JONES, CHRISTOPHER MICHAEL, M. S. Piscivore Effect On Size Distribution and Planktivorous Behavior of Slimy Sculpin in Arctic Alaskan Lakes. (2010) Directed by Dr. Anne E. Hershey. pp. 41.

Slimy sculpin (*Cottus cognatus*) are known as a bottom-dwelling fish that feed primarily on benthic invertebrates. However, in arctic lakes, sculpin may also be somewhat planktivorous. Previous studies have shown that the habitat distribution of sculpin is modified by lake trout (*Salvelinus namaycush*), a piscivore. Here, I hypothesized that lake trout and another piscivore, arctic char (*Salvelinus alpinus*), alter sculpin behavior to restrict planktivory and reduce growth. Sculpin were sampled from three different lake types: lakes with lake trout, lakes with arctic char and lakes with no piscivore. Results showed that sculpin were significantly larger in lakes lacking piscivores, consistent with my hypothesis. Piscivores did not affect prey mass or prey types based on sculpin stomach content analyses. However, in all lakes, zooplankton were a substantial prey item of sculpin. Stable isotope analyses showed enrichment in ^{13}C and depletion in ^{15}N in sculpin from arctic char lakes in comparison to both of the other lake types. These results are indicative that the effects of piscivores on sculpin populations are generally indirect, altering body size but not habitat distribution or prey selection. However, differences in stable isotope ratios suggest a trophic segregation may be present in sculpin in arctic char lakes compared to sculpin only lakes.

PISCIVORE EFFECT ON SIZE DISTRIBUTION AND PLANKTIVOROUS
BEHAVIOR OF SLIMY SCULPIN IN ARCTIC ALASKAN LAKES

by

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A Thesis Submitted to
The Faculty of the Graduate School at
The University of North Carolina at Greensboro
In Partial Fulfillment
of the Requirements for the Degree
Master of Science

Greensboro
2010

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APPROVAL PAGE

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ACKNOWLEDGEMENTS

First, I would like to thank Dr. Anne Hershey. She stepped in to guide my thesis at a pivotal time and without her I would be completely lost. Her constant support through a tough time for not only me, but herself as well has been the cornerstone in completing this research. I would like to thank Dr. Parke Rublee and Dr. Matina Kalcounis-Ruppell for their guidance throughout the writing of my thesis. I would like to thank Dr. Steve Whalen for all his help at the Toolik Lake Field Station, as well as his willingness to step onto my committee on short notice. Dr. Chris Luecke was instrumental in my fieldwork in Alaska and without him this project would not have gotten off the ground. Thank you to Dr. Sat Gupta for guiding me through the extensive statistical analyses needed for this research.

I would also like to thank Robert Northington, Robert Isdell, Matt Bostick, Danielle Hayes, Lindsey Pollard, Tracy Gentzel and Rachel Cuellar for all of the assistance through the long days at Toolik. Without Danielle Rosson, my lab work back at UNCG would not have been possible. She was instrumental in finishing this research. Candace Berkeley has been there for me through the highs and lows of my time at UNCG, she deserves a special thank you. I also want to thank all the crew and staff of Toolik Lake Field Station; they kept us happily fed and were always quick to find a solution to any problem.

There is no doubt that, without the constant support and love from my parents, I would not be where I am today. They have done more than words can express and I owe all my success, not only in academics, but in life, to them.

Lastly, I want to not only thank, but also remember Dr. W. John O'Brien. Dr. O'Brien saw potential and took a chance on me. His guidance, knowledge, humor and wealth of stories have proved invaluable. I will keep these lessons with me for the rest of my life. I hope that this project makes him proud.

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CHAPTER I

INTRODUCTION

Interactions between predators and prey have been well defined (Brooks and

Dodson 1965, O'Brien 1979, Northcote 1988, O'Brien et al. 1990; 2004, Molles 2002,

Broom and Ruxton 2005, Miller et al. 2006). For example, a study by Lamberti and Resh

(1983) observed that caddisflies (*Helicopsyche borealis*) could significantly reduce the

abundance of algae and bacteria. The predator-prey interaction is also dynamic. The

ratio of predators to prey can fluctuate over various lengths of time (Molles 2002). In

1963, Keith proposed a hypothesis to better understand this pattern. According to Keith,

predators will increase in numbers in response to increasing prey numbers, which will

then result in a reduced prey population. At this point, the predator population will begin

to decrease due to disease, parasitism and starvation. The decrease of predators will

allow the prey community to rebound, therefore completing the cycle (Molles 2002).

Such interactions are common across different habitats and species.

Many fishes are simultaneously predator and prey (Moyle and Cech 2004).

Consequently, fishes have evolved mechanisms for both hunting and predator evasion.

Predators often control the populations of prey fish (Moyle and Cech 2004). For

example, Möller (1984) observed the regulation of herring (*Clupea harengus*) in a fjord

off the Baltic Sea, by jellyfish (*Aurelia aurita*). The jellyfish in the fjord were preying

upon the herring larvae, which, consequently, controlled the population of herring. In another example, Christensen (1996) observed that predation by adult Eurasian perch (*Perca fluviatilis*) was the most important factor determining the maximum size of their roach (*Rutilus rutilus*) prey. Fish may occupy several trophic levels and must be efficient at both feeding and predator evasion.

It is also well established that fish predation can structure freshwater zooplankton communities (Brooks and Dodson 1965, O'Brien 1979, Northcote 1988, O'Brien et al. 1990; 2004). O'Brien et al. (2004) observed that the abundance of all but one species of zooplankter (*Diaptomus priblofensis*) was significantly correlated with the presence of at least one of four species of fish which inhabit the Arctic Foothills region of Alaska. Patterns observed by O'Brien et al. (2004) are consistent with those associated with known planktivores. Lakes that contain slimy sculpin (*Cottus cognatus*) demonstrated the most variation in zooplankton presence and density compared with other fishes. Sculpin presence was significantly correlated with the presence or absence of six of nine zooplankton species. O'Brien et al. (2004) considered that juvenile sculpin might be more planktivorous than adults. However, adult sculpin were observed in insect emergence traps that were placed several meters off the bottom of the lakes (Holland 2006). Therefore, adults were also present in the areas inhabited by zooplankton. The presence of sculpin may be affecting the zooplankton communities in these lakes.

The slimy sculpin is a small, bottom-dwelling fish that maintains a cryptic lifestyle (Gray et al. 2004, Yokoyama and Goto 2005, Spencer et al. 2008). Sculpin are known to be a predatory species that mainly prey upon benthic invertebrates (Hershey

1985, Brandt 1986). Previous studies have shown that in addition to the sculpin's diet of benthic invertebrates, microcrustaceans accounted for up to 23% of their diet (Hershey and McDonald 1985, Cuker et al. 1992). Size-selective predation by sculpin on chironomids has not been observed (Hershey 1985).   Sculpin are considered to be a sentinel species. Sculpin are amenable to ecological studies due to their limited mobility and small home ranges (Spencer et al. 2008). The sculpin's habitat in arctic lakes includes both soft-sediment littoral zones (Hershey 1985) and areas with cobble and other cover (McDonald et al. 1982, Cuker et al. 1992, Gray et al. 2004). The multiple species in the genus *Cottus* include species that are amphidromous, lacustrine and fluvial (Yokoyama and Goto 2005); the species discussed in this paper, *Cottus cognatus*, is lacustrine and fluvial.

