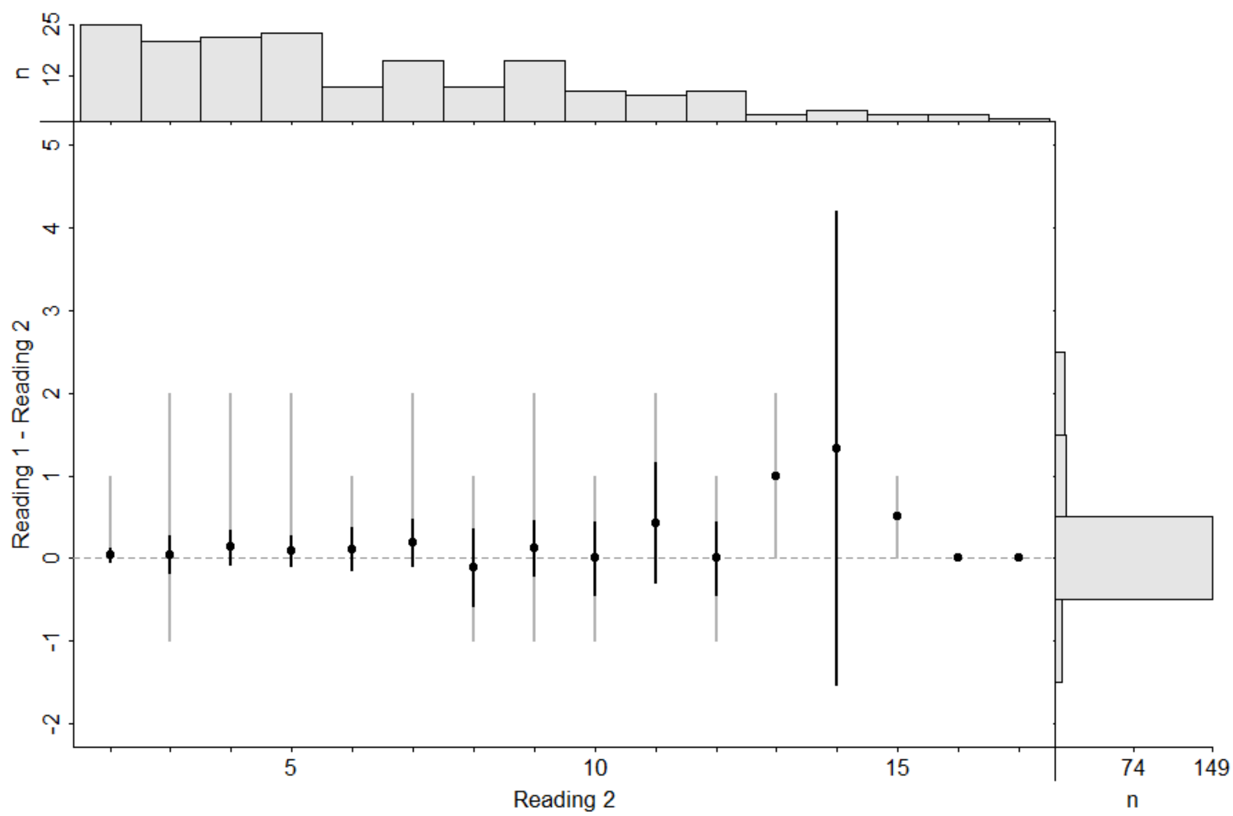

Figure 4. Age-difference plot with age distribution (top) and agreement distribution (right) for comparing the estimated ages among 2 readings. Dots represent the mean difference between reading 1 – reading 2. Grey bars indicate the range. Black bars indicate the 95% confidence interval.

The length-frequency distribution for Deepwater Sculpin captured between 2011 and 2017 contained some small peaks at lengths of 20 to 30 mm in some years (Figure 4). The strength of these peaks was not enough to indicate the sizes of any year classes for comparison to otolith age estimates (Figure 4). Thus, I was unable to corroborate age estimates made from otoliths.

