POPULATION DYNAMICS AND TROPHIC ECOLOGY OF NORTHERN PIKE AND SMALLMOUTH BASS IN COEUR D'ALENE LAKE: IMPLICATIONS FOR THE CONSERVATION OF WESTSLOPE CUTTHROAT TROUT

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

Adfluvial Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* populations have declined significantly since the 1900s in Coeur d'Alene Lake, Idaho. The Coeur d'Alene Tribe has an intense Passive Integrated Transponder (PIT) tagging program and has reported poor juvenile to adult return rates, which is hypothesized to be a result of predation by nonnative species, such as Northern Pike *Esox lucius* and Smallmouth Bass *Micropterus dolomieu*. Sampling occurred on 138 days and 15,645 individual fishes representing 24 species were captured. The population structure and dynamics of Northern Pike and Smallmouth Bass were similar across sampling locations. After pooling data for Coeur d'Alene Lake, growth of Northern Pike and Smallmouth Bass was compared using meta-analysis to other populations across their distributions. The potential effect of predation by Northern Pike on Westslope Cutthroat Trout was evaluated with bioenergetics modeling. Northern Pike (i.e., 2008-2011 year classes) consume an estimated 5,641 Westslope Cutthroat Trout annually from the four sampling locations (i.e., Cougar, Wolf Lodge, Windy bays, Benewah Lake) in Coeur d'Alene Lake.

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DEDICATION

This thesis is dedicated to my supportive family.

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CHAPTER 1: GENERAL INTRODUCTION

Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* is one of 14 subspecies of Cutthroat Trout *O. clarki.* The native distribution of Westslope Cutthroat Trout is the most widespread of the 14 subspecies of Cutthroat Trout spanning both sides of the Continental Divide (Behnke 2002). East of the Continental Divide they are distributed in the upper Missouri River basin in Montana, the northwest corner of Wyoming, and the upper Saskatchewan River basin in southern Alberta (Behnke and Wallace 1986; Behnke 2002). Their distribution west of the Continental Divide spans the upper Columbia River basin of northeastern Washington, the upper John Day River basin in Oregon, and systems throughout northern Idaho (Behnke and Wallace 1986; Behnke 1988). Unfortunately, the current distribution of Westslope Cutthroat Trout has been severely restricted across their distribution and were petitioned for listing as a threatened species under the Endangered Species Act in 1997 (Liknes and Graham 1988; Allendorf et al. 2004).

Populations of Westslope Cutthroat Trout have declined for a variety of reasons. One of the greatest factors contributing to the decline of Cutthroat Trout is their interaction with nonnative Rainbow Trout *Oncorhynchus mykiss*, with which they compete and hybridize (Marnell 1988; Allendorf et al. 2004; Shepard et al. 2005; Muhlfeld et al. 2009). Currently, non-hybridized populations of Westslope Cutthroat Trout inhabit less than 10% of their historic distribution in the United States and less than 20% in Canada (Muhlfeld et al. 2009). A reduction in habitat quality and quantity is a primary factor related to the decrease of Westslope Cutthroat Trout (Gresswell 1988; Liknes and Graham 1988; Marnell 1988; Shepard et al. 2005). The creation of movement barriers (i.e., culverts and dams) has interfered with spawning and other important life history events (Liknes and Graham 1988).

Many populations also exist in watersheds where agriculture is a common land use practice and as a result, channel dewatering and sedimentation are common habitat degradation issues (Moeller 1981; Liknes and Graham 1988). A recent study has shown that damage to riparian habitat from livestock grazing has negatively affected Westslope Cutthroat Trout populations from trampling and sediment accumulation on redds (Peterson et al. 2010). In addition, Westslope Cutthroat Trout were the most common fish species encountered by European settlers in the 19th century and as a result, were important for subsistence and commerce (Behnke 1988). High catchability of Westslope Cutthroat Trout and lack of harvest regulations prompted the overexploitation of many Westslope Cutthroat Trout populations in less than 100 years (Behnke 1988).

In Idaho, Westslope Cutthroat Trout are native to the Kootenai, Pend Oreille, Spokane, Clearwater, and Salmon river systems. The large lakes of northern Idaho originally had abundant populations of Westslope Cutthroat Trout, particularly Coeur d'Alene Lake (Behnke and Wallace 1986). Since the time of early European settlement, Westslope Cutthroat Trout in Coeur d'Alene Lake have declined due to overfishing, loss of stream and riparian habitat to agriculture, pollution from mining in the Coeur d'Alene River basin, and the introduction of nonnative species (Ellis 1932; Mallet 1969; Rankel 1971; Dunham 2002). Historically, reports of anglers catching 3-4 kg Westslope Cutthroat Trout and fishing trips where anglers caught 50 to 100 Westslope Cutthroat Trout averaging 1-2 kg were not uncommon (Vitale et al. 1998). Around the same time, Westslope Cutthroat Trout were also reported to have been harvested from Coeur d'Alene Lake and taken to the "Silver Valley" to feed miners (Vitale et al. 1998).

In an attempt to recover populations of adfluvial Westslope Cutthroat Trout, the Coeur d'Alene Tribe has implemented restoration practices in Lake and Benewah creeks (i.e., two tributaries to Coeur d'Alene Lake; Firehammer et al. 2012). Recently, the Tribe implemented an intensive Passive Integrated Transponder (PIT) tagging study to better understand juvenile survival and adult return rates. The Tribe determined that of the 5,300 outmigrating juveniles that were tagged during 2005-2010, only 1.7% returned as adults to Lake Creek and 2.3% to Benewah Creek (Firehammer et al. 2012). These poor juvenile-adult return rates are two to three times lower than estimates reported for juvenile Westslope Cutthroat Trout in comparable systems using similar techniques (Huston 1984; Stapp and Hayward 2002; Muhlfeld et al. 2009). The mechanism associated with poor survival of adfluvial Westslope Cutthroat Trout is unknown, but is hypothesized to be the result of predation occurring in Coeur d'Alene Lake by nonnative species, such as Northern Pike *Esox lucius* (Rich 1992; Naughton et al. 2004; Muhlfeld et al. 2008; Tabor et al. 2007). However, few studies have focused on the potential effect of nonnative species on Westslope Cutthroat Trout in Coeur d'Alene Lake.

The most extensive study on Northern Pike in the Coeur d'Alene basin was completed by Rich (1992) who focused on their population dynamics, food habits, and movement patterns. Diet analysis for Northern Pike revealed that consumption of Westslope Cutthroat Trout was highly variable among locations and seasons. The work of Rich (1992) provides an excellent foundation for additional research, but the study was spatially and temporally (i.e., one spring and fall sampling) limited resulting in tenuous conclusions regarding the effect of Northern Pike on adfluvial Westslope Cutthroat Trout. Little research has been conducted on Smallmouth Bass *Micropterus dolomieu* in Coeur d'Alene Lake since their introduction. In 2001-2002, the Coeur d'Alene Tribe conducted a study to evaluate the diets of native and nonnative piscivores in Coeur d'Alene Lake (Anders et al. 2003). While the study provided important data on food habits of Northern Pike and Smallmouth Bass, conclusions were unclear due to temporal limitations and low sample sizes (e.g., <30 Northern Pike). Given the shortcomings of previous research and a need to better understand factors influencing Westslope Cutthroat Trout in Coeur d'Alene Lake, the objectives of this project were to: (1) describe the population structure (i.e., size and age structure) and dynamics (i.e., density, growth, mortality) of Northern Pike and Smallmouth Bass and (2) determine the seasonal food habits of Northern Pike and model the consumption of Westslope Cutthroat Trout in Coeur d'Alene Lake.

THESIS ORGANIZATION

This thesis consists of three chapters. In chapter two, the population structure and dynamics for Northern Pike and Smallmouth Bass were analyzed and compared to other populations across North America. This chapter will be submitted to the *Journal of Freshwater Ecology*. Chapter three is a description of Northern Pike food habits from four study sites, along with estimates from a bioenergetics model of the total number of Westslope Cutthroat Trout consumed by Northern Pike. This chapter will be submitted to the *North American Journal of Fisheries Management*. Chapter four is a general summary and synthesis of the thesis.

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CHAPTER 2: POPULATION STRUCTURE AND DYNAMICS OF NORTHERN PIKE AND SMALLMOUTH BASS IN COEUR D'ALENE LAKE, IDAHO

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ABSTRACT

Knowledge of the population structure and dynamics of nonnative species is critical for determining potential problems and solutions for management. Numerous species have been introduced to Coeur d'Alene Lake, Idaho over the last century, but minimal research has been completed to understand their population dynamics. The objective of this study was to describe the population demographics and dynamics of northern pike *Esox lucius* and smallmouth bass *Micropterus dolomieu*, two important nonnative sport fishes in the system. Age and size structure of northern pike and smallmouth bass were similar across bays. The oldest northern pike was age 7 and the oldest smallmouth bass was age 11. The recruitment coefficient of determination was 1.00 for northern pike and 0.98 for smallmouth bass, indicating highly stable recruitment. Total annual mortality was estimated as 66% for northern pike and 42% for smallmouth bass. Growth of northern pike in Coeur d'Alene Lake was comparable to the 50-75th percentiles of growth exhibited by lentic northern pike populations across North America. Growth of northern pike in Coeur d'Alene Lake was most similar to populations in the north-central and northeast United States with faster growth rates and shorter life spans. In contrast, smallmouth bass growth was extremely slow and generally fell within the 5th percentile of lentic smallmouth bass populations in North America. Smallmouth bass growth in Coeur d'Alene Lake was similar to other populations in northern regions of the United States displaying slow growth rates with high longevity. Results of this study provide important insight on nonnative northern pike and smallmouth bass population dynamics. These data will be useful for future comparisons and guiding management decisions in Coeur d'Alene Lake.

INTRODUCTION

The introduction of fishes into systems outside their native distribution has occurred for centuries throughout the world (Gozlan et al. 2010). North America is no exception with some systems even having more nonnative than native species (Horak 1995). A multitude of reasons are responsible for species introductions; however, most fishes have been introduced to meet societal desires (Cambray 2003). Nonnative fishes have been dispersed unintentionally via live bait releases, escapes from aquaculture operations, and the release of pets. Historically, government agencies or other entities introduced species deliberately to provide a food resource (Fuller et al. 1999). More recently, deliberate stockings have occurred to create or supplement a fishery, as a biomanipulation tool, and(or) for conservation efforts. Although not all introductions result in self-sustaining populations, some species become abundant and cause substantial negative ecological and economical effects (Kolar et al. 2010). Nonnative species pose challenges for natural resource management and an understanding of the population dynamics of nonnative species is critical for guiding management actions.

Information on population dynamics or rate functions (i.e., mortality, growth, recruitment) is used in nearly every aspect of fisheries management. Growth is important because it integrates internal (e.g., genetics) and external (e.g., habitat and prey availability) factors, and has been used to evaluate habitat suitability, prey availability, and the influence of management activities (Quist et al. 2012). Estimates of mortality are also essential for assessing fish populations; particularly in exploited populations (Allen and Hightower 2010). Recruitment is also an important rate function, but it is one of the most variable and difficult functions to quantify (Isermann et al. 2002). While each of these functions is important, information on all aspects of fish population dynamics are central to making informed management decisions. Nonnative species are of particular interest because factors influencing their population dynamics are likely quite different than in areas where they are native.

Two nonnative species of interest in western North America are northern pike *Esox lucius* and smallmouth bass *Micropterus dolomieu*. Northern pike are top-level piscivores with a circumpolar distribution. They are a mesothermal fish that occur across a wide range of environmental conditions; however, they prefer shallow and vegetated habitats (Casselman and Lewis 1996; Craig 2008). Their popularity as a sport fish prompted northern pike to be introduced to systems across North America (Crossman 1978). In addition to being stocked for sport fishery enhancement, they have also been introduced as a biomanipulation tool (Pflieger 1997). Smallmouth bass have a native distribution spanning from the Great Lakes and St. Lawrence River south to the Mississippi River and its tributaries (Page and Burr 1991; Carey et al. 2011). Like northern pike, smallmouth bass are a popular sport fish and have been stocked throughout North America (Carey et al. 2011). In addition to frequent and widespread introductions, the success of smallmouth bass outside their native distribution is attributed to their ability to thrive in diverse habitats (Coble 1975; Brown and Bozek 2010).

Northern pike and smallmouth bass were introduced either legally or illegally in Idaho as a result of growing interest by anglers for coolwater and warmwater sport fisheries (Dillon 1992). Little is known about the illegal introduction of northern pike to Idaho, but they were first encountered in floodplain lakes along the Coeur d’Alene River, known as the “chain lakes” in the early 1970s (Rich 1992). The availability of prey items and quantity of optimum habitat resulted in a high abundance of northern pike in the chain lakes, as well as Coeur d'Alene Lake. Northern pike quickly became a very popular sport fish due to their novelty, abundance, and ability to reach a large size. The Idaho Department of Fish and Game introduced smallmouth bass to Idaho in 1905. Not only were smallmouth bass introduced in response to angler interest, but also their ability to occupy cool and coldwater habitats common throughout the state (Simpson and Wallace 1982; Dillon 1992). Unfortunately, smallmouth bass were transported to additional water bodies by anglers. For example, smallmouth bass are thought to have been illegally introduced to Coeur d'Alene Lake, Idaho from Hayden Lake in the early 1990s (Anders et al. 2003).

Regardless of how a species entered a system and is managed, an understanding of their population dynamics is important to guide management actions. Unfortunately, the population demographics and dynamics of northern pike and smallmouth bass in Coeur d'Alene Lake have not been thoroughly studied. This lack of knowledge limits the ability of managers to make informed decisions. Thus, the objectives of this study were to describe the population demographics and dynamics of northern pike and smallmouth bass in Coeur d'Alene Lake, Idaho. Additionally, growth data were compared to other northern pike and smallmouth bass populations across their distributions to place the growth of these two nonnative species in the context of other populations and discern any large-scale patterns.

METHODS AND MATERIALS

Coeur d'Alene Lake is the second largest natural lake in Idaho with a surface area of 12,700 ha (Figure 2.1). The lake has a mean depth of approximately 24 m and a maximum depth of 61 m (Rich 1992; Vitale et al. 2004). Primary tributaries to Coeur d'Alene Lake are the Coeur d'Alene and St. Joe rivers, with many small streams also contributing to the system. Post Falls Dam was constructed on the outlet in 1906 and raised the water level of the lake by 2.5 m creating an abundance of shallow, vegetated habitat (Rich 1992). The lake has been classified as mesotrophic based on nutrient concentrations; however, heavy metals from 100 years of mining and ore processing in the watershed limit biological production (Committee on Superfund Site Assessment Remediation in the Coeur d'Alene River Basin National Research Council 2005).

Study sites (i.e., Wolf Lodge, Cougar, and Windy bays and Benewah Lake) in Coeur d'Alene Lake were selected based on current locations of Westslope Cutthroat Trout PIT tag research and previous studies on northern pike. Stratified random sampling was used to select sampling sites by dividing the shoreline of four bays into 300 m sections and randomly assigning a section to a gear type. A sampling event consisted of sampling eighteen non-overlapping sections (i.e., 12 gill net and 6 electrofishing sites). A sampling event occurred once per month in Cougar and Wolf Lodge bays (i.e., March 2012 – May 2013). Windy Bay and Benewah Lake were sampled once per month during June - November (2012) and twice per month from March – May (2012 and 2013).

Fish were sampled using a variety of sampling gears to maximize capture of northern pike and smallmouth bass. Gears included pulsed-DC electrofishing and experimental gill nets (46 m × 1.8 m with panels of 25, 32, 38, 44, 50-mm bar-measure mesh). Electrofishing was conducted using a 5,000 W generator mounted in an aluminum boat with Smith-Root (Smith-Root, Inc., Vancouver, Washington) equipment. Power output was standardized to 2,750-3,250 W based on ambient water conductivity (µS/cm; Miranda and Boxrucker 2009). Gill nets were fished for 1.5 - 2.0 hours to minimize mortality. Kobler et al. (2008) found that northern pike movement was more homogenous during the winter than in other months, with higher movement occurring during the day. Thus, nets were set at dusk, except during October - April when nets were fished during the day. Additionally, operating a boat at night during periods with low water (e.g., fall, winter) was hazardous due to ice and the emergence of obstacles (e.g., logs, islands).

Total length from northern pike and smallmouth bass was measured to the nearest millimeter and weight was recorded to the nearest gram. Dorsal spines from smallmouth bass and pelvic fin rays from northern pike were collected from ten fish per centimeter length group (Laine et al. 1991; Quist et al. 2012). Spines and fin rays were placed into coin envelopes and allowed to air dry before processing (Koch and Quist 2007). Otoliths from smallmouth bass and cleithra from northern pike were collected to corroborate ages from pelvic fin rays and dorsal spines. Agreement between ages for otoliths and dorsal spines from smallmouth bass was 100%. Similarly, age agreement was 100% between cleithra and fin rays from northern pike.

Half of the captured northern pike were tagged using an individually-numbered, non-reward FD-94 T-bar anchor tag (76 mm; Floy Tag Inc., Seattle, Washington) that was inserted near the posterior end of the dorsal fin. All other northern pike were tagged with an individually-numbered, non-reward 6 mm × 16 mm Carlin dangler tag (Floy Tag Inc., Seattle, Washington) that was inserted in the caudal peduncle (Quist et al. 2010). Tag loss was assessed on all northern pike by completely removing the left pelvic fin (Nielson 1992; Guy et al. 1996). All tags also had the telephone number for the Idaho Department of Fish and Game's tag reporting hotline. Smallmouth bass exploitation was reported to be low from a creel survey performed by the Idaho Department of Fish and Game (Hardy et al. 2009).

Therefore, smallmouth bass were only marked by completely removing the left pelvic fin (Nielson 1992; Guy et al. 1996).

Proportional size distribution (PSD) was estimated to describe the length-frequency distribution:

$$PSD = \left(\frac{a}{b}\right) \times 100,$$

where *a* equals the number of fish greater than or equal to the minimum quality length and *b* is the number of fish greater than or equal to the minimum stock length. Length-frequency distributions were further summarized with PSDs for other length categories (i.e., preferred, memorable). Minimum total lengths for length categories were provided by Neumann et al. (2012).

Total annual mortality was estimated from age-3 and older northern pike and age-2 and older smallmouth bass using a weighted catch curve (Miranda and Bettoli 2007; Smith et al. 2012). Younger individuals were excluded from the analysis as they were not fully recruited to the sampling gears. Recruitment variation was measured using the coefficient of determination (r^2; recruitment coefficient of determination [RCD]) from a simple linear regression of $\log_e$(catch) as a function of age (Isermann et al. 2002). The RCD varies from -1 to 1; values approaching 1 indicate stable recruitment (Isermann et al. 2002). Exploitation for northern pike was estimated using the non-reward tag reporting estimator described by Meyer et al. (2012) along with estimates of tag loss (10.2%) and tagging mortality (0.4%).

Mean back-calculated lengths-at-age were estimated using the Dahl-Lea method:

$$L_i = \frac{S_i}{S_c} \times L_c,$$

where L_i is the back-calculated length of the fish when the *i*th increment was formed, L_c is length of the fish at capture, S_c is the radius of the ageing structure at capture, and S_i is the radius of the ageing structure at the *i*th increment (Quist et al. 2012). Mean back-calculated lengths-at-age for northern pike and smallmouth bass were summarized by bay and for the lake. In addition, a von Bertalanffy growth model was fit for northern pike and smallmouth bass populations in Coeur d'Alene Lake:

$$L_t = L_\infty \times (1 - e^{-K(t-t_0)}),$$

where L_t is the length at time *t*, L_∞ is the theoretical maximum length, *K* is the Brody growth coefficient, and t_0 is the time when length would theoretically equal 0 mm.

Growth estimates of northern pike and smallmouth bass in Coeur d'Alene Lake were compared to North America percentiles (i.e, 5th, 25th, 50th, 75th, and 95th) of mean lengths-at-age of fish from lentic systems (Bonar et al. 2009). Nonmetric multidimensional scaling (NMDS) was used to examine how growth of northern pike and smallmouth bass in Coeur d'Alene Lake compared to other populations on a large-scale (Kruskal and Wish 1984). Data used for NMDS analysis were gleaned from published literature across northern pike and smallmouth bass distributions from lentic systems. Growth data used for the NMDS analysis consisted of *K* and L_∞ from the von Bertalanffy growth model, maximum age, and length-at-age 3. Northern pike and smallmouth bass growth data were grouped into regions. Regions used for northern pike included north-central United States (i.e., Iowa, Minnesota, South Dakota, Wisconsin), northeast United States (i.e., New York, Ohio), Ontario, Northwest Territories, and Europe (i.e., Croatia, England, Lithuania, Ireland, Italy, Scotland). Smallmouth bass regions were divided into the northwest United States (i.e., Idaho, Washington), north-central United States (i.e., Illinois, Wisconsin, Great Lakes), northeast

United States (i.e., Maryland, Massachusetts, New York, Pennsylvania, Virginia), southwest United States (i.e., Southern California), south-central United States (i.e., Oklahoma, Texas), and southeast United States (i.e., North Carolina, Tennessee). The NMDS ordinations were conducted using Bray-Curtis dissimilarity measures in the Vegan package, Program R (R Development Core Team 2009).

