INTERACTIONS BETWEEN LAKE TROUT AND BULL TROUT IN THE PRIEST LAKE SYSTEM, IDAHO

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INTERACTIONS BETWEEN LAKE TROUT AND BULL TROUT IN THE PRIEST LAKE SYSTEM, IDAHO

A Thesis

Presented To

Eastern Washington University

Cheney, Washington

In Partial Fulfillment of the Requirements

for the Degree

Master of Science

By

Derek C. Entz

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MASTER’S THESIS

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# TABLE OF CONTENTS

ACKNOWLEDGEMENTS ................................................................................................. iv
LIST OF TABLES ............................................................................................................. vii
LIST OF FIGURES .......................................................................................................... viii
GENERAL INTRODUCTION ............................................................................................. ix

CHAPTER 1. Directional and Seasonal Movements of Lake Trout and Bull Trout between Two Northern Idaho Lakes
   Abstract ......................................................................................................................... 2
   Introduction ..................................................................................................................... 2
   Methods .......................................................................................................................... 7
   Results ............................................................................................................................ 10
   Discussion ....................................................................................................................... 12
   Literature Cited .............................................................................................................. 15

CHAPTER 2. Diets of Lake Trout in Upper Priest Lake, Idaho
   Abstract ......................................................................................................................... 31
   Introduction ..................................................................................................................... 31
   Methods .......................................................................................................................... 34
   Results ............................................................................................................................ 36
   Discussion ....................................................................................................................... 37
   Literature Cited .............................................................................................................. 39

VITA ..................................................................................................................................... 46
LIST OF TABLES

Table 1.1. Summary of Bull Trout and Lake Trout tagged and released within Priest Lake (PL) and Upper Priest Lake (UPL). Means of total length (mm) and weight (g) of all fish tagged with SD..........................19

Table 1.2. Summary of seasonal and directional movements of Bull Trout and Lake Trout between Priest Lake (PL) and Upper Priest Lake (UPL)...20

Table 2.1. Summary of Upper Priest Lake (UPL) Lake Trout stomach contents from 2015 and 2016. Frequency of Occurrence (F.O.), percent by number, and percent by weight were calculated from stomach contents ..........................................................43
LIST OF FIGURES

Figure 1.1. Study area including Priest Lake, Upper Priest Lake, and the Thorofare which connects the two lakes .........................................................21

Figure 1.2. Locations of Lotek JSATS WHS4000L acoustic receivers in Priest Lake (PL) and Upper Priest Lake) at either end of the Thorofare. Detection ranges of each array is shown by hashed circles .................22

Figure 1.3. Telemetry grid for Priest Lake (PL) and Upper Priest Lake (UPL) with sites marked by (triangles) ..........................................................23

Figure 1.4. Temperatures recorded in the Thorofare from 4 August, 2015 to 15 April, 2017. Vertical lines indicate when Thorofare temperatures reach 15°C. Dates of Lake Trout (LKT) from UPL and PL, and Bull Trout (BLT) movements are shown using colored arrows explained by direction .................................................................24

Figure 1.5. The mean and standard error of days Lake Trout spent within detection range of Priest Lake (PL) and Upper Priest Lake (UPL) acoustic arrays based on seasons. Seasons are denoted by number, 1=Spring, 2=Summer, 3=Fall, and 4=Winter and * signifies significance at an alpha of 0.05 ..................................................................................................25

Figure 1.6. The mean and standard error of days Bull Trout spent within detection range of Priest Lake (PL) and Upper Priest Lake (UPL) acoustic arrays based on seasons. Seasons are denoted by number, 1=Spring, 2=Summer, 3=Fall, and 4=Winter and * signifies significance at an alpha of 0.05 ..................................................................................................26

Figure 1.7. The mean and standard error of days Lake Trout from the northern and southern tagging regions spent within detection range of Priest Lake (PL) acoustic array based on seasons. Seasons are denoted by number, 1=Spring, 2=Summer, 3=Fall, and 4=Winter ....................................................27

Figure 1.8. Seasonal heat maps of Lake Trout (LKT) distribution histories in Upper Priest Lake (UPL). Number of detections in each site are indicated by color; 1: Green, 2: Yellow, 4: Orange. No LKT were detected in the Spring and Summer due to inaccessibility to UPL.......28

Figure 1.9. Seasonal heat maps of Lake Trout (LKT) distribution histories in Upper Priest Lake (UPL). A) Spring UPL LKT distributions, b) Summer UPL LKT distributions, and c) Fall UPL LKT distributions. There are no data during the winter season due to inaccessibility ..................................................................................................29
Figure 1.10. Seasonal heat maps of Lake Trout (LKT) distribution histories in Priest Lake (PL) A) Spring PL LKT distributions, b) Summer PL LKT distributions, c) Fall PL LKT distributions, and d) winter PL LKT distributions.

Figure 2.1. Von Bertalanffy Growth Model of Lake Trout in Upper Priest Lake (UPL) aged using scales. $R^2=0.88721$

Figure 2.2. Proportion of Upper Priest Lake (UPL) Lake Trout diet items based on size. >500 mm (blue), <500 mm (grey)
GENERAL INTRODUCTION

Introduced species are recognized as one of the biggest threats to world-wide biodiversity (Simberloff 2001). Aquatic systems in particular are susceptible to invasions by the introduction of non-native fishes and the interactions with native species can have detrimental consequences and cause changes in ecosystem functions (Kohler and Courtenay 1986; Vitousek et al. 1997; Thurow et al. 1997; Dunham et al. 2004). In the U.S. alone, fish introductions have increased dramatically, growing from 67 species (1850-1900) to 488 species (1951-1996; Nico and Fuller 1999). These introductions have been so widespread that Ricciardi and Rasmussen (1999) indicated that temperate North American freshwater fauna have extinction rates (0.037; percent loss per decade) comparable to that of tropical rainforests.