Lake trout (*Salvelinus namaycush*) are an apex predator in lakes in the Arctic Foothills region of Alaska. As predators mature in size, their diet expands to include larger prey items (Christensen 1996).   Lake trout generally feed on benthic insects and mollusks but as lake trout mature, they have piscivorous habits (Keyse et al. 2007). Merrick et al. (1992) observed that approximately 12% of adult lake trout had sculpin in their stomach contents. Due to a diet of mainly benthic invertebrates, lake trout in the Arctic Foothills region tend to have stunted growth (O'Brien et al. 1997).

It is known that fish can control the size and distribution of their prey (Dodson 1970). Lake trout have been observed controlling the size and distribution of their main prey, the snail *Lymnaea elodes* (Hershey 1990, Merrick et al. 1991). Trap sampling using the catch per unit effort (CPUE) method (e.g., McDonald et al. 1982) for sculpin

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increased 15% in Toolik Lake over the same time period that lake trout size declined (McDonald and Hershey 1992). This increase in CPUE of sculpin suggests that lake trout were potentially controlling the distribution of sculpin.

Arctic char (*Salvelinus alpinus*) also have been recognized as apex predators in Arctic Foothills lakes which lack lake trout (Hershey et al. 1999). Similar to the lake trout, arctic char mainly subsist on mollusks and other benthic invertebrates. Arctic char also include smaller fish as a part of their diet (Power 1978). Like lake trout, arctic char are also a potential predator of sculpin.

Predation by lake trout and arctic char on sculpin has the potential to alter sculpin behavior. The threat of predation has implications for sculpin prey selection, habitat selection and growth. Previous studies in Arctic Foothills lakes found that sculpin were most abundant at the interface of rocky littoral habitats, where there is refuge from trout predation but less food, compared to soft sediment habitats, where there is more food but a greater risk of predation (McDonald et al. 1982, Hanson et al. 1992). This pattern suggests that sculpin are choosing to reduce foraging efficiency in order to avoid predation (Werner and Anhold 1996, Anholt et al. 2000, Skalski & Gilliam 2002).

While stomach content analyses provide a snapshot of the diet composition of sculpin, they can be misleading. Stomach content analyses reflect what a sculpin has eaten within approximately the last twenty-four hours (Hershey and McDonald 1985). In order to look at longer-term diet, stable isotope tracers of carbon and nitrogen can be analyzed. Isotopic fractionation is caused by the many physical and chemical reactions which change the ratio of heavy to light isotopes between food source and consumer

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(Peterson and Fry 1987). Changes in $\delta^{13}C$ (~ 1 ‰) are used as the primary determinant

of an animal's diet. Changes in $\delta^{15}N$ (~ 3.4 ‰) are used to determine trophic links within

a food web. These changes in carbon and nitrogen isotope ratios can be expressed as

follows: $\delta X = [(R_{sample} / R_{standard}) - 1] \times 1000$, where X is ^{13}C or ^{15}N and R is the ratio of

$^{13}C/^{12}C$ or $^{15}N/^{14}N$, respectively (Peterson and Fry 1987). The standard for carbon is

PeeDee limestone and the standard for nitrogen is N_2 from the atmosphere (Peterson and

Fry 1987). Stable isotope analyses are a useful tool in ecology, especially when paired

with stomach content analyses, for studying diet composition because predator stable

isotope ratios reflect long-term assimilation, whereas stomach composition reflects short-

term diet choices.

This research has three main objectives:

    •Objective 1: To determine if the presence of lake trout or arctic char affects the

    average length of sculpin in nearshore (1 m) and offshore (5 m) zones.

        —H_o: There is no difference in sculpin size between lakes that have lake

        trout or arctic char and lakes that do not, regardless of habitat.

        —H_a: Lake trout and arctic char affect sculpin size differently in nearshore

        and offshore habitats.

        Prediction: Sculpin will have smaller mean length in lakes with lake trout

        or arctic char, but the effect will be more pronounced in offshore areas.

    •Objective 2: To determine if the presence of lake trout or arctic char alters the

    relative abundance of sculpin in nearshore and offshore zones.

—H_o: There is no relationship between the relative abundance of sculpin

and the presence of predators, regardless of habitat.

—H_a: Lake trout and arctic char alter the spatial distribution of sculpin

between nearshore and offshore habitats in arctic lakes.

Prediction: The presence of lake trout or arctic char will result in a higher

CPUE of sculpin in nearshore zones compared to offshore zones.

•Objective 3: To determine if the presence of lake trout or arctic char alters the

diet composition of sculpin.

—H_o: The presence of lake trout or arctic char will not alter sculpin diet

composition.

—H_a: Diet composition of sculpin in lakes with no predator will differ

from diet composition of sculpin in lakes with lake trout or arctic char.

Prediction 1: Sculpin will be more planktivorous in the absence of lake

trout or arctic char.

Prediction 2: Sculpin $\delta^{13}C$ and $\delta^{15}N$ signatures will differ among lake

types, consistent with differences in planktivory.

CHAPTER II

METHODS

I collected sculpin from 13 lakes in the Arctic Foothills region of the Brooks
Mountains in the vicinity of the Toolik Lake Field Station (TLFS) (68º38'00"N,
148º36'15"W), 248 km south of Prudhoe Bay, Alaska (Table 1). I categorized lakes by
the presence or absence of lake trout or arctic char, the two main piscivorous predators in
the region. Knowledge of the distribution of burbot (*Lota lota*), the other piscivorous
predator in the region, is limited, but they have been observed co-occurring with lake
trout (Hanson et al. 1992). Due to the limited knowledge of the distribution of burbot, I
did not consider them in my study. I sampled lakes N1, N2, E1 and Toolik between June
and August 2008. Lakes N1 and Toolik support lake trout, and Lakes N2 and E1 do not
(Table 1). I sampled lakes Fog 1, Fog 2, GTH 65, GTH 91, GTH 100, S-6, I-6, I-8 and
N-3 between June and August 2009 (Table 1). Three lakes (GTH 100, I-6, I-8) were
lakes known to have lake trout present (lake trout lakes), three lakes (Fog 1, Fog 2, GTH
65) were known to have arctic char present (arctic char lakes) and three lakes (GTH 91,
S-6 and N-3) were known to not have a piscivorous fish present (sculpin only lakes)
(Table 1).

