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Predation, turbidity, and other factors influencing juvenile Salmonid survival in the lower Snake River

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Predation, Turbidity, and Other Factors Influencing Juvenile Salmonid Survival in the Lower Snake River

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MASTER'S THESIS

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Abstract

The object of this study was to quantify consumption rates of juvenile salmonids by three introduced species, smallmouth bass (*Micropterus dolomieu*), walleye (*Sander vitreus*) and channel catfish (*Ictalurus punctatus*). Consumption information is crucial because the construction of the Snake River hydrosystem has created a series of reservoirs, which have altered the river's flow regimes, riparian vegetation, and turbidity. Further, several non-native fishes have been introduced as sport fish into the Lower Snake River. This combination of physical alterations and new biological interactions with introduced species has reduced the survival of anadromous salmonids in the Lower Snake River. Currently all Snake river salmonids are listed as threatened or endangered under the Endangered Species Act. A series of 12 sites, in four Lower Snake River reservoirs, were sampled via nighttime electrofishing in the spring and summer of 2011. All fish captured were identified, measured (mm) and weighed (g). Relative abundance of smallmouth bass was 4.6%, walleye 0.13% and channel catfish 0.08%. By weight, salmonids comprised 2% (smallmouth bass), 32% (channel catfish), and 0% (walleye) of the predator diet. The ability of smallmouth bass to consume juvenile salmonid prey was investigated *in vitro*, using four turbidity levels (0, 0.5, 5 and 10 NTUs), and five prey densities (1,2,4,8,16 prey items). In trials with 16 prey items, predation was significantly lower in treatments with 5 or 10 NTU than trials with 0.5 or 0 NTU, suggesting that under high prey densities, turbidity may reduce with smallmouth bass feeding predation. Flows and turbidity were high during the entirety of field sampling, which likely reduced the incidence of salmonids in predator stomachs. Reduced predator metabolic rate (due to lowered temperatures), and turbidity are associated with high

flows. Future management efforts may include maintaining turbidity in the water column, along with spring and summer flow augmentation as a way to enhance juvenile salmonid survival during outmigration to the ocean.

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Introduction

Snake River Salmonids

The purpose of this study was to investigate anthropogenic effects on juvenile salmonid survival in the Lower Snake River. The Lower Snake River is affected by four dams, which have caused numerous physical changes in the system. Numerous factors relating to dam effects have affected juvenile salmonid survival during the freshwater life stage. I investigated differences in fish community structure at potential dredge sediment disposal sites, performed a diet analysis on three introduced piscivores, and conducted an *in vitro* investigation of turbidity effects on smallmouth bass feeding rate.

The Snake River is home to several anadromous salmon species: Chinook (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss)*, and sockeye (*O. nerka)*. Chinook salmon and steelhead are listed under the Endangered Species Act (FR Notice: 57 FR 34639, 4/22/1992 and FR Notice 62 FR 43937, 8/18/1997 respectively) as threatened, while sockeye are listed as endangered (FR Notice 56 FR 58619, 11/20/1991). Millions of dollars are spent yearly on protecting and restoring these stocks.

Historically, Snake River salmon accounted for nearly 50% of the Columbia Basin salmon run (Hassemer et al. 1997). The enormous historic productivity of this population is evidenced by the estimated return runs of adult Chinook salmon of 1.5 million in the late 1800's (Matthews and Waples 1991). However, during out-migration to the ocean, and the subsequent return to spawn, Pacific Northwest salmon run a gauntlet of dangers, including: dam effects, degraded habitat, overfishing, and predatory fish (Craig and Hacker 1940). The purpose of this study was to investigate predation rates on juvenile salmonids by introduced piscivores, as well as to investigate consumption rates of juvenile salmonids by smallmouth bass under various turbidity levels *in vitro*.

Following construction of the Columbia Basin hydrosystem, including the four lower Snake River dams (constructed between 1955 and 1972), salmon populations plummeted to a low of under 35,000 returning adults in 1979 (FPC 2008). Evidence suggests that spawning and subsequent recruitment as a measure of stock performance decreased for all Snake River stocks post completion of the Snake River hydrosystem, with Snake River stocks showing a larger decline than lower Columbia River stocks. These differences in survival rates and productivity coincide with the development of the hydropower system, suggesting the completion of the hydropower system may have had a negative effect on salmon stocks. Survival rates and recruitment also became more variable for upstream stocks, while downstream stocks remained much more stable (Schaller et al 1999). The decreases in escapement (fish that "escape" ocean hazards, including fishing pressure, and return to fresh water), and subsequent spawning and recruitment are based upon many factors.

One of the most important factors contributing to adult salmon returns in the North Pacific Ocean is the pattern of climate shifts known as the Pacific Decadal Oscillation (PDO). The PDO is separated into a negative phase, during which surface waters near the Pacific Northwest coast are cool, and a positive phase, during which the opposite pattern occurs. Mantua et al. (1997) were some of the first researchers to note a correlation between changes in the PDO pattern and salmon productivity. A negative PDO period tends to lead to enhanced streamflows in the Pacific Northwest, as well as higher biological productivity in the near-shore ocean, leading to a "bottom up" enhancement of salmon production. Salmon runs, and salmon harvest, declined sharply in the Northwest in around 1977, as the PDO shifted from a cool to a warm phase (Hare et al. 1999). This climate driven decrease in salmon returns lead a wave of government regulation in the 80's and 90's. When the PDO reversed to a cold regime in 1999, total adult salmon and steelhead counts at Bonneville Dam have increased dramatically, increasing from around 600,000 fish annually to over 2.5 million (Northwest Power and Conservation Council 2003).

While climatic shifts may have a huge impact on salmon production, they are difficult to predict with any degree of certainty. My research presented here focused on anthropogenic effects on salmonid production, as they may be simpler to quantify, and mitigating their effects may be easier.

River flow has been shown to have a strong effect on smolt survival. Connor (2001) found that survival of outmigrating Chinook salmon was influenced by flow and water temperature. Survival and flow were positively correlated, while survival and water temperature were inversely correlated. Dam operations, by the creation of reservoirs, typically reduce flow and raise temperature. The study by Connor (2001) also estimated the magnitude of the effect of such water changes, reporting changes in survival of 3% with a flow change of 100 m^3/s when temperature was held constant, and a 7% change in survival with a temperature change of 1^o C when flow was held constant. While direct dam effects are a large contributing factor to the decline of the native salmonids, there are many other secondary and tertiary effects that contribute to lower salmonid populations.

A study by Nilsson et al. (1991) suggested that the alteration of rivers by damming can have profound effects on the riparian vegetation. In systems that are heavily managed, with large swings in reservoir level, effects are pronounced. As the four dams on the lower Snake River are “run of the river” dams, with a limited ability to control water levels, the main vegetation effects stem from the armoring that has starved the river banks of sediment. In a comparison of rivers in northern Sweden analyzing percent cover, the highest values were found in undammed stretches with abundant fine-grained sediment (Nilsson et al. 1991). The resulting reduction in vegetative cover in the Snake River’s riparian zone likely has a significant impact on juvenile salmonids.