RESULTS

A total of 736 northern pike was captured, of which 573 were marked and 98 were recaptured. The proportion of recaptures of northern pike was highest (38%) in Windy Bay, while the proportion of recaptures in other bays was roughly 9% (Table 2.1). A total of 1,418 smallmouth bass was also sampled, of which 772 were marked and 19 were recaptured. Smallmouth bass recaptures were rare (~2%) in Wolf Lodge, Cougar, and Windy bays and none were recaptured in Benewah Lake (Table 2.1). Fifty-eight northern pike were sampled with electrofishing and 678 were sampled with gill nets. Electrofishing catch rates for northern pike were generally low, but were the highest in the fall (Figure 2.2). Northern pike catch rates using gill nets were highest in the spring and decreased by about 50% in the summer and fall (Figure 2.2). Electrofishing sampled 1,316 smallmouth bass and 102 smallmouth bass were sampled with gill nets. Catch rates for smallmouth bass were consistently high in Wolf Lodge Bay and low in Benewah Lake across all seasons (Figure 2.2). Catch rates of smallmouth bass using gill nets were relatively low for all seasons (Figure 2.2).

Size structure of northern pike was similar across all bays with slightly smaller fish in Benewah Lake (Figure 2.3). Proportional size distribution of preferred-length northern pike was highest in Windy Bay. Similar to northern pike, the PSD for smallmouth bass was similar in each bay with smaller fish in Windy Bay (Figure 2.4). The smaller size structure of smallmouth bass in Windy Bay was made more evident by the lower PSD-P and PSD-M (i.e., memorable) values. Smallmouth bass PSDs of preferred and memorable-length for Benewah Lake were not calculated as individuals greater than or equal to 280 mm (i.e., quality length) were not captured. The RCD was 1.00 for northern pike and 0.98 for smallmouth bass, indicating highly stable recruitment (Figure 2.5). Total annual mortality was estimated as 66% for northern pike and 42% for smallmouth bass (Figure 2.5). A total of 566 northern pike that varied from 162-1080 mm in total length was either tagged with individually numbered Floy T-bar or Carlin dangler tags. Anglers reported 93 tags to the Idaho Department of Fish and Game. Of the fish caught and reported, 79 (85.0%) were harvested and 51.6% of the fish reported were captured during spring. Exploitation of northern pike was estimated at 31.0%.

Growth of northern pike was similar across all bays with the exception of Wolf Lodge Bay, where growth began to slow at age 3 (Figure 2.6). Growth of northern pike in Coeur d'Alene Lake was between the 50^{th} and 75^{th} percentiles for North America lentic populations (Figure 2.7). Growth of smallmouth bass in Windy and Wolf Lodge bays was similar for all ages (Figure 2.6). Interestingly, mean length-at-age of smallmouth bass was generally highest in Cougar Bay. Mean length-at-age of smallmouth bass in Benewah Lake was not calculated due to small sample sizes. Smallmouth bass in Coeur d'Alene Lake grew extremely slow and was most similar to populations in the 5^{th} percentile for North America (Figure 2.7).

The NMDS analysis of growth from lake systems produced stable ordinations for northern pike (2 axes; stress = 0.03; Figure 2.8) and smallmouth bass (2 axes; stress = 0.04; Figure 2.9). Northern pike populations clustered into four groups (e.g., Ontario, Northwest Territories, Europe, northern United States). Growth of northern pike in Coeur d'Alene Lake was most similar to populations in the north-central and northeast United States with fast growth rates and short life spans. The NMDS ordination of growth for smallmouth bass was highly variable between regions and clustered into north and south groups. Smallmouth bass growth in Coeur d'Alene Lake was similar to other populations in northern regions of the United States displaying slow growth rates with high longevity.

DISCUSSION

Stock assessment indices (e.g., PSDs) have been used as a tool to describe population structure, for assessing dynamics of populations, and various interactions in fish assemblages (Neumann et al. 2012). The size structure of northern pike was high with the majority of individuals longer than quality length (530 mm) in each bay suggesting fast growth. Interestingly, Rich (1992) also reported that the PSD of northern pike in Cougar Bay was 94 and hypothesized that the size structure would decrease due to increased angler interest and high exploitation. Twenty years later, PSDs near 90 were observed throughout the Coeur d'Alene system. Size structure of smallmouth bass was similar between bays with the majority of individuals below stock length (180 mm). Low PSDs are indicative of slow growth or high mortality of large fish (Anderson and Weithman 1978). Smallmouth bass in Coeur d'Alene Lake do not reach quality length (i.e., 280 mm) until age 7, suggesting that slow growth is at least partly responsible for the low PSDs.

Estimates of total annual mortality for northern pike and smallmouth bass vary greatly across their distributions. Kempinger and Carline (1978) reported high total annual mortality rates for northern pike varying from 59% to 91% in Escanaba Lake, Wisconsin. Alternatively, low total annual mortality rates varying from 19% to 57% were reported by Mosindy et al. (1987) for Savanne Lake, Ontario and Diana (1983) for three Michigan lakes. Total annual mortality for northern pike in Coeur d'Alene Lake was relatively high (i.e., 66%). Total annual mortality of smallmouth bass was lower (i.e., 42%) than those reported for other systems in the Pacific Northwest. For example, Anglea (1997) reported that total annual mortality was 52% for smallmouth bass in Lower Granite Reservoir, Washington. Beamesderfer and North (1995) reported that growth and mortality rates of smallmouth bass were lower in waters in northern latitudes, but also noted that smallmouth bass in unproductive northern waters could display slow growth and high mortality.

Exploitation of northern pike was moderately high (31.0%) with the majority of fish caught during the spring. Few tags were reported during the summer, likely due to northern pike inactivity and individual fish moving to deeper water after spawning (Diana et al. 1977; Rosell and MacOscar 2002). A noticeable decrease in anglers targeting northern pike after spring is also likely a result of anglers seeking other nonnative sport fish species such as largemouth bass *Micropterus salmoides*, Chinook salmon *Oncorhynchus tshawyscha*, and kokanee *O. nerka*. The primary drivers for mortality of smallmouth bass are also difficult to identify. Dunlop et al. (2005) argued that higher mortality of smallmouth bass in Provoking Lake, Ontario relative to Opeongo Lake, Ontario was due to resource limitations. Similar mechanisms may be regulating survival of smallmouth bass in Coeur d'Alene Lake.

Growth is often used as an indication of resource availability. Fast growth rates are often common for populations with abundant food resources and quality habitat (Allen and Hightower 2010). Alternatively, slow growth rates often indicate that fish densities are too high for available resources (Allen and Hightower 2010). Rich (1992) reported that lengths of northern pike from Cougar Bay were 31% higher than the North American average reported by Carlander (1969). Rich (1992) also found the oldest individual was age 8 and noted that the rapid growth rate was likely limiting longevity. We showed similar growth rates and age structure of northern pike. Age-1 to age-4 northern pike had growth rates that were similar to the 50th percentile of North American populations (Bonar et al. 2009). Individuals older than age 4 approached the 75th percentile. In contrast to northern pike, growth of smallmouth bass in Coeur d'Alene Lake was extremely slow compared to other smallmouth bass populations in North America (Bonar et al. 2009). Similarly, Anglea (1997) reported smallmouth bass in Lower Granite Reservoir, Washington grew slowly (~25th percentile of North America populations).

Growth of individuals can be influenced by many factors such as inter- and intraspecific competition, food availability, physiological demands, and temperature (Weatherley 1976). We are unable to identify the primary driver for the high growth rate of northern pike in Coeur d'Alene Lake. However, high mortality and abundant prey fishes likely prompted their fast growth. In relation to the slow growth of smallmouth bass, the Coeur d'Alene basin has a long history of mining and has resulted in a significant reduction in the productivity of invertebrates in Coeur d'Alene Lake (Savage and Rabe 1973). Dunlop et al. (2005) suggested intraspecific competition of smallmouth bass was a primary factor for slow growth in Provoking Lake, Ontario. Similarly, low invertebrate productivity of Coeur d'Alene Lake coupled with intraspecific competition could explain the slow growth of smallmouth bass in the system.

Latitudinal patterns in fish population dynamics have been well documented (Quist et al 2003; Denit and Sponaugle 2004). Populations in northern latitudes often exhibit slower growth rates, greater longevity, and lower total annual mortality than southern latitudes (Beverton 1987; Quist et al. 2003; Porter et al. in press). Several mechanisms are likely related to these latitudinal patterns. Studies have shown that fishes in northern latitudes will often invest more energy into somatic growth and delay reproduction, whereas those at southern latitudes will reproduce at a younger age and smaller size (Heibo et al. 2005; Blanck and Lamouroux 2007). Braaten and Guy (2002) reported that increases in water temperature, degree-days, and the duration of the growing season from north to south were related to increased growth of numerous fishes in the Missouri and lower Yellowstone rivers. Rypel (2012) stated annual growth rates of northern pike in North America were primarily driven by water temperature and decreased with increasing latitude. Similar mechanisms are likely responsible for the large-scale patterns in growth we observed for northern pike and smallmouth bass populations. Northern pike in northern latitudes (i.e., Northwest Territories) grew at slower rates with greater longevity compared to the Coeur d'Alene Lake population; Coeur d'Alene Lake is near the southern end of their circumpolar distribution. Similarly, smallmouth bass at southern latitudes grew at faster rates and had lower longevity compared to northern populations such as Coeur d'Alene Lake. Acknowledging latitudinal differences in population dynamics can result in better management of sport fish populations and provides a broader context for understanding population dynamics.

Northern pike in Coeur d'Alene Lake exhibited fast growth and a large size structure, likely due to their low densities, high mortality, and diet plasticity. Smallmouth bass grew slowly and had poor size structure, likely due to low availability of invertebrates and intraspecific competition. Additionally, the steady recruitment of northern pike and smallmouth bass in Coeur d'Alene Lake indicated that density-dependent effects influenced the population dynamics of their year classes similarly. Hopefully, the description of the population dynamics and their potential drivers for these two species will provide insight on their ecology and management.

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Table 2.1. Frequency of northern pike and smallmouth bass marked or recaptured in bays in Coeur d’Alene Lake, Idaho.

	Northern pike		Smallmouth bass	
Site	# marked	# recaptured	# marked	# recaptured
Wolf Lodge Bay	44	3	372	11
Cougar Bay	85	7	57	1
Windy Bay	143	55	337	7
Benewah Lake	301	33	6	0

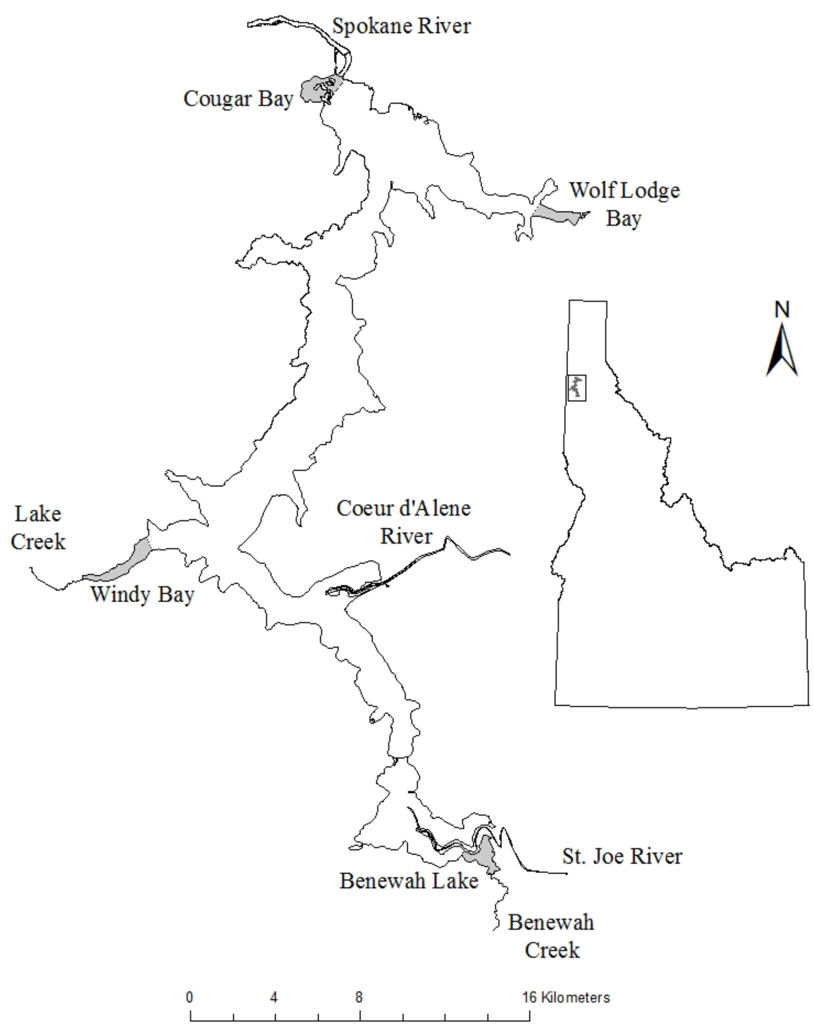


Figure 2.1. Map of Coeur d'Alene Lake in northern Idaho. Idaho Department of Fish and Game manages the lake north of the mouth of the Coeur d'Alene River. The Coeur d'Alene Tribe manages the lake south of the mouth of the Coeur d'Alene River as well as the Lake Creek watershed. Sampling sites were located in Cougar, Wolf Lodge, and Windy bays, and Benewah Lake.

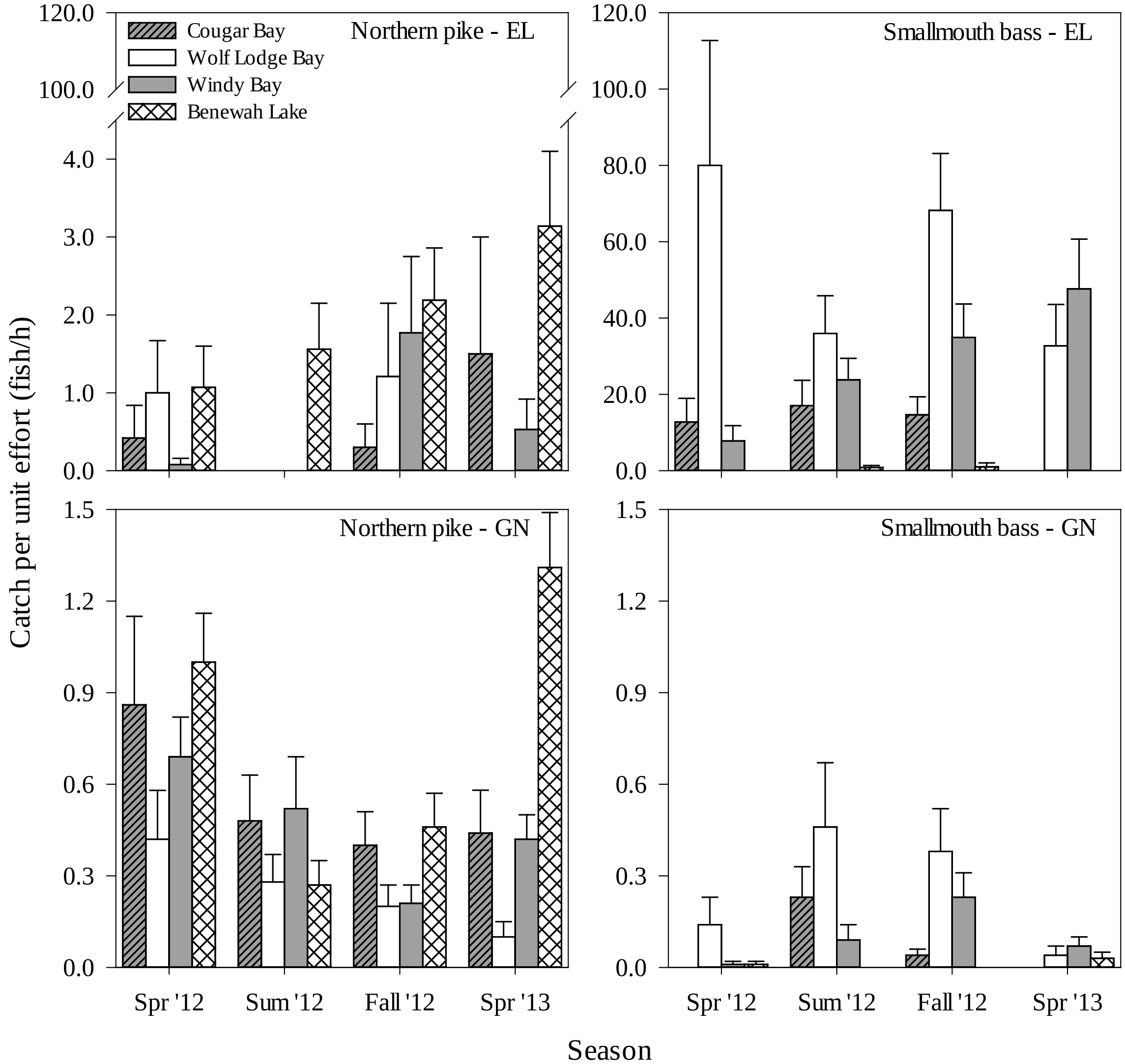


Figure 2.2. Mean catch per unit effort (fish/hr) of northern pike (left panels) and smallmouth bass (right panels) with electrofishing (EL; top panels) and gill netting (GN; bottom panels) by season in Coeur d'Alene Lake, Idaho. Months were grouped together based on water temperature: spring (March, April, May), summer (June, July, August), and fall (September, October, November). Error bars represent one standard error.