Invasions of aquatic systems by novel predators can be devastating due to the lack of competition, and exploitable prey species that evolved without predators (Kiesecker and Blaustein 1997; Craig et al. 2000). For example, introductions of trout significantly alter vertebrate and invertebrate communities, often causing extirpations of native fish, amphibians, and benthic macroinvertebrates (Bradford et al. 1998; Carlisle and Hawkins 1998; Tyler et al. 1998; Knapp and Matthews 2000). Despite providing successful recreational fisheries, the introduction of trout species to Chile has had detrimental impacts on native fish fauna, including an absence of native fish in 40% of surveyed streams (Soto et al. 2006). Following Brown and Rainbow Trout (Salmo trutta and Onchorhynchus mykiss, respectively) introductions to Chile in the early 1900's these species represent 95% of total fish biomass in streams and rivers (Soto et al. 2006).
In addition to Chile, nonnative trout have been introduced extensively on every continent except Antarctica (Moyle 1986) in efforts to provide commercial fisheries (Soto et al. 2001) or recreational fisheries (Donald 1987; Bahls 1992; Townsend 1996). Historically fishless water bodies and even "protected" areas have been subject to nonnative trout introductions (Donald 1987; Bahls 1992; Knapp et al. 2001). Nonnative trout species can successfully colonize new habitats because trout are highly effective predators (Flecker and Townsend 1994) and are able to readily establish self-sustaining populations (Fausch et al. 2001). In order to conserve native species, managers have had to enact conservation efforts to eliminate or control introduced species (Kaiser 2001).

The introduction of Lake Trout (Salvelinus namaycush), a salmonid native to the Great Lakes, to western U.S. lakes, has negatively impacted native species and in extreme cases has caused extirpations (e.g., Bull Trout (Salvelinus confluentus), Bow Lake, Alberta, Canada; Donald and Alger 1993). A well-known example of Lake Trout predation on a native species is from Yellowstone Lake where Yellowstone Cutthroat Trout (Onchorynchus clarki bouvieri) have experienced a severe decline in population size since the introduction of Lake Trout (Ruzycki et al. 2003). Ruzycki et al. (2003) found that a single Lake Trout consumed on average 41 Cutthroat Trout annually that averaged 27-33% of their total body length.

Another species that has been negatively impacted by introductions of Lake Trout is Bull Trout, which is listed as a threatened species by the Endangered Species Act (USFWS 1998). Bull Trout and Lake Trout have similar ecological roles (growth rates, food habits, and life histories) and competition is likely (Donald and Alger 1993; Guy et al. 2011). Due to competition, Lake Trout can cause displacement of Bull Trout as well
as preventing Bull Trout from reestablishing populations (Donald and Alger 1993). This displacement is due to the fact that Lake Trout and Bull Trout prey on similar species at similar life stages (Guy et al. 2011). Juveniles of both species prey on *Mysis diluviana*, a freshwater shrimp that inhabits western U.S. lakes (Martin and Olver 1980). When both species reach adult stages they become piscivorous, feeding on Kokanee Salmon (*Oncorhynchus nerka*; Jeppson and Platts 1959) and other similar species (Beauchamp and Van Tassell 2001).

In addition, Bull Trout could also be subject to predation by Lake Trout due to niche overlap between the two species (Guy et al. 2011; Donald and Alger 1993). Lake Trout become primarily piscivorous at approximately 500mm or at approximately age-class 6 (Ruzycki et al. 2003).

Lake Trout introduced to the Priest Lake system, which is within the Selkirk Mountains of northern Idaho, has coincided with a decrease in the Bull Trout population. The Priest Lake system includes Priest Lake (PL) and Upper Priest Lake (UPL) which are connected via a river channel known as the Thorofare. Lake Trout were originally introduced to the Priest Lake system in 1925 to create a sport fishery (Bjornn 1961) and their population remained relatively stable (5,700 fish harvested annually) until the 1970’s, then started to increase (30,000 fish harvested in 2003; Davis et al. 1997). It was believed that no Lake Trout inhabited UPL until immigration through the Thorofare was seen in the 1990’s. Lake Trout subsequently became established in UPL (IDFG 2013b). A sharp decline in native Bull Trout populations occurred concurrently with the Lake Trout increase in PL (Reiman and Lukens 1979), and Bull Trout reproduction is currently functionally restricted to UPL with an estimated population between 100-150 adults
Due to the possibility of the extirpation of Bull Trout in the Priest Lake system, the effects of competition between Bull Trout and Lake Trout are of particular concern (Fredericks 1999). The Priest Lake system is predicted to be a cold-water stronghold under most climate change models (Reiman et al. 1997) increasing the importance of conserving native species in this system.

Lake trout suppression using sinking gillnets has become an increasingly common management practice for the conservation of native fishes and ecosystems throughout the western USA (Martinez et al. 2009) as seen in Yellowstone Lake, Wyoming, Pend Oreille Lake, Idaho, and Flathead Lake, Montana. Population models suggest that in order to see a successful decline in Lake Trout populations, an annual mortality rate of 0.45-0.50 is needed (Healy 1978). Some large lake systems including Lake Pend Oreille, Idaho have had some success in reducing Lake Trout populations by 67% by 2015 via suppression efforts (Hansen et al. 2010).

To reduce the potential impacts on Bull Trout and other native species, annual removal efforts of Lake Trout in UPL have occurred since 1998 (Fredericks et al. 2013). Recent depletion estimates (2007-2013) of the UPL Lake Trout population range from 0.59-1.0, which is more than the necessary rate needed in order to see a successful decline of lake trout within large lake systems (Hansen et al. 2013; IDFG 2013b).

Despite Lake Trout depletion estimates above the necessary rate needed (0.45-0.50) within UPL, the population has stayed constant but simultaneously a reduced catch per unit effort has been seen (IDFG 2013a). This is possibly due to immigration of Lake Trout from Priest Lake via the Thorofare or recruitment of Lake Trout from within UPL. Venard and Scarnecchia (2005) documented that Lake Trout move through the Thorofare
frequently during the spring (March-June) and fall (September-November) months when surface water temperatures are below 15°C.