The importance of riparian vegetation for juvenile salmonids is based on several factors. Primarily, overhanging or littoral vegetation provides cover from predation. Stream cover also keeps water temperature low, which decreases metabolic rate, decreases activity of pathogens, and increases the solubility of oxygen. A significant portion of juvenile salmonid diet is terrestrial in origin, the removal of overhanging vegetation may reduce a crucial salmonid food source (Bugert 1985). A similar study by Paulsen and Fisher (2001) investigating the effects of land use indices in the Snake River on Chinook parr survival concluded that parr reared in wilderness areas (along undammed stretches of river) had higher survival than parr reared in lands managed for timber production. This would suggest that dam and other anthropogenic effects on riparian vegetation have a significant impact on juvenile survival.

Adult and juvenile fish face a variety of hazards during upstream (adult) and downstream (juvenile) migration. For upstream migration, fish ladders were included or added for all four Snake River dams, to provide salmon with a method of accessing their natal tributary. A study by Sandford and Smith (2002), found that adult salmon are able to effectively use provided fish ladders, suggesting that fish passage may be as much as 98% during upstream migration. This would suggest that adult fish are only slightly affected by hydrosystem itself during upstream migration. Conventional wisdom would suggest that the greatest dam effects would occur during downstream migration as smolts, when the fish are small, and less resistant to environmental effects. Dam effects for smolts include fish killed directly by turbines, injuries from gas supersaturation (gas bubble trauma), mammal and bird predation directly below the dams, as well as reservoir effects. These include increased water temperatures, delayed migration, and increased exposure to predation.

While the impacts of any one dam may be minimal, upriver stocks may have to pass through as many as eight dams during the migration to the Pacific Ocean. While these direct effects are implicated in severe smolt mortality, indirect effects may be even more damaging to salmon stocks. Budy et al. (2002), provided evidence that while the cumulative effects of these stressors might not lead to direct mortality for fish during their time in the hydrosystem, delayed mortality might explain discrepancies in smolt-to-adult return (SAR) rates. This type of mortality is difficult to measure directly, and more difficult to mitigate. A study by Muir et al. (2006) suggested that smolts collected from Lower Granite dam, and released below Bonneville dam may have higher mortality than smolts left to migrate in-river through the dams. Post-hydrosystem mortality was higher for smolts transported early in the season, however, mortality was higher for in-river migrating smolts later in the season. Smolts left to migrate in-river took between two and four weeks, while transported fish took two days to cover the same distance. During this time, in-river fish grew 5-8 mm. The larger size likely protected juveniles from predation by northern pikeminnow (*Ptychocheilus oregonensis*), leading to a reduced ratio of transported to migrant adult return rates. Muir et al. (2006) concluded that perhaps the simplest explanation for post-hydrosystem mortality is not due to stress directly, but instead to differential timing and size at ocean entry. This would seem to suggest that for maximum smolt survival, juvenile fish should be left to migrate in channel to maximize feeding and growth potential. However, these salmonids must run a gauntlet of predators during their downstream migration, including several species of piscivorous fish and birds. These include native species such as northern pikeminnow, as well as a variety of introduced species, including smallmouth bass, walleye, and channel catfish (Carey et al. 2011, Sanderson et al. 2009).

As salmon species use a r-selection life history (many offspring with low parental investment), natural mortality is high. Fewer than 10% of eggs spawned in the Snake River or tributaries hatch and successful grow to the smolt stage (Kareiva et al. 2000). Additionally, fewer than 5% of juveniles that successful migrate to the ocean return as adult fish. Ocean conditions are the largest single factor effecting adult salmon return rates (Scheuerell and Williams 2005). Fisheries managers can do little to affect egg to smolt survival rates, or adult survival rates in the marine environment. Mortality from dam effects and introduced species are the only losses than may be reduced by active management.

This combination of predation and dam effects as described in Williams and Matthews (1995) have led Columbia and Snake River stocks of salmon to be among the most intensively managed fish in the world. Quantifying predation rates on juvenile salmon by piscivorous predatory fish may lead to improved management techniques. As evidenced by the success of the Northern Pikeminnow Management Program (NPMP), control of predatory fish may be one of the most successful and easily implemented management tools. Hence, I examined predation on salmonids in the four Lower Snake River reservoirs by three nonindigenous fish (smallmouth bass, channel catfish, and walleye) and investigated the role that turbidity plays in predator-prey interaction between smallmouth bass and salmonids.

Study Area

The Snake River is the largest tributary of the Columbia River, draining over 250,000 km^2 in parts of six states (Kammerer 1990). By length, the river is the 12th longest in the United States, providing hundreds of kilometers of waterway for transportation, wildlife habitat and recreation. The study area was a 175 km section of the river between Ice Harbor Dam near Pasco, WA (river kilometer 43.4), to upstream of Lewiston, ID (rkm 235.7) that encompassed the four Lower Snake River reservoirs (See Figure 1 for map of study sites). Reservoirs were created by Ice Harbor Dam (rkm 15.6), Lower Monumental (rkm 67), Little Goose (rkm 113) and Lower Granite (rkm 173). Study sites were identified by the United States Army Corp of Engineers (USACE). Sites were divided into an upstream (A) and downstream (B) transect. The majority of sites represent areas the USACE has identified as high quality shallow water habitat. A description of sampling transects are included in Table 1.