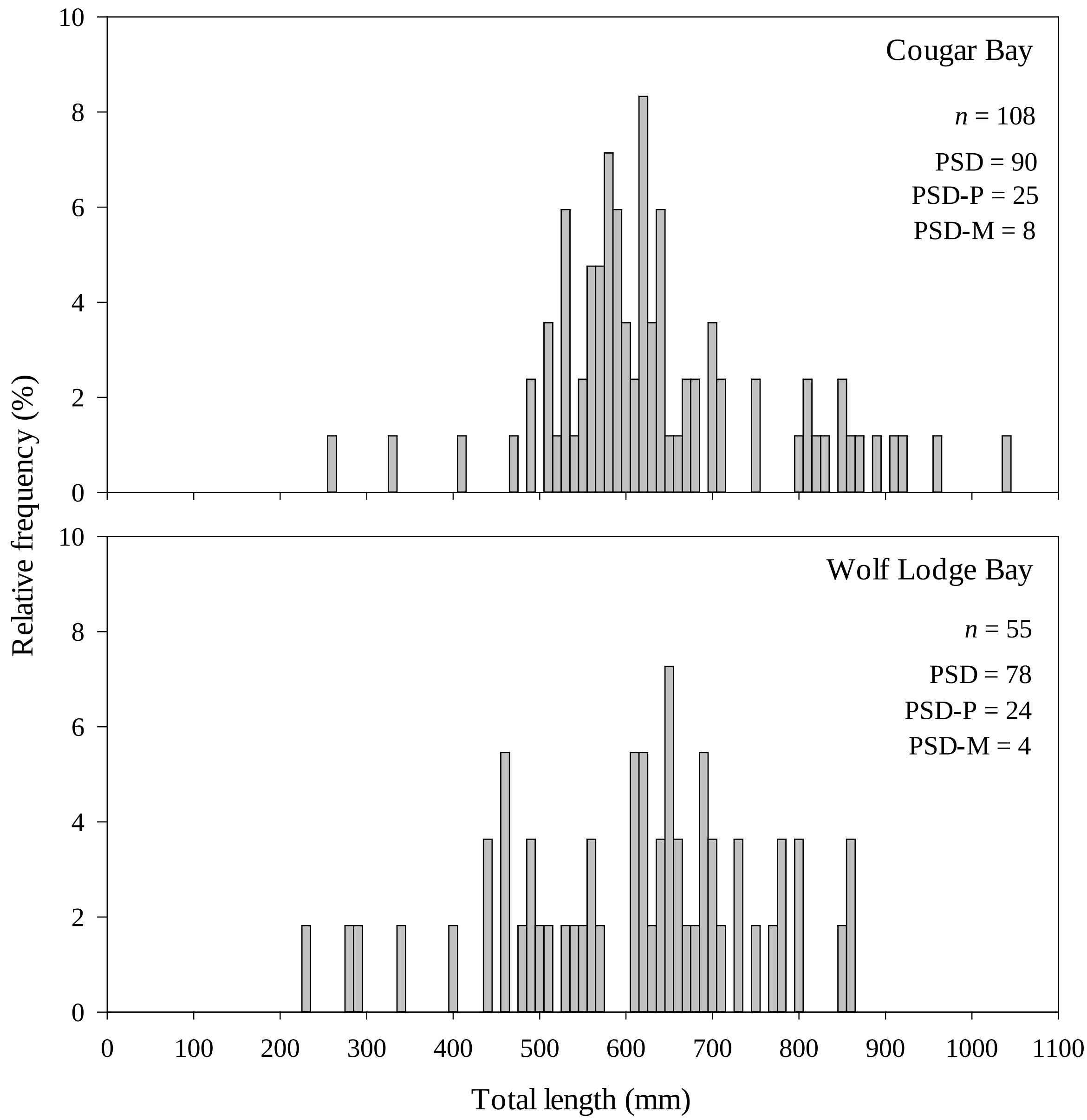
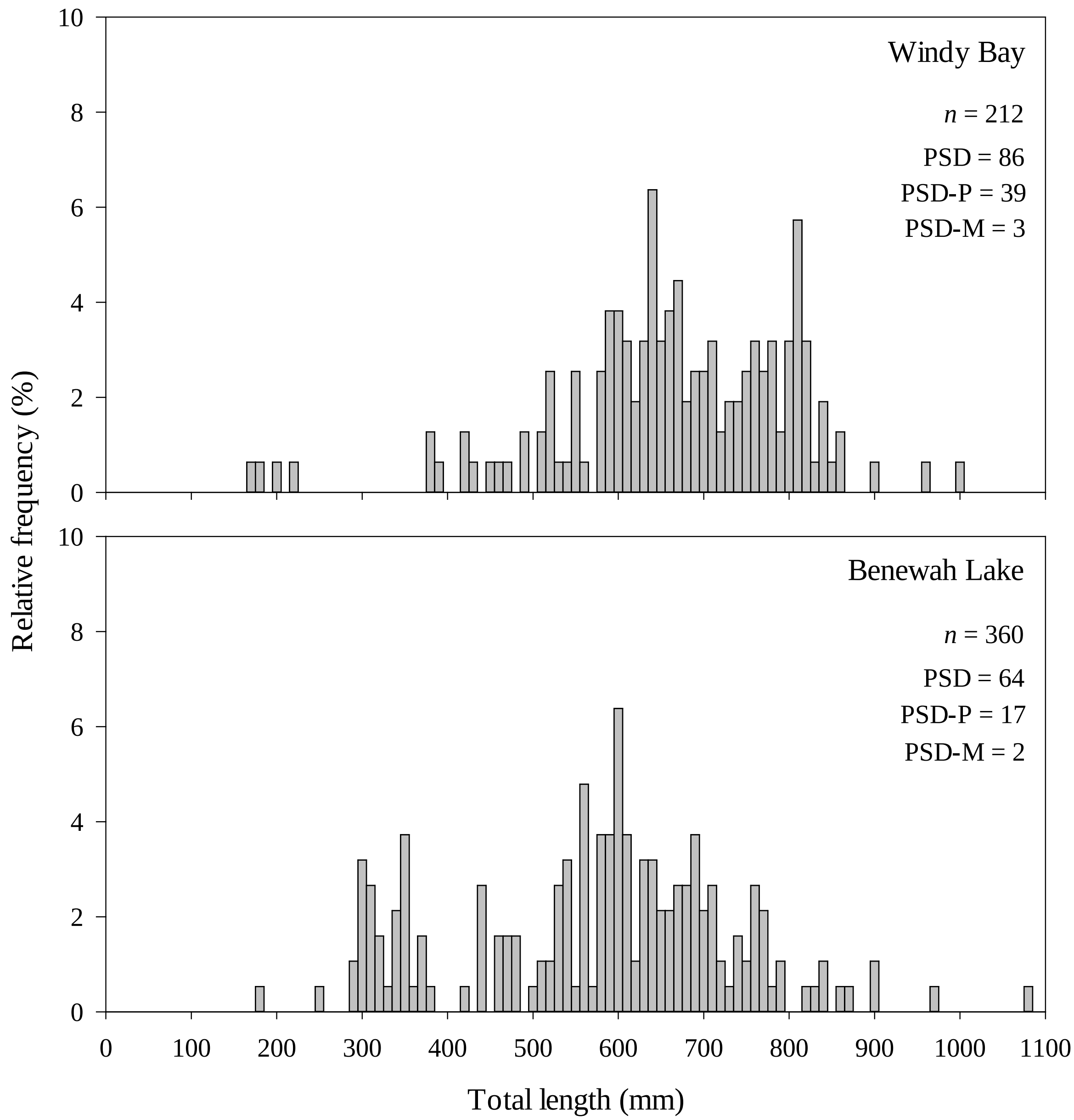


Figure 2.3. Length-frequency distribution, sample size, proportional size distribution (PSD), preferred size distribution (PSD-P), and memorable size distribution (PSD-M) for northern pike in Cougar, Wolf Lodge, and Windy bays, and Benewah Lake in Coeur d'Alene Lake, Idaho.



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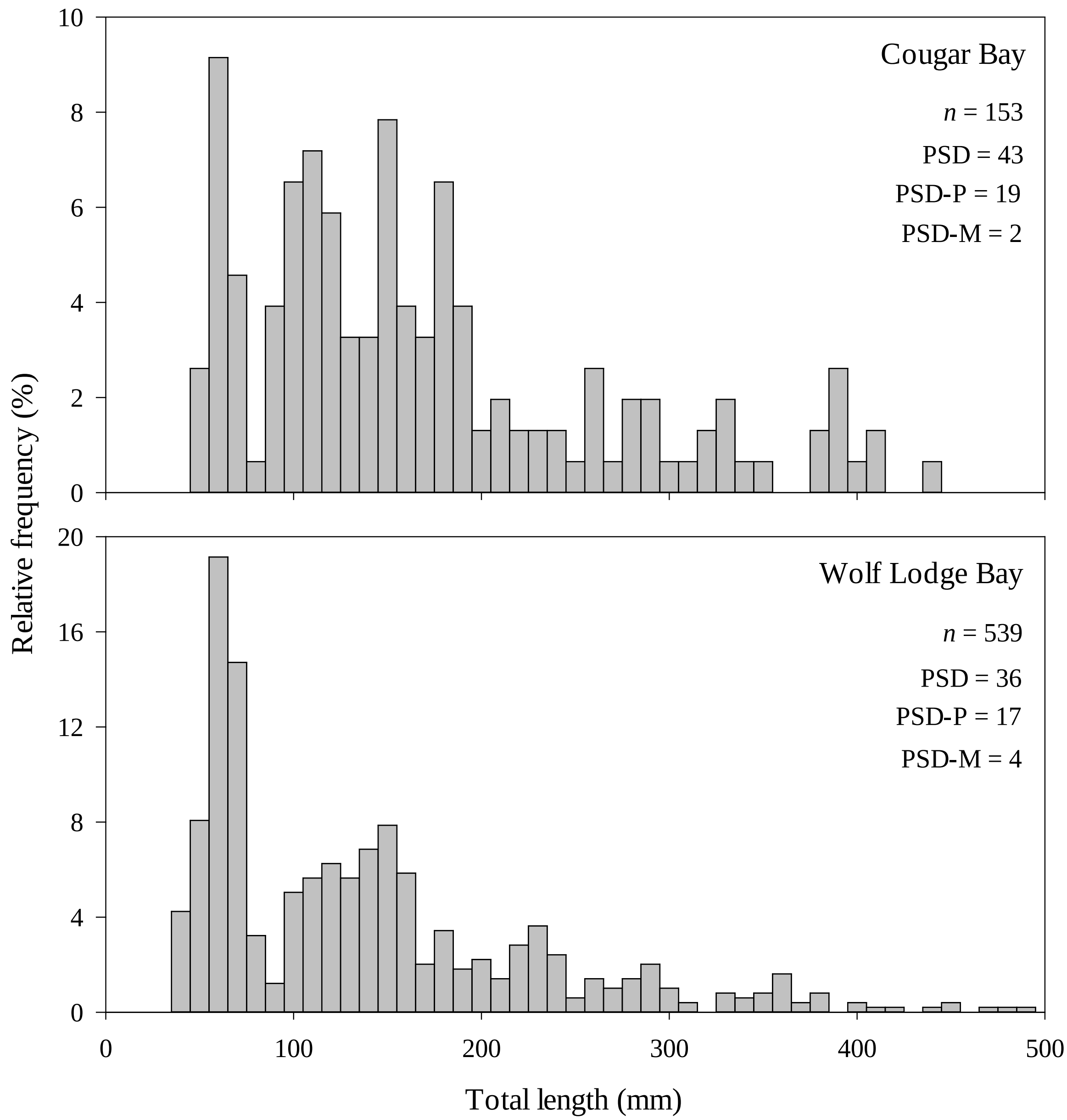
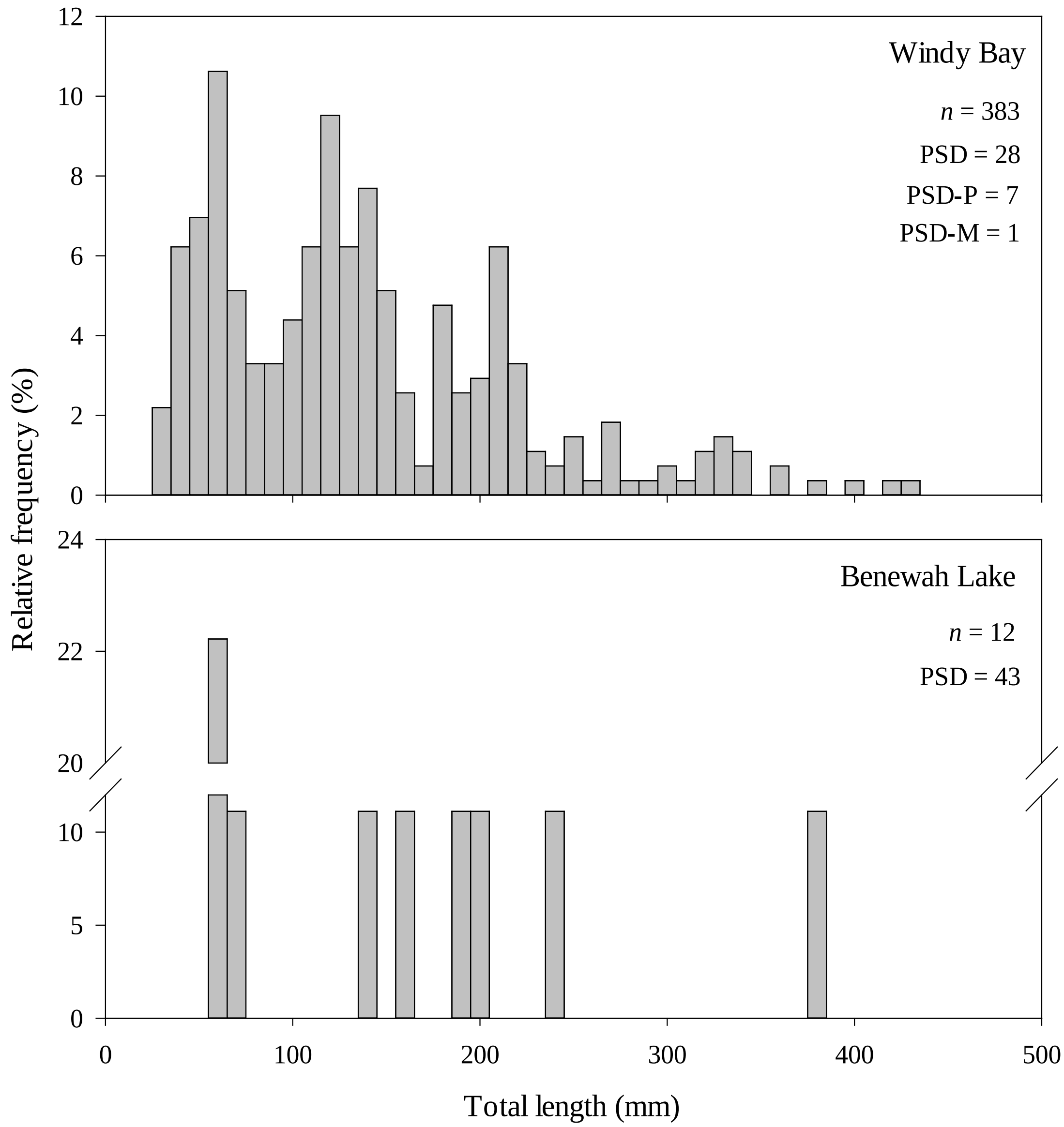


Figure 2.4. Length-frequency distribution, sample size, proportional size distribution (PSD), preferred size distribution (PSD-P), and memorable size distribution (PSD-M) for smallmouth bass in Cougar, Wolf Lodge, and Windy bays, and Benewah Lake in Coeur d'Alene Lake, Idaho. Note that the y-axis scales are different.



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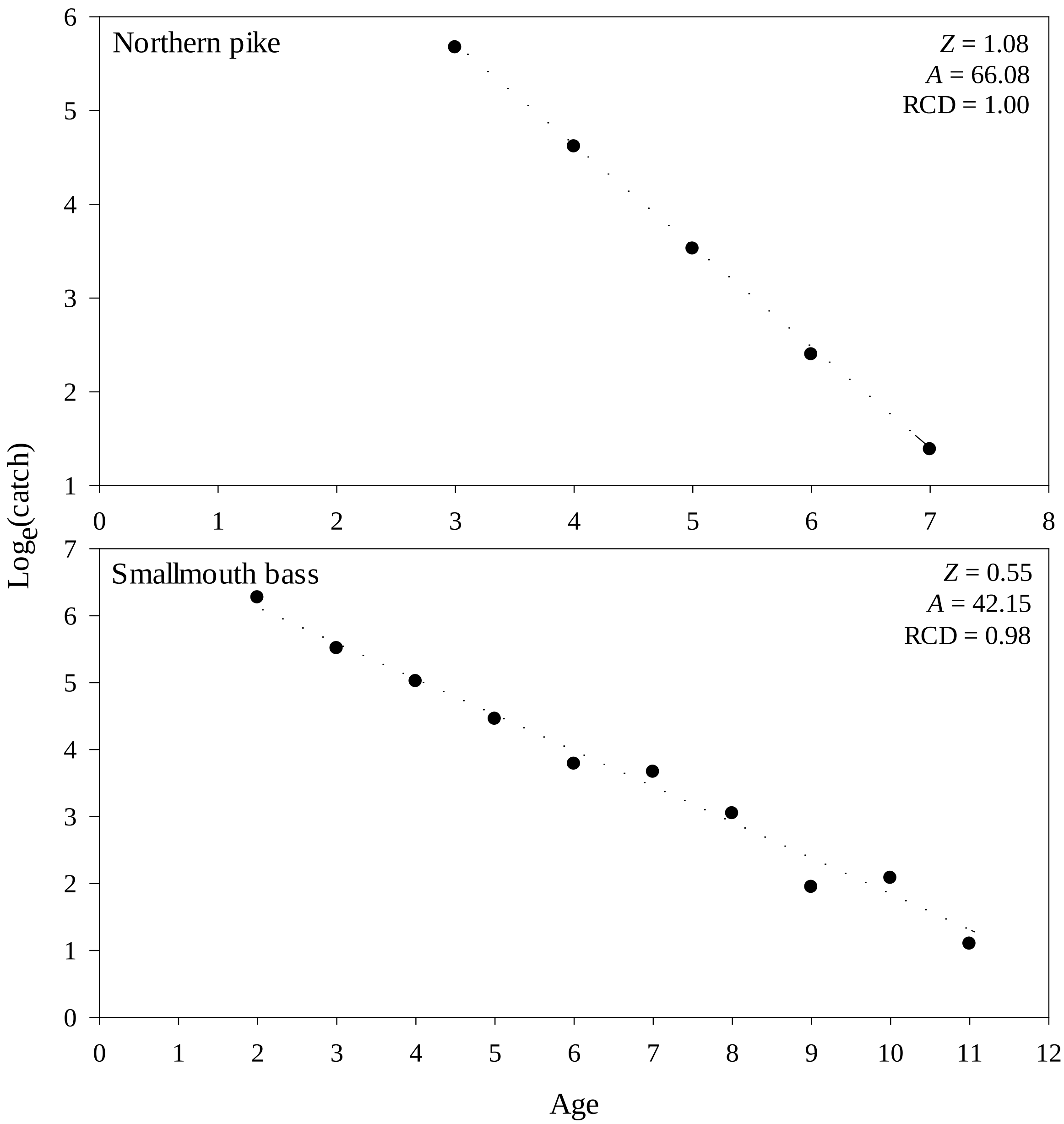

Figure 2.5. Instantaneous (*Z*) total mortality, total annual mortality (*A*), and recruitment coefficient of determination (RCD) for northern pike (top panel) and smallmouth bass (bottom panel) in Coeur d'Alene Lake, Idaho.

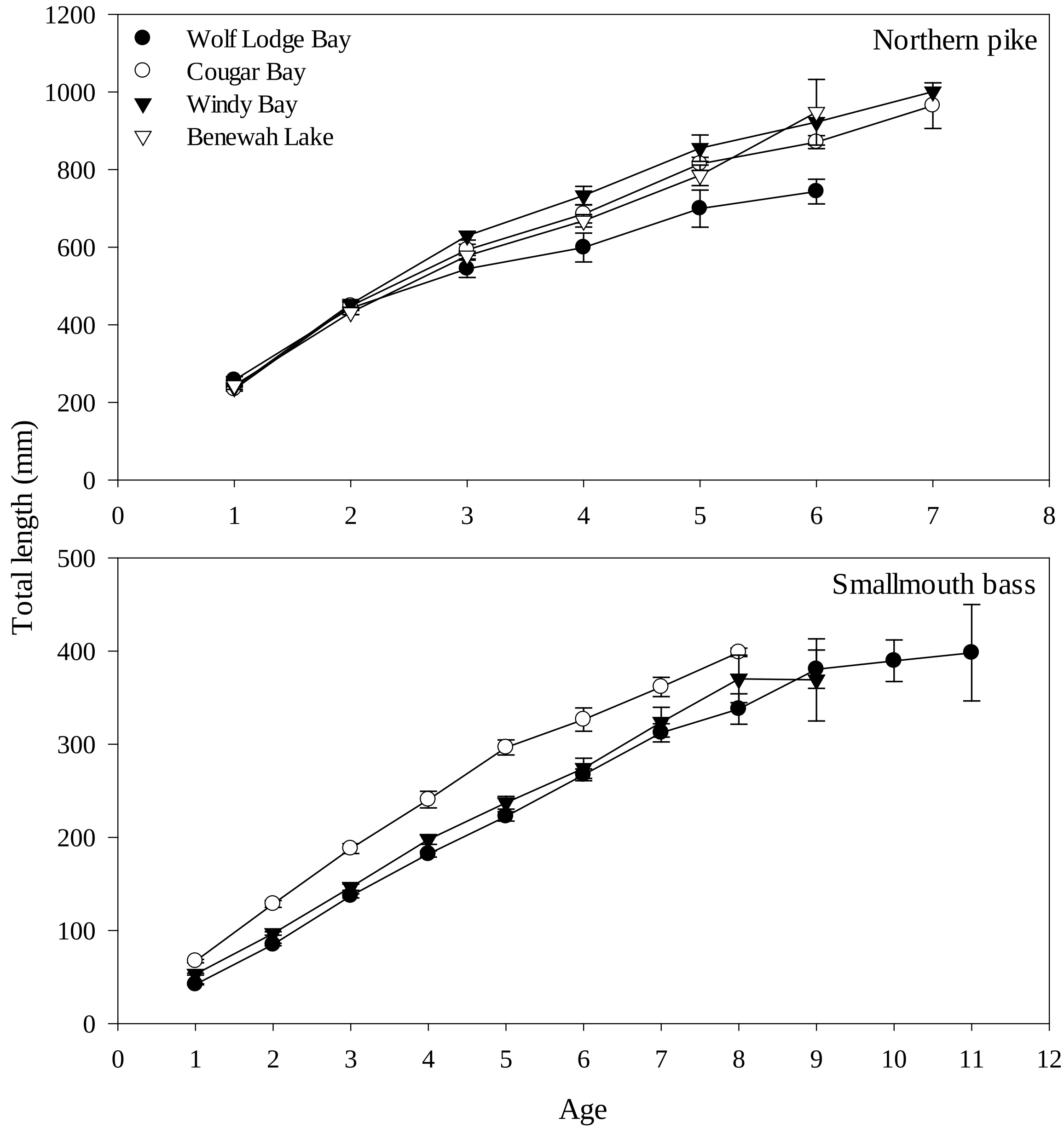

Figure 2.6. Mean back-calculated length-at-age for northern pike (top panel) and smallmouth bass (bottom panel) in bays sampled in Coeur d'Alene Lake, Idaho. Mean back-calculated length-at-age could not be derived in Benewah Lake for smallmouth bass due to the small sample size. Error bars represent one standard error.