I collected sculpin at depths of 1m and 5m using collapsible mesh fish traps set on
the bottom of the lake. I baited traps for Lake GTH 65 due to limited time for collecting

samples at that site. I used deli ham as bait because it was easy to distinguish from

natural prey items when analyzing the stomach contents. Traps were set and then

checked at intervals throughout the day. In lakes where lake trout or arctic char were

present, traps were sometimes left out for as long as 24 hours. I removed the sculpin

from the trap as soon as possible to maximize the likelihood that stomach contents were

reflective of regular diet composition, not just food available in the traps. 10 fish were

collected at each depth, for a total of 20 fish per lake. I placed the sculpin in a small

concentration of clove oil for mild sedation to reduce the stress on the fish.

Once sedated, I measured the sculpin from the mouth to the tip of the caudal fin.

I analyzed data for the mean fish lengths, in regards to depth distribution and predator

presence, using a two-way analysis of variance (ANOVA) and a Tukey's post hoc test

using SPSS analysis software.

Once the sculpin was sedated and measured, I filled a 10 mL syringe, fitted with

an 18-gauge gavage needle, with water that had been filtered through a 256 μm mesh net.

I injected the needle through the mouth into the stomach of the sculpin. I flushed the

stomach content into a clean weigh boat and then transferred the material into a labeled

scintillation vial. I added ethanol to the vials to preserve the stomach content.

I removed a small tissue sample from the pectoral fin of the sculpin by scissor

snip. I sent the pectoral fin sample to UC Davis for $\delta^{13}C$ and $\delta^{15}N$ stable isotope analysis.

I placed the sculpin in a recovery bucket after sampling. After the sculpin was actively

swimming, I returned the fish to the lake where it was caught. Using SPSS, I analyzed

these data with a one-way ANOVA and a Tukey's post hoc test.

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I shipped stomach content samples back to the lab at UNC-Greensboro. In the lab, I identified the stomach contents under a dissecting microscope. I counted zooplankton and considered them as one group. I identified chironimid larvae to sub-family, except the genus *Procladius*, which I counted separately. The rest of the prey items I classified as "other," with many of them being mutilated beyond identification. I ran a multivariate analysis of variance (MANOVA) to analyze the stomach content, using the Pillai's Trace statistic since it is the most powerful and robust test in the MANOVA. I vacuum-filtered each sample onto 100-μm mesh Nitex netting. Then, I weighed the samples to obtain a wet-weight of the stomach contents of each fish. I analyzed total wet weight means using a one-way ANOVA and a Tukey's post hoc test.

I measured CPUE in fish caught per trap day; a trap day is defined as one trap set in a lake for one day. I averaged CPUE for each depth in each lake. I analyzed CPUE averages using a one-way ANOVA and a Tukey's post-hoc test using SPSS data analysis software.

I used sculpin length measurements in lakes with and without predators at depths of 1 and 5 meters to evaluate Objective 1. To evaluate Objective 2, I used CPUE of sculpin, measured in trap days. To evaluate Objective 3, I identified stomach contents in the lab, examined the mass of stomach contents and examined stable isotope data obtained from pectoral fin samples.   The results obtained in this study were used to evaluate the importance of planktonic food resources in the presence or absence of a piscivore, and the impact of predators on sculpin size and habitat distribution.

CHAPTER III

RESULTS

Sculpin Length

The overall mean length of sculpin was significantly different between lake types (df = 2; p = 0.001, Figure 1). Sculpin were significantly longer in sculpin only lakes than in lakes with lake trout present (p = 0.004, Figure 1), or in lakes where arctic char also occurred (p = 0.002, Figure 1). Sculpin in sculpin only lakes were an average of 13.9 mm longer than sculpin from lake trout lakes and 17.6 mm longer than sculpin from arctic char lakes. There was no difference in sculpin lengths between depths (df = 1; p = 0.203, Figure 2). There was no significant interaction between lake type and depth (df = 2; p = 0.867, Figure 2).

Relative Abundance

There was no significant difference in CPUE across lake types (df = 2; p = 0.120, Figure 3) or depths (df = 1; p =0 .901, Figure 3). There was no significant interaction of lake type and depth on CPUE of sculpin (df = 2; p = 0.609, Figure 3).

Diet Composition

Sculpin in lakes with arctic char present were an average of 2.7‰ more enriched in ^{13}C than sculpin in sculpin only lakes (p = 0.033, Figure 4). There was no significant difference in δ^{13}C in sculpin from lakes with lake trout present than from lakes with arctic

char present (p = 0.685, Figure 4). Sculpin from sculpin only lakes were not significantly different in $\delta^{13}C$ than sculpin from lakes with lake trout present. There was no significant difference in $\delta^{13}C$ between depths (df = 1; p = 0.217). Lake type and depth did not interact significantly to affect $\delta^{13}C$ (df = 2; p = 0.526).

Sculpin in lakes with arctic char present were 1.97‰ more depleted in ^{15}N than sculpin from lakes with lake trout present (p = 0.005, Figure 5) and 1.31‰ more depleted than sculpin from sculpin only lakes (p = 0.048, Figure 5). There was no effect of depth on $\delta^{15}N$ (df = 1; p =0.086), and no significant interaction of lake type and depth on $\delta^{15}N$ (df = 2; p = 0.833).

There was no significant effect of lake type on the four different prey categories (p = .734, Table 2). There was no significant difference between prey categories between depths (p = 0.248, Table 2). There was no significant interaction of lake type and depth on the different prey categories (p = 0.959, Table 2).

Stomach contents from sculpin caught in offshore zones weighed an average of 16.3 mg more than stomach contents from sculpin caught in nearshore zones (df = 1; p = 0.040, Figure 6). There was no effect of lake type on the weight of sculpin stomach contents (df = 2; p =0.207, Figure 7) and no significant interaction of lake type and depth on the weight of sculpin stomach contents (df = 2; p = 0.401, Figure 7).

CHAPTER IV

DISCUSSION

My data suggest that the presence of an apex predator affects sculpin on multiple

levels, including size, aspects of diet and trophic position. In arctic lakes that support

lake trout or arctic char, these fishes function as top predators and sculpin are secondary

consumers, as are arctic grayling (*Thymallus arcticus*), round whitefish (*Prosopium*

cylindraceum), young-of-year and juvenile fish of all the species of this region (Hershey

et al. 1999). Dominant primary consumers include zooplankton, snails, chironomids and

caddisfly larvae. Abundance and size distribution of secondary consumers differs

between lakes that support piscivores and those that do not, or where piscivore

distribution is experimentally altered (Carpenter et al. 1985, Bronmark et al. 1992,

Hershey et al. 1999). In this study, I found that when sculpin exist without the presence

of lake trout or arctic char, they grew significantly larger (Figure 1). However, there was

no difference in sculpin length or CPUE of sculpin between depths, suggesting that

piscivores do not alter sculpin habitat distribution (Figure 2).