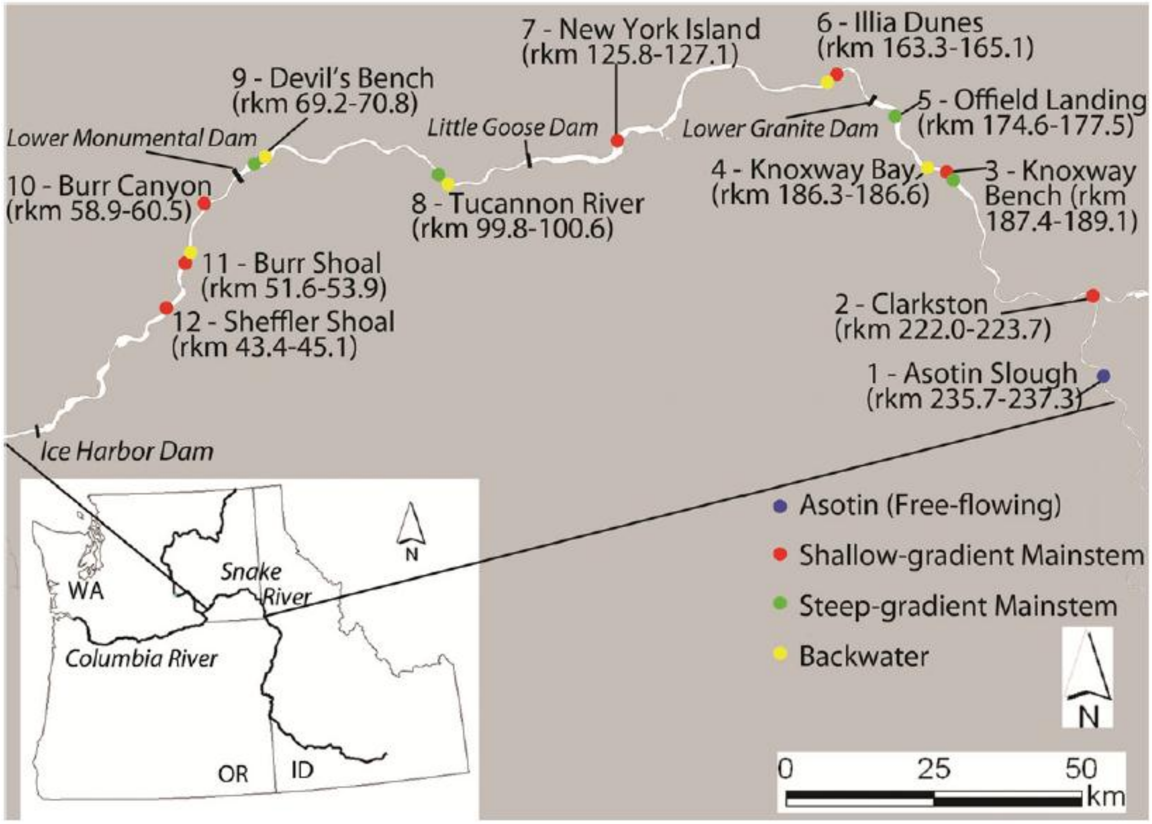

Figure 1. **Twelve study sites located on the Lower Snake River. Sites were grouped into the above categories based on bed slope and river flow. (rkm=river kilometers from mouth at Columbia River.)**

Table 1. Study Site and Transect Characteristics

Site name	Transect Number	Classification	Bed Slope	Substrate Size	Aspect
Asotin Slough Upper	1A	Free Flowing River	Gradual	Coarse	North
Asotin Slough Lower	1B	Free Flowing River	Gradual	Coarse	North
Clarkston Upper	2A	Shallow Mainstem	Gradual	Coarse with Silt Deposition	North
Clarkston Lower	2B	Shallow Mainstem	Gradual	Coarse with Silt Deposition	North
Knoxway Bench Upper	3A	Steep Gradient	Rapid	Cobbles and Talus	North
Knoxway Bench Lower	3B	Shallow Mainstem	Gradual	Sand and Silt	North
Knoxway Bay Upper	4A	Backwater	Rapid	Sand and Silt	West
Knoxway Bay Lower	4B	Backwater	Gradual	Cobbles with sand and silt	East
Offield Landing Upper	5A	Steep Gradient	Rapid	Cobbles with sand and silt	North
Offield Landing Lower	5B	Steep Gradient	Rapid	Cobbles with sand and silt	North
Illia Dunes Upper	6A	Shallow Mainstem	Gradual	Sand with few cobbles	North
Illia Dunes Lower	6B	Backwater	Gradual	Sand and Silt	North
New York Island North	7A	Shallow Mainstem	Rapid	Cobbles	North
New York Island South	7B	Shallow Mainstem	Gradual	Silt	South
Tucannon River Upper	8A	Backwater	Rapid	Cobbles and Talus	North
Tucannon River Lower	8B	Steep Gradient	Rapid	Talus	North
Devil's Bench Upper	9A	Backwater	Gradual	Sand and Silt	South
Devil's Bench Lower	9B	Steep Gradient	Rapid	Cobbles with sand and silt	South
Burr Canyon Upper	10A	Shallow Mainstem	Gradual	Cobbles with sand and silt	South
Burr Canyon Lower	10B	Shallow Mainstem	Gradual	Cobbles	South
Burr Shoal Upper	11A	Backwater	Gradual	Sand and Silt	North
Burr Shoal Lower	11B	Shallow Mainstem	Gradual	Cobbles with sand and silt	North
Sheffler Shoal Upper	12A	Shallow Mainstem	Gradual	Cobbles with sand and silt	North
Sheffler Shoal Lower	12B	Shallow Mainstem	Gradual	Cobbles with sand and silt	North

The dams are “run of the river” dams; having a limited ability to control water levels, which results in fairly constant reservoir levels. The inundation of formerly free flowing sections of the river has had a profound effect on the organisms that use the river. One of the most apparent and ecologically widespread changes brought by the dams is the removal of sediment from the water column, and the subsequent depositing of this sediment in the slackwater behind the dams.

Dam Effects-

As the Snake River joins with the Clearwater near the city of Clarkston, WA, it flows into Lower Granite Lake. Water velocity is reduced, and suspended sediments settle out. This leads to several downstream effects: First, downstream of the dams, the river has become starved for small sized particles. Rivers continually move sediment downstream, particularly during the spring floods. Below the dams, the average sediment size increases, as fine particles are continually moved downstream. With no small particles moving into the system from upstream, the river bed becomes armored, leading to large cobbles deeply embedded in the river bed. Second, the trapped sediments build up in the reservoirs, reducing flood control ability and hindering passage of barges (Ligon et al. 1995). In the lower Snake hydrosystem, this problem is most acute in the reservoir behind Lower Granite Dam, near the city of Clarkston, WA, where the Clearwater River enters the Snake. The United States Army Corp of Engineers (USACE) estimates that over 1.5 million cubic meters (m^3) of sediment enters the confluence of the Snake and Clearwater rivers annually. Approximately 610,000 m^3 of sediment are deposited at the confluence every year, and the remainder continues to be transported by the river (Teasdale 2010). In order to provide a continuous shipping channel for passing barges, the river is dredged and sediments are disposed of elsewhere. On land disposal has not been considered as an option for sediments, due to the steep talus cliffs that line most of the river. Available land would be quickly filled. Moving sediment to disposal areas out of the river valley would be prohibitively expensive. However, several options exist for in-channel disposal of sediments. Options proposed by the USACE include the creation of above-water islands, below-water bars, and deep water disposal.

Dredging of the shipping channel near the confluence of the Clearwater and Snake rivers was first conducted in 1986. Approximately 610,000 m^3 of sediment, consisting of fine sands and silts, was removed from the channel. The sediment was placed in holding ponds, with a stand pipe returning water to Lower Granite Lake. A study by Bennett and Shrier (1987) found minimal effects on many different river metrics, including turbidity, dissolved oxygen, and total suspended solids. Dredging sites were compared to sites located near the outfall from disposal ponds, turbidity was the only measure that differed significantly between the two types of sites. However, there was no significant difference in turbidity as measured above or below the dredging site during dredging. While disposal activities increased turbidity slightly, measurements taken 425 m downstream from either activity detected no enhanced turbidity. Bennett and Shrier concluded that the effects are significant enough to warrant seasonal timing of dredging and disposal to avoid a possibility of interfering with salmonid migration.

Experimental disposal was first conducted in 1988 in Lower Granite Reservoir, including the construction of bar at mid-depth (6-18 m) and additional disposal at deep sites (>18 m) (Bennett et al. 1991). Immediate effects of both the dredging and disposal were found to be minimal, Bennett and Shrier (1986) have shown that shallow water provides feeding and “holding” habitat for juvenile salmonids, as well as for resident game fishes. Mid-depth habitat was shown to host higher benthic community diversity, as well as higher game fish diversity.