Within both chapters of this thesis I aim to better understand Lake Trout and Bull Trout movement patterns both between and within Priest and Upper Priest lakes, and characterize the potential impacts of Lake Trout feeding within UPL. The objectives of this study are to 1) characterize the frequency, timing, and direction of Lake Trout movements between UPL and PL, 2) Evaluate seasonal distribution of Lake Trout within PL and UPL, 3) Characterize upstream/downstream movements of Bull Trout, originating in UPL, between UPL and PL, and 4) Describe feeding habits of Lake Trout in UPL.
REFERENCES


CHAPTER 1. Directional and Seasonal Movements of Lake Trout and Bull Trout between Two Northern Idaho Lakes

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ABSTRACT

Seasonal and directional movements, and distributions of Bull Trout and Lake Trout between Priest Lake and Upper Priest Lake, Idaho, were studied from May 2015 to April 2017. Lake Trout (n=220) and Bull Trout (n=40) movements were monitored using Lotek JSATS transmitters and hydrophones both passively, using gate formations at either end of the Thorofare, and actively in both lakes. No significant difference was found between directional or seasonal movements of either species (P>0.05) and all movements were observed when water surface temperatures were below 15°C. Poisson regression analysis indicated that there were significantly more detections by the Upper Priest Lake array than the Priest Lake array (P<0.01). Bull Trout distributions in Upper Priest Lake varied significantly between near shore and open water detections, with a higher use of near shore sites (P<0.05). Lake Trout tagged in two locations within Priest Lake were not more likely to migrate towards the Priest Lake acoustic array (P>0.05). Lake Trout distributions in Priest Lake varied insignificantly from their original capture and release points (P>0.05). These results indicate that Lake Trout have use the southern portion of Priest Lake at high rates and movement to Upper Priest Lake is random.

INTRODUCTION

Introduced species are recognized as one of the biggest threats to world-wide biodiversity (Simberloff 2001) and not only have the capability to alter competitive interactions and reduce native populations but can also cause extinctions (Wilcove et al. 1998). For example, nonnative trout have been successfully introduced into various freshwater ecosystems (Lever 1996, Lowe et al. 2000). The intention for most trout
introductions was to create recreational fisheries (Dunham et al. 2004). But there is a growing body of evidence to suggest that nonnative trout can substantially change the aquatic ecosystems where they have been introduced (Simon and Townsend 2003).

Lake Trout (*Salvelinus namaycush*) were widely introduced to many western United States lakes and reservoirs during the late 1800’s and early 1900’s (Crossman 1995) in order to create a trophy fishery (Healy 1978). Despite creating successful Lake Trout trophy fisheries, effects of competition with and predation by Lake Trout have proven problematic for native fishes (Martinez et al. 2009). For instance, Bull Trout (*Salvelinus confluentus*) populations have declined and in some cases become extirpated (Bow Lake, Alberta, Canada) since the introduction of Lake Trout (Donald and Alger 1993; Guy et al. 2011).

Competition between Lake Trout and Bull Trout can cause displacement, as well as preventing Bull Trout from reestablishing populations after local extirpation (Donald and Alger 1993). Bull Trout, which are a “threatened species” under the United States Endangered Species Act (USFWS 1998) share similar ecological roles with Lake Trout (Donald and Alger 1993; Guy et al. 2011). Both species are top piscivores with a potential for overlapping food habits, growth rates (Donald and Alger 1993) and have been known to switch from invertebrates to fish prey at similar life stages (Guy et al. 2011). Lake Trout predation on Bull Trout is not well documented but is possible due to niche overlap of the two salmonids (Donald and Alger 1993).

Among systems where Lake Trout and Bull Trout interactions are of concern is Priest Lake, Idaho. The Priest Lake system consists of Priest Lake (PL) and Upper Priest Lake (UPL) which are connected by a river channel known as the Thorofare (Figure 1.1).
Lake Trout were introduced to PL in 1925 (Bjornn 1961) but maintained a relatively small population until the 1970’s due to low juvenile survival (Mauser et al. 1988). Shortly after Mysis shrimp (*Mysida diluviana*) were introduced in 1965, juvenile Lake Trout survival increased and resulted in a significant increase of the Lake Trout population (Mauser et al. 1988). Historically, Bull Trout were abundant throughout the Priest Lake system and in the 1950’s supported an annual catch of 1,800 fish (Bjornn 1961). In 1978, the native Bull Trout population experienced a sharp decline which ultimately led to a closure of the fishery in 1984 in an attempt to preserve the remaining individuals. The decline of PL Bull Trout was concurrent with an increase in Lake Trout (Rieman and Lukens 1979; Mauser et al. 1988). Currently, the Bull Trout population in UPL is estimated between 100-150 adults (Fredericks 1999; IDFG 2013a). Following the decline of the Bull Trout fishery, very few individuals remain in Priest Lake and population estimates have remained low. Recently the number of observed Bull Trout redds within index reaches of the Upper Priest River drainage has increased to 52 and 53 in 2012 and 2013, respectively (IDFG 2013b). Furthermore, the number of Bull Trout redds in 2012 and 2013 in the Upper Priest River drainage is above the previous 10-year average of 28 redds (IDFG 2013b).

Prior to the 1980’s it was thought that Lake Trout did not inhabit UPL until immigration through the Thorofare was documented in the 1990’s (IDFG 2013a). By 1998, the Lake Trout population in UPL was estimated at 859 fish (Fredericks and Venard 2001) and in 2013 was estimated to be above 6,500 fish using the Leslie Depletion Model (Ricker 1975; IDFG 2013b).
Lake Trout can be susceptible to over-fishing due to the slow growth rate and late maturing (Martin and Olver 1980; Healey 1978). Healy (1978) found that in order to cause a decrease in Lake Trout populations within large lake systems, an annual mortality rate of 0.45-0.50 is needed. Annual suppression efforts in UPL have occurred since 1998 using gillnets and have removed between 150 and 5,355 fish annually. Since 2007, removal efforts by IDFG have averaged 3,184 (SE = 1,559) been above the aforementioned threshold (0.59-1.0; IDFG 2013a).

Despite Lake Trout depletion estimates above the necessary rate needed (0.45-0.50) within UPL, Lake Trout have annually repopulated to or near pre-removal efforts. This is possibly due to immigration of Lake Trout from Priest Lake via Thorofare or recruitment of Lake Trout from within UPL. Idaho Department of Fish and Game (IDFG) has used trap nets intermittently in the Thorofare to remove Lake Trout and in 2013, 305 Lake Trout were captured migrating to UPL; the majority of fish removed were sexually mature (>400mm TL; IDFG 2013a). The immigration of adult Lake Trout to UPL is potentially preventing the positive effects on native species expected to be seen with Lake Trout removal efforts.