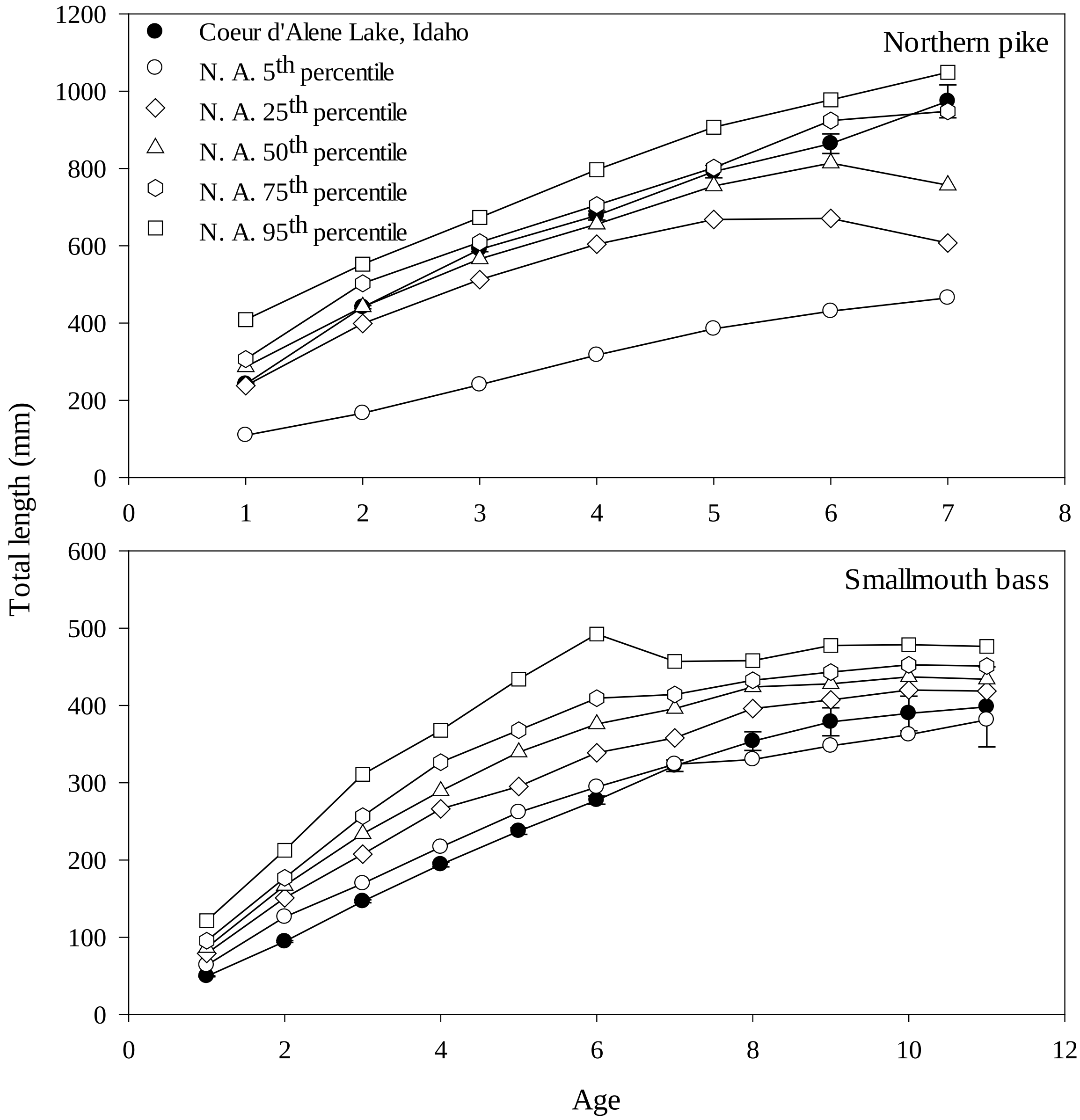

Figure 2.7. Mean back-calculated length-at-age for northern pike (top panel) and smallmouth bass (bottom panel) in Coeur d’Alene Lake, Idaho compared to North America (N. A.) lentic percentiles. Error bars represent one standard error.

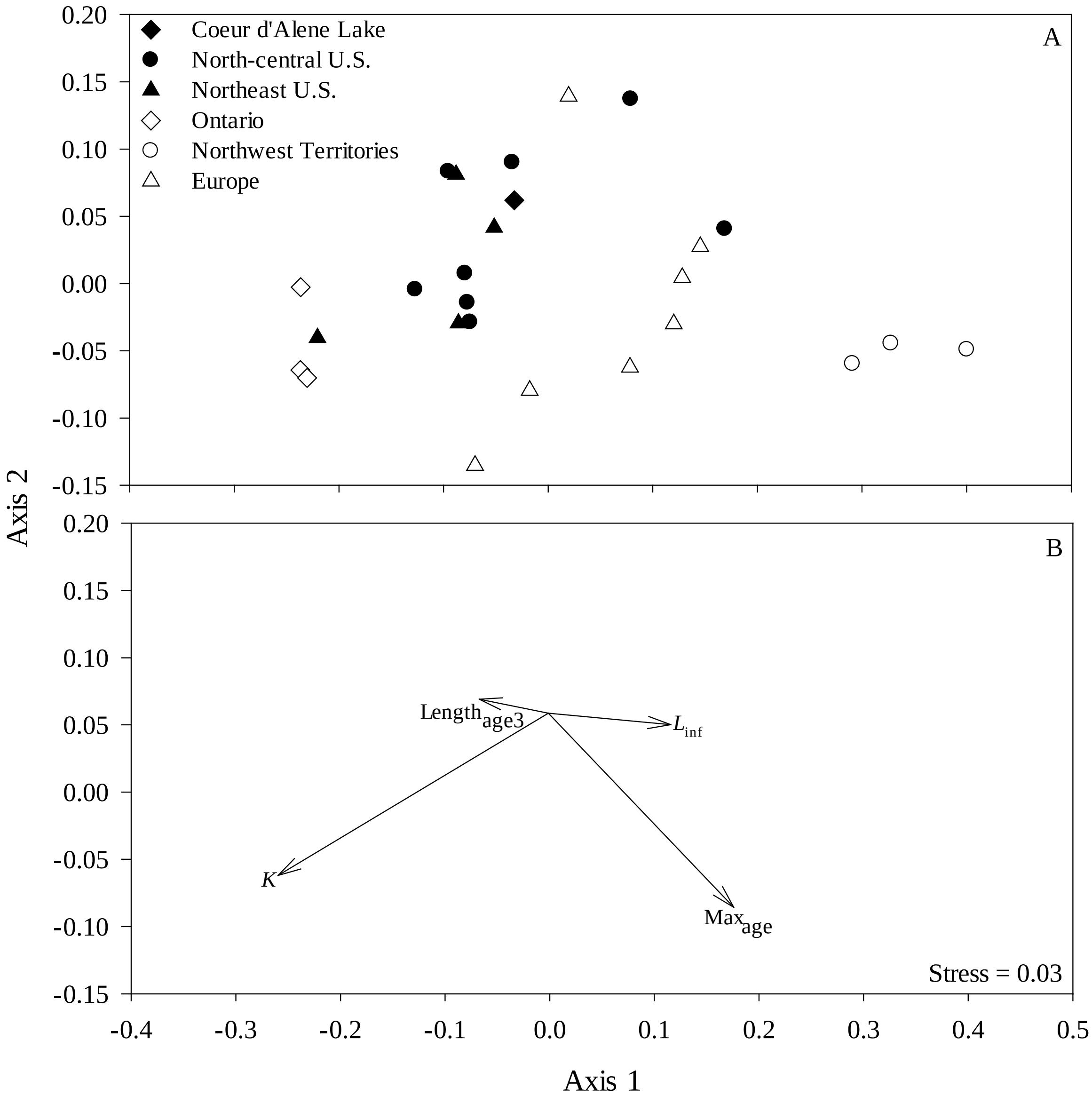

Figure 2.8. Nonmetric multidimensional scaling (NMDS) ordination of growth (A) from 27 lentic northern pike populations from across their circumpolar distribution. Vectors (B) indicate directions and strength of correlations within the NMDS ordination. Growth vectors were the growth coefficient (K), the theoretical maximum length (L_{inf}), maximum age (Max_{age}), and the mean length-at-age three ($Length_{age3}$).

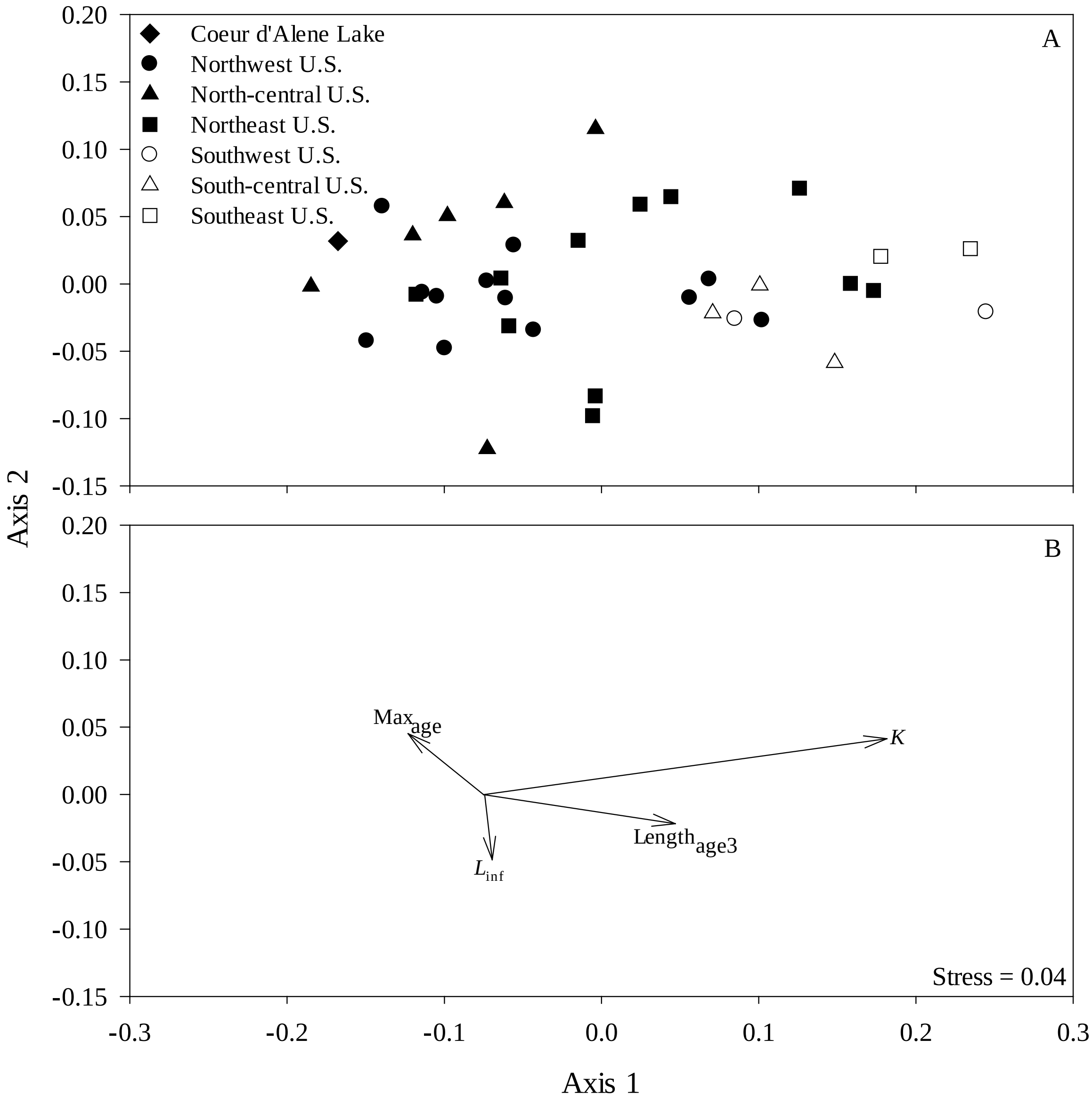

Figure 2.9. Nonmetric multidimensional scaling (NMDS) ordination of growth (A) from 37 lentic smallmouth bass populations. Vectors (B) indicate directions and strength of correlations within the NMDS ordination. Growth vectors were the growth coefficient (K), the theoretical maximum length (L_{inf}), maximum age (Max_{age}), and the mean length-at-age three ($Length_{age3}$).

CHAPTER 3: TROPHIC ECOLOGY OF NORTHERN PIKE AND THEIR EFFECT ON CONSERVATION OF WESTSLOPE CUTTHROAT TROUT

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ABSTRACT

Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* in Coeur d'Alene Lake, Idaho have declined in recent years and predation by Northern Pike *Esox lucius,* a nonnative sport fish, is thought to be a causative mechanism. The goal of this study was to describe the seasonal food habits of Northern Pike and determine their influence on Westslope Cutthroat Trout in Coeur d'Alene Lake using a bioenergetics modeling approach. Fishes were sampled monthly from March 2012 to May 2013 in four bays using pulsed-DC electrofishing and experimental gill nets. Electrofishing catch rates for Northern Pike were generally low, but increased slightly each season and were highest in the southern portion of the lake. Northern Pike catch rates using gill nets were approximately 50% higher during the two spring sampling periods compared to the summer and fall. Seasonal growth and food habits were analyzed from 695 Northern Pike varying from 162 to 1,080 mm in total length and 24 to 9,628 g in weight. The diet of Northern Pike primarily consisted of Kokanee *Oncorhynchus nerka*, Westslope Cutthroat Trout, and Yellow Perch *Perca flavescens*. Results of a bioenergetics model estimated that Westslope Cutthroat Trout represented approximately 2-30% of the biomass consumed by age 1-4 Northern Pike. The highest occurrence of Westslope Cutthroat Trout in Northern Pike diets occurred during spring. Thus, reducing predation of Westslope Cutthroat Trout by Northern Pike might be a useful tool for conserving Westslope Cutthroat Trout populations in Coeur d'Alene Lake.

INTRODUCTION

Cutthroat Trout *Oncorhynchus clarkii* have the most widespread historical distribution of any salmonid in North America with the exception of Lake Trout *Salvelinus namaycush* (Behnke 2002). The native distribution of Cutthroat Trout extends along the Pacific coast of North America, eastward across the Continental Divide, and as far south as New Mexico. Currently, Cutthroat Trout are taxonomically divided into 14 subspecies; two subspecies are now extinct and two subspecies are protected under the Endangered Species Act (Behnke 2002). Of the remaining subspecies, Westslope Cutthroat Trout *O. clarkii lewisi* is the only inland subspecies of Cutthroat Trout that is naturally sympatric with other salmonids (Dunham 2002). Cutthroat Trout populations have been declining since the 19th century and are now a major focus of management and conservation across their distribution (Gresswell 1988; Dunham 2002).

Populations of Cutthroat Trout have declined as a result of various factors. A primary factor contributing to the decline of Cutthroat Trout is a reduction in habitat quality and quantity (Liknes and Graham 1988; Marnell 1988; Shepard et al. 2005; Gresswell 2011). The construction of dams has created movement barriers that interfere with spawning and other important life history events (Liknes and Graham 1988). Many populations also exist in watersheds with extensive agriculture, where channel dewatering and sedimentation are common (Moeller 1981; Liknes and Graham 1988). A recent study has also shown that changes in water quality and damage to riparian habitat from livestock grazing have had negative effects on Cutthroat Trout populations (Peterson et al. 2010). In addition, Cutthroat Trout was among the most common fish species encountered by European settlers in the 19th century, and as a result, was important for subsistence and commerce (Behnke 1988). Due to the high catchability of Cutthroat Trout and lack of harvest regulations, many Cutthroat Trout populations were overexploited in less than 100 years (Behnke 1988).

As populations of Cutthroat Trout became less abundant, water bodies were often stocked with nonnative species to create or supplement fisheries. In turn, nonnative fishes have had a negative influence on Cutthroat Trout populations across western North American. One of the greatest factors contributing to the decline of Cutthroat Trout is their interaction with nonnative Rainbow Trout *Oncorhynchus mykiss*, which compete and hybridize with Cutthroat Trout (Marnell 1988; Allendorf et al. 2004; Shepard et al. 2005; Muhlfeld et al. 2009). Many remaining genetically-pure populations of Westslope Cutthroat Trout exist in headwater streams where movement barriers protect them from nonnative species (Rasmussen et al. 2010). In fact, non-hybridized populations of Westslope Cutthroat Trout currently inhabit less than 10% of their historic distribution in the United States and less than 20% in Canada (Muhlfeld et al. 2009). Rainbow Trout are not the only nonnative species that have been shown to negatively affect Cutthroat Trout. Other species, such as Brown Trout *Salmo trutta* in large streams, Brook Trout *Salvelinus fontinalis* in small streams, and Lake Trout in lake systems have replaced Cutthroat Trout across their distribution (Behnke 2002; Quist and Hubert 2004). In addition to salmonids, various warmwater and coolwater species have been introduced to systems with Cutthroat Trout, primarily to diversify recreational angling opportunities. Some of these species include Smallmouth Bass *Micropterus dolomieu*, Largemouth Bass *M. salmoides*, Northern Pike *Esox lucius*, Walleye *Sander vitreus*, and Sauger *S. canadensis*. Nonnative top-level predators not only have an influence on native fishes, but they can greatly alter prey population structure and dynamics (Tabor et al. 2007; Muhlfeld et al. 2008).

Introductions of nonnative species have contributed to declines in Cutthroat Trout populations across much of the Pacific Northwest. The subspecies that is most threatened by these introductions is the Westslope Cutthroat Trout. In Idaho, Westslope Cutthroat Trout are native to the Kootenai, Pend Oreille, Spokane, Clearwater, and Salmon river systems in the northern part of the state. Historically, Westslope Cutthroat Trout were an abundant salmonid in Idaho and as a result were important for subsistence and commerce (Wallace and Zaroban 2013). In addition, Westslope Cutthroat Trout have cultural significance to Native Americans. In the past, the Coeur d'Alene Tribe in northern Idaho relied on Westslope Cutthroat Trout for subsistence, harvesting roughly 42,000 per year from Coeur d'Alene Lake and the St. Joe River (Firehammer et al. 2012). However, Westslope Cutthroat Trout in Coeur d'Alene Lake have declined drastically and conservation efforts have been initiated.

Over the last 10-15 years, the Coeur d'Alene Tribe has implemented restoration practices in Lake and Benewah creeks (i.e., two tributaries to Coeur d'Alene Lake) to recover populations of adfluvial Westslope Cutthroat Trout. The Tribe is focused on restoring stream spawning and rearing habitat by increasing sinuosity, creating deep pools, enhancing large woody debris, and reconnecting streams to their floodplains (Firehammer et al. 2012). Stream renovations were initiated to increase in-stream survival, but there is a critical knowledge gap associated with the survival of adfluvial Westslope Cutthroat Trout once they out-migrate to Coeur d'Alene Lake as juveniles and return to spawn as adults. Recently, the Tribe embarked on an intensive Passive Integrated Transponder (PIT) tagging study to better understand juvenile survival and adult return rates. Of the 5,300 outmigrating juveniles that were tagged during 2005-2010, only 1.7% have returned as adults to Lake Creek and 2.3% to Benewah Creek (Firehammer et al. 2012). These juvenile-adult return rates are two to three times lower than estimates reported for juvenile Westslope Cutthroat Trout in comparable systems using similar techniques (Huston et al. 1984; Stapp and Hayward 2002; Muhlfeld et al. 2009). The mechanism associated with poor survival of adfluvial Westslope Cutthroat Trout is unknown, but is hypothesized to be the result of predation occurring in Coeur d'Alene Lake by nonnative species, particularly Northern Pike (Rich 1992; Naughton et al. 2004; Tabor et al. 2007; Muhlfeld et al. 2008).

Northern Pike are a top-level predator with a circumpolar distribution. Due to their popularity in recreational fisheries, Northern Pike have been introduced to systems across North America (Crossman 1978). In addition to being stocked for sport fishery enhancement, they have also been introduced to reduce densities of "nuisance" species, such as Common Carp *Cyprinus carpio* and Gizzard Shad *Dorosoma cepedianum* (Pflieger 1997). Northern Pike are ambush predators that require littoral habitat with abundant vegetation for successful spawning (Crossman 1978; Casselman 1996). They are also opportunistic predators that prefer soft-rayed fishes (Eklöv and Hamrin 1989).

In the Coeur d'Alene River basin of northern Idaho, shallow vegetated habitat and sloughs are common where tributaries enter Coeur d'Alene Lake. Juvenile adfluvial Westslope Cutthroat Trout outmigrate to Coeur d'Alene Lake during spring and must pass through habitat that is also highly suitable for Northern Pike. Thus, there is potential for high spatial and temporal overlap between Westslope Cutthroat Trout and Northern Pike in areas where tributaries enter Coeur d'Alene Lake. Given the need to better understand factors influencing Westslope Cutthroat Trout in Coeur d'Alene Lake, the objectives of this project were to describe the seasonal food habits of Northern Pike and estimate their consumption of

Westslope Cutthroat Trout and other prey items in Coeur d'Alene Lake using a bioenergetics model.