Bennett et al. (1988) investigated the possibility of using in-river disposal of sediments to enhance the existing habitat. The study compared fish community structure at three sites, a shallow water reference site, a mid-depth disposal site, and a mid-depth reference site. Community structure at the mid-depth disposal site had characteristics of both the shallow and mid-depth reference sites, with most metrics equal across the three sites. However, Chinook and steelhead salmon were not present at the sites prior to sediment disposal, while both species were found post-sediment disposal at the mid-depth disposal site, possibly due to the decreased depth.

Outmigrating Chinook salmon are able to use fine substrate disposal sites as feeding stations, thus the potential for salmon specific improvements through the creation of shallow water habitat via dredge sediments is high (Bennett 1988a, Bennett 1988b, Curet 1994). Disposal effects on fishes of the Snake River continue to be studied, and potential deposition sites have been identified.

While the need to dredge the river is an unfortunate side effect of dam operations, dam operations may be used to help reduce the most deleterious side effects on the river. A study by Bratovich (1985) found that smallmouth bass nests were affected by normal dam operations. Twenty seven percent of surveyed smallmouth bass nests containing eggs and/or fry were left exposed above water level during the course of normal dam operations in 1980. During the spring and summer of 1991 and 1992, water levels in the Lower Granite reservoir were stabilized at minimum operating pool (MOP). This reduction of the water level opened up habitat for fishes that require stable shallow water habitats for spawning and rearing.

As part of this water management strategy change, water temperature was lowered in the reservoir by increasing flow out of the Dworshak Dam on the Clearwater River. Evidence had shown that a reduction in water temperature can force community shifts to favor fishes that prefer colder water. The colder water release in 1991 and 1992 delayed spawning of smallmouth bass nearly three weeks, leading to a weaker 1993 year class (Bennett et al. 1994). Altering flow regimes may have a beneficial effect by temporarily restoring the river to a condition that mimics a more natural system.

The effects of the disposal stations on the relationship between juvenile salmonids and their predators was first studied by Bennett et al. (1990). The study suggested that predator numbers, including northern pikeminnow, channel catfish, and smallmouth bass, were lower at the disposal stations as compared to reference stations elsewhere in the reservoir. However, the study concluded that there was not a significant difference in fish community structure between reference and disposal stations.

Non-Native Fish in the Snake River

The introduction of non-native game fish into the Snake River, including walleye, smallmouth bass, and channel catfish has increased predation pressure on already threatened stocks of native salmonids. In the John Day reservoir, through which Snake River salmon must pass through during their out-migration, Rieman et al. (1991) estimated an annual loss through predation of 2.7 million, or 14% of all juvenile salmonids that entered the reservoir. Historically, apex piscivores in the Northwest's lotic systems have included the northern pikeminnow (NPM) as well as mammal and bird species (Ward et al. 1995). NPM are actively managed in the Snake and Columbia rivers through the Pikeminnow Sport-Reward Program, which began in 1990 (Porter 2011). The program was designed to reduce the number of NPM > 228 mm, as larger NPM consume larger numbers of fish prey, with NPM > 400 mm acting as the most important predators of salmonids (Rieman et al. 1988). Additionally, northern pike minnow have been the subject of many predation studies in the Snake River, and much data has been collected on feeding habits of these fish. However, a study by Fritts and Pearsons (2006) suggests that smallmouth bass may be a larger source of juvenile Chinook salmon mortality than the northern pikeminnow. In the lower Yakima River, which confluences with the Columbia River just downstream of the confluence with the Snake River, smallmouth bass appear to have upset the “size-based predation risk dynamics”, with small bass actually acting as the more important consumer of salmonid prey. The maximum relative length of salmon consumed (measured by a ratio of prey to predator length) was found to be 56.6%. The study concluded that smallmouth bass appear to feed on salmonids starting at a younger age and smaller size than northern pikeminnow. Most salmonids found in stomach contents were from bass smaller than 250 mm.

Most research on piscivory in the Snake River has focused on the diet habits of smallmouth bass and the habits of northern pikeminnow. Little to no research has been conducted on the diet habits of walleye or channel catfish in the Snake River.

Walleye:

Walleye are known to be voracious predators, particularly of juvenile salmonids, when available. In Lake Roosevelt, the reservoir behind Grand Coulee dam, walleye are estimated to consume 9-15% of hatchery released kokanee within 41 days of the release (Baldwin et al 2003). The Sanpoil River arm of Lake Roosevelt is the site of release for kokanee fry and yearlings from the Spokane Tribal Hatchery. Walleye predation on these fish is high, age 0.5 kokanee composed 45.1% of the diet by weight, and even age 1.5 kokanee contributed 16.9% by weight to walleye diet (Stroud et al. 2010). Using bioenergetics modeling, 470,000 kokanee fry were consumed during the study (March 24 to July 14, 2010). This predation accounted for 79.7% of the kokanee fry release in 2010. While walleye feeding is likely stimulated by these large additions of forage fish into the lake, walleye are a huge source of salmon mortality in the Columbia River system. In John Day Reservoir, walleye are estimated to account for 13% of juvenile salmonids lost to fish predators during outmigration (Rieman et al. 1991). McMahon and Bennett (1996) estimated that walleye are responsible for one-third of the annual predation loss in the Columbia River.

Channel Catfish:

Channel catfish, while being facultative omnivores, may be a very important source of juvenile salmonid mortality, especially during migration. An analysis of channel catfish diets in John Day Reservoir on the Columbia River suggested that juvenile Pacific salmon and steelhead composed 33% of channel catfish diet (Poe et al. 1991). Seasonally, salmonids were an even higher dietary component, up to 49% of stomach content weight during April to July. Vigg et al. (1991) estimated a daily consumption of salmonids by channel catfish at 0.5 prey/predator for channel catfish greater than 400 mm, a daily consumption higher than those estimated for smallmouth bass or walleye. Consumption peaked in July, which coincided with maximum temperature, as well as the maximum abundance of salmonids.

Smallmouth Bass:

Salmonid consumption by smallmouth bass may be extremely high in the Snake River. Many previous studies have examined smallmouth bass predation in small sections of river.

A study by Anglea (1997) suggested that consumption rates of juvenile salmonids in Lower Granite Reservoir by smallmouth bass may be up to 0.38 smolts/bass/day. This lead to a total consumption of juvenile salmonids of 83,476 and 64,020 in 1994 and 1995 respectively (April through November sampling). The study concluded that predation rates were highest during outmigration, suggesting that smallmouth bass are largely opportunistic feeders. A smallmouth bass tracking study conducted by Piaskowski (1998) showed that smallmouth bass were largely found in near shore habitat, leading to a habitat overlap between smallmouth bass and out-migrating salmonids. This behavior would lead to variable, but high predation rates during outmigration.

In 1994, Curet reported that smallmouth bass consumed 31,512 subyearling Chinook salmon in Lower Granite Reservoir (Based on sampling conducted in May 1992). With an estimated 786,000 subyearling Chinook moving through the reservoir that year, smallmouth bass were responsible for a loss of 3.8% of the naturally produced Chinook cohort that that year. This 3.8% loss was also only calculated for the one reservoir, there are likely similar predation rates in other downstream reservoirs.

In the Columbia River, Tabor et al. (1993) found that smallmouth bass predation during outmigration of juvenile salmonids was very high. Salmonids made up 59% of the diet by weight, and salmonids were present in 65% of bass stomachs.