Although limitations on sculpin growth in arctic regions has been observed

previously (Craig and Wells 1976, Johnson 1976, Power 1978), sculpin were caught

between 40 mm and 115 mm total length, which ranges close to the maximum size of

Cottus cognatus, which is generally reported to be approximately 120 mm total length

(Scott and Crossman 1973).   As is typical of most fish species, a minimum size threshold

for sculpin must be achieved for sexual maturity (Hanson et al. 1992). As growth rates of

sculpin increase, time from juvenile to sexual maturity will decrease. Hanson et al.

(1992) found that sculpin had faster growth rates in lakes with no lake trout present,

suggesting that sculpin were reaching sexual maturity faster. Since fish were not aged in

this study, I cannot assess growth rates. Further study, including aging and growth rates

of sculpin in all three lake types, could determine whether the absence of an apex

predator allows sculpin to grow faster, thereby reaching sexual maturity faster.

Large predators have the ability to control the size distribution of smaller

organisms within an ecosystem (Brooks and Dodson 1965). Townsend (1996) saw that a

species of endemic grayling (*Prototroctes oxyrhynchus*) in New Zealand became extinct

after the introduction of brown trout (*Salmo trutta*) to their habitat. Brown trout

introduction resulted in large changes in abundance and distribution of other fish species

in New Zealand. While Hanson et al. (1992) saw that sculpin presence was higher over

sediment in lakes with no lake trout than over rocky or rock-mud interface zones, my

study found no difference in sculpin habitat distribution, regardless of lake type (Figure

3). One explanation for this discrepancy could be a difference in size between piscivores

in the two studies. A study by Doupe et al. (2008) found that larger predators kill more

prey and, therefore, have a larger effect on the prey community. Previous studies in

arctic Alaska have seen that the lake trout are relatively small and slow growing, due to a

diet of mostly snails, which are a low quality food from a bioenergetic perspective

(McDonald and Hershey 1989). In addition to the poor diet, increased fishing pressure in

the region caused a shift toward smaller trout (McDonald and Hershey 1989). If the trend toward smaller size of piscivores has continued since that report, it would provide a mechanism for sculpin to occur at similar size and abundance at all depths.

Several approaches were taken to address the question of predator impact on sculpin diet composition. One response variable considered was a direct count of stomach contents. Using direct counts of stomach contents, no significant differences were found in ingestion of prey groups between lake types. Sculpin in arctic Alaska can fully digest food in approximately one day (Hershey and McDonald 1985) and prey availability may vary seasonally. Stomach contents in fish can be variable, due to individual foraging habits, dietary habits and foraging success (Keyse et al. 2007). While no statistical differences in stomach contents were observed between lake types in my study, zooplankton were a large part of sculpin diet, ranging from 20% - 60% by direct count, of diet items (Table 2). Sculpin are a predator that mainly feed upon benthic invertebrates (Hershey 1985, Brandt 1986). However, zooplankton were found in the stomachs of sculpin in all lake types at all depths, which suggests that zooplankton are a regular dietary component for sculpin in this region.

My study suggests that zooplankton form a larger portion of sculpin diet than previously reported (Hershey 1985, Cuker et al. 1992). However, Hershey (1985) counted prey from the entire gut, while in my study, prey were only counted from the stomach, which could account for the lower numbers of food items per fish seen here. It is also possible that with my technique of flushing the stomach with water, zooplankton were more easily dislodged than other prey items. Furthermore, sculpin were collected in

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traps. Thus, to some extent, stomach contents might reflect food that was available to them while they were in the traps. Zooplankton were more likely to be available in the mesh fish traps, while benthic invertebrates were less available. While zooplankton appear to be a regular dietary component for sculpin, there are several confounding factors relevant to such a conclusion.

Another response variable studied was the weight of stomach contents of each individual fish. Fish caught in offshore zones had significantly heavier stomach contents than fish caught in nearshore zones. These findings are consistent with Hanson et al. (1992) who found greater food availability in offshore zones. However, zooplankton were not considered by Hanson et al. (1992). Goyke and Hershey (1992) found lower biomass of chironomid larvae in the sediment in lakes lacking piscivores. These observations are consistent with my observation of larger sculpin in lakes lacking piscivores (Figure 1), suggesting that the sculpin are feeding more and therefore growing larger.

Since direct stomach content counts only represent a very recent snapshot of dietary habits, stable isotopes of carbon and nitrogen were used to examine longer-term assimilation (Peterson and Fry 1987, Vander Zanden and Rasumssen 1999, Vander Zanden and Vadeboncoeur 2002, Keyse et al. 2007). The observed ^{13}C enrichment in sculpin from lakes where arctic char were present compared to lakes where piscivores were absent suggests that the sculpin were feeding, at least partially, on different organisms or from different basal resources (Peterson and Fry 1987, Vander Zanden and Rasmussen 1999). Furthermore, ^{15}N depletion in sculpin from arctic char lakes compared

to both other lake types suggests that sculpin in arctic char lakes occupy a different trophic level within the food webs of these lakes than sculpin from lake trout or sculpin only lakes. This latter result is not inconsistent with the observed differences in $\delta^{13}C$ between lake types. However, the mechanism contributing to these stable isotope signatures is not clear.

The differences in $\delta^{13}C$ and $\delta^{15}N$ values seen between lake types are interesting because of the similarity of prey items identified in stomach contents. Even though stomach content analyses only provide a recent snapshot of diet composition, there are few alternative prey types in any of the lakes of this region that would have been available to sculpin. Thus, different isotope signatures for the same prey types in different lakes is the most plausible explanation for the observed differences in sculpin $\delta^{13}C$ and $\delta^{15}N$ among lake types. A study by Keyse (2006) compared $\delta^{13}C$ and $\delta^{15}N$ values of benthic invertebrates in lakes where arctic char were present and lakes where lake trout were present. Prey items from lakes with lake trout and no arctic char were more enriched in both ^{13}C and ^{15}N than prey items from lakes with arctic char and no lake trout by a range of 1‰ to 6‰. However, the study by Keyse (2006) did not include sculpin only lakes. The difference in $\delta^{13}C$ and $\delta^{15}N$ values of prey items of sculpin in lakes with arctic char seen by Keyse (2006) could explain the $\delta^{13}C$ and $\delta^{15}N$ values seen in this study. A shift in the isotope values in the prey will be reflected in the predator. Therefore, the shift in $\delta^{13}C$ and $\delta^{15}N$ values could potentially be attributed to a shift in $\delta^{13}C$ and $\delta^{15}N$ values of the prey. Further study of the stable isotope values of sculpin

prey items in sculpin only lakes would be needed to evaluate the patterns observed in this study.

Yoshii et al. (1999) studied food webs in Lake Baikal and observed that as sculpin increased in body length, they increased in δ^{15}N. A similar study in Canada on shorthorn sculpin (*Myoxocephalus scorpius*) observed similar increases in δ^{15}N correlating with increasing body size of sculpin (Dick et al. 2009). Since body length is a cue for reaching sexual maturity, it is possible that the diet of sculpin could shift upon maturing. However, since fish were not aged in this study, I cannot compare dietary habits of juveniles to sexually mature sculpin. This aspect of my research warrants future study.