METHODS

Coeur d'Alene Lake is the second largest natural lake in Idaho with a surface area of 12,700 ha (Figure 3.1). The lake has a mean depth of approximately 24 m and a maximum depth of 61 m (Rich 1992; Vitale et al. 2004). Primary tributaries to Coeur d'Alene Lake are the Coeur d'Alene and St. Joe rivers; many small streams also contribute to the system. Post Falls Dam was constructed on the outlet of Coeur d'Alene Lake in 1906 and raised the water level of the lake by 2.5 m creating an abundance of shallow, vegetated habitats (Rich 1992). The lake has been classified as mesotrophic based on nutrient concentrations; however, heavy metals from 100 years of mining and ore processing in the watershed limit biological production (Committee on Superfund Site Assessment Remediation in the Coeur d'Alene River Basin National Research Council 2005). Coeur d'Alene Lake is managed by the Coeur d'Alene Tribe and the Idaho Department of Fish and Game.

Native sport fish species in Coeur d'Alene Lake include Westslope Cutthroat Trout, Bull Trout *Salvelinus confluentus*, and Mountain Whitefish *Prosopium williamsoni*. Today, sport fish species are primarily nonnative species such as Kokanee *O. nerka*, Chinook salmon *O. tshawytscha*, Rainbow Trout, Brook Trout, Largemouth Bass, Smallmouth Bass, Black Crappie *Pomoxis nigromaculatus*, Pumpkinseed *Lepomis gibbosus*, Yellow Perch, Brown Bullhead *Ameiurus nebulosus*, Black Bullhead *A. melas*, and Northern Pike. Other notable native species in the basin include Northern Pikeminnow *Ptychocheilus oregonensis* and

Longnose Sucker *Catostomus catostomus*. Tench *Tinca tinca*, a nonnative species in North America, is also common in Coeur d'Alene Lake.

Four major bays (i.e., Wolf Lodge, Cougar, and Windy bays, and Benewah Lake) were selected for this study because they are the primary areas in Coeur d'Alene Lake where Northern Pike are common or represent areas with ongoing Westslope Cutthroat Trout PIT tag research (Rich 1992). Stratified random sampling was used to select sampling sites by dividing the shoreline of each bay into 300 m sections and randomly assigning a gear type to a section. A sampling event consisted of sampling eighteen non-overlapping sections (i.e., 12 gill net and 6 electrofishing sites). A sampling event occurred once per month in Cougar and Wolf Lodge bays (i.e., March 2012 – May 2013). Windy Bay and Benewah Lake were sampled once per month during June - November (2012) and twice per month from March – May (2012 and 2013). Spring bi-weekly sampling was performed to increase the resolution in Windy Bay and Benewah Lake where the Coeur d'Alene Tribe is intensely monitoring Westslope Cutthroat Trout in tributaries (i.e., Lake and Benewah creeks).

Fish were sampled using a variety of sampling gears to maximize capture of Northern Pike. Gears included pulsed-DC electrofishing and experimental gill nets (46 m × 1.8 m with panels of 25, 32, 38, 44, 50-mm bar-measure mesh). Electrofishing was conducted using a 5,000 W generator mounted in an aluminum boat with Smith-Root (Smith-Root, Inc., Vancouver, Washington) equipment. Power output was standardized to 2,750-3,250 W based on ambient water conductivity (µS/cm; Miranda and Boxrucker 2009). In an effort to minimize mortality and prey digestion, gill nets were fished for 1.5 - 2.0 hours. Kobler et al. (2008) found that Northern Pike movement was more homogenous during the winter than in other months, with slightly higher movement occurring during the day. Therefore, nets were set at dusk, except during October - April when nets were fished during the day. Additionally, operating a boat at night with low water levels (e.g., fall, winter) and ice became hazardous.

All Northern Pike were measured for total length to the nearest millimeter and weighted to the nearest gram. All Northern Pike were marked by completely removing the left pelvic fin (Nielson 1992; Guy et al. 1997). Half of the captured Northern Pike were tagged using an individually-numbered, non-reward FD-94 (76 mm) T-bar anchor tag (Floy Tag Inc., Seattle, Washington) inserted near the posterior end of the dorsal fin. All other Northern Pike were tagged with an individually-numbered, non-reward 6 mm × 16 mm Carlin dangler tag (Floy Tag Inc., Seattle, Washington; Quist et al. 2010) in the caudal peduncle. Individually-numbered tags were used to obtain individual recapture histories that were used to estimate their population abundance in Program MARK (Cooch and White 2010). Gastric lavage was used to obtain the stomach contents from five fish per centimeter length group. A 12-volt 14.4 L/min pump (Fimco, North Sioux City, South Dakota) equipped with a pressure gauge, changeable hose fittings, and a pressure-release valve was used to flush stomachs (Light et al. 1983; Bowen 1996; Venturelli and Tonn 2006). Large prey items that were not flushed from the stomach were removed using forceps. Filtered water, held in an on-board container, was used for the lavage process to ensure samples were not contaminated with organisms from the lake. Before a fish was released, a gastroscope was inserted through the esophagus and into the stomach to ensure all prey items, water, and air were removed. If prey items were observed, the lavage process was repeated until the stomach was empty. Stomach contents were fixed with 10% buffered formalin (Garvey and Chipps 2012). The efficiency of removing all prey items from stomachs using the pulsed gastric lavage technique was evaluated from mortalities and found to be 98%. Individual Northern Pike stomach contents were also scanned for PIT tags (i.e., adfluvial Westslope Cutthroat Trout in Lake and Benewah creeks are PIT tagged) using an Allflex ISO compact reader (Allflex, San Antonio, Texas).

In the laboratory, vertebrate and invertebrate diet items were enumerated and identified to species and order, respectively. Lengths of prey items were measured using a caliper (Mitutoyo, Aurora, Illinois) to the nearest 0.02 mm. Weights (i.e., wet and dry) were measured to the nearest milligram. Total lengths and weights of partially digested taxon were estimated using published length-weight equations using hard structures (e.g., vertebrae, head capsule; Appendix A).

Relative weight (W_r) was used to evaluate body condition of Northern Pike,

$$W_r = \left(\frac{W}{W_s}\right) \times 100,$$

where W is the weight of an individual and W_s is the standard weight from a species-specific length-weight regression (Neumann et al. 2012). A W_r over 100 indicates above average body condition.

Food habit data were pooled by season based on water temperature: spring (March, April, May), summer (June, July, August), and fall (September, October, November). Ages of Northern Pike were estimated using pelvic fin rays and corroborated with cleithra. All data were summarized by year class for those year classes represented by at least five individuals in each season (i.e., 2008-2011 year classes). Frequency of occurrence, percent by number, percent energy contribution, and prey-specific energy contribution were used to summarize the diet data (Garvey and Chipps 2012). Percent energy contribution was estimated by multiplying the weight of a taxon by its caloric value and then dividing the total taxon energy by the total energy of all prey items. Prey-specific energy contribution was the percentage of energy a prey taxon comprised of all taxa energy in only those stomachs in which the prey taxon occurred (Amundsen et al. 1996). Only fish with identifiable prey items in their stomach were used in the food habits analysis. Unidentifiable prey items were rare (<1%) and removed from further analysis.

Prey-specific energy contribution was plotted against frequency of occurrence to provide insight on the trophic ecology of Northern Pike in Coeur d'Alene Lake. We used a modification to the Costello method because it allows for interpretation of prey importance, feeding strategy, and components of diet niche width (Amundsen et al. 1996). Feeding strategies can be defined as follows: rare taxa occur at low frequencies, contribute little energy, and are typical of a generalist diet; prey taxa that occur at high frequencies and that contribute substantial amounts of energy indicate specialization at the population level; and prey taxa with low frequency of occurrence and high prey-specific energy contribution indicate specialization by individuals.

Bioenergetics models for Northern Pike were conducted using Fish Bioenergetics 3.0 software (Hanson et al. 1997). Bioenergetics models are popular for understanding the growth and trophic ecology of fishes using the generalized equation:

$$C = (R + A + S) + (F + U) + (\Delta B + G),$$

where C = consumption, R = respiration, A = active metabolism, S = specific dynamic action, F = egestion, U = excretion, ΔB = somatic growth, and G = gonad production (Hanson et al. 1997). The two most common uses of bioenergetics models are to estimate how environmental conditions affect growth and the weight of prey consumption by predators (Hartman and Kitchell 2008). The model requires water temperature data, prey energy densities, and cohort-specific information on seasonal diet proportions, initial weights, and final weights (e.g., Hanson et al. 1997; Muhlfeld et al. 2008). Bioenergetics models also require physiological parameters. The Northern Pike physiological parameters from the Fish Bioenergetics 3.0 software (i.e., Bevelhimer et al. 1985) were used for the 2011 year class and parameters for the 2008-2010 year classes were provided by Bean (2010). Physiological parameters from Bevelhimer et al. (1985) were developed for 128 to 227 mm Northern Pike and 9.5 to 53.2 g. Results from Bean (2010) show there is risk of overestimating consumption when using parameters developed by Bevelhimer (1985) on larger individuals (i.e. >227 mm). Therefore, Bean (2010) developed parameters for Northern Pike varying from 250 to 718 mm and 86 to 2,146 g to correct inaccuracies for larger individuals. Water temperature was recorded from three Onset Model H08-001-02 temperature loggers (Onset, Cape Cod, Massachusetts) in each bay (i.e., Wolf Lodge, Cougar, Windy bays, Benewah Lake). Temperature loggers recorded a temperature (ºC) every six hours to generate a mean daily temperature (Appendix B). Caloric densities for prey items were obtained from Hanson et al. (1997) and published literature (Appendix C).

A daily time step over 440 days from March 1, 2012 to May 31, 2013 was used for the simulation. The daily time step was divided into four periods (i.e., spring, summer, and fall of 2012; spring of 2013) to better represent seasonal trends in consumption and growth for each year class. Initial and final weights for each period and year class were estimated using the median weights from individuals from each year class. In the event an initial or final weight was less than the previous, the weight was assumed to be the same as the previous period. Dietary information was summarized by year class and input into the bioenergetics model as the proportion of prey taxa (i.e., by weight) consumed on days sampling occurred.

After all species and site-specific data were entered, the proportion of maximum consumption (P_c) was calculated as:

$$P_c = \frac{C}{(C_{\max} \times r_c)},$$

where, C is the estimated consumption, C_{max} is maximum consumption of a specific ration at a given temperature, and r_c is a temperature-dependent proportional adjustment of consumption rate (Hanson et al. 1997). In the present model, P_c was estimated by solving the equation with observed growth and temperature data.

Program MARK was used to estimate the population abundance of Northern Pike in Coeur d'Alene Lake using closed population capture-recapture models (Cooch and White 2010). Closed capture models include a single mixture so only two parameters are used: the capture probability (p_i) and the recapture probability (c_i). We used this method to estimate population abundance using four models: M_0, M_b, M_t, and M_{tb}. The model M_0 was the null model with constant detection probabilities. The M_b model assumed the probability of recapture was the same as the probability of capture. The third model M_t assumed that capture and recapture probabilities were equal, but were allowed to vary through time. In the final model M_{tb}, p_i and c_i were modeled as a constant offset of one another. The four candidate models were compared with an information theoretical framework using Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2002). The abundance of individual Northern Pike year classes was calculated by multiplying the estimate of total population abundance by the percent age composition derived from an age-length key.

The total weight of Westslope Cutthroat Trout consumed annually for Northern Pike was estimated by multiplying the population abundance of Northern Pike year classes (i.e., 2008-2011; estimated using an age-length key) by the biomass estimates of Westslope Cutthroat Trout consumed by an individual Northern Pike. The total estimated number of Westslope Cutthroat Trout consumed by Northern Pike was derived by coupling the total biomass of Westslope Cutthroat Trout, their length-weight relationship, and the frequency of consumed Westslope Cutthroat Trout by Northern Pike.

RESULTS

Sampling occurred on 138 days and 15,645 individual fishes representing 24 species were captured. We captured 736 Northern Pike, of which 573 were marked, 98 were recaptured, and 73 were mortalities. The recapture rate of Northern Pike was highest (38%) in Windy Bay, while the recapture rate in other bays was roughly 9% (Figure 3.2). Electrofishing effort totaled 62.4 hours and 638 gill nets were fished for 1,166.0 hours. A total of 58 Northern Pike was sampled with electrofishing and 678 with gill nets. Electrofishing catch rates for Northern Pike were generally low, but increased slightly over the course of the study and were highest in Benewah Lake (Figure 3.3). Northern Pike catch rates using gill nets were approximately 50% higher during the two spring sampling periods than during the summer and fall. Northern Pike relative weights were comparable across all bays (Figure 3.4). The data suggest that body condition of Northern Pike steadily decreased between summer and fall and increased again the following spring. Additionally, Northern Pike in Windy Bay tended to be in better condition than those in other bays across all seasons.

Seasonal growth and food habits were analyzed from 695 Northern Pike varying from 162 to 1,080 mm and from 24 to 9,628 g. Northern Pike varied from age one to age seven and the majority (~95%) were age one to age four. In general, the majority of growth occurred between fall and spring for most year classes (Figure 3.5). Similar results were observed for growth in weight (Figure 3.5). Sampling was not conducted during the winter of 2012 due to low water levels and hazardous ice conditions; therefore, winter growth could not be estimated.

The proportion of empty stomachs varied by year class, but was highest (52%) during the spring of 2012 (Figure 3.6, Appendix D). The diet of Northern Pike from the 2011 year class was dominated by warmwater species (i.e., Yellow Perch, Bluegill, Brown Bullhead). Salmonids became an important prey item for the 2011 year class the following spring (i.e., 2013) and accounted for approximately 40% of the total energy for the year class. Diets of older individuals (2008-2010 year classes) were dominated by salmonids (i.e., Kokanee, Westslope Cutthroat Trout). Throughout the year, the highest percent by occurrence, number, and energy contribution was represented by Kokanee. Kokanee were consumed at the highest rate during summer, accounting for 87% of the total energy. Interestingly, consumption of Westslope Cutthroat Trout was highly variable between seasons. During the spring of 2012, Westslope Cutthroat Trout occurred in approximately 25% of Northern Pike stomachs while contributing roughly 75% of the total energy consumed (Figure 3.6). During the summer and fall, percent occurrence and energy contribution of Westslope Cutthroat Trout decreased by about 50%. During the spring of 2013, the occurrence of Westslope Cutthroat Trout in Northern Pike diets increased again relative to the summer and fall (Figure 3.6). Seasonal P_c values of Northern Pike in Coeur d'Alene Lake were generally highest during the spring and lowest during the summer (Figure 3.7). Interestingly, results of the bioenergetics models estimated Westslope Cutthroat Trout contributed approximately 2-30% of the biomass consumed by age 1-4 Northern Pike (Table 3.1; Table 3.2).

The top model of population abundance was M_t with an estimated 3,268 (lower-upper 95% confidence intervals; 2,000-6,361) Northern Pike in the four study bays. The abundance of Northern Pike year classes used in the bioenergetics model (i.e., 2008-2011) was estimated at 3,056 (1,793-5,947; Table 3.3). Total length of Westslope Cutthroat Trout consumed by Northern Pike varied from 87 to 437 mm and averaged 250 mm (228-272; Figure 3.8). The total biomass of Westslope Cutthroat Trout consumed by Northern Pike (i.e., 2008-2011 year classes) annually in the four study bays was estimated to be 1,231 kg (723-2,396 kg) and the total number was approximately 5,641 (3,311-10,979).

DISCUSSION

Northern Pike have been introduced into many watersheds to create recreational fishing opportunities throughout North America and Canada, including Coeur d'Alene Lake. Unfortunately, many studies have found that Northern Pike can have detrimental effects on native fishes (Muhlfeld et al. 2008; Sepulveda et al. 2013). Therefore, understanding the effects of Northern Pike on native fishes is critical for developing management strategies to balance recreational sport fisheries with native fish conservation efforts, especially species like Westslope Cutthroat Trout.

The food habits of Northern Pike have been extensively studied throughout their distribution and although they are generally piscivorous, they are highly opportunistic. For example, Soupir et al. (2000) reported that invertebrates were common in Northern Pike diets when the availability and abundance of fishes was low in six lakes in Voyageurs National Park, Minnesota. Similarly, Northern Pike introduced into three eutrophic lakes in northeast Alberta lacking prey fishes consumed leeches and other invertebrates (Venturelli and Tonn 2006). Northern Pike in the current study consumed a diversity of food items including invertebrates, fishes, and salamanders. Invertebrates were consumed sporadically throughout the year but contributed little to the overall energy consumed by Northern Pike in Coeur d'Alene Lake. Rather, Kokanee contributed the greatest amount of energy each season. Westslope Cutthroat Trout were consumed at the highest frequency during spring. Northern Pike also preyed on spiny-rayed fishes (e.g., Yellow Perch, Black Crappie) throughout the year with the highest occurrence in the fall and spring (i.e., 2013), likely a result of prey availability. Eklöv and Hamrin (1989) reported that Northern Pike preferred soft-rayed fishes and switched to spiny-rayed fishes or cannibalism when preferred prey items were unavailable.

Ontogenetic changes in diet are common in Northern Pike (Frost 1954; Miller and Kramer 1971). The only exception appears to be in systems with simple fish assemblages (Soupir et al. 2000). In Coeur d'Alene Lake ontogenetic shifts in food habits were apparent, particularly between age 1 and age 2. Food habits of the 2011 year class into the fall of 2012 primarily consisted of Yellow Perch less than 150 mm, Brown Bullhead, and centrarchids. In the spring of 2013, their diets shifted towards large Yellow Perch (i.e., ≥150 mm) and salmonids. Although the data suggest an ontogenetic shift in feeding habits at a young age towards salmonids, prey availability, habitat, and gape size also likely play a role in the shift (Nilsson and Bronmark 2000).

Growth of Northern Pike varied among year classes and seasons in Coeur d'Alene Lake. Most year classes increased in weight from spring to summer, but then decreased in the fall. Interestingly, about 50% of the annual growth in terms of weight was achieved between fall and the beginning of the following spring. Headrick and Carline (1993) found similar results where Northern Pike lost weight from May to October and then gained weight from October to March. A majority of growth occurring in the fall has also been observed for other coolwater species. For example, Quist et al. (2002) observed that approximately 80% of the length and weight of Walleyes in Glen Elder Reservoir, Kansas was achieved between August and October. They also noted that seasonal growth was regulated by water temperature mediating metabolic rates and prey availability.

Percentage of maximum consumption reflects the intensity of predation and prey availability (Rice et al. 1983). Seasonal P_c values were consistently highest for the 2011 year class of Northern Pike in Coeur d'Alene Lake, likely the result of the increased metabolic demand for juveniles (Bean et al 2010). We also observed a seasonal pattern where estimates of P_c were generally highest during spring for all cohorts. The high percentages of maximum consumption estimates during spring likely reflect prey availability of salmonids and post-spawn feeding intensity of Northern Pike. Low P_c values of Northern Pike in the summer and fall probably reflect a decrease in prey availability and lower metabolic rates achieved by Northern Pike moving to cooler water in the summer and fall (Bevelhimer et al. 1985).

With the concern of nonnative species increasing, many nonnative species have been the focus of removal or suppression efforts. However, a high density of other nonnative species may actually assist with recovery of native fish populations. When a predator's preferred prey item is depleted, predators often switch to another prey item, thereby allowing the preferred prey item to recover (Sinclair et al. 2006). The current study suggests that some nonnative species may act as a predation buffer for Westslope Cutthroat Trout throughout much of the year. Specifically, nonnative species such as Kokanee and Yellow Perch each accounted for 30% of the total annual biomass consumed by Northern Pike. The occurrence of a predation buffer has also been reported in other aquatic systems. For instance, Stapanian and Madenjian (2007) determined that Sea Lamprey *Petromyzon marinus* began preying on Lake Trout *Salvelinus namaycush* in Lake Erie. A shift in hosts of Sea Lamprey allowed Burbot *Lota lota* to increase in abundance.