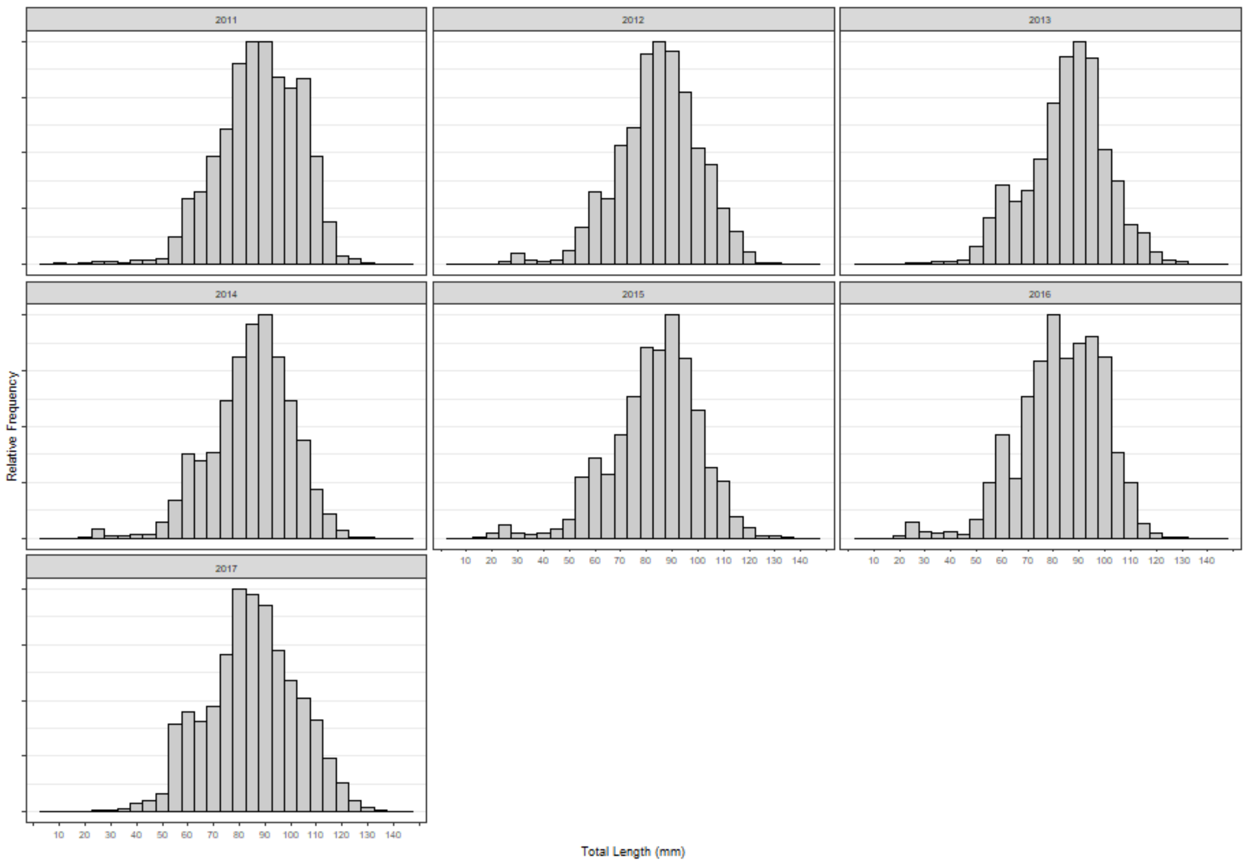

Figure 5. Relative length-frequency distributions for each years catch of Deepwater Sculpin from 2011 to 2017.

More large fish were captured at sites greater than 200 meters deep while more small fish were captured at sites less than 150 meters deep (Figure 6). The Kolmogorov Smirnov test (p-value < 2.2e-16) indicated a significant difference in the length distribution of Deepwater Sculpin among depth classes.