Another smallmouth bass predation study based in the Snake River (Naughton et al. 2004) found that juvenile salmonids accounted for only 11% of smallmouth bass diets by weight in 1996. Based on smallmouth bass population in 1996/1997, 17,500 juvenile salmonids were estimated to have been consumed by smallmouth bass just in the Lower

Granite Reservoir. However, the study concluded that high flows, lower water temperatures, and high turbidity likely lowered predation rates.

A study conducted in 1965-67 (prior to the construction of the lower Snake River hydrosystem) examining the food habits of smallmouth bass in the Snake River found no predation on salmonids. Smallmouth bass larger than 100 mm (n=95) were sampled. Fish prey items composed 13% of the diet by weight, with no salmonids found (Keating 1970). While sample size for this study was fairly small, a larger study conducted in 1996-97 compared smallmouth bass predation between an upstream section of the Snake River (between confluence with Imnaha River and Pittsburg Landing, ID) that is relatively unaffected by damming, with a downstream section (between confluence with Salmon River and Asotin, WA) that contains the edge of Lower Granite Reservoir. The study found that smallmouth consumed a significantly higher proportion of crayfish in the upstream section, and significantly more fish in the downstream section (Nelle 1999). Overall, the study concluded that predation on juvenile salmon (Chinook) was very low in these upstream sections, at less than 0.01 Chinook/bass/day.

A study conducted in Brownlee Reservoir, ID (a middle Snake River reservoir) found that smallmouth bass grew slowly, possibly limited by a low number of possible forage fish, especially forage fish available to the smaller size classes. Salmonids were found in smallmouth bass stomachs only during the fall of the study year, and only stocked *O. mykiss* were present in stomachs. Significant *Daphnia* predation occurred at all size classes, as well as cannibalism. The study concluded that slow growth of young-of-the-year (YOY) fish due to low number of forage fish, combined with high fishing pressure contribute to a mean total length of only 251 mm (Dunsmoor 1990).

Knox (1982) found that smallmouth bass made the largest contribution to the sport fishery in some sections of the river, most notably in Little Goose Reservoir. Knox found angler catch rates of up to 0.45 bass/angler hour in 1980, a rate that is similar to many other bass fishery reservoirs across North America. Additionally, smallmouth bass accounted for 40% of fish biomass harvested from Little Goose in 1979. While anglers might preferentially target bass, this is a high yield for what was previously a cold water fishery.

The success of the northern pikeminnow removal program in the Snake River has raised questions about the ability of smallmouth bass to expand into niches left partially empty by northern pikeminnow. Studies have suggested that the populations of smallmouth bass in the Snake River reservoirs are likely to remain fairly static (Ward and Zimmerman 1991). Curet (1993) suggested that even in 1993, juvenile salmonids consumed per predator per day was higher for smallmouth bass than northern pikeminnow. This evidence all suggests that smallmouth bass may be a higher source of juvenile salmonid mortality than previously thought.

While stocks have rebounded from the low of 49,000 returning adults in 1979, to a 2011 return of over 500,000 returning adults (FPC) at Ice Harbor Dam, Chinook, coho and sockeye remain on the endangered species list. Numbers of returning adults are roughly comparable to pre-hydrosystem numbers, nearly 125,000 adult Chinook were counted at Ice Harbor Dam in 2012. Fulton (1968) estimated an average return of 125,000 adult Chinook in the decade of 1950-1960. Recent studies suggest that wild population level changes in Pacific salmon stocks may not be due entirely to anthropogenic disturbance. Climate effects and coastal upwelling are important factors in the survival of juvenile salmon during their first year in coastal waters. Coastal upwelling may influence salmon production through "bottom-up forcing of the marine food web" (Nickelson 1986). Correlating indices of coastal upwelling with SAR (Smolt to Adult Return) rates may serve as a predictor for salmon populations independent of anthropogenic effects (Scheuerell and Williams 2005). The influence of PDO and other oceanic factors on adult salmon return rates is not an easily quantifiable variable. Snake River salmonids will likely remain on the endangered species list for the forseeable future, even as populations rebound.

Salmon are ecologically very important to the Pacific Northwest, not only as a food source for many predatory species, but as a crucial “conveyer belt” that returns marine-derived nutrients back to terrestrial systems (Schindler et al 2003). Salmon returning to spawn are consumed by predators and scavengers, and nutrients contained in salmon flesh are incorporated into riparian biota at many trophic levels. Helfield and Naiman (2001) discovered that trees and shrubs along spawning streams derive up to 24% of foliar nitrogen from salmon.

While the removal of the Snake River dams has been suggested as a management technique for improving endangered salmon runs, the political reality keeps this suggestion from becoming more than an option for the future. Quantifying predation of juvenile salmonids may result in new management techniques. With dam removal currently indefinitely postponed, improved management is one of the only tools left to help improve Pacific salmon runs.

Improving Pacific salmon runs will have a broad range of ecological, financial and cultural benefits. Ecological benefits of returning salmon have been discussed earlier, however, it is important to note that many of these benefits cannot be mitigated by human intervention, at least without enormous cost. Salmon provide a direct monetary resource to inhabitants of the Pacific Northwest, in the form of salmon products. Helvoigt and Charlton (2009) estimated an beneficial economic impact of $63 per Chinook salmon caught out of the Rogue River, OR. There are also indirect financial benefits to restoring salmon. A study by Goodstein and Matson (2007) found that households in Washington and Oregon are willing to pay up to $130 per year to finance salmon restoration efforts. This money could fund thousands of jobs, while the trickle-down effect multiply the economic benefits of this cash infusion. However, simply maintaining Snake River salmonids stocks is an expensive proposition. Landry (2003) estimated a cost of $575.5 million annually of salmon related mitigation expenditures in the combined Columbia and Snake river system, leading to a per fish cost of $399.14 (as measured by 1998 return rates).

Pacific salmon are a cultural resource for many native peoples. Salmon are included as religious symbols for some tribes, and many Indian nations have reserved fishing rights in treaties. The general public of the Northwest have assumed salmon as a regional symbol, and “Save our Salmon” bumper stickers can be seen on the roads. Native and non-native peoples have a connection to salmon, and are willing to work to improve salmon numbers.

Salmon in the Pacific Northwest have been extensively studied, but many data are missing from the current body of knowledge. The issues related to restoring historic salmon runs in the Pacific Northwest are of particular concern. While there is a substantial body of research involving predation on juvenile salmon in the Snake River, most research is focused on the northern pikeminnow. While scientists have begun to investigate the effects of other piscivorous species, recent research has focused on single reservoirs or a single predator species. This was the first study to conduct a diet analysis on three predators, in all four Snake River reservoirs. Data from this study could be used to guide restoration efforts, including predator removal or habitat enhancement. When combined with a predator population estimate, diet analysis data could be used to develop a bio-energetics model for the reservoirs.