While nonnative prey species may create a predation buffer for Westslope Cutthroat Trout, numerous studies in the Pacific Northwest have shown that Northern Pike consume large quantities of Westslope Cutthroat Trout when present. For example, Muhlfeld et al. (2008) estimated that Northern Pike in the upper Flathead River system of Montana annually consumed approximately 13,000 Westslope Cutthroat Trout. Similarly, Rich (1992) reported that Westslope Cutthroat Trout was responsible for about 45% of the weight consumed by Northern Pike in Killarney Lake, Idaho. More importantly, the ability of Northern Pike to consume large quantities of Westslope Cutthroat Trout suggests that high densities of Westslope Cutthroat Trout may not be feasible in a system with Northern Pike. An exception is provided by Sepulveda et al. (2013) who reported that salmonid escapement objectives were met in Wood River Lake, Alaska, despite a high level of predation by Northern Pike. The authors hypothesized that salmonid and Northern Pike habitats were spatially segregated. Westslope Cutthroat Trout predation by Northern Pike in Coeur d'Alene Lake decreased in the summer and fall and is suggestive of habitat segregation. Habitat segregation can exist for salmonid species as they typically spend minimal time in shallow and vegetated water commonly occupied by Northern Pike (D'Angelo and Muhlfeld 2013). Unfortunately, increased occurrence of Westslope Cutthroat Trout in Northern Pike diets during spring may negate any benefits of habitat segregation during other time periods. While the period of spatial overlap appears to be relatively short (i.e., April and May) based on diets, previous research has shown that Northern Pike can consume large quantities of prey over a short time period. Jepsen et al. (1998) found that Northern Pike predation over a three-week period in the Danish River, Denmark was responsible for 56% of the Atlantic salmon *Salmo salar* smolt mortalities. In Coeur d'Alene Lake, approximately 80% of the predation on Westslope Cutthroat Trout in 2012 occurred during spring. However, the potential effects of Northern Pike predation on Westslope Cutthroat Trout varied by location. Although only 29% of the Northern Pike were captured in Windy Bay, they accounted for 75% of the Westslope Cutthroat Trout that were consumed. Based on our estimates of abundance and consumption, Northern Pike consumed approximately 335 Westslope Cutthroat Trout during the spring of 2012 in Windy Bay. The estimated abundance of spawning adult Westslope Cutthroat Trout (≥300 mm) in Lake Creek, the tributary that enters Windy Bay, was 410 (SE = 85; Firehammer et al. 2012). Unfortunately, similar estimates are not available for 2013 or for any of the other tributaries. Nevertheless, the observed predation by Northern Pike is concerning and may explain the low juvenile to adult rates observed during the Tribe's PIT tag study (Firehammer et al. 2012). Fortunately, intense seasonal predation suggests that predation on Westslope Cutthroat Trout might be alleviated by reducing Northern Pike densities near tributaries used by Westslope Cutthroat Trout for spawning.

Various mechanical removal methods have been used or recommended to reduce densities of nonnative predators (Broughton and Fisher 1981; Mann 1985; Kulp and Moore

2000; Mueller 2005). Suppressing a nonnative predator, such as Northern Pike, may be important for conserving salmonids and other native fish species. However, desired effects from suppression efforts usually diminish because remaining fishes typically display compensatory increases in recruitment, survival, and growth (Kolar et al. 2010). Additionally, the amount of resources needed to reduce piscivore biomass is generally prohibitive on larger systems (Goeman et al. 1993). Some systems have required complete eradication of nonnative piscivores for viable salmonid populations (Spens and Ball 2008); however, eradication of Northern Pike has been unsuccessful in large systems (Aguilar et al. 2005). Additionally, Northern Pike are an important sport fish in Coeur d'Alene Lake and great opposition to a removal plan by anglers is likely. Future research should focus on Coeur d'Alene Lake management strategies (i.e., harvest regulations) that might be used to reduce Northern Pike densities at small spatial and(or) temporal scales.

Results of this study have important implications for the management of Northern Pike and conservation of Westslope Cutthroat Trout in Coeur d'Alene Lake. High spatial and temporal overlap during spring results in relatively large quantities of Westslope Cutthroat Trout being consumed in some areas. Thus, the Coeur d'Alene Tribe's management objective to restore Westslope Cutthroat Trout to a level that allows for subsistence harvest, maintains genetic diversity, and increases the probability of persistence from anthropogenic influences might be achieved if predation of Northern Pike near tributaries used by adfluvial Westslope Cutthroat Trout could be reduced during the spring. Before any actions are taken, however, further research is needed to determine other factors influencing Westslope Cutthroat Trout in the system and the relative benefits of reducing predation on Westslope Cutthroat Trout compared to other management actions.

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Table 3.1. Estimates of biomass (g) consumed of individual prey items from bioenergetics models for Northern Pike in Coeur d'Alene Lake. Estimates are provided by year class (2008-2011) and season. Months were grouped together based on water temperature.

	Year class							
	2011				2010			
Taxa	Spring 2012	Summer 2012	Fall 2012	Spring 2013	Spring 2012	Summer 2012	Fall 2012	Spring 2013
Invertebrates								
Annelida	28.88	0.00	0.00	0.05	0.00	0.00	0.00	0.01
Coleoptera	0.00	0.00	0.00	0.00	0.07	0.90	0.00	0.00
Decapoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hymenoptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Odonata	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
Fish								
Catostomidae								
Largescale Sucker	7.04	0.00	0.00	0.00	30.31	1.47	58.50	0.00
Centrarchidae								
Black Crappie	30.20	0.00	0.00	1.18	0.00	0.00	8.67	29.42
Bluegill	0.00	0.00	549.67	4.82	0.00	0.00	18.02	0.00
Largemouth Bass	0.00	87.63	0.00	0.00	0.00	0.08	7.66	0.00
Unknown species	0.00	0.00	0.00	0.00	0.00	0.00	12.38	0.00
White Crappie	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00
Clupeidae								
Pacific Herring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.81
Cottidae								
Sculpin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cyprinidae								
Northern Pikeminnow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tench	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Esocidae								
Northern Pike	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Ictaluridae								
Brown Bullhead	0.00	17.82	0.00	0.00	17.77	0.00	17.27	0.74
Percidae								
Yellow Perch <150mm	24.50	134.96	264.77	32.25	46.59	19.33	97.55	196.65
Yellow Perch ≥150mm	0.00	0.00	0.00	155.60	106.07	92.76	174.83	77.91
Salmonidae								
Kokanee	0.00	0.00	0.00	94.53	238.26	55.03	108.86	98.50
Unknown species	0.00	0.00	0.00	0.68	0.00	0.00	0.00	3.88
Westslope Cutthroat Trout	0.00	0.00	0.00	26.80	216.79	345.48	0.00	96.55
Other								
Idaho Giant Salamander	0.00	0.00	0.00	0.00	0.00	0.00	1.99	0.00
Detritus	32.99	46.24	0.00	0.00	0.00	12.23	0.01	0.00

Table 3.1 cont'd.

	Year class							
	2009				2008			
Taxa	Spring 2012	Summer 2012	Fall 2012	Spring 2013	Spring 2012	Summer 2012	Fall 2012	Spring 2013
Invertebrates								
Annelida	0.24	0.00	0.00	64.88	0.21	0.00	0.00	0.00
Coleoptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decapoda	0.00	196.72	0.00	0.00	0.00	0.00	0.00	0.00
Hymenoptera	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
Odonata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fish								
Catostomidae								
Largescale Sucker	0.00	0.00	35.57	19.95	0.00	0.00	0.00	0.00
Centrarchidae								
Black Crappie	0.00	0.00	53.73	0.00	0.21	0.00	0.00	22.87
Bluegill	0.00	0.00	53.05	0.00	0.00	0.00	0.00	0.00
Largemouth Bass	18.63	0.00	230.66	0.00	0.00	0.00	0.00	0.00
Unknown species	0.00	0.00	0.00	0.00	0.00	0.00	9.76	64.19
White Crappie	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clupeidae								
Pacific Herring	0.00	0.00	0.00	113.99	0.00	0.00	0.00	0.00
Cottidae								
Sculpin	0.00	0.00	0.00	0.00	0.52	0.00	0.00	0.00
Cyprinidae								
Northern Pikeminnow	0.00	0.00	44.36	12.82	0.00	0.00	0.00	0.00
Tench	0.00	0.00	0.00	125.10	36.29	0.00	0.00	0.00
Esocidae								
Northern Pike	0.00	0.00	0.00	0.00	13.16	0.00	0.00	0.00
Ictaluridae								
Brown Bullhead	18.05	217.82	38.88	0.00	0.05	0.00	0.00	16.56
Percidae								
Yellow Perch <150mm	76.59	3.68	210.26	95.65	41.55	0.00	0.22	0.00
Yellow Perch ≥150mm	50.40	118.98	29.73	87.16	16.76	73.15	160.93	129.20
Salmonidae								
Kokanee	233.62	186.63	339.03	181.87	80.85	786.76	296.44	178.93
Unknown species	13.44	0.00	0.00	0.00	37.31	0.00	56.42	0.00
Westslope Cutthroat Trout	142.29	4.80	128.28	52.04	74.39	18.66	287.11	160.69
Other								
Idaho Giant Salamander	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Detritus	0.00	0.00	0.02	0.00	0.00	36.72	0.00	0.00

Table 3.2. Total estimates of biomass (g) consumed of individual prey items from bioenergetics models for Northern Pike in Coeur d'Alene Lake. Estimates were summed over prey item and year class (2008-2011).

	Year class				
Taxa	2011	2010	2009	2008	Total
Invertebrates					
Annelida	28.93	0.01	65.12	0.21	94.27
Coleoptera	0.00	0.97	0.00	0.00	0.97
Decapoda	0.00	0.00	196.72	0.00	196.72
Hymenoptera	0.00	0.00	0.00	0.04	0.04
Odonata	0.00	0.04	0.00	0.00	0.04
Fish					
Catostomidae					
Largescale Sucker	7.04	90.27	55.52	0.00	152.83
Centrarchidae					
Black Crappie	31.39	38.09	53.73	23.08	146.29
Bluegill	554.49	18.02	53.05	0.00	625.57
Largemouth Bass	87.63	7.74	249.29	0.00	344.66
Unknown species	0.00	12.38	0.00	73.95	86.33
White Crappie	0.41	0.00	0.00	0.00	0.41
Clupeidae					
Pacific Herring	0.00	3.81	113.99	0.00	117.80
Cottidae					
Sculpin	0.00	0.00	0.00	0.52	0.52
Cyprinidae					
Northern Pikeminnow	0.00	0.00	57.18	0.00	57.18
Tench	0.00	0.00	125.10	36.29	161.39
Esocidae					
Northern Pike	0.00	0.02	0.00	13.16	13.17
Ictaluridae					
Brown Bullhead	17.82	35.78	274.75	16.61	344.96
Percidae					
Yellow Perch <150mm	486.48	360.13	386.19	41.77	1,274.56
Yellow Perch ≥150mm	155.60	451.57	286.28	380.04	1,273.48
Salmonidae					
Kokanee	94.53	500.65	941.14	1,342.98	2,879.31
Unknown species	0.68	3.88	13.44	93.73	111.73
Westslope Cutthroat Trout	26.80	658.82	327.40	540.85	1,553.86
Other					
Idaho Giant Salamander	0.00	0.35	0.00	0.00	0.35
Detritus	79.23	12.24	0.02	36.72	128.22
All prey	1,571.02	2,196.74	3,198.94	2,599.93	

Table 3.3. Total estimates of Westslope Cutthroat Trout (WCT) consumed by 2008-2011 year classes of Northern Pike in Coeur d'Alene Lake, Idaho. Age composition percentages were derived from an age-length key. Lower and upper 95% confidence intervals are in parentheses for Northern Pike abundance (*N*) and total biomass of Westslope Cutthroat Trout (kg).

Year class	Age composition (%)	*N*	Total WCT (kg)
2011	19.5	637 (358-1,240)	17.1 (9.6-33.2)
2010	31.4	1,026 (576-1,997)	676.1 (379.8-1,315.8)
2009	30.8	1,007 (565-1,959)	329.6 (185.1-641.4)
2008	11.8	386 (217-751)	208.6 (117.2-405.9)
Total	93.5	3,056 (1,717-5,947)	1,231.3 (691.7-2,396.4)

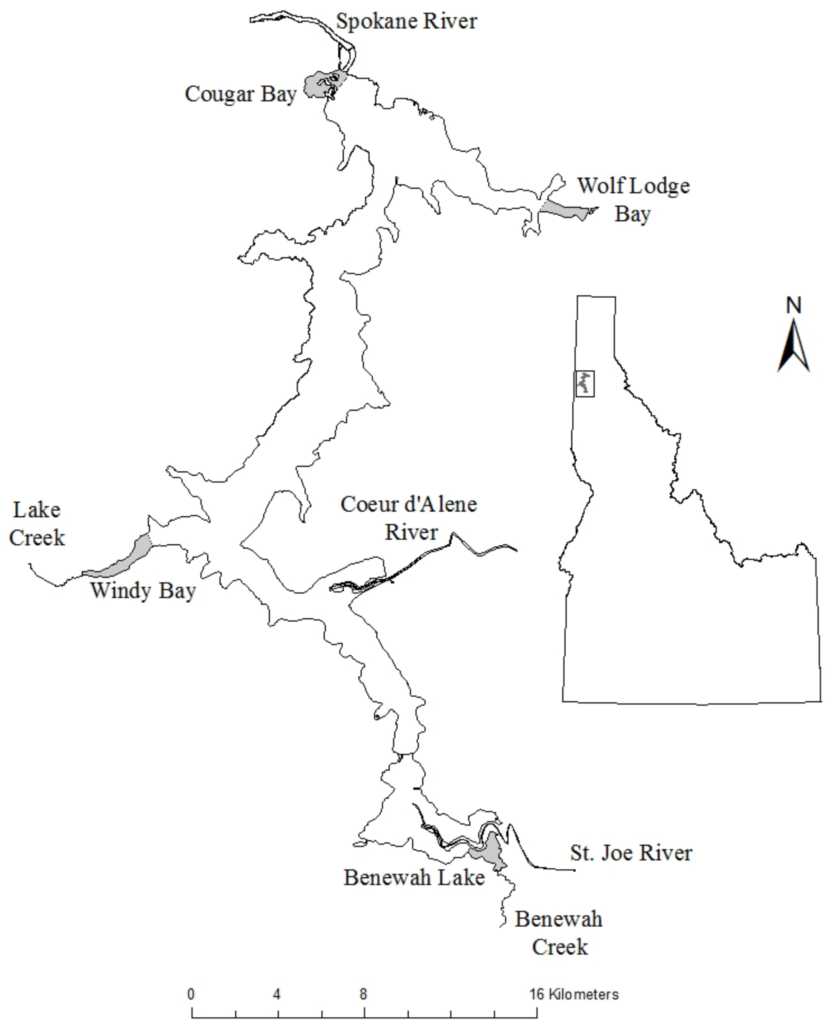

Figure 3.1. Map of Coeur d’Alene Lake in northern Idaho. Idaho Department of Fish and Game manages the lake north of the mouth of the Coeur d’Alene River. The Coeur d’Alene Tribe manages the lake south of the mouth of the Coeur d’Alene River as well as the Lake Creek watershed. Sampling sites were located in: Cougar, Wolf Lodge, and Windy bays, and Benewah Lake.

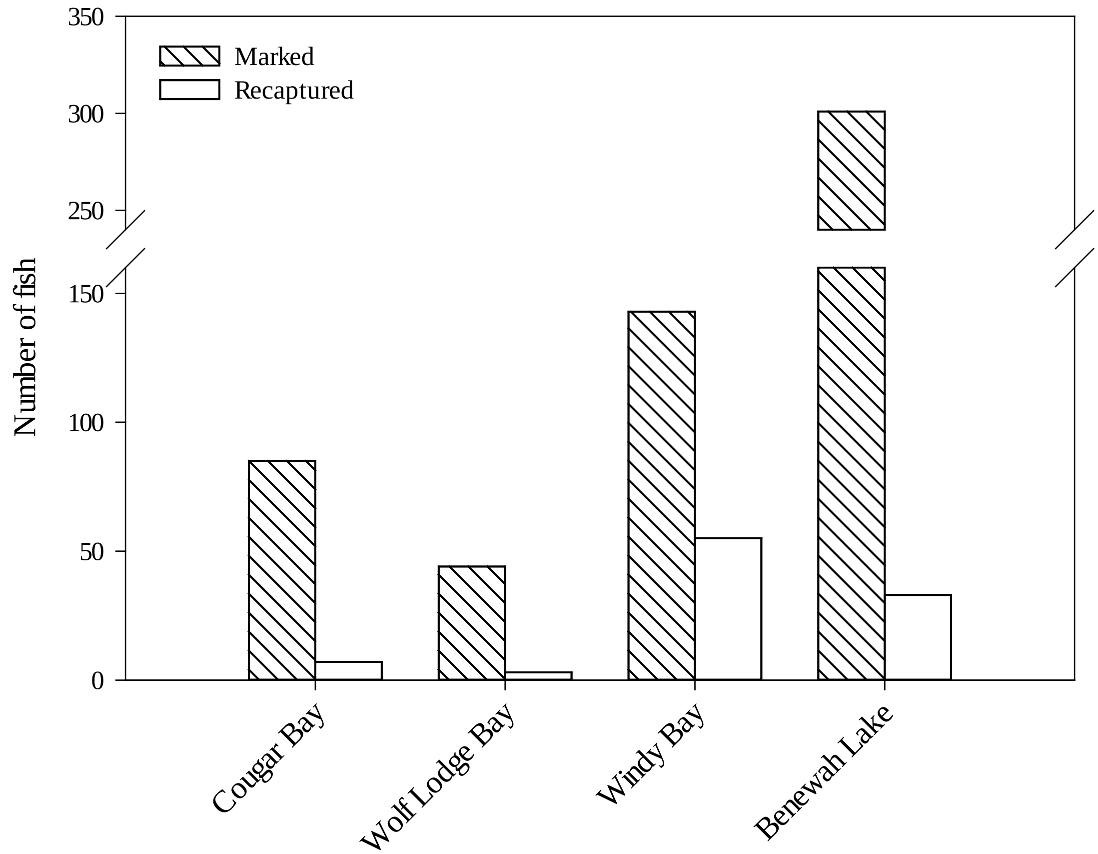

Figure 3.2. Number of Northern Pike marked or recaptured in each bay in Coeur d'Alene Lake, Idaho, 2012-2013.

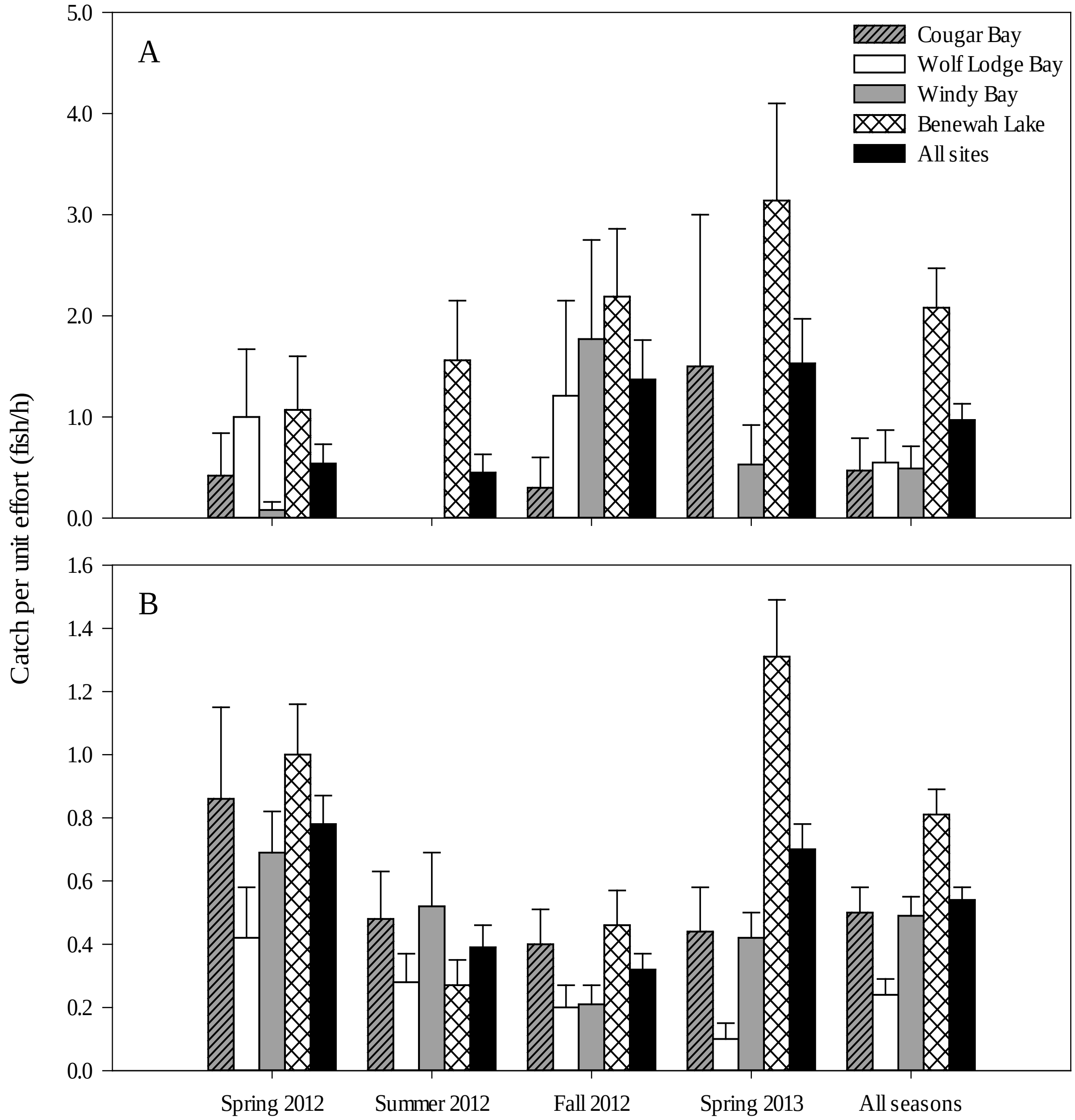

Figure 3.3. Mean catch per unit effort (fish/hr) of Northern Pike with electrofishing (A) and gill netting (B) by season in Coeur d'Alene Lake, Idaho. Months were grouped together based on water temperature: spring (March, April, May), summer (June, July, August), and fall (September, October, November). Error bars represent one standard error.