Previous studies to understand Lake Trout movements included floy tagging, gillnetting, and trap netting. For instance, using gillnets Venard and Scarnecchia (2005) found that Lake Trout move frequently during the spring (March-June) and fall (September-November) months when surface water temperatures are below 15°C. These techniques provide valuable data but have limitations on determining when Lake Trout are moving or the direction of such movements, and only provide a snapshot of movements. For example, at least 11 floy tagged Lake Trout migrated to UPL from PL...
during 2013-2016 but it is not known when these fish moved during the three-year span (R. Ryan, Idaho Department of Fish and Game, personal communication).

Acoustic monitoring of large numbers of animals has become a more widely used research tool (Standora and Nelson 1977). To gather directional movements of individuals, acoustic receivers can be set up in an acoustic curtain/gate system to monitor when a fish passes or approaches each series of acoustic curtains (Comeau et al. 2002; Welch et al. 2003). In this case all acoustic receivers within each curtain would have overlapping detection ranges (Comeau et al. 2002; Welch et al. 2004). The advantages of acoustic telemetry setups such as curtains/gates is increased coverage, and an opportunity to better monitor individual’s precise movements and behaviors for a larger subset of the population (Heupel et al. 2006).

Acoustic telemetry can be used to further understand fish distributions within large lake systems. Most knowledge on Lake Trout movements is within their native range, and there is a limited amount of information for Lake Trout within their introduced range (Dux et al. 2005). Understanding areas of utilization of Lake Trout using acoustic telemetry is important in order to facilitate appropriate management strategies.

The purpose of this study was to estimate the rate of and document the timing of Lake Trout and Bull Trout movements between UPL and PL continually throughout the course of two years. A better understanding of Lake Trout and Bull Trout movement patterns both between and within Priest and Upper Priest lakes would help evaluate the efficacy of the current suppression strategy in UPL and help aid future management goals. The objectives of this study were to 1) Evaluate movements of Lake Trout through the Thorofare, 2) Evaluate seasonal distributions of Lake Trout in PL and UPL 3)
Evaluate the movements of Bull Trout, captured in UPL, through the Thorofare 4
Evaluate seasonal distributions of Bull Trout in UPL and PL.

METHODS

Equipment. -WHS4000L series hydrophones (Lotek Ltd.) were used to establish a
gate in order to identify Bull Trout and Lake Trout directional movements. WHS4250L
series hydrophones (Lotek, Ltd.) were used to identify Bull Trout and Lake Trout fish
distributions throughout both lakes. JSATS L-AMT-8.2 acoustic transmitter (3.5 g in air,
417 kHz, 5-s pulse rate, ~508-d battery life) and a PIT tag (DF TX 1400BE, 12 mm long,
134 kHz; CBFWA 1999) were surgically implanted into the body cavity as described
below.

Fish Collection. -In 2015, 20 Bull Trout and 40 Lake Trout were collected in UPL
using angling methods and gillnets. In 2015, 60 Lake Trout were collected in PL using
angling methods, two main areas were targeted during this effort, one in the northern half
of PL and one in the southern basin of PL (Figure 1.1). Lake Trout collected in PL during
the spring of 2015 were held in 20’x20’x100’ deep net pen for three weeks as a part of an
IDFG barotrauma study. In 2016, 20 Bull Trout and 20 Lake Trout were collected in UPL
using angling methods and gillnets. In 2016, 100 Lake Trout were collected in PL using
angling methods within the two aforementioned areas of PL (Table 1.1).

Anesthesia and Tagging. -In 2015, Bull Trout were anesthetized using 70-100 mg/L
tricaine methanesulfonate (MS-222) following the methods by Muhlfeld et al. (2002) and
in 2016, Bull Trout were anesthetized using Low-volt Electroanesthesia (LVEA)
following methods described by Hudson et al. (2005). During both years, Lake Trout
were anesthetized using LVEA. LVEA is a common anesthetic used in fisheries due to very short take down and recovery times (Barbara et al. 1998; Tesch et al. 1999; Hudson and Johnson 2011; Gunstrom & Bethers 2011; Redman et al. 2011). All Bull Trout and Lake Trout were surgically implanted with JSATS acoustic and passive integrated transmitters following the methods described by Brown et al. (1999).

Identifying Thorofare Movement. -Three stationary receivers, attached to anchored buoys, were situated in curtain formats, at each end of the Thorofare and operated year-round (Figure 1.2). Three temperature gauges were placed in the Thorofare in order to measure temperature. These loggers recorded temperature every 30 minutes. To observe Bull Trout spawning migrations a receiver was placed in Upper Priest River approximately 1 km upstream from the inlet to UPL. Stationary receivers were downloaded monthly and batteries were changed if necessary, when weather and water levels permitted.

Identifying Fish Distributions. -Identifying fish distributions was done using a grid of 400m$^2$ cells placed over both lakes in ArcMap (Figure 1.3). This grid size was chosen based on the maximum range of the receivers found via range testing. The grid was split into three equal sections (130 sites each). The center of each grid cell was numbered in order to keep track of sites visited. In order to cover a maximum amount of distance, each grid section was split into odd/even groups and in consecutive weeks an entire section (odds/evens) would be tracked. One section was surveyed each week when weather permitted. With the motor turned off, the boat was positioned at the center of each grid cell and the receiver was lowered underwater at a depth of 2.5 m for 2 minutes. When UPL was inaccessible due to low water levels in the Thorofare or ice was present
(November-April), identifying fish distributions occurred exclusively in Priest Lake. During the 2016 winter no tracking occurred from December to March due to both lakes being completely iced over.

Data Management and Processing. - Data files downloaded from receivers contained fish detection information. Detections were downloaded from the internal SD card to a computer as a “.csv” file. Raw “.csv” files were formatted from decimal time to standard 24-hour format using “RStudio” with an individual tag code (Tag ID), time stamp, receive signal strength indicator (RSSI; McMichael et al. 2010) and then saved as a text file. Due to high frequency of false detections the JSATS Autonomous Receiver Data Filtering Software developed by Pacific Northwest National Laboratory, Richland, Washington (PNNL) was used. This software compared known deployed Tag ID’s to the text file and removed all false Tag ID’s that do not meet the criterion (false detections; Deng et al. 2017).