In the lower Snake River hydrosystem, approximately 2,000,000 m^3 of sediments are trapped annually by the effects of Lower Granite Dam (USACE 2003). Of these sediments, approximately 40% are fine sediments, which would normally be transported in the water column in the absence of a dam effect (Tealsdale 2010). Sediments are trapped by the reduced water velocity caused by the dam. As water velocity decreases, suspended particles settle out in the river channel. These sediments are deposited at the confluence of the Snake and Clearwater rivers, creating a navigational hazard, as well as robbing the lower river of sediment inputs. The settling of these sediments may lead to a reduction of sediment downstream of Lower Granite Dam. Reduced sediment supply may have many effects on a river system, including bank armoring, riparian vegetation changes, and lowered turbidity.

Many studies have suggested that higher flow (discharge) increases salmonid survival by reducing predation (Vigg et al. 1991, Cada et al. 1997). The mechanism for the reduction is likely both reduced spatial overlap between predator and prey (due to higher water velocity), and increased turbidity. In the Snake River, discharge is positively related to turbidity (Connor et al. 1998). Carlander (1977) described smallmouth bass as a visual predator. Increased turbidity may interfere with the ability of a visual predator to find and consume prey. A study of Pacific salmon survival in California found that predation on age-0 Chinook salmon was significantly higher in a "clear" water (0-6 NTU) tributary than in the main stem (27-108 NTU) (Gregory and Levings 1998). The authors concluded that turbidity likely acted as a form of cover, reducing encounter rate between predator and prey.

Sweka and Hartman (2001) reported a decreasing curvilinear relationship between turbidity and reactive distance in brook trout (*Salvelinus fontialis*). The probability of a brook trout reacting to a prey item was highly correlated with reactive distance, and also decreased with increasing turbidity. Probability of prey attack, prey capture, or prey ingestion did not vary with increasing turbidity. The authors conclude that reactive distance is the most important factor in driving encounter rate. The greatest change in reactive distance per unit change in turbidity occurred at the lowest turbidity levels, from zero to 15 NTU. In a natural system, a small positive change in turbidity may lead to reduced piscivore feeding rate, or a change in prey preference to larger, slower moving species.

A limited amount of *in vitro* research has been conducted to quantify the effect of turbidity on smallmouth predation efficiency. A study conducted in 2003 by Sweka and Hartman examined the reactive distance of smallmouth bass, using housefly larvae as the prey item. Carter et al. 2010 examined the effect of turbidity on consumption rate of SMB on golden shiners (*Notemigonus crysoleucas)* and round gobies (*Neogobius melanostomus***).**   Round gobies were selectively consumed under clear water conditions, while golden shiners were selected under turbid conditions. This may be due to golden shiners' propensity for inhabiting the upper part of the water column, as increasing turbidity reduced the amount of light in the water column. However, I was unable to find any previous research on the effect of increased turbidity on the consumption rate of salmonids. My research will quantify the ability of smallmouth bass to forage on salmonid prey at several turbidity levels.

This study had the following objectives:

Objective 1: To investigate community structure at sampling sites, and to test for differences between sites, transects, and reservoirs. Identify optimal dredge sediment disposal sites.

Objective 2: Conduct a diet analysis of the three introduced piscivores in the Lower Snake River, smallmouth bass, channel catfish, and walleye

Objective 3: To test the effect of turbidity on smallmouth bass predation rates *in vitro*.

Methods

Fish were collected during night-time electroshocking. All four reservoirs on the Snake River were sampled, with 3 sites in Lake Sacajawea (behind Ice Harbor Dam), 2 sites in Lake Herbert G. West (behind Lower Monumental Dam), 2 sites in Lake Bryan (behind Little Goose Dam), and 5 sites in Lower Granite Lake (behind Lower Granite Dam). See Figure 1.

Locations of sites sampled were set by the USACE. Sampling began at sunset, and began with the most downstream site. Sites were sampled in the same order during each subsequent sampling trip. Each sampling site was divided into two adjacent transects, which were each electrofished for 10 minutes. The starting and ending coordinates of each electrofishing transect were recorded, and all trips sampled the same area. Fish were netted out of the water using dip nets, and stored in a continuously aerated livewell until processing. Length, weight, and species data were recorded for all fish. Adult fish were identified to species using key from Wydoski and Whitney (1979,2003) and Scholz and McClellan (2009,2010). Juveniles were identified using a key from Martinson et al. 2009. Stomach contents and structures for aging were collected from a subset of collected fish. Sampling trips began on January 14, April 2, April 21, May 12, June 2, and June 25, 2011.

Pulsed gastric lavage was used to collect stomach contents from smallmouth bass (SMB) and walleye (WAL) larger than 170 mm. Dissection was used to collect contents from channel catfish (CC) larger than 270 mm, due to the inefficiency of gastric lavage in this species (Busbee 1968, Raborn 2003). Samples were stored in Whirl-Pak bags with 95% ethanol until analysis as in Hansel et al. 1988.

In the lab, stored samples were sorted under a dissecting microscope. Prey items were sorted into six major groups (Fish, Insect, Crustacean, Annelid, Plant, Other). The category "insect" included taxa such as Diptera, Hemiptera, Ephemeroptera, Odonata, unidentified exuviae, and unidentified partial insects. The category "crustacean" included the taxa: Amphipoda, Mysida, Decapoda. The "other" category included non-organics such as fishing lures and rocks. The number of individual prey items comprising a group was counted. Each prey group was blotted dry, and weighed to the nearest 0.01 gram to obtain a wet weight (Shively et al. 1996). Fish prey items were identified to species, and insect and larval prey were identified to the lowest possible taxonomic group. Whole prey fish found were measured to obtain a total length. Partially digested fish prey were briefly boiled to loosen flesh from bones, and diagnostic bones were removed. A key (Hansel 1988; Frost 2003) to diagnostic bones (including cleithra, dentaries, opercles, and pharyngeal arches) was used to identify partial or digested prey items. Weights of wet prey items may not show exactly what the predatory fish consumed, instead showing the weight ingested minus the weight digested. For purposes of comparison between the three predatory fish species, I assumed that differences in digestion rate would equally bias the diet description for each species.

Index of Relative Importance:

Percentage by number may over estimate importance of small food items, and percent by weight may overestimate the importance of large items due to the longer time it takes to capture and eat a large number of small organisms (Pinkas et al. 1971). An alternative approach that combines frequency of occurrence, percentage by number, and percentage by weight data can be calculated. This "index of relative importance" (IRI) was suggested by George and Hadley (1979), and is calculated by:

$Ri_a = 100Ai_a / \sum Ai_a$, in which Ai_a is summed over all food types.

Ai_a = % frequency of occurrence + % total number + %total weight, where Ai_a is the "absolute importance index."

Walleye and Smallmouth Bass Aging:

Scales were collected from walleye from just below the lateral line immediately posterior to the pectoral fin (Isermann 2003). Scales were collected from smallmouth bass from 3 rows below the lateral line even with the middle of the spinous dorsal fin (Carlander 1982). Scales were stored in small coin envelopes until reading. Scales were read using a microfiche reader at 24x magnification. Scales that were difficult to read were used to make impressions in 0.76 mm acetate plastic sheets using a roller press as in Smith (1954).

