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Differences in pyloric caeca counts between lean and siscowet lake trout (*Salvelinus namaycush*) in southern Lake Superior

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ABSTRACT

There are four documented morphotypes of lake trout (*Salvelinus namaycush*) in Lake Superior, with the two dominant forms being the shallow water lean and the deep water siscowet. These morphotypes are differentiated externally by morphometrics and meristics. Pyloric caeca counts have been used to distinguish closely related fish species including the *Salvelinus* genus. From samples collected in 2009, 2011–2013, and 2017, we counted and measured pyloric caeca from 116 lean and 119 siscowet lake trout from southern Lake Superior. For a subset of 22 leans and 19 siscowets between 575 and 625 mm, we measured individual pyloric caecum basal diameter, length, and estimated individual caecum and total caeca surface areas. Siscowets had significantly fewer and thicker pyloric caeca than leans, but caecum length did not differ between the morphotypes. Mean pyloric caeca count for siscowets and leans was 131 and 153, respectively. Mean individual caecum surface area was 31% higher in siscowets than in leans. When adjusted for mean total number of pyloric caeca, total caecum surface area for siscowets was 12% greater than leans. We postulate that greater pyloric caecum surface area in siscowets may be an adaption for greater lipid uptake because they have substantially higher lipid content than leans. Based on our findings, pyloric caeca counts can be used in addition to other meristic and morphometric characteristics to help distinguish lean and siscowet lake trout.

Introduction

Lake trout (*Salvelinus namaycush*) are the keystone piscivore in Lake Superior (Smith, 1972) and are a major focus of fisheries management in the Great Lakes (Hansen, 1999). Resource polymorphism (Skulason and Smith, 1995) is hypothesized to be a basis for divergence of four extant lake trout morphotypes in Lake Superior (Muir et al., 2014). The most familiar form of lake trout is the lean that typically inhabits shallow depths < 80 m. The most abundant form is the siscowet lake trout, which mostly is found at depths > 80 m (Muir et al., 2014). Humper and redfin lake trout are less common forms and are found at offshore sea mounts and near islands (Hansen et al., 2016; Muir et al., 2014). Lake trout forms differ externally by morphological measures of the head, maxillary, paired fins, and caudal peduncle (Moore and Bronte, 2001; Muir et al., 2014). Identifying morphotypes is challenging because they are closely related and the degree of differentiation is subtle. However, each morphotype can generally be differentiated by a suite of characters (Muir et al., 2014).

Pyloric caeca morphology and counts have been used to distinguish closely related fish species (Applegate, 1966) and subspecies, including members of the *Salvelinus* genus (Knudsen et al., 2008; Scott and Crossman, 1973). Although pyloric caeca morphology may be influenced by environmental conditions, there are indications that the number of pyloric caeca in fish may be a heritable trait (Bergot et al., 1981; Blanc and Poisson, 2006). Martin and Olver (1980) summarized reports of lake trout pyloric caeca counts that ranged from 81 to 210. More recently for Lake Superior, Burnham-Curtis (1993) reported mean numbers of pyloric caeca in leans to be 151 (95% CI: 145–157; n = 35; total length range: 115–691 mm), and for siscowets to be 144 (95% CI: 141–148; n = 85; total length range: 100–780 mm).

The objectives of this study were to assess whether pyloric caeca size, count and surface area differed between lean and siscowet lake trout in southern Lake Superior. Specifically, we measured pyloric caeca counts between lean and siscowet lake trout and tested whether counts varied by total length and sex.

Methods

During lake trout gill net surveys (Sitar, 2017), we collected whole digestive tracts (with all pyloric caeca) from lean and siscowet lake trout of various lengths from Michigan waters of southern Lake Superior (Fig. 1) in 2009, 2011–2013, and 2017 to measure pyloric caeca count (PCC) and size. Identification of lean and siscowet lake trout were based on key morphological characters including head shape, eye size