The three criteria used were, 1) Detections were from known deployed tags, 2) A minimum of 3 detections in 12 seconds was required, and 3) Time between detections had to match the 5-second pulse rate expected. This approach is also used by PNNL, studying juvenile salmon emigration movements through the Columbia River system (Deng et al. 2017).

Data Analysis. – To analyze objectives 1, 3, data gathered identifying seasonal Thorofare movements between UPL and PL a Fischer’s Exact test was used. When testing for seasonal difference of days spent at the acoustic arrays by Lake Trout and Bull Trout a Poisson regression was used. To test objectives 2, 4 data gathered identifying fish
distributions between tagging areas in PL and differences of near shore preference of Bull Trout and Lake Trout a Fisher’s Exact test was used in “R”.

RESULTS

Identifying Thorofare Movement. From May 22, 2015 to April 21, 2017, a total of 93 fish was detected by at least one of the acoustic gate arrays on either end of the Thorofare, 23 of which were Bull Trout and 70 were Lake Trout. Of the 93 fish detected by at least one array, 13 were observed moving through the Thorofare to the lake opposite of their original tagging origin. These movements between UPL and PL included three Bull Trout, all of which were tagged in UPL and detected moving to PL but were not observed returning to UPL. Also, six Lake Trout originally tagged and released in UPL were detected traveling downstream to PL, three of the six UPL Lake Trout returned back to UPL. One Lake Trout originally tagged in PL was detected moving upstream on the UPL array and again repeating the upstream and downstream movements twice more from 4 May, 2016 to 28 May, 2016. No significant differences were found between seasonal or directional movements ($P>0.05$; Table 1.2). Two Bull Trout were detected within Upper Priest River upstream of the inlet to UPL. Six Lake Trout were harvested by anglers, four were mortalities during the 2016 UPL suppression effort, and three were caught and released by anglers, one of which was caught approximately 117 km away from UPL in the Pend Oreille River near Newport, Washington.

There were more detections of both Bull Trout and Lake Trout on the UPL array than the PL array (Poisson regression; $P<0.01$; Figure 1.5 & 1.6). Seasonal variation of detections at both arrays by both species were also observed. The number of detections of
Bull Trout at the PL acoustic array were significantly higher in autumn than all other seasons ($P<0.01$) and the number of Bull Trout detections at the UPL acoustic array were significantly higher in the summer and winter ($P<0.01$; Figure 1.5). Seasonal variations of Lake Trout detections on the PL array were not significantly different ($P>0.05$). Additionally, Lake Trout detections on the UPL acoustic array were significantly higher during the summer and winter seasons ($P<0.01$). There were fewer detections of Lake Trout at the UPL array in the autumn than during the spring and winter seasons ($P<0.01$; Figure 1.6). Lake Trout tagged in the two tagging areas of PL showed no difference in time spent at the PL acoustic array ($P>0.05$). Also, no seasonal variation of Lake Trout tagged within the two tagging locations of PL was seen ($P>0.05$; Figure 1.7).

Identifying Fish Distributions. -From June 21, 2015 to December 3, 2016 a total of 107 telemetry detections was obtained from 69 Lake Trout within PL and UPL. During that same period, a total of 18 telemetry detections was obtained from 11 Bull Trout within UPL and one Bull Trout was observed once in PL. Bull Trout were observed (n=15) in near shore sites more than open water sites ($X^2=8$, df=1, $P<0.01$; Figure 1.5). Conversely, 30 Lake Trout were detected in near shore sites while 18 were detected in open water sites. Lake Trout did not show a significant preference to near shore sites in UPL ($X^2=3$, df=1, $P>0.05$; Figure 1.6). When testing for location fidelity of Lake Trout in the north and south tagging areas of PL 11 of 27 Lake Trout released in the north area were detected at sites in the southern tagging area and only 2 of 18 Lake Trout released in the south tagging area were detected in the northern tagging area. Location fidelity was seen with Lake Trout captured and released in the southern area of PL (Fisher’s Exact
test; \( P<0.05 \) but not with Lake Trout captured and released in the northern area of PL (Fisher’s Exact Test; \( P>0.05 \)).

**DISCUSSION**

We observed an unexpected amount of downstream movements through the Thorofare which prior to this study were not seen due to the focus on upstream movements using trap nets and gillnets. Movements between UPL and PL occurred when surface temperatures within the Thorofare were below 15°C, which coincided with previous work done in the Thorofare (Figure 1.4; Venard and Scarrnechia 2005). The data collected during this study showed that there is a considerable amount of downstream movement by Lake Trout from UPL. Although Lake Trout were captured, tagged and released in UPL during this study we do not know whether these individual fish originated from UPL or were existing migrants from a prior upstream movement from PL when water temperatures were below 15°C. It is unknown whether Lake Trout migrate to UPL from PL stay within UPL for an extended period of time or return to PL at some point. Although we lack information of repetitive upstream movements throughout the life span of Lake Trout our results may give some insight into that possibility due to the high percentage of downstream movement by Lake Trout.

Furthermore, downstream movements by Bull Trout give insight that Bull Trout may use PL as a rearing ground due to the fact that we have not observed these fish returning to UPL. However, the lack of detections after their original downstream movement leaves room for speculation. Conversely, the upstream movement of two Bull Trout in the Upper Priest River is helpful in estimating times of movements for spawning. Although
the end destination is unknown of those two Bull Trout they were observed returning to UPL in October. These movements support prior data that Bull Trout within the Priest Lake system spawn during September within the Upper Priest River drainage (Bjornn 1961).

Movements of Lake Trout originally tagged within the southern tagging area in PL showed little movement away from their original capture and release points. A trend seen was that Lake Trout tagged within the main southern body of PL stayed within that same area and the same was not seen with Lake Trout tagged in the northern end of PL. Lake Trout tagged in the northern end of PL showed a higher rate of detection by the PL acoustic array than Lake Trout tagged in the southern body of the lake.