Another interesting pattern observed in my study was the lack of *Procladius* in the stomach of sculpin from arctic char lakes. *Procladius* could potentially be the prey item causing shifts in both δ^{13}C and δ^{15}N values in sculpin from arctic char lakes. *Procladius* is common in lakes throughout this region. However, a more extensive study of sculpin from arctic char lakes would determine whether sculpin are feeding on *Procladius* in these lakes.

CHAPTER V

CONCLUSIONS

In arctic Alaskan lakes, the presence of an apex predator affects sculpin on multiple levels. For my first objective, I predicted that sculpin would have smaller mean length in lakes with a piscivore present. My results supported this prediction. Sculpin did grow larger when there is no piscivore present. This has potential implications for reproduction because sexual maturity and fecundity are both positively related to body size. However, I also predicted that the effect of piscivores on sculpin size would be habitat specific, which was not found to be the case.

In objective two, I predicted that the presence of a piscivore would result in a higher CPUE of sculpin in nearshore zones. However, I saw no difference in CPUE of sculpin between lake types or depth zones. I was just as likely to catch a sculpin in any lake, at any depth, at any given time. A potential shift toward smaller piscivores (McDonald and Hershey 1989) could explain these results.

For objective three, I predicted that sculpin would be more planktivorous in the absence of a piscivore. I also predicted that this shift toward planktivory would be reflected in the $\delta^{13}C$ and $\delta^{15}N$ signatures. Stomach content analyses showed no difference in prey mass or prey types between lake types. However, in all lakes, zooplankton comprised a substantial component of sculpin diet at all depths. Mass of

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stomach contents was greater in deeper water than near shore. This result was consistent

with previous research, which showed greater food availability in offshore zones. Stable

isotope analyses showed that sculpin from lakes with arctic char are isotopically distinct

from sculpin from other lake types. There are many potential causes for this, but further

study is needed to fully evaluate the mechanisms.

Considered collectively, these results indicate that piscivore effects on sculpin

populations are largely indirect, altering body size, but not habitat distribution or prey

selection. However, stable isotope analyses suggest some trophic segregation between

sculpin in char lakes, which requires further study to resolve.

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Table 1. Study area lakes. All lakes are in the arctic foothills region of Alaska in the vicinity of the Toolik Lake field station.

Lake Name	Lake Type	Depth (m)	Latitude	Longitude	Area (ha)
N-1	Lake Trout	14.0	68º38'38"N	-149º35'24"W	4.34
Toolik	Lake Trout	25.0	68º37'57"N	-149º36'20"W	149.41
GTH 100	Lake Trout	15.8	68º29'47"N	-149º36'07"W	5.04
I-6	Lake Trout	15.0	68º35'36"N	-149º39'17"W	16.87
I-8	Lake Trout	9.5	68º36'37"N	-149º34'59"W	16.78
Fog 1	Arctic Char	15.0	68º41'18"N	-149º08'13"W	3.40
Fog 2	Arctic Char	20.0	68º41'11"N	-149º08'58"W	5.65
GTH 65	Arctic Char	16.5	68º35'17"N	-149º14'34"W	4.31
E-1	Sculpin Only	11.0	68º37'35"N	-149º33'19"W	2.57
N-2	Sculpin Only	10.7	68º38'45"N	-149º41'37"W	1.66
N-3	Sculpin Only	appr. 4.5	68º38'34"N	-149º38'24"W	0.8
S-6	Sculpin Only	7.0	68º37'46"N	-149º38'31"W	2.8
GTH 91	Sculpin Only	10.5	68º37'27"N	-149º28'12"W	2.23

Table 2. Average number of prey items (± SE) found in sculpin stomach contents by lake type in nearshore (1m) and offshore (5m) zones.