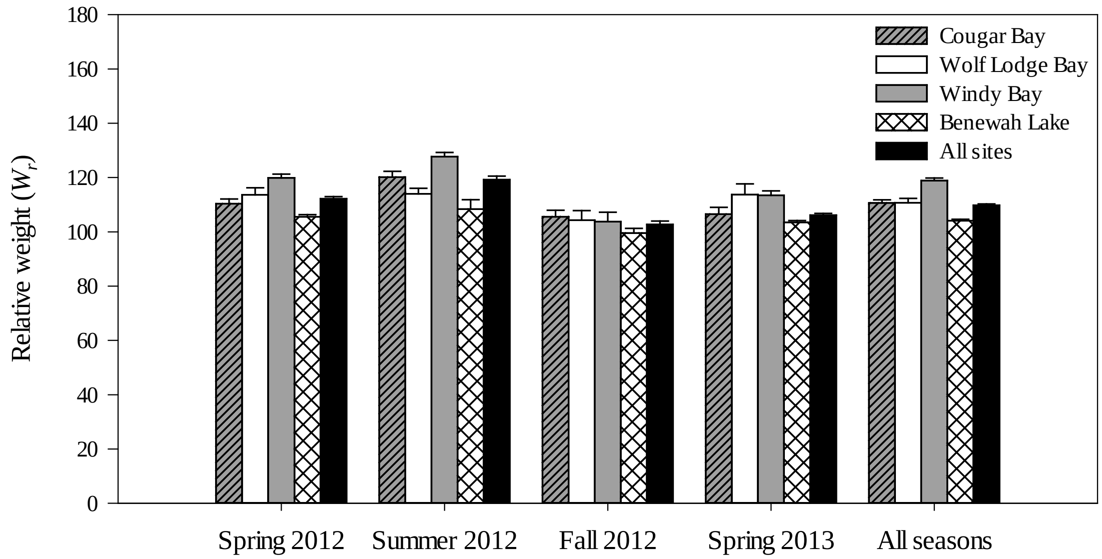

Figure 3.4. Mean relative weights for Northern Pike by season, captured from each bay in Coeur d'Alene Lake, Idaho. Means were also calculated for each season as well as each site across all seasons. Months were grouped together based on water temperature: spring (March, April, May), summer (June, July, August), and fall (September, October, November). Error bars represent one standard error.

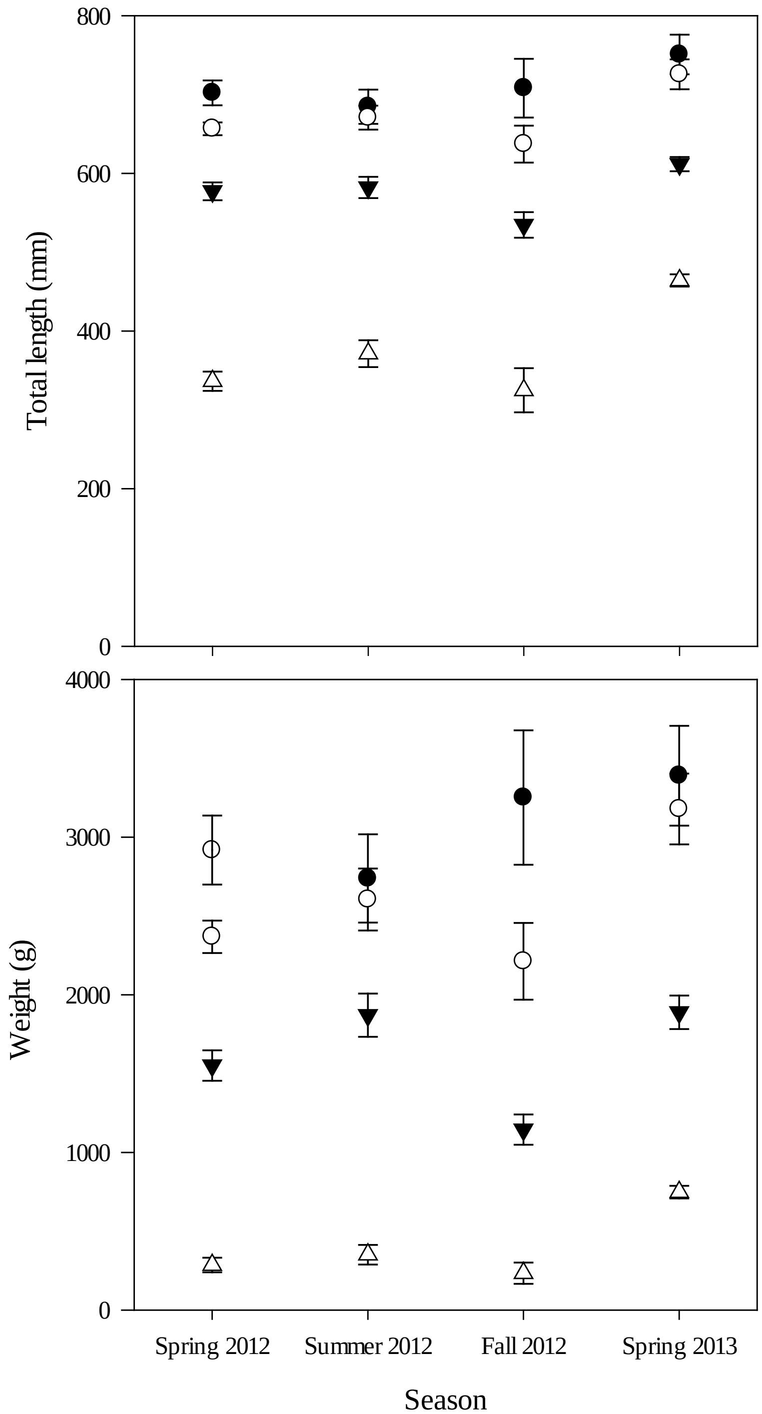

Figure 3.5. Mean length and weight of four year classes (●, 2008; ○, 2009; ▼, 2010; △, 2011) of Northern Pike in Coeur d'Alene Lake, Idaho from March 2012 to May 2013. Months were grouped together based on water temperature: spring (March, April, May), summer (June, July, August), and fall (September, October, November). Error bars represent one standard error.

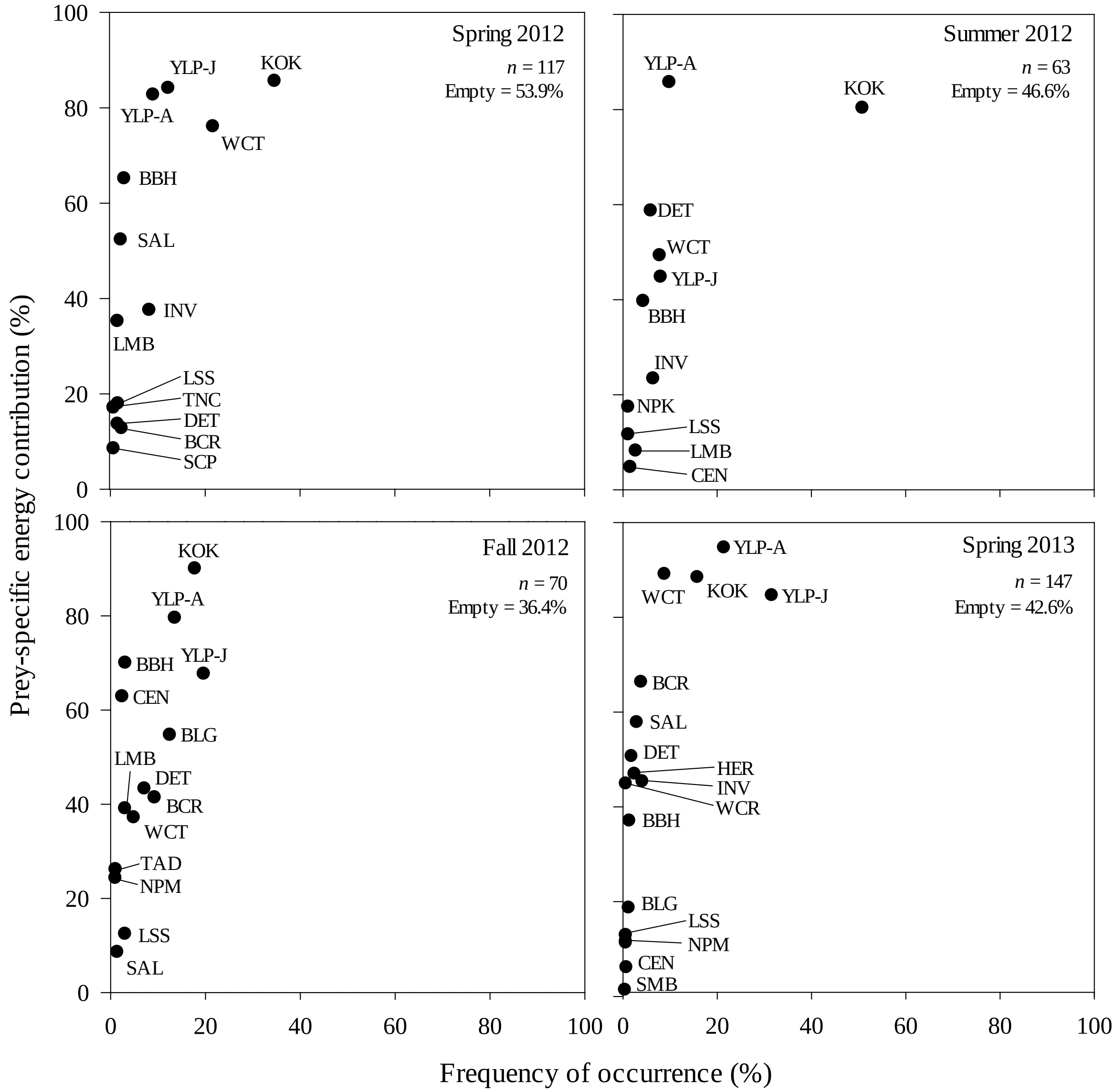

Figure 3.6. Frequency of occurrence and prey-specific energy contribution of prey items from spring, summer, and fall of 2012 and the spring of 2013 for Northern Pike in Coeur d'Alene Lake, Idaho. Seasonal frequency of empty stomachs and sample size (*n*), which is the number of Northern Pike containing diet content, are also provided. Species abbreviations are: INV (invertebrates), LSS (Largescale Sucker), BCR (Black Crappie), BLG (Bluegill), LMB (Largemouth Bass), WCR (White Crappie), CEN (Centrarchidae), HER (Pacific Herring), SCP (Sculpin), NPM (Northern Pikeminnow), TNC (Tench), NPK (Northern Pike), BBH (Brown Bullhead), YLP-A (Yellow Perch ≥150 mm), YLP-J (Yellow Perch <150mm), KOK (Kokanee), WCT (Westslope Cutthroat Trout), SAL (Salmonidae), SAM (Idaho Giant Salamander), and DET (detritus).

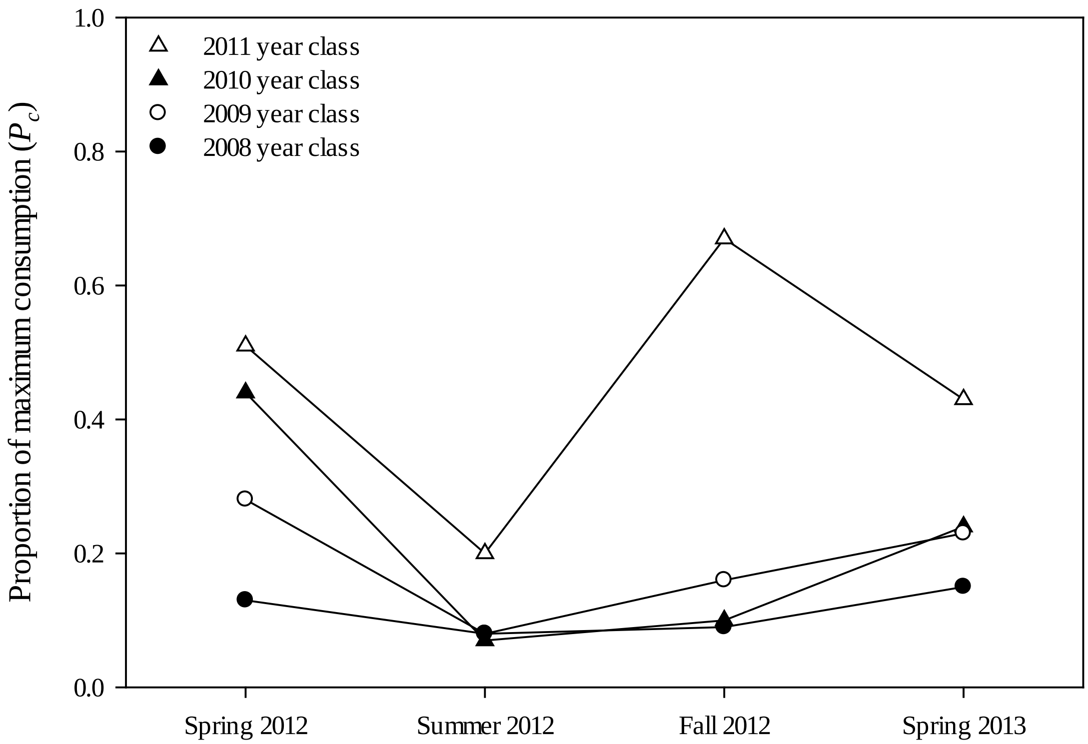

Figure 3.7. Proportion of maximum consumption (P_c) from bioenergetics model used to estimate consumption and growth of four year classes of Northern Pike in Coeur d'Alene Lake, Idaho. Months were grouped together based on water temperature: spring (March, April, May), summer (June, July, August), and fall (September, October, November).

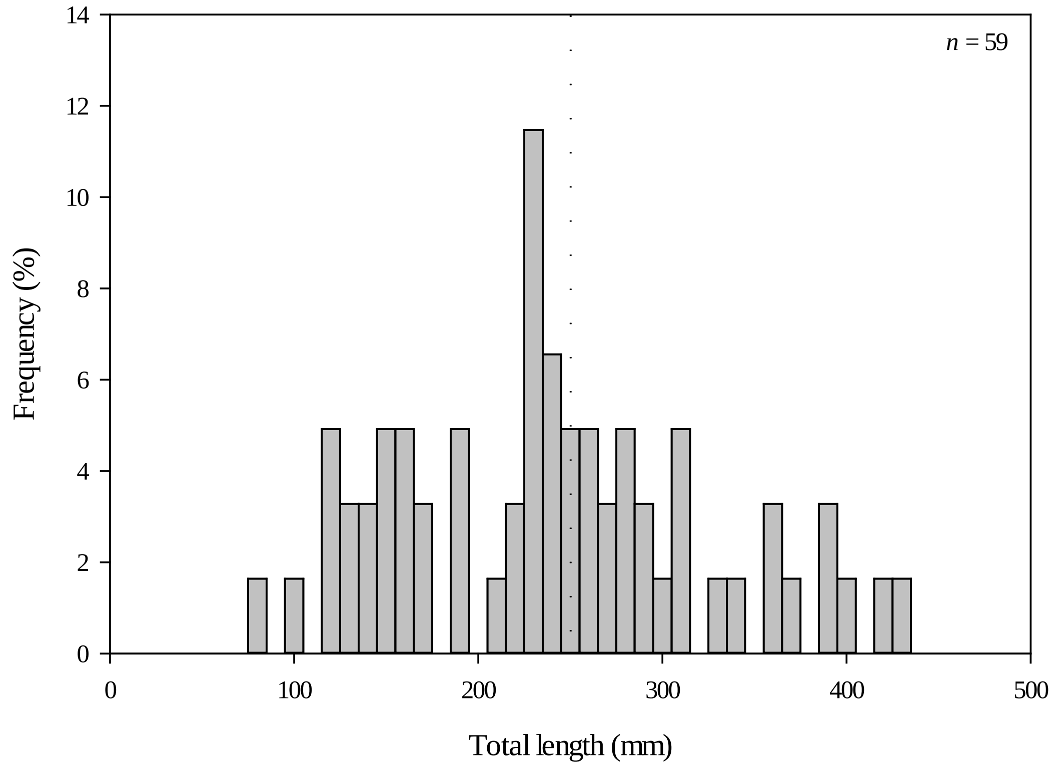

Figure 3.8. Length-frequency histogram of adfluvial Westslope Cutthroat Trout consumed by Northern Pike in Coeur d'Alene Lake, Idaho from March 2012 to May 2013. Dashed line represents the mean length of Westslope Cutthroat Trout consumed.

CHAPTER 4: GENERAL CONCLUSIONS

An understanding of the population size structure and dynamics of fishes is important for meeting management objectives. Concurrent sampling and analysis of population structure and dynamics can also be used to determine effects of biotic and abiotic factors. My hope is that managers will use chapter two of this thesis as a starting point for monitoring Northern Pike *Esox lucius* and Smallmouth Bass *Micropterus dolomieu* in Coeur d'Alene Lake to better inform management decisions. Results from this chapter revealed that growth of Northern Pike in Coeur d'Alene Lake is comparable to average lentic Northern Pike populations. This study also showed that exploitation on Northern Pike was relatively high in Coeur d'Alene Lake. Alternatively, this study showed that Smallmouth Bass in Coeur d'Alene Lake are growing extremely slow. Smallmouth Bass were also in poor body condition, suggesting intraspecific competition for limited prey resources.

The effect of predation on native fishes by nonnative species is a growing concern for many managers. Results from chapter three suggest that Northern Pike consume large quantities of Westslope Cutthroat Trout, primarily in the spring. Furthermore, this study showed that predation by Northern Pike might conceal the benefits of activities (i.e., stream renovation) that have been implemented to increase survival of adfluvial Westslope Cutthroat Trout.. With the spread of nonnative species likely to continue, it becomes more important to understand their effect on native fishes. This thesis should be a valuable resource to managers for developing and analyzing alternative management scenarios.

LIST OF APPENDIX TABLES

Appendix A: Length-weight relationship sources for encountered prey items. The notation * indicates the prey items were identified as being undigested so the wet and dry weights were assumed to be exact.

Taxonomic group	Common name	Data source
Invertebrates		
Annelida	Ringed worms	*
Amphipoda	Scuds	Baumgartner and Rothhaupt (2003)
Arachnida	Spiders	Ganihar (1997)
Cladocera	Water fleas	Dumont et al. (1975)
Coleoptera	Beetles	Smock (1980)
Copepoda	Oar-footed crustaceans	Dumont et al. (1975)
Decapoda	Crayfish	Garvey & Stein (1993)
Diptera	Flies	Smock (1980)
Ephemeroptera	Mayflies	Smock (1980)
Hemiptera	True bugs	Smock (1980)
Hymenoptera	Wasps and ants	Rust (1991)
Isopoda	Scuds	Ganihar (1997)
Odonata	Dragonflies	Smock (1980)
Orthoptera	Grasshoppers	Duke and Crossley (1975)
Plecoptera	Stoneflies	Benke et al. (1999)
Tricoptera	Caddisflies	Smock (1980)
Fish		
Pomoxis nigromaculatus	Black Crappie	Anders et al. (2003)
Lepomis macrochirus	Bluegill	Anders et al. (2003)
Ameiurus nebulosus	Brown Bullhead	Anders et al. (2003)
Lepomis cyanellus	Green Sunfish	Anders et al. (2003)
Oncorhynchus nerka	Kokanee	Anders et al. (2003)
Micropterus salmoides	Largemouth Bass	Anders et al. (2003)
Esox lucius	Northern Pike	*
Ptychocheilus oregonensis	Northern Pikeminnow	Anders et al. (2003)
Clupea pallasii pallasii	Pacific Herring	Wigley et al. (2003)
Salmonidae	Salmon and trout	Anders et al. (2003)
Cottus bairdii	Sculpin	Anders et al. (2003)
Micropterus dolomieu	Smallmouth Bass	Anders et al. (2003)
Centrarchidae	Sunfish	Anders et al. (2003)
Tinca tinca	Tench	Altindag et al. (1998)
Oncorhynchus clarkii lewisi	Westslope Cutthroat Trout	Anders et al. (2003)
Pomoxis annularis	White Crappie	Anders et al. (2003)
Perca flavescens	Yellow Perch	Anders et al. (2003)
Other		
Detritus	Plant material	*
Dicamptodon aterrimus	Idaho Giant Salamanders	*

Appendix B: Mean daily temperatures (ºC) for Coeur d'Alene Lake, Idaho. Day corresponds to actual calendar date and in this case the simulation day. Data from the table was used for Fish Bioenergetics 3.0 program.