Lake Trout originally tagged within UPL were seen moving outside of the detection range of the UPL acoustic array during the fall season which could be related to Lake Trout moving to spawning areas. Lack of detection and movement to UPL by Lake Trout tagged in PL could have been influenced by the high area fidelity seen from Lake Trout that were captured and released in the southern area of PL.

Lake Trout have shown an ability to establish populations beyond the introduction site if suitable conditions exist (Crossman 1995). Evidence from invasions of Yellowstone Lake, Wyoming and Lake McDonald, Montana help with understanding movements of Lake Trout within a system (Crossman 1995; Ruzycki et al. 2003). The Priest Lake system is another example of Lake Trout establishment outside of their originally transplanted locations. With a growing body of evidence within the Priest Lake system of Lake Trout reestablishing a healthy population within UPL yearly it is
important to provide information that will aid management decisions regarding the future of the Priest Lake system.

ACKNOWLEDGMENTS

I would like to thank Rob Ryan, Andy Dux, Jim Fredericks, and the Idaho Department of Fish and Game, Scott Deeds and the United States Fish and Wildlife Service, as well as Hickey Brothers Limited Liability Company for working cohesively with me. I thank our peers in the Fisheries Lab at Eastern Washington University for their advice and support. This work was funded by the Kalispel Tribe of Indians.
REFERENCES


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<table>
<thead>
<tr>
<th>Species</th>
<th>Total Length (mm)</th>
<th>Weight (g)</th>
<th>Location</th>
</tr>
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<tr>
<td>Bull Trout (n=40)</td>
<td>449 (115.8)</td>
<td>989.6 (733.1)</td>
<td>UPL</td>
</tr>
<tr>
<td>Lake Trout (n=60)</td>
<td>493.9 (53.6)</td>
<td>998.8 (332.6)</td>
<td>UPL</td>
</tr>
<tr>
<td>Lake Trout (n=160)</td>
<td>447.3 (51.7)</td>
<td>728.3 (248.3)</td>
<td>PL</td>
</tr>
</tbody>
</table>

Table 1.1. Summary of Bull Trout and Lake Trout tagged and released within Priest Lake (PL) and Upper Priest Lake (UPL). Means of total length (mm) and weight (g) of all fish tagged with standard deviation (SD).
Table 1.2. Summary of seasonal and directional movements of Bull Trout and Lake Trout between Priest Lake (PL) and Upper Priest Lake (UPL).

<table>
<thead>
<tr>
<th>Direction of Movement</th>
<th>Season</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
<th>Winter</th>
</tr>
</thead>
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<td>PL-UPL</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td></td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Bull Trout</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>UPL-PL</td>
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<td>4</td>
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</tr>
<tr>
<td>Bull Trout</td>
<td></td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
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</tbody>
</table>
Figure 1.1. Study area including Priest Lake, Upper Priest Lake, and the Thorofare which connects the two lakes.
Figure 1.2. Locations of Lotek JSATS WHS4000L acoustic receivers in Priest Lake (PL) and Upper Priest Lake) at either end of the Thorofare. Detection ranges of each array is shown by hashed circles.
Figure 1.3. Telemetry grid for Priest Lake (PL) and Upper Priest Lake (UPL) with sites marked by (triangles).
Figure 1.4. Temperatures recorded in the Thorofare from 4 August, 2015 to 15 April, 2017. Dashed vertical lines indicate when Thorofare temperatures reach 15°C. Dates of Lake Trout (LKT) from UPL and PL, and Bull Trout (BLT) movements are shown using colored arrows explained by direction.
Figure 1.5. The mean and standard error of days Bull Trout spent within detection range of Priest Lake (PL) and Upper Priest Lake (UPL) acoustic arrays during each season. Seasons are denoted by number, 1=Spring, 2=Summer, 3=Fall, and 4=Winter and * signifies significance at an alpha of 0.05.
Figure 1.6. The mean and standard error of days Lake Trout spent within detection range of Priest Lake (PL) and Upper Priest Lake (UPL) acoustic arrays during each season. Seasons are denoted by number, 1=Spring, 2=Summer, 3=Fall, and 4=Winter and * signifies significance at an alpha of 0.05.
Figure 1.7. The mean and standard error of days Lake Trout from the northern and southern tagging regions spent within detection range of Priest Lake (PL) acoustic array during each season. Seasons are denoted by number, 1=Spring, 2=Summer, 3=Fall, and 4=Winter.
Figure 1.8. Seasonal heat maps of Lake Trout (LKT) distribution histories in Upper Priest Lake (UPL). Number of detections in each site are indicated by color: 1: Green, 2: Yellow, 4: Orange. No LKT were detected in the Spring and Summer due to inaccessibility to UPL.
Figure 1.9. Seasonal heat maps of Lake Trout (LKT) distribution histories in Upper Priest Lake (UPL). A) Spring UPL LKT distributions, b) Summer UPL LKT distributions, and c) Fall UPL LKT distributions. There is no data during the winter season due to inaccessibility.
Figure 1.10. Seasonal heat maps of Lake Trout (LKT) distribution histories in Priest Lake (PL) A) Spring PL LKT distributions, b) Summer PL LKT distributions, c) Fall PL LKT distributions, and d) winter PL LKT distributions.
Diets of Lake Trout in Upper Priest Lake, Idaho

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ABSTRACT
The effects and impacts introduced species have on native species is well known in some cases and less well for others. The introduction and success of Lake Trout in the Priest Lake system, in Idaho, poses a threat to native fish populations. In an effort to further understand the potential competition and predation on native species in Upper Priest Lake, 283 stomachs were collected from Lake Trout in 2015 and 2016. Small Lake Trout (<500 mm total length (TL)) fed at a significantly higher rate on Mysis shrimp (Mysis diluviana) than larger Lake Trout (>500 mm TL; P<0.001). Larger Lake Trout (>500 mm TL) fed at a significantly higher rate on fish than small Lake Trout (P<0.001). Additionally, large Lake Trout had a significantly higher proportion of empty stomachs suggesting that large Lake Trout do not supplement their diet with Mysis shrimp (P<0.001). Based on the diet items of Lake Trout at different lengths suggest that competition between Lake Trout and Bull Trout in UPL is possible and predation was not seen.