Lake Type:	Lake Trout	Arctic Char	Sculpin Only
Food type			
Near shore - 1 meter			
Procladius	0.64±0.74	0	0.22±0.44
Other Chironomids	0.12±0.13	1.00±0.72	0.46±0.27
Zooplankton	2.64±1.9	0.80±0.44	1.28±2.26
Other	1.18±0.71	1.63±0.32	2.04±1.66
Offshore - 5 meters			
Procladius	4.30±7.46	0	3.60±7.18
Other Chironomids	2.64±2.58	1.43±1.21	2.86±1.93
Zooplankton	3.32±3.13	0.60±0.56	1.10±1.84
Other	1.68±1.08	2.17±0.61	2.22±1.01
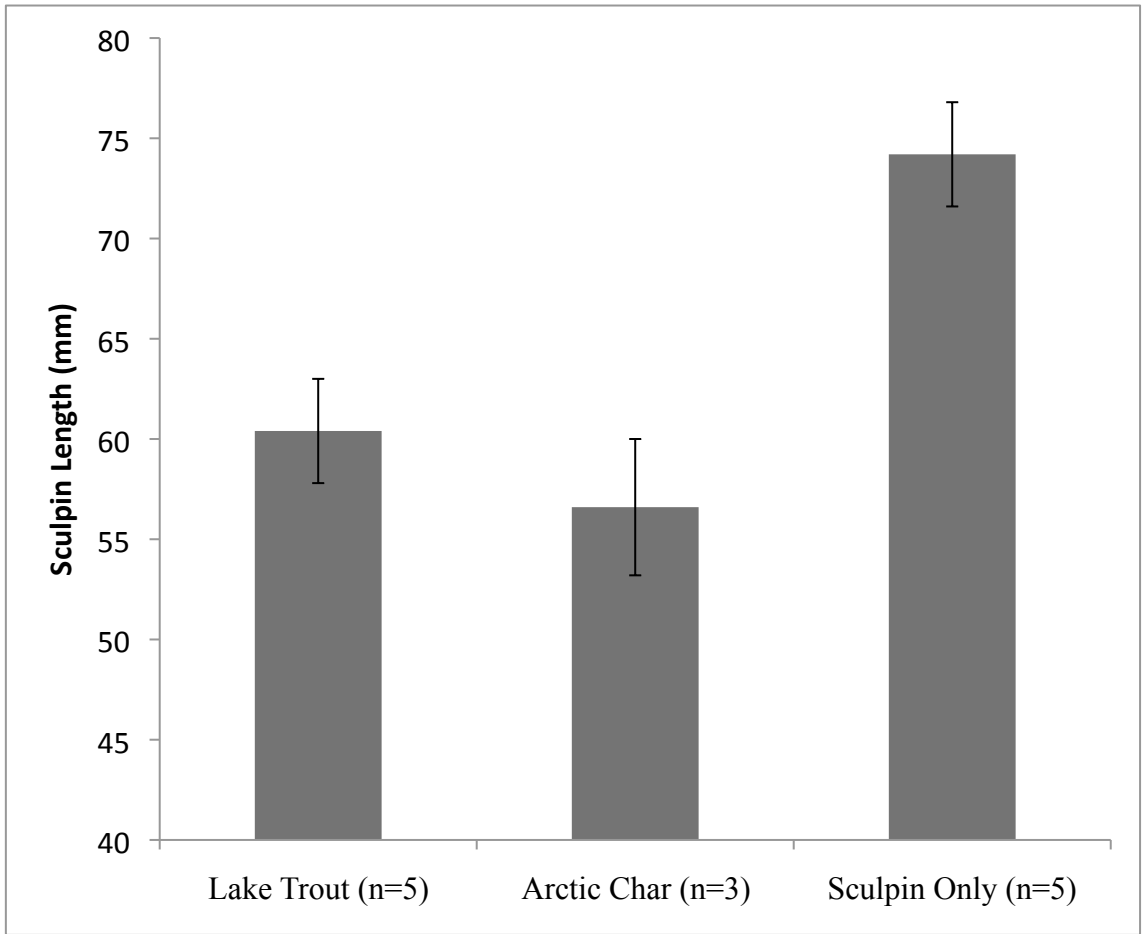
Figure 1. Mean sculpin length by lake type (± SE).
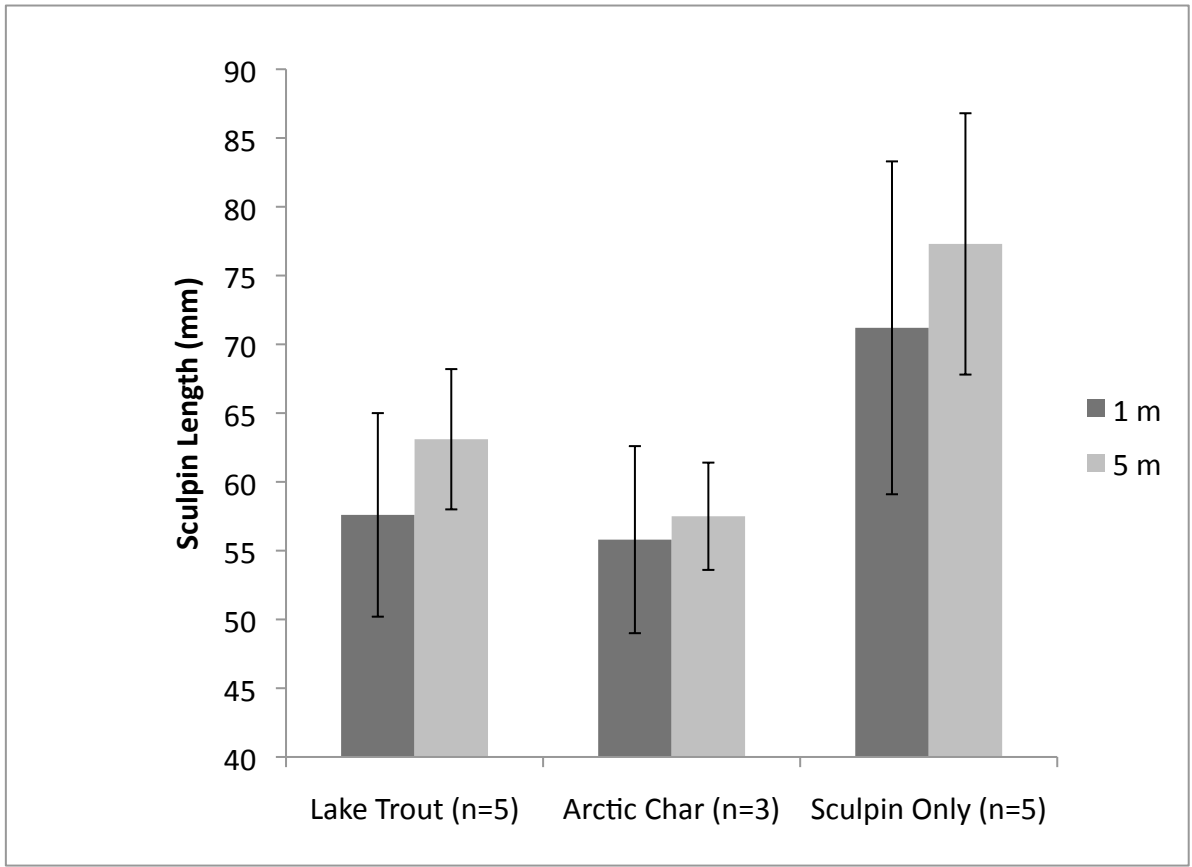
Figure 2. Mean sculpin length by lake type and depth (± SE).
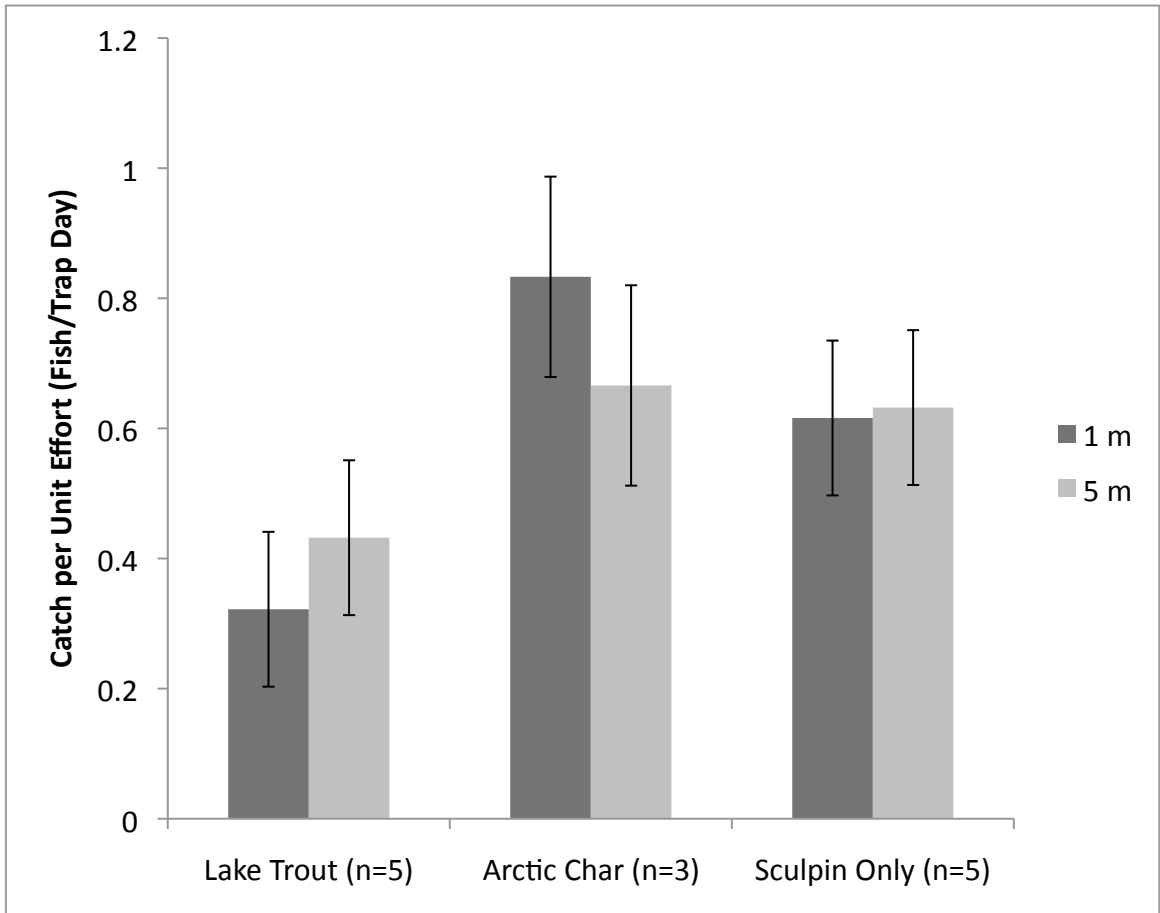
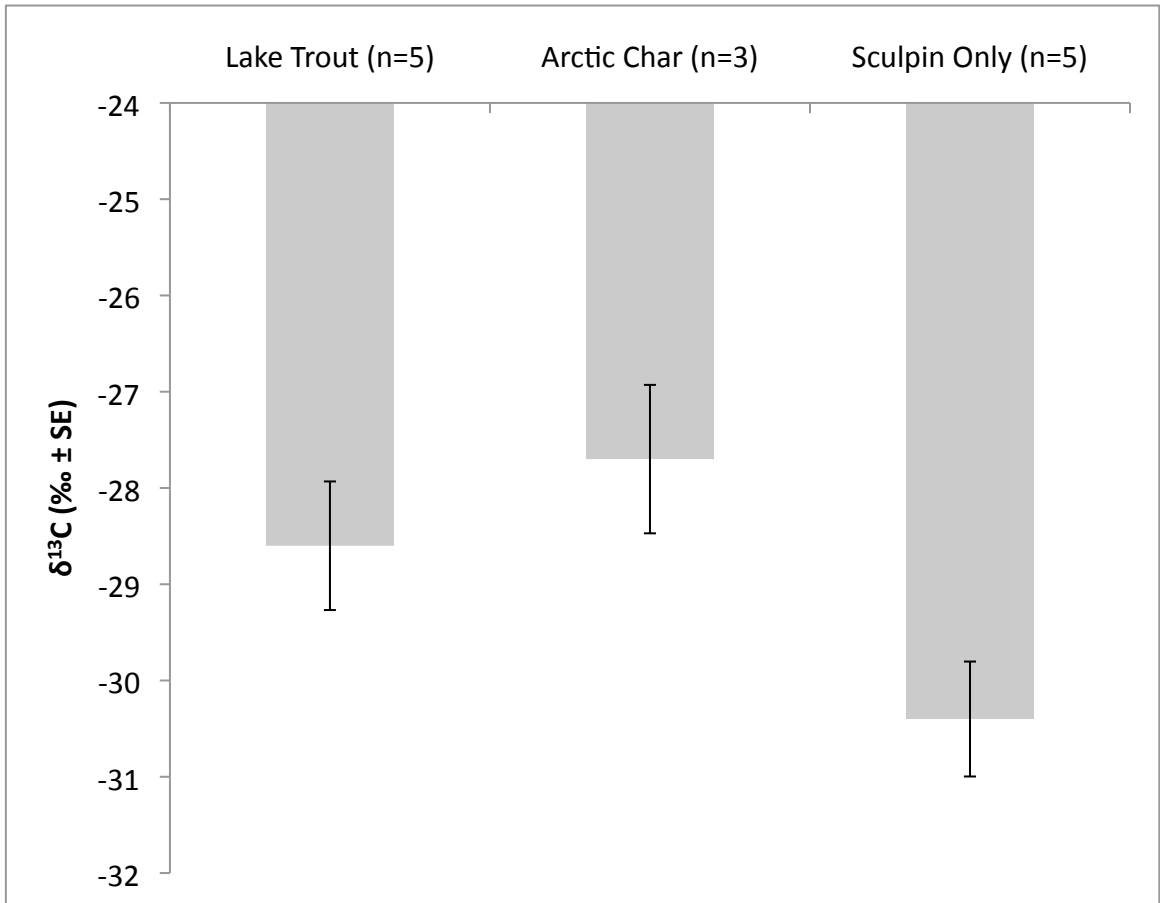Figure 3. Relative abundance of sculpin in catch per unit effort by lake type and depth (± SE).