Day	ºC	Day	ºC	Day	ºC	Day	ºC	Day	ºC	Day	ºC	Day	ºC
75	2.94	115	6.56	155	9.33	195	18.19	235	22.62	275	16.52	315	9.42
76	3.10	116	5.09	156	11.23	196	18.71	236	21.71	276	16.19	316	9.37
77	3.00	117	8.02	157	10.21	197	21.38	237	17.81	277	15.76	317	9.13
78	3.00	118	5.09	158	9.03	198	22.67	238	19.43	278	15.67	318	9.08
79	3.05	119	4.83	159	9.03	199	22.48	239	20.71	279	15.47	319	9.03
80	3.10	120	4.83	160	8.98	200	21.48	240	20.86	280	15.33	320	9.03
81	3.10	121	5.55	161	9.23	201	20.00	241	20.71	281	15.23	321	9.08
82	2.94	122	5.09	162	8.53	202	21.77	242	19.14	282	14.99	322	9.03
83	3.05	123	4.99	163	9.18	203	19.81	243	19.81	283	14.80	323	8.78
84	3.05	124	5.25	164	10.06	204	21.15	244	20.19	284	14.71	324	8.73
85	3.26	125	5.96	165	9.77	205	17.33	245	19.28	285	14.66	325	8.73
86	3.53	126	5.30	166	9.52	206	17.57	246	18.61	286	14.47	326	8.58
87	3.63	127	5.20	167	9.62	207	20.23	247	18.95	287	14.14	327	8.33
88	3.68	128	5.35	168	9.82	208	21.43	248	18.99	288	14.09	328	8.23
89	3.63	129	6.82	169	10.31	209	21.52	249	18.99	289	13.75	329	8.23
90	3.78	130	7.13	170	8.88	210	19.90	250	19.33	290	11.71	330	7.93
91	3.68	131	6.01	171	8.33	211	20.62	251	19.47	291	8.28	331	7.83
92	3.95	132	5.91	172	9.27	212	21.04	252	19.57	292	11.28	332	7.83
93	3.90	133	7.58	173	13.46	213	19.66	253	19.57	293	12.50	333	7.68
94	4.00	134	9.42	174	14.80	214	21.09	254	15.98	294	10.55	334	7.53
95	4.10	135	10.30	175	12.79	215	19.76	255	13.44	295	9.57	335	7.68
96	4.00	136	10.59	176	11.33	216	20.86	256	16.81	296	10.50	336	7.63
97	3.95	137	9.12	177	12.83	217	21.81	257	17.19	297	10.70	337	7.53
98	4.05	138	7.58	178	13.30	218	22.48	258	17.33	298	10.80	338	7.33
99	4.52	139	7.13	179	10.55	219	22.67	259	17.33	299	10.89	339	7.28
100	5.04	140	7.18	180	14.85	220	23.00	260	17.28	300	10.60	340	7.18
101	5.71	141	9.57	181	15.19	221	22.86	261	17.33	301	10.60	341	7.03
102	5.96	142	10.84	182	14.37	222	22.14	262	17.33	302	10.65	342	6.77
103	5.19	143	9.91	183	14.18	223	22.91	263	17.33	303	10.60	343	6.57
104	4.93	144	7.53	184	13.08	224	22.86	264	17.43	304	10.45	344	6.22
105	5.09	145	7.33	185	13.17	225	23.34	265	17.52	305	10.70	345	6.22
106	4.78	146	9.18	186	11.53	226	23.20	266	17.66	306	10.75	346	6.22
107	4.57	147	9.82	187	15.33	227	22.05	267	17.38	307	10.70	347	6.22
108	4.41	148	9.97	188	15.62	228	22.29	268	17.19	308	10.55	348	6.22
109	4.52	149	10.02	189	17.23	229	22.67	269	17.19	309	10.60	349	6.12
110	4.78	150	9.62	190	18.66	230	22.67	270	17.00	310	10.80	350	6.02
111	4.94	151	9.32	191	19.00	231	22.96	271	17.14	311	10.60	351	5.86
112	4.68	152	9.22	192	19.33	232	23.00	272	17.14	312	10.55	352	5.66
113	5.29	153	10.01	193	18.90	233	22.96	273	16.95	313	10.16	353	5.40
114	7.92	154	10.31	194	18.95	234	22.76	274	16.81	314	9.82	354	5.25

Appendix B cont'd.

Day	ºC	Day	ºC	Day	ºC	Day	ºC
355	4.99	396	2.89	437	3.53	478	5.61
356	5.09	397	3.00	438	3.73	479	6.07
357	5.14	398	3.05	439	3.73	480	6.01
358	5.09	399	3.10	440	3.94	481	5.81
359	4.68	400	2.84	441	3.94	482	5.81
360	4.68	401	2.94	442	3.74	483	5.61
361	4.57	402	3.00	443	3.58	484	5.71
362	4.52	403	2.89	444	3.74	485	5.81
363	4.41	404	2.89	445	3.95	486	5.86
364	4.15	405	3.00	446	3.79	487	6.06
365	3.79	406	2.89	447	3.79	488	6.27
366	3.79	407	2.84	448	3.84	489	7.48
367	3.58	408	3.00	449	3.90	490	9.47
368	3.58	409	3.05	450	3.95	491	10.75
369	3.31	410	3.00	451	4.26	492	11.62
370	2.94	411	3.00	452	4.31	493	11.13
371	3.21	412	3.00	453	4.62	494	11.32
372	3.21	413	3.05	454	4.78	495	10.16
373	3.21	414	3.05	455	4.93	496	10.64
374	3.36	415	3.00	456	5.44	497	10.50
375	3.36	416	3.00	457	5.80	498	9.61
376	3.21	417	3.05	458	5.40	499	8.23
377	2.94	418	2.84	459	4.26	500	7.18
378	2.51	419	2.94	460	4.31	501	7.78
379	2.73	420	2.84	461	4.52	502	10.94
380	2.73	421	2.83	462	4.57	503	11.52
381	2.51	422	2.84	463	4.78	504	9.32
382	2.25	423	2.84	464	4.78	505	9.52
383	2.25	424	2.89	465	5.14	506	9.61
384	2.25	425	3.00	466	5.30	507	10.94
385	2.41	426	3.05	467	4.93	508	7.68
386	2.19	427	3.00	468	4.99	509	8.43
387	2.14	428	3.05	469	4.88	510	10.11
388	1.71	429	3.21	470	4.99	511	10.41
389	1.55	430	2.94	471	5.19	512	11.33
390	1.49	431	2.89	472	5.45	513	10.99
391	1.60	432	3.00	473	5.66	514	9.67
392	1.71	433	3.16	474	5.61	515	9.32
393	1.98	434	3.42	475	5.45	516	9.52
394	2.62	435	3.37	476	5.30		
395	2.73	436	3.47	477	5.40		

Appendix C: List of prey items consumed by Northern Pike, their energy densities, corresponding units of measure, and their source. The caloric value for Salmonidae was derived by averaging the caloric values reported in literature of species within the family.

Taxonomic group	Common name	Energy density	Unit of measure	Source
Invertebrates				
Annelida	Ringed worms	3,910	Cal/g dry wt	Cummins and Wuycheck (1971)
Amphipoda	Scuds	4,002	Cal/g dry wt	Cummins and Wuycheck (1971)
Arachnida	Spiders	4,825	Cal/g dry wt	Cummins and Wuycheck (1971)
Cladocera	Water fleas	5,232	Cal/g dry wt	Cummins and Wuycheck (1971)
Coleoptera	Beetles	5,371	Cal/g dry wt	Cummins and Wuycheck (1971)
Copepoda	Oar-footed crustaceans	5,741	Cal/g dry wt	Cummins and Wuycheck (1971)
Decapoda	Crayfish	3,766	J/g wet wt	Roell and Orth (1993)
Diptera	Flies	4,276	Cal/g dry wt	Cummins and Wuycheck (1971)
Ephemeroptera	Mayflies	5,469	Cal/g dry wt	Cummins and Wuycheck (1971)
Hemiptera	True bugs	5,638	Cal/g dry wt	Cummins and Wuycheck (1971)
Hymenoptera	Wasps and ants	4,629	Cal/g dry wt	Cummins and Wuycheck (1971)
Isopoda	Scuds	3,786	Cal/g dry wt	Cummins and Wuycheck (1971)
Odonata	Dragonflies	5,117	Cal/g dry wt	Cummins and Wuycheck (1971)
Orthoptera	Grasshopper	5,300	Cal/g dry wt	Cummins and Wuycheck (1971)
Plecoptera	Stoneflies	5,066	Cal/g dry wt	Ciancio and Pascual (2006)
Tricoptera	Caddisflies	4,999	Cal/g dry wt	Cummins and Wuycheck (1971)
Fish				
Pomoxis nigromaculatus	Black Crappie	5,812	J/g wet wt	Liao et al. (2004)
Lepomis macrochirus	Bluegill	3,807	J/g wet wt	Liao et al. (2004)
Ameiurus nebulosus	Brown Bullhead	3,694	J/g wet wt	Liao et al. (2004)
Lepomis cyanellus	Green Sunfish	1,160	Cal/g wet wt	Bryan et al. (1996)
Oncorhynchus nerka	Kokanee	8,987	J/g wet wt	Yule and Luecke (2011)
Micropterus salmoides	Largemouth Bass	4,306	J/g wet wt	Liao et al. (2004)
Esox lucius	Northern Pike	4,928	J/g wet wt	Liao et al. (2004)
Ptychocheilus oregonensis	Northern Pikeminnow	4,650	J/g wet wt	Antolos et al. (2005)
Clupea pallasii pallasii	Pacific Herring	3.69	kJ/g wet wt	Paul et al. (1998)
Salmonidae	Salmon and trout	7,376	J/g wet wt	Muhlfeld et al. (2008) Yule and Luecke (2011)
Cottus bairdii	Sculpin	1.24	Kcal/g wet wt	Perez (1994)
Micropterus dolomieu	Smallmouth Bass	3,856	J/ g wet wt	Liao et al. (2004)
Catostomidae	Suckers	4,350	J/g wet wt	Antolos et al. (2005)
Centrarchidae	Sunfish	1,160	Cal/ g wet wt	Bryan et al. (1996)
Tinca tinca	Tench	4,120	J/g wet wt	Kamler and Stachowiak (1992)
Oncorhynchus clarkii lewisi	Westslope Cutthroat Trout	5,764	J/g wet wt	Muhlfied (2008)
Pomoxis annularis	White Crappie	5,812	J/g wet wt	Liao et al. (2004)
Perca flavescens	Yellow Perch <150mm	2,512	J/g wet wt	Hanson (1997)
Perca flavescens	Yellow Perch >150mm	5,097	J/g wet wt	Liao et al. (2004)
Other				
Detritus	Plant material	4,414	Cal/g dry wt	Cummins and Wuycheck (1971)
Dicamptodon aterrimus	Idaho Giant Salamanders	21,656	J/g dry wt	Burton and Likens (1975)

Appendix D: Frequency of occurrence (%*O*), percent by number (%*N*), and percent energy contribution (%*EC*) of prey items consumed from four year classes of Northern Pike in Coeur d'Alene Lake, Idaho (March 2012 to May 2013). Sample size (*n*) and the percentage of empty stomachs are provided for each class and season.

	Year class											
	2011			2010			2009			2008		
Summary of taxa	%*O*	%*N*	%*EC*	%*O*	%*N*	%*EC*	%*O*	%*N*	%*EC*	%*O*	%*N*	%*EC*
Season	Spring 2012											
Sample size	17			54			129			36		
Empty	64			44			57			44		
Invertebrates												
Annelida	17	29	[a]	0	0	0	6	3	[a]	8	5	[a]
Coleoptera	0	0	0	6	10	[a]	0	0	0	0	0	0
Decapoda	0	0	0	0	0	0	0	0	0	0	0	0
Hymenoptera	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0
Odonata	0	0	0	3	4	[a]	2	1	[a]	0	0	0
Fish												
Catostomidae												
Largescale Sucker	17	14	76	3	1	[a]	0	0	0	0	0	0
Centrarchidae												
Black Crappie	17	14	3	0	0	0	0	0	0	4	3	[a]
Bluegill	0	0	0	0	0	0	0	0	0	0	0	0
Largemouth Bass	0	0	0	0	0	0	3	2	1	0	0	0
Unknown species	0	0	0	0	0	0	0	0	0	0	0	0
White Crappie	0	0	0	0	0	0	0	0	0	0	0	0
Clupeidae												
Pacific Herring	0	0	0	0	0	0	0	0	0	0	0	0
Cottidae												
Sculpin	0	0	0	0	0	0	0	0	0	4	3	[a]
Cyprinidae												
Northern Pikeminnow	0	0	0	0	0	0	0	0	0	0	0	0
Tench	0	0	0	0	0	0	0	0	0	4	3	20
Esocidae												
Northern Pike	0	0	0	0	0	0	0	0	0	4	3	2
Ictaluridae												
Brown Bullhead	0	0	0	3	1	[a]	3	2	1	4	3	[a]
Percidae												
Yellow Perch <150mm	33	29	21	6	2	[a]	15	12	1	8	5	0
Yellow Perch ≥150mm	0	0	0	11	3	5	6	4	2	8	13	3
Salmonidae												
Kokanee	0	0	0	51	71	68	35	61	54	28	45	36
Unknown species	0	0	0	0	0	0	3	2	9	4	3	3
Westslope Cutthroat Trout	0	0	0	17	7	26	26	14	31	20	13	36
Other												
Idaho Giant Salamander	0	0	0	0	0	0	0	0	0	0	0	0
Detritus	17	14	[a]	0	0	0	0	0	0	4	3	[a]

[a]Frequency <1%

Appendix D cont'd.

	Year class											
	2011			2010			2009			2008		
Summary of taxa	*%O*	*%N*	*%EC*	*%O*	*%N*	*%EC*	*%O*	*%N*	*%EC*	*%O*	*%N*	*%EC*
Season	Summer 2012											
Sample size	9			47			37			15		
Empty	44			53			46			33		
Invertebrates												
Annelida	0	0	0	3	1	[a]	0	0	0	0	0	0
Coleoptera	0	0	0	3	72	[a]	0	0	0	0	0	0
Decapoda	0	0	0	0	0	0	4	3	[a]	0	0	0
Hymenoptera	0	0	0	0	0	0	0	0	0	10	27	[a]
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0
Odonata	0	0	0	3	2	0	0	0	0	0	0	0
Fish												
Catostomidae												
Largescale Sucker	0	0	0	3	1	3	0	0	0	0	0	0
Centrarchidae												
Black Crappie	0	0	0	0	0	0	0	0	0	0	0	0
Bluegill	0	0	0	0	0	0	0	0	0	0	0	0
Largemouth Bass	20	20	11	3	1	[a]	0	0	0	0	0	0
Unknown species	0	0	0	0	0	0	0	0	0	0	0	0
White Crappie	0	0	0	0	0	0	0	0	0	0	0	0
Clupeidae												
Pacific Herring	0	0	0	0	0	0	0	0	0	0	0	0
Cottidae												
Sculpin	0	0	0	0	0	0	0	0	0	0	0	0
Cyprinidae												
Northern Pikeminnow	0	0	0	0	0	0	0	0	0	0	0	0
Tench	0	0	0	0	0	0	0	0	0	0	0	0
Esocidae												
Northern Pike	0	0	0	3	1	[a]	0	0	0	0	0	0
Ictaluridae												
Brown Bullhead	20	20	57	0	0	0	9	7	1	0	0	0
Percidae												
Yellow Perch <150mm	20	20	31	10	2	[a]	4	3	[a]	0	0	0
Yellow Perch ≥150mm	0	0	0	7	1	2	9	7	2	20	13	4
Salmonidae												
Kokanee	0	0	0	50	17	80	65	72	93	50	47	90
Unknown species	0	0	0	0	0	0	0	0	0	0	0	0
Westslope Cutthroat Trout	0	0	0	10	2	14	9	7	3	10	7	6
Other												
Idaho Giant Salamander	0	0	0	0	0	0	0	0	0	0	0	0
Detritus	40	40	[a]	3	1	[a]	0	0	0	10	7	[a]

[a]Frequency <1%

Appendix D cont'd.

	Year class											
	2011			2010			2009			2008		
Summary of taxa	*%O*	*%N*	*%EC*	*%O*	*%N*	*%EC*	*%O*	*%N*	*%EC*	*%O*	*%N*	*%EC*
Season						Fall 2012						
Sampling size	8			41			34			19		
Empty	50			22			50			37		
Invertebrates												
Annelida	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda	0	0	0	0	0	0	0	0	0	0	0	0
Hymenoptera	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0
Odonata	0	0	0	0	0	0	0	0	0	0	0	0
Fish												
Catostomidae												
Largescale Sucker	0	0	0	2	1	2	8	7	7	0	0	0
Centrarchidae												
Black Crappie	0	0	0	16	19	2	8	7	[a]	0	0	0
Bluegill	60	67	63	9	28	1	13	25	0	0	0	0
Largemouth Bass	0	0	0	2	1	1	8	7	[a]	0	0	0
Unknown species	0	0	0	2	1	[a]	0	0	0	8	8	1
White Crappie	0	0	0	0	0	0	0	0	0	0	0	0
Clupeidae												
Pacific Herring	0	0	0	0	0	0	0	0	0	0	0	0
Cottidae												
Sculpin	0	0	0	0	0	0	0	0	0	0	0	0
Cyprinidae												
Northern Pikeminnow	0	0	0	0	0	0	4	4	8	0	0	0
Tench	0	0	0	0	0	0	0	0	0	0	0	0
Esocidae												
Northern Pike	0	0	0	0	0	0	0	0	0	0	0	0
Ictaluridae												
Brown Bullhead	0	0	0	5	3	3	4	4	1	0	0	0
Percidae												
Yellow Perch <150mm	40	33	37	28	25	10	8	7	1	8	8	[a]
Yellow Perch ≥150mm	0	0	0	14	8	33	13	11	10	25	23	7
Salmonidae												
Kokanee	0	0	0	9	6	48	21	18	63	33	38	82
Unknown species	0	0	0	0	0	0	0	0	0	8	8	5
Westslope Cutthroat Trout	0	0	0	0	0	0	8	7	10	17	15	5
Other												
Idaho Giant Salamander	0	0	0	0	0	0	0	0	0	0	0	0
Detritus	0	0	0	12	7	[a]	4	4	[a]	0	0	0

[a]Frequency <1%

Appendix D cont'd.

	Year class											
	2011			2010			2009			2008		
Summary of taxa	%*O*	%*N*	%*EC*	%*O*	%*N*	%*EC*	%*O*	%*N*	%*EC*	%*O*	%*N*	%*EC*
Season	Spring 2013											
Sample size	112			93			28			16		
Empty	41			46			32			44		
Invertebrates												
Annelida	3	2	[a]	2	1	[a]	5	8	[a]	0	0	0
Coleoptera	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda	0	0	0	0	0	0	0	0	0	0	0	0
Hymenoptera	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	3	5	[a]	0	0	0	0	0	0	0	0	0
Odonata	0	0	0	0	0	0	0	0	0	0	0	0
Fish												
Catostomidae												
Largescale Sucker	0	0	0	0	0	0	5	2	15	0	0	0
Centrarchidae												
Black Crappie	4	3	[a]	4	4	1	0	0	0	13	8	14
Bluegill	3	4	[a]	0	0	0	0	0	0	0	0	0
Largemouth Bass	0	0	0	0	0	0	0	0	0	0	0	0
Unknown species	0	0	0	0	0	0	0	0	0	13	8	[a]
White Crappie	1	3	[a]	0	0	0	0	0	0	0	0	0
Clupeidae												
Pacific Herring	0	0	0	2	4	1	14	27	3	0	0	0
Cottidae												
Sculpin	0	0	0	0	0	0	0	0	0	0	0	0
Cyprinidae												
Northern Pikeminnow	0	0	0	0	0	0	5	19	1	0	0	0
Tench	0	0	0	0	0	0	5	2	3	0	0	0
Esocidae												
Northern Pike	0	0	0	0	0	0	0	0	0	0	0	0
Ictaluridae												
Brown Bullhead	0	0	0	2	1	[a]	0	0	0	13	8	5
Percidae												
Yellow Perch <150mm	41	42	8	31	30	2	19	8	1	0	0	0
Yellow Perch ≥150mm	23	16	51	20	19	13	14	10	6	25	15	10
Salmonidae												
Kokanee	12	19	24	19	23	73	19	17	68	25	46	65
Unknown species	1	1	1	6	4	3	0	0	0	0	0	0
Westslope Cutthroat Trout	5	5	15	11	9	6	14	6	4	13	15	6
Other												
Idaho Giant Salamander	0	0	0	2	2	[a]	0	0	0	0	0	0
Detritus	3	2	[a]	2	2	[a]	0	0	0	0	0	0

[a]Frequency <1%