INTRODUCTION
The threats of introduced species can vary widely from undetectable to dramatic, and can affect every level of ecosystems (Simon and Townsend 2003). Reductions and extirpations of native species due to introduced species are common but they can also have effects on a multitude of ecological levels (Mack et al. 2000). For instance, introduced species can alter behaviors, abundance or distributions, direct and indirect interactions with native species, and cause trophic cascades (Simon and Townsend 2003). Invasions of aquatic systems by novel predators can be devastating due to the lack of competition, and exploitable prey species that evolved without predators (Kiesecker and Blaustein 1997; Craig et al. 2000).
Nonnative trout have been introduced extensively on every continent except Antarctica (Moyle 1986) in efforts to provide commercial fisheries (Soto et al. 2001) as well as recreational fisheries (Donald 1987; Bahls 1992; Townsend 1996). Historically fishless water bodies and even "protected" areas have been subject to nonnative trout introductions (Donald 1987; Bahls 1992; Knapp et al. 2001). Nonnative trout species can successfully colonize new habitats because trout are highly effective predators (Flecker and Townsend 1994) and are able to readily establish self-sustaining populations (Fausch et al. 2001).

At the individual and population levels, introductions of trout can significantly alter vertebrate and invertebrate communities, often causing extirpations of native fish, amphibians, and benthic macroinvertebrates (Bradford et al. 1998; Carlisle and Hawkins 1998; Tyler et al. 1998; Knapp and Matthews 2000;). Introduced predators can also alter the behavior of native species, mainly through predation or competition (Simon and Townsend 2003). Native species have been observed shifting their diel patterns and distributions (McIntosh and Townsend 1996) due to exposure to novel predators such as introduced fish species. Native invertebrate species and been observed shifting size class structure in response to introduced fish species (Simon and Townsend 2003).

At the community and ecosystem levels, introduced trout species can reduce native fish populations and cause trophic cascades (Simon and Townsend 2003). For instance, Brown and Rainbow Trout (*Salmo trutta* and *Onchorynchus mykiss*, respectively) were introduced to Chile in the early 1900's and they now represent 95% of total fish biomass in streams and rivers (Soto et al. 2006). These introductions have caused detrimental
impacts on native fish fauna, including an absence of native fish in 40% of surveyed streams (Soto et al. 2006).

Similar to other introductions of trout, Lake Trout (*Salvelinus namaycush*), were introduced widely to the western United States in the late 1890’s and early 1900’s in order to create recreational trophy fisheries (Crossman 1995; Martinez et al. 2009). With the success of some of these introductions, Lake Trout have become problematic predators and potential competitors with native trout species (Donald and Alger 1993; Martinez et al. 2009). Lake Trout have fared well in western oligotrophic mountain lakes with extensive hypolimnia (Ruzycki et al. 2003; Dux et al. 2011). Their success in some lakes where they have been introduced has been aided by the presence of sympatric prey such as Mysis shrimp (*Mysida diluviana*; Scott and Crossman 1973; Johnson 1976).

Interactions between Lake Trout and native species are well known in some systems and rather unknown in others. For instance, in Yellowstone Lake, Wyoming, the Lake Trout population consumed an estimated 15 metric tons of Yellowstone Cutthroat Trout (*Onchorynchus clarkii bouvieri*) in 1996 (Ruzycki et al. 2003). Lake Trout require a massive prey demand (Martinez et al. 2009) and are capable of consuming fusiform prey, such as Yellowstone Cutthroat Trout, 50% of their own body length (Ruzycki et al. 2003). Ruzycki et al. (2003) documented that Lake Trout became exclusively piscivorous at lengths >500 mm.

Lake Trout were introduced to the Priest Lake system in 1925 (Bjornn 1957) but maintained a relatively low population until the introduction of Mysis shrimp caused an increase in juvenile survival (Mauser et al. 1988).
Current management of UPL aims to preserve native populations of Bull Trout, a threatened species, Westslope Cutthroat Trout (*Onchorhynchus clarkii lewisi*), and Pygmy Whitefish (*Prosopium coulterii*; USFWS 1998; IDFG 2013). The interactions between Lake Trout and the native species in UPL are not well known and are of interest.

The objective of this study was to identify and quantify UPL Lake Trout diets and potential predation on native fish species. Describing diets of Lake Trout in UPL will help understand the impacts on native species, including Bull Trout and Westslope Cutthroat Trout, and Pygmy Whitefish populations.

**METHODS**

Study Area. - The Priest Lake system, within the Selkirk Mountains of northern Idaho, contains Priest Lake (9,545 ha) and Upper Priest Lake (567 ha) which are connected via a river channel known as the Thorofare. Priest Lake has a mean depth of 38 m, and a maximum depth of 112 m, while Upper Priest Lake has a mean depth of 18 m, and a maximum depth of 32 m. The Thorofare is 2.5 km long, 70 m wide and generally 2-3 m deep.

Fish Capture. - In 2015 and 2016, monofilament sinking gill nets were used for 10 days each year to capture Lake Trout from UPL. Individual gill nets were 91 m long x 2.7 m high and were strung together end to end to form a single long net string. Each long net string contained a standardized range of mesh sizes including 45 mm, 51 mm, 57 mm, 64 mm, 76 mm, 89 mm, 102 mm, 114 mm, and 127 mm stretched mesh. Daily effort consisted of 30 boxes set each day, a box is the equivalent of three 91 m long nets. Specifically, 18 boxes were set in the morning and 12 boxes were set in the evening.
except on initial and final days when only the morning and evening sets, respectively, were deployed. Typically, all nets were deployed for between 2-5 hours.

Stomach Collection. - All Lake Trout captured during gill netting efforts were measured (total length; mm). Stomachs were collected from 25 Lake Trout per every 50 mm size class from 200-500 mm (Table 2.1; n=150). Stomachs were taken from every Lake Trout with a total length >500 (n=133) due to the small proportion of large fish removed. All stomachs were stored in Whirl-Pak bags with 70% Ethanol and kept in a freezer to reduce decomposition rates of prey items.