Channel Catfish Aging:

Left pectoral spines were collected from sacrificed catfish, cleaned of tissue and skin, and stored in standard scale envelopes until reading. Since the collection of the pectoral spine necessitates sacrificing the fish, spines were only collected from individuals large enough to have likely switched to piscivory, above the size of 270 mm (Busbee 1968, Raborn 2003). In the lab, spines were sectioned at the distal end of the basal groove in the effort to include all annuli. Sections were placed in a watch glass with enough water to cover, and read with a dissection microscope at 25x magnification (Marzolf 1955; Lucinda Morrow 2010, WDFW Personal Communication). A micrometer was used to measure the spine radius to each annulus (Sneed 1951). An age/length key was constructed as above, with spine radius substituted for scale radius.

Data Analysis:

Catch per unit effort (CPUE) was used to determine community structure differences between reservoirs. As a proportion of total catch, CPUE numbers give an idea of community structure.

Condition Factor (CF) was computed for all fishes, and compared to values from the literature to identify any potential growth deficiencies. Condition factor was used to test for seasonal differences between juvenile Chinook salmon sampled during different trips. Condition Factor was calculated using the following formula:

$\mathbf{K_{TL}}$ = (W/L^3)*100,000

A Kruskal-Wallis ANOVA was used to test for differences in juvenile Chinook CF between sampling trips. Testing for differences in CF between sites was conducted the same way, with Dunn's Method to perform pairwise comparisons.

A Kruskal-Wallis ANOVA on ranks was used to compare species richness between reservoirs, as well as between habitat categories. Differences between transects were tested as above, with a Tukey test to determine at which transects differences occurred.

Shannon's diversity index was used to compare species richness between reservoirs, between sites, and between habitat groupings. An ANOVA was used on index values to test for these differences, a Tukey post-hoc test was used to identify differences between specific sites.

A number of ANOVA comparisons were used to compare diet data. We tested for differences in salmonid consumption among age groups of predators. Differences in salmonid predation between reservoirs were also tested using an ANOVA.

Turbidity Trials:

Smallmouth bass were collected from the Pend Oreille River, ID (48.178649, -117.011193). The fish were transported in a holding tank filled with river water, with supplemental oxygen bubbled through an airstone at 1 Liter/minute. The bass were housed in the EWU Aquarium facility, which features 1100 liter recirculating tanks. Bass were maintained at 18° C, on a diet of feeder goldfish while not used in trials.

Kokanee fry (*Oncorhynchus nerka*) were obtained from the Spokane Tribal Fish Hatchery. Fry were transported back to the EWU Aquarium facility in non-chlorinated well water, with supplemental oxygen. Fry were housed in a Living Stream at 12°. The fish were maintained on a diet of fry starter fed *ad libitum*.

Trial tanks were filled with dechlorinated tap water to a depth of 500 mm for a total volume of approximately 800 L. Tanks were not heated or chilled, so remained at the ambient room temperature, which ranged from 19°C to 21°C.

We used sodium bentonite clay to create turbidity levels in the trial tanks. Bentonite was weighed and added to a small volume of water in a sample bottle (≤ 0.5 L). The mixture was homogenized, then added to the treatment tank and agitated thoroughly. Each treatment tank contained a 40 mm air stone, with pressurized room air constantly supplied. A Hydor Koralia Nano 1600 liters per hour (lph) powerhead was included in each tank to circulate water and keep the bentonite in suspension. We used four turbidity treatments (0, 0.5, 5.0 and 10.0 NTUs), and five prey densities (1, 2, 4, 8, 16). Treatment combinations were randomly sorted into runs of increasing turbidity, allowing the next trial to be conducted without needing to drain tanks. Trial runs were no more than three trials long, after which tanks were drained, scrubbed, and refilled with de-chlorinated water.

To conduct feeding trials a smallmouth bass was selected at random, measured, and added to a treatment tank. A delay of 30 minutes was included to allow the bass to acclimate to the tank conditions before the addition of prey items. The number of kokanee necessary for the trial were randomly selected from the Living Stream, and acclimatized in a bucket placed into a treatment tank. Once temperatures equalized, kokanee were randomly selected, measured, and added to the treatment tanks. For the trials involving one, two or four kokanee, all were measured. For trials involving eight or 16 kokanee, a subset was measured to obtain an average length for the treatment.

Tanks were checked for the number of prey consumed at 1.5, 3, 6, 12 and 24 hour intervals. Every effort was made to reduce disturbance to the fish during tank checks. Turbidity measurements were taken from each tank at the same time interval. Trials were ended after 24 hours, the bass and kokanee were returned to their holding tank. Feces and other debris were removed from the tank with a fine mesh net after each trial. Bass were fasted for a minimum of 24 hours (not exceeding 48 hours) before trials.

A two-factor ANOVA was used to test for a turbidity effect, a number of prey offered effect, and an interaction effect. Dependent variables were the total numbers of prey consumed, as well as proportion of prey consumed in each trial. Linear regression was used to test for a predator length effect.

Results

Community Structure

A total of 6,141 fish were collected during the survey. A species list and number caught by reservoir is shown in Table 2. Largescale sucker, *Catostomus macrocheilus,* was the most commonly caught fish (n= 1,753), followed by juvenile Chinook salmon, *Onchorhynchus tshawytscha,* (n=1,474) and peamouth, *Mylocheilus caurinus,* (n=1,468). Native fishes were the most commonly caught, although many species of introduced fishes were also found. These included smallmouth bass, *Micropterus dolomieu* (n = 284), channel catfish, *Ictalurus punctatus* (n = 5), and walleye, *Sander vitreus* (n = 8).

The project goal was to maintain 10 minutes of current-on electrofishing time at each sampling site. The length of each site varied, as did river currents, leading to electrofishing times that varied from the 10 minute goal. To standardize the number of fish caught at each site to allow for comparisons, catch per unit effort was calculated.

Catch per Unit Effort, or CPUE, was calculated by dividing the number of fish captured at a site multiplied by a correction value to bring the effective effort to 1 hour. See Table 4 for CPUE as calculated per reservoir for all species.

Relative Abundance, or RA, is the proportion of the catch separated by species. See Table 3 for RA as calculated per reservoir for all species.

Table 2. Total fish captures in the Lower Snake River and by Reservoir. Stomach samples collected from potentially piscivorous fish species marked in bold.