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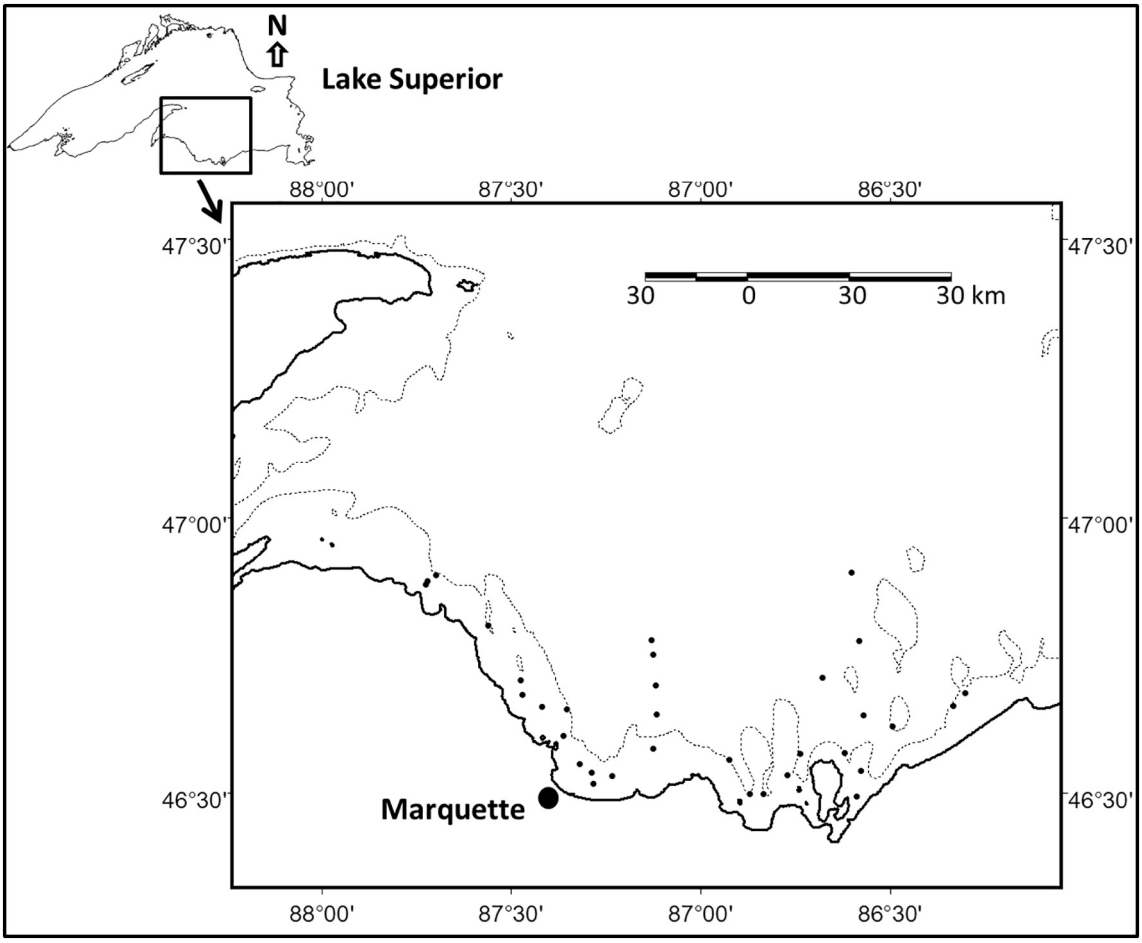

Fig. 1. Collection sites for pyloric caeca measurements of lean and siscowet lake trout in southern Lake Superior during in 2009, 2011–13, and 2017. The dashed line is the 80 m depth contour.

and position, snout length, head length, and maxilla length (Moore and Bronte, 2001; Muir et al., 2014). Any fish with uncertain characters were excluded. Standard biological measurements including total length were recorded for each fish. Excised digestive tracts were immediately placed on ice and then frozen (−20 °C) at the end of the sampling day. Subsequently, digestive tracts were thawed and dissected for diet analysis in the laboratory. Midgut sections with all pyloric caeca were then excised and preserved in 10% formalin for pyloric caeca enumeration at a later time. We conducted total PCC for each fish by excising individual caeca from each midgut section, placed them in piles of 10, then counted the piles, and multiplied the number of piles by 10.

Based on preliminary research indicating a potential relationship between PCC and fish length, we first tested our dataset using linear and $\log_e$-linear models for lean and siscowet lake trout (lm function, R version 3.2.4, R Core Team, 2016). A significant length term would be treated as a covariate in generalized linear models (ANCOVA or ANOVA) to assess differences in PCC between leans and siscowets with morphotype and sex as independent factors.

In order to assess differences in pyloric caeca size and surface area between morphotypes, we measured pyloric caeca from an additional 22 leans and 19 siscowets with total lengths (TL) between 575 and 625 mm that were collected in 2017. We restricted fish to this length

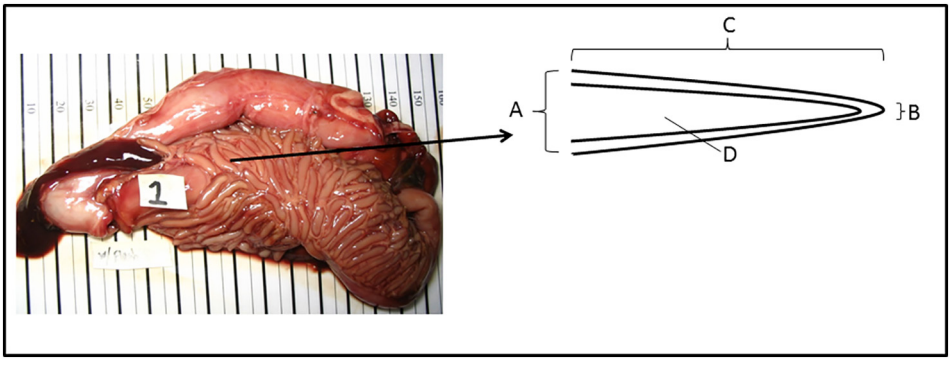

Fig. 2. Digestive tract of Lake Superior lake trout with pyloric caeca (left) and diagram of individual pyloric caecum longitudinal-section (right). A = basal diameter, B = distal diameter, C = length, and D = internal chamber of caecum.