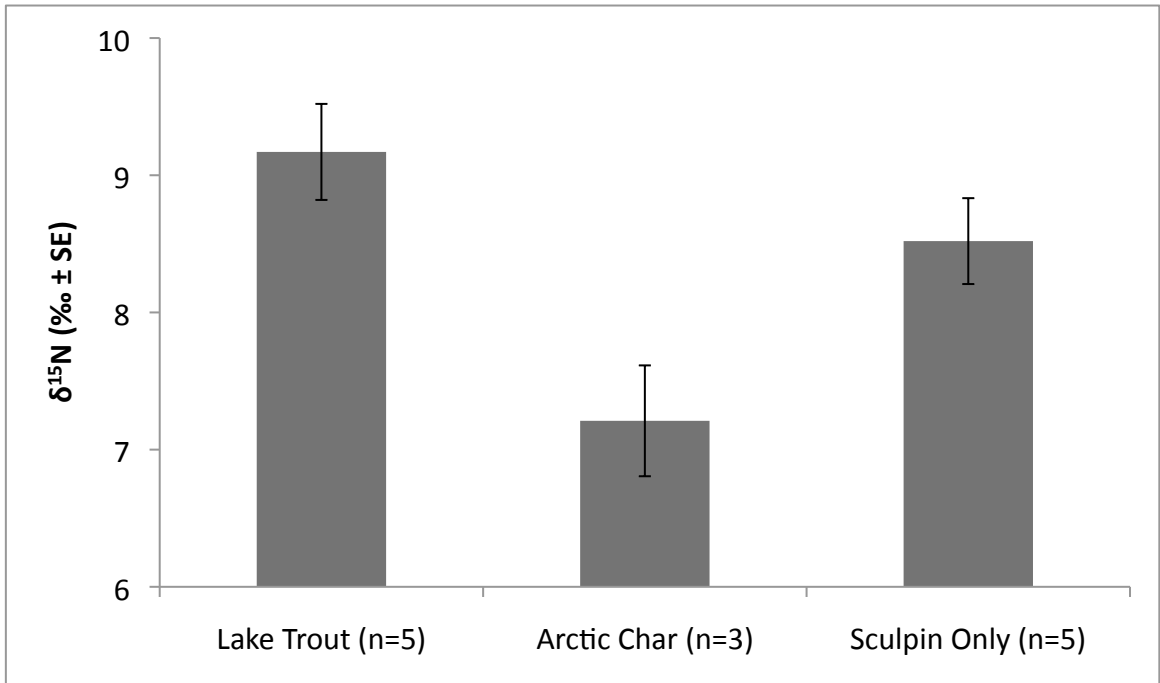Figure 4. δ^{13}C of sculpin by lake type ($\pm$ SE).
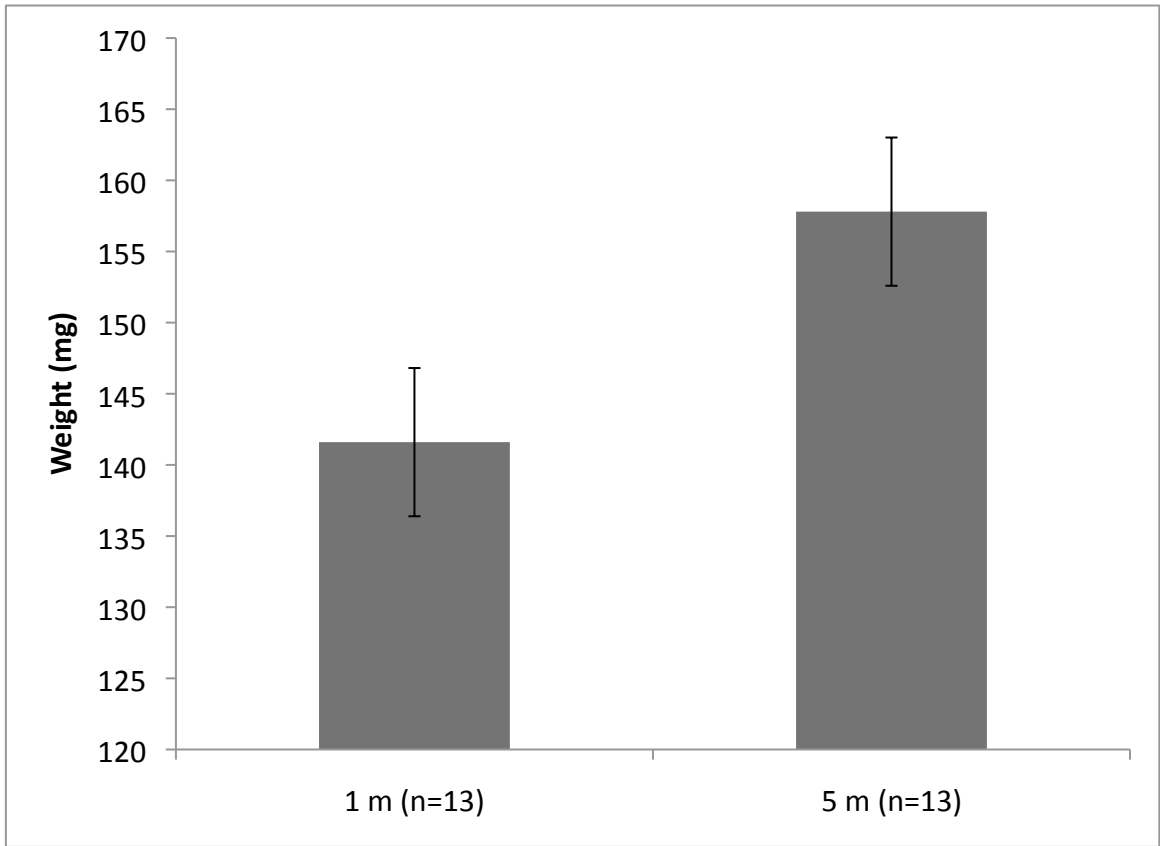
Figure 5. $\delta^{15}N$ of sculpin by lake type (± SE).