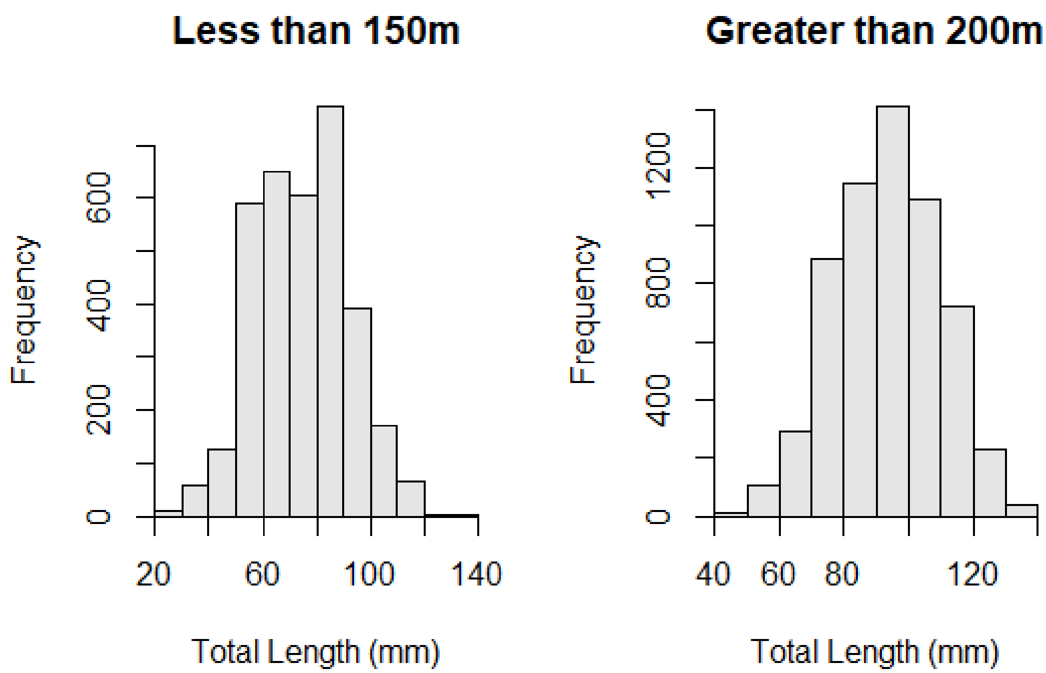

Figure 6. Length-frequency Distribution of Deepwater Sculpin captured from 2011-2017.

The maximum estimated age of Deepwater Sculpin was 17 years. The minimum estimated age was 2 (Figure 5). The Francis VGBF where all parameters differ by depth (Model A) provided a better fit relative to all of the Francis VBGFs where two parameters differ between depth categories (Models 1, 2, and 3; all p-value< 2.2e-16; These results suggest that the growth of Lake Superior Deepwater Sculpin differs between depth for all ages (Figure 7).

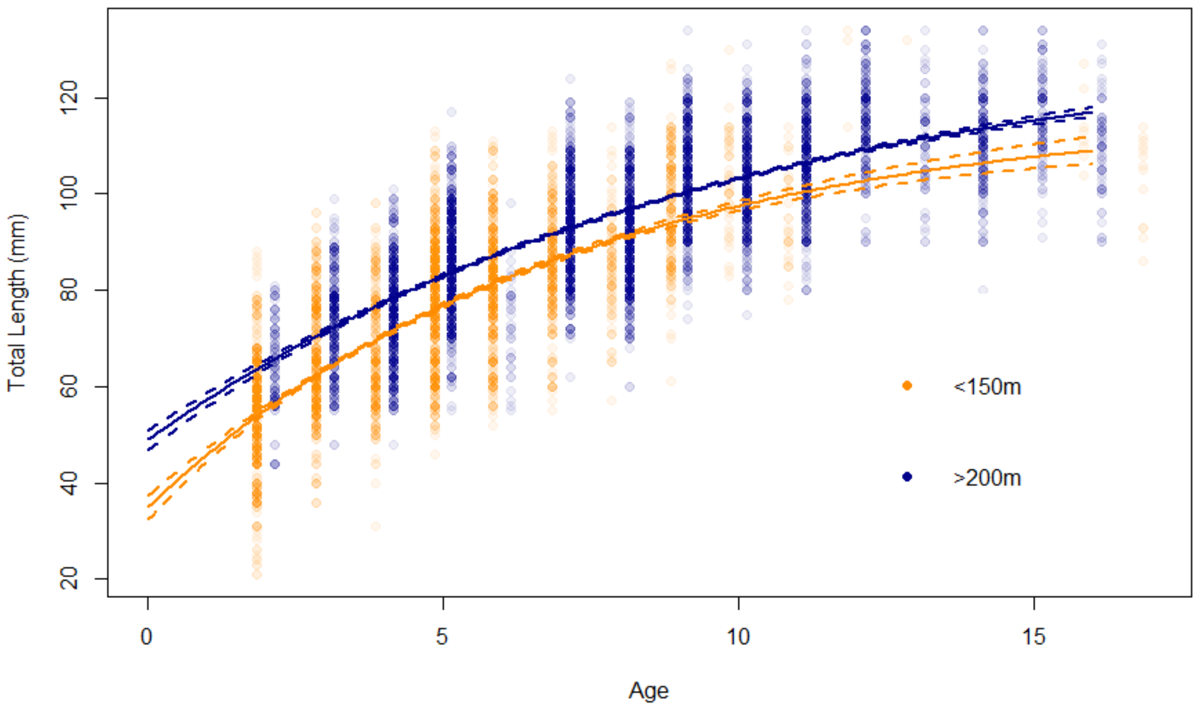

Figure 7. — The fit (solid lines) and 95% confidence bands (dashed lines) from Francis Parametrizations of the Von Bertalanffy growth function of total length and estimated otolith age for Lake Superior Deepwater Sculpin from habitats <150m (orange) and >200m (Blue). Circles represent length at age assigned from age-length keys.

I observed an older maximum age for Lake Superior Deepwater Sculpin in 2017 than Selgeby (1988). My mean lengths-at-age were higher than what Black and Lankester (1980), Bruch (1986), and Selgeby (1988) reported. Sheldon (2006) did not report mean lengths-at-age.