Age and Growth of Lake Trout. - Growth histories of individual fish were determined by aging scales and then back-calculating lengths at previous ages from scales (Busacker et al. 1990; Francis 1990). Five or more scales were cleaned and mounted between glass slides following methods described by Pierce et al. (1996) and viewed using a Microfiche reader on high resolution setting. All scales were viewed and aged by a single person. Five scales total from each 50-mm size class were aged by a second person without knowledge of previous age assignments and both age assignments were in 100% agreement. For Lake Trout, the Von Bertalanffy growth model fit to the scale size-to-age data was $r^2=0.88721$.

Prey Item Identification. - Stomachs were cut open and all contents were placed in a petri dish by flushing 70% ethanol through the stomach. Stomach contents were keyed down to order for all invertebrates, Arthropods, and Mollusks and sorted into individual containers. Lake Trout diets were quantified using percent composition by weight, percent composition by number, and frequency of occurrence (Chipps and Garvey 2007).
Fish prey items were keyed to species when possible and all insects other than Mysida were grouped into one category (Table 2.2).

Data Analysis. - Lake Trout age-length relationship was analyzed using the “FSA” and “nlstools” packages in “RStudio” (Ogle 2013; Baty et al. 2015). When analyzing differences in proportions of prey items found in Lake Trout stomachs Fisher’s Exact Tests were used.

RESULTS

Age and growth of Lake Trout. - The oldest Lake Trout aged (9 yr) measured 912 mm TL, and the youngest (2 yr) measured 207 mm TL. The analyses were restricted to the size and age range of fish sampled (ages 2-9). Ages assigned by reading scales matched well with previous length-frequency distributions of Priest Lake (Bjornn 1957).

Diets of Lake Trout. - In 2015, 221 stomach were collected from Lake Trout during the annual suppression effort. In 2016, 61 stomachs were taken from Lake Trout >500 mm in order to increase our sample size of larger fish. Lake Trout were placed into two size categories (<500 mm, >500 mm) based on shifts in proportion of prey fish in their diets. Young Lake Trout diets were dominated by Mysis shrimp, but reliance of fish prey items increased as Lake Trout grew (Figure 2.2). Proportions of fish prey items in the diet differed significantly among age groups of Lake Trout (Fischer’s Exact Test P<0.001). Mysis shrimp accounted for 87% of Lake Trout <500 mm diets and 12% of the diet for Lake Trout >500 mm (P<0.001). Fish prey items represented 47% of the diet for Lake Trout >500 mm (P<0.001). Most fish eaten were unable to be identified due to high rates of decomposition at the time of stomach removal. There was a significant difference observed with Lake Trout stomachs having no diet items at all (P<0.001). No prey items
were found in 41% of Lake Trout >500 mm and only 3% of <500 mm had empty stomachs (Figure 2.2).

Lake Trout >500 mm TL had a low rate of feeding on *Mysis diluviana* and most often were seen feeding on fish or had no stomach contents at all. Other invertebrates including Diptera, Ephemeroptera were found in stomachs at low densities.

**DISCUSSION**

Lake Trout in systems within the western United States have been observed competing with and predating on native species (Ruzycki et al. 2003; Donald and Alger 1993). During this study, we found that smaller Lake Trout (<500 mm) supplemented their diet with fish while mainly feeding on Mysis shrimp whereas large Lake Trout (>500 mm) feed primarily on other fish but do not supplement their diet with Mysis shrimp. Since the introduction of Lake Trout to the Priest Lake system in 1925, native species have been adversely impacted and prompted yearly removal efforts in UPL to help preserve native species since 1998. Bull Trout which were abundant prior to the 1950's have experienced a population decline which was concurrent with the population increase of Lake Trout (IDFG 2013). The number of Bull Trout redds declined from 80 in 1985 to 28 per year from 2002-2011. Recently the number of observed Bull Trout redds within index reaches of the Upper Priest River drainage increased to 52 and 53 in 2012 and 2013, respectively (IDFG 2013), possibly owing to gillnetting efforts to remove Lake Trout from UPL from 1998-2016. For example, from 2007 to 2013 it was estimated that the Lake Trout population was depleted by an average of 0.73-1.0 per year (IDFG 2013).

Despite underestimation of aging mature Lake Trout when using scales as the principle measurement (Schram and Fabrizio 1998) these data were similar to previous
studies using scales when aging Lake Trout in Priest Lake, UPL, and Lake Pend Oreille (Bjornn 1957; Scholz and McLellan 2010). Although scales can be inaccurate when aging juvenile Lake Trout, there is agreement with aging juvenile Lake Trout using sagittal otoliths and scales (Schram and Fabrizio 1998). Age of fish is another metric used when identifying shifts to piscivory, for instance, Lake Trout >5 years old are generally piscivorous (Ruzycki et al. 2003). Recent work in Priest Lake aging Lake Trout using sagittal otoliths found maximum ages up to 35 (Ng et al. 2016).

The analysis of 2015 and 2016 Lake Trout stomachs from UPL found results that were comparable to those of Yellowstone Lake where Lake Trout had a diet of 81-98% fish (Ruzycki et al. 2003). Ruzycki et al. (2003) found Lake Trout becoming predominately piscivorous at an approximate length of 500 mm. A similar shift to piscivory was seen in Lake Trout in UPL with diets of >500 mm Lake Trout consisting of fish prey. Furthermore, 41% of Lake Trout >500mm TL collected were absent of any prey items suggesting that Lake Trout >500mm TL in UPL feed primarily on fish and do not supplement their diet with Mysis shrimp.

ACKNOWLEDGEMENTS

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Table 2.1. Summary of Upper Priest Lake (UPL) Lake Trout stomach contents from 2015 and 2016. Frequency of Occurrence (F.O.), percent by number, and percent by weight were calculated from stomach contents.

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<thead>
<tr>
<th>Taxon</th>
<th>F.O.</th>
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<th>% by Weight</th>
</tr>
</thead>
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<tr>
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<td>Other invertebrates</td>
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<td>0.64</td>
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Figure 2.1. Von Bertalanffy Growth Model of Lake Trout in Upper Priest Lake (UPL) aged using scales. $R^2=0.88721$. 
Figure 2.2. Proportion of Upper Priest Lake (UPL) Lake Trout diet items based on size. >500 mm (blue), <500 mm (grey).
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