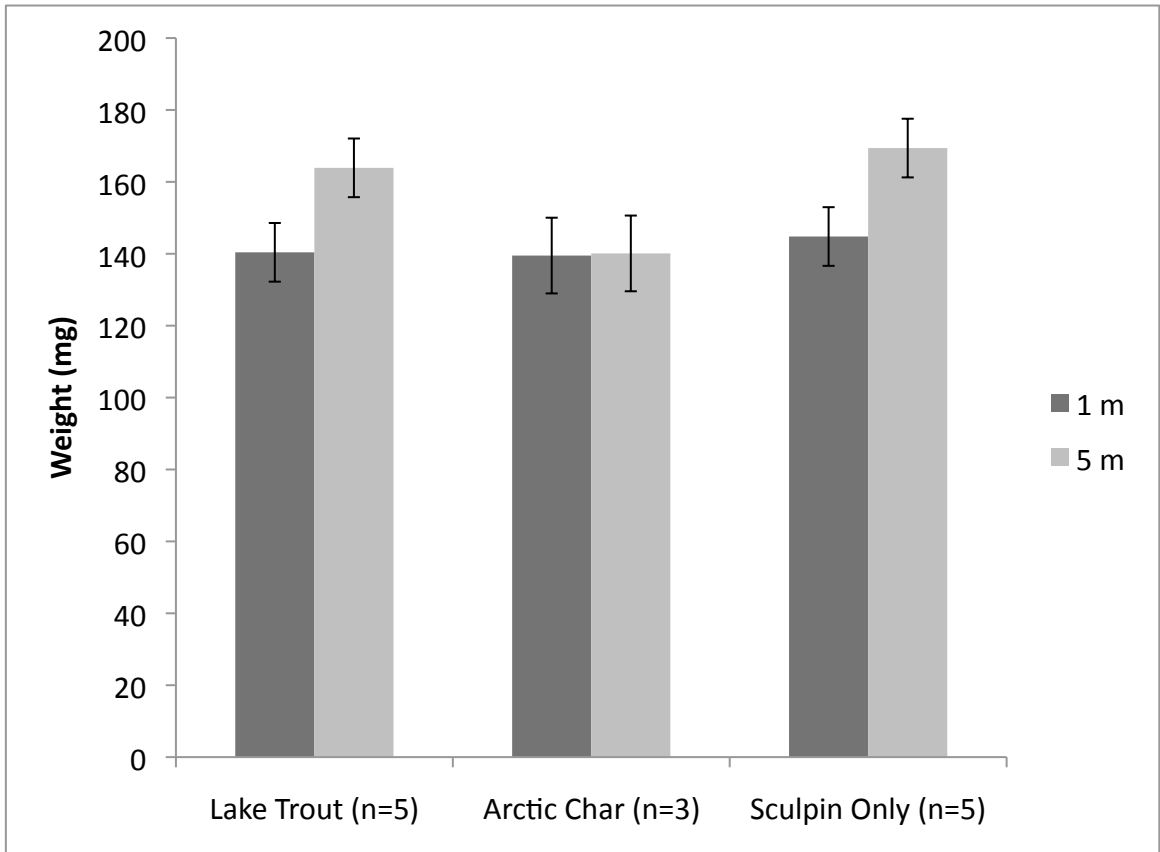Figure 6. Mean weight of sculpin stomach contents by depth (± SE).

Figure 7. Mean weight of sculpin stomach content by lake type and depth (± SE).