Table 1. Estimated mean total length-at-age (mm) from the Francis Parameterization of the Von Bertalanffy Growth function for Deepwater Sculpin from this study at sites <150 and >200m, versus mean estimated total length-at-age for sculpins from Bruch (1986) captured in 1981 and 1984, Black & Lankester (1981) captured in 1980, Selgeby captured in 1971-74.

Age	This Study (<150m)	This Study (>200m)	Bruch (1984)	Bruch (1981)	Black & Lankester	Selgeby
1+	46	57	25	25	41	41
2+	55	64	58	62	65	58
3+	64	71	78	83	81	74
4+	71	78	92	101	83	93
5+	77	83	105	113	92	108
6+	82	88	114	122	NA	125
7+	87	92	126	129	NA	140
8+	91	96	137	140	NA	NA
9+	94	100	141	147	NA	NA
10+	97	103	NA	NA	NA	NA
11+	100	106	NA	NA	NA	NA
12+	102	109	NA	NA	NA	NA
13+	104	111	NA	NA	NA	NA
14+	106	113	NA	NA	NA	NA
15+	108	115	NA	NA	NA	NA
16+	109	117	NA	NA	NA	NA
17+	110	119	NA	NA	NA	NA

Discussion:

I found it difficult to age Deepwater Sculpins as annuli were only present in one lateral direction from the nucleus and often not distinct. On some sections, the first annulus was sometimes difficult to place while on others, the annuli near the margins were very faint and difficult to read.

Many age classes were present in multiple length classes which lead to significant amounts of variability among my estimated ages of Deepwater Sculpin. Results from comparisons of the nested Francis models in this study already suggest that there are differences in the growth of Deepwater Sculpin among different depths. There may also be spatial factors (e.g., regions) that influence Deepwater Sculpin growth that were overlooked by the two broad depth classes I selected.

My estimates of average length at age-1 for Lake Superior Deepwater Sculpin from habitats shallower than 150m were similar to estimates from Selgeby (1988) and Black and Lankester (1981) but nearly twice as large as estimates made by Bruch (1986) for both years of collection (Table 1). My estimated mean lengths for age-1 Deepwater Sculpin from habitats deeper than 200m exceeded estimates from Selgeby (1988) and Black and Lankester (1981) by 15mm and were more than twice the estimates from Bruch (1986) (Table 1). Estimates of mean length at age-2 were much more consistent among previous studies than estimates of mean length at age-1 (Table 1). My estimates of mean length for age-2 fish were also consistent with estimates from previous research (Table 1).

For ages greater than two, my estimates of mean length deviated from the general trend of the previous studies. My estimates suggested much lower annular increments of mean length for Lake Superior Deepwater Sculpin than sculpins from the other studies (Table 1). At their oldest ages the Francis VBGF predicted that Lake Superior Deepwater Sculpins only gain one or two millimeters of total length per year. These findings are likely the result of my use of otolith sections instead of whole otoliths. Unfortunately, Sheldon (2006) did not estimate mean age-at-length; thus, our results could not be compared to theirs.

My interpretations of otolith sections indicated that Lake Superior Deepwater Sculpin are more long-lived than previously thought. My maximum estimated age of 17 is more than twice the previous maximum estimated age of 7 (Selgeby 1998). This assertion assumes that the light – dark banding pattern indicative of slow and fast periods of growth is a response to annual stimuli. Lake Superior Deepwater Sculpin live at extreme depths where standard temporal cues, such as photic period and water temperature, remain relatively constant over the year (Riseng et al 2017). One driver of Deepwater Sculpin growth that may be subject to temporal fluctuations is the abundance of *Mysis,* their main prey item.

While the assumption of an annular growth pattern may undermine the assertion of the maximum age of Deepwater Sculpin, it does not discredit differences in their growth rates among different depths. The alternating hyaline banding appeared to be repeating at a relatively stable temporal rate, as the widths of annular rings declined in a typical fashion as the number of growth cycles increased. While the number of annuli may not accurately represent the age of an individual Deepwater Sculpin in years, they are indicative the number of these slow-fast growth cycles the individual has experienced.

Although they lack commercial and recreational value, Deepwater Sculpin are a trophic link between *Mysis relicta* and Lake Trout, the top predator in Lake Superior, a fish of great recreational and commercial importance. For the management of these species, understanding the relationship between age, length, and growth for Deepwater Sculpin is of great importance. However, I had difficulty estimating the ages of Deepwater Sculpin and the contrast between my results and the results of previous studies support the need for further investigation, perhaps through the development of known age collections or observations of lab reared individuals, to fully understand the relationship between age and growth for this species.

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