Total Fish Captures								
Family	**Genus**	**Species**	**Common Name**	**Sacajawea**	**West**	**Bryan**	**Granite**	**Total**
Cyprinidae	*Cyprinus*	*carpio*	Common Carp	7	2	10	15	34
Cyprinidae	*Acrocheilus*	*alutaceus*	Chislemouth	0	22	4	43	69
Cyprinidae	*Ptychocheilus*	*oregonensis*	Northern Pikeminnow	61	15	24	26	126
Cyprinidae	*Mylocheilus*	*caurinus*	Peamouth	944	26	135	363	1468
Cyprinidae	*Richardsonius*	*balteatus*	Redside Shiner	2	0	0	0	2
Catostomidae	*Catostomus*	*columbianus*	Bridgelip Sucker	8	14	6	153	181
Catostomidae	*Catostomus*	*macrocheilus*	Large Scale Sucker	325	226	128	1074	1753
Ictaluridae	*Ameiurus*	*nebulosus*	Brown Bullhead	0	1	0	0	1
Ictaluridae	***Ictalurus***	***punctatus***	**Channel Catfish**	**1**	**1**	**0**	**3**	**5**
Ictaluridae	*Ameiurus*	*natalis*	Yellow Bullhead	2	1	0	1	4
Salmonidae	*Salvelinus*	*confluentus*	Bull Trout	0	1	0	0	1
Salmonidae	*Oncorhynchus*	*tshawytscha*	Chinook	142	38	231	1063	1474
Salmonidae	*Oncorhynchus*	*kisutch*	Coho	7	2	2	19	30
Salmonidae	*Prosopium*	*williamsoni*	Mountain Whitefish	8	0	1	180	189
Salmonidae	*Oncorhynchus*	*mykiss*	Steelhead	1	0	0	1	2
Percopsidae	*Percopsis*	*transmontana*	Sandroller	79	3	293	106	481
Cottidae	*Cottus*		Unidentified Sculpin	0	0	0	1	1
Centrarchidae	*Pomoxis*	*nigromaculatus*	Black Crappie	0	1	0	0	1
Centrarchidae	*Lepomis*	*macrochirus*	Bluegill	1	1	0	2	4
Centrarchidae	*Lepomis*	*gibbosus*	Pumpkinseed	1	3	0	4	8
Centrarchidae	***Micropterus***	***dolomieu***	**Smallmouth Bass**	**64**	**31**	**15**	**174**	**284**
Centrarchidae	*Pomoxis*	*annularis*	White Crappie	0	0	0	3	3
Percidae	***Sander***	***vitreus***	**Walleye**	**1**	**7**	**0**	**0**	**8**
Percidae	*Perca*	*flacescens*	Yellow Perch	4	7	1	0	12
			Total	1658	402	850	3231	6141

Table 3. Relative Abundance (RA) in the Lower Snake River as separated by reservoir. Potentially piscivorous species marked in bold.

Relative Abundance by Reservoir					
Species	**Sacajawea**	**Herbert G. West**	**Bryan**	**Granite**	**Total**
Brown Bullhead	0.00	0.25	0.00	0.00	0.02
Black Crappie	0.00	0.25	0.00	0.00	0.02
Bluegill	0.06	0.25	0.00	0.06	0.07
Bull Trout	0.00	0.25	0.00	0.00	0.02
Bridgelip Sucker	0.48	3.48	0.71	4.74	2.95
Common Carp	0.42	0.50	1.18	0.46	0.55
Channel Catfish	**0.06**	**0.25**	**0.00**	**0.09**	**0.08**
Chinook	8.56	9.45	27.18	32.90	24.00
Chislemouth	0.00	5.47	0.47	1.33	1.12
Coho	0.42	0.50	0.24	0.59	0.49
Sculpin	0.00	0.00	0.00	0.03	0.02
Large Scale Sucker	19.60	56.22	15.06	33.24	28.55
Mountain Whitefish	0.48	0.00	0.12	5.57	3.08
Northern Pikeminnow	3.68	3.73	2.82	0.80	2.05
Peamouth	56.94	6.47	15.88	11.23	23.90
Pumpkinseed	0.06	0.75	0.00	0.12	0.13
Redside Shiner	0.12	0.00	0.00	0.00	0.03
Smallmouth Bass	**3.86**	**7.71**	**1.76**	**5.39**	**4.62**
Sandroller	4.76	0.75	34.47	3.28	7.83
Steelhead	0.06	0.00	0.00	0.03	0.03
Walleye	**0.06**	**1.74**	**0.00**	**0.00**	**0.13**
White Crappie	0.00	0.00	0.00	0.09	0.05
Yellow Bullhead	0.12	0.25	0.00	0.03	0.07
Yellow Perch	0.24	1.74	0.12	0.00	0.20

Peamouth were the most abundant species collected in Lake Sacajawea. Large scale suckers were the most abundant fish in Lake Herbert G. West and Lower Granite Lake. Sandrollers were the most abundant fish in Lake Bryan. Juvenile Chinook salmon composed at least 8% of the total collection in all reservoirs, and were as high as 32.9% of the collection in Lower Granite Lake.

Table 4. Catch per unit effort (CPUE) in the Lower Snake River as separated by reservoir. Potentially piscivorous species marked in bold.

CPUE by Reservoir (fish/h)					
Species	**Sacajawea**	**Herbert G. West**	**Bryan**	**Granite**	**Total**
Brown Bullhead	0	<0.1	0	0	0.01
Black Crappie	0	<0.1	0	0	0.01
Bluegill	<0.1	<0.1	0	<0.1	0.03
Bull Trout	0	<0.1	0	0	0.01
Bridgelip Sucker	0.2	0.6	0.2	3	1.32
Carp	0.2	0.1	0.4	0.3	0.25
Channel Catfish	**<0.1**	**<0.1**	**0**	**<0.1**	**0.04**
Chinook	3.9	1.6	8.6	20.9	10.71
Chislemouth	0	0.9	0.1	0.8	0.50
Coho	0.2	0.1	0.1	0.4	0.22
Sculpin	0	0	0	<0.1	0.01
Large Scale Sucker	9	9.5	4.8	21.1	12.74
Mountain Whitefish	0.2	0	<0.1	3.5	1.37
Northern Pikeminnow	1.7	0.6	0.9	0.5	0.92
Peamouth	26	1.1	5.1	7.1	10.67
Pumpkinseed	<0.1	0.1	0	0.1	0.06
Redside Shiner	0.1	<0.1	<0.1	<0.1	0.01
Smallmouth Bass	1.8	1.3	0.6	3.4	2.06
Sandroller	2.2	0.1	11	2.1	3.50
Steelhead	<0.1	0	0	<0.1	0.01
Walleye	<0.1	0.3	0	0	0.06
White Crappie	0	0	0	0.1	0.02
Yellow Bullhead	0.1	<0.1	0	<0.1	0.03
Yellow Perch	0.1	0.3	<0.1	0	0.09

Peamouth were the most numerous fish, captured at an average rate of 26 fish/h, in Lake Sacajawea. Large scale suckers were found at an average rate of 9.5 fish/h in Lake West. Sandrollers were the most numerous capture in Lake Bryan, at a rate of 11 fish/h. In Lower Granite Lake, large scale suckers were the most numerous capture at 21.1 fish/h, followed by juvenile Chinook at an average rate of 20.9 fish/h.

Condition factor (CF) was calculated for all fishes collected from the study sites.

Table 5 contains comparisons for K_{TL}. For fusiform fishes, including salmonids, K_{TL} is typically around 1.0 (Carlander 1969). K_{TL} values for laterally compressed fishes such as centrarchids are more variable. Condition factor values found in the literature are typically highly water body specific. Average condition factors for sampled fish, as well as values from the literature (when available) are listed in Table 5.

Table 5. Condition factor (K_{TL}) comparison between fish captured during 2011 sampling and values from literature.

Species	N	Literature	Snake River 2011 (SD)
Brown Bullhead	1	1.06-1.80	1.48 (NA)
Black Crappie	1	0.58-2.35	2.00 (NA)
Bluegill	4	0.66-5.6	2.36 (0.24
Bull Trout	1	No Data	1.01 (NA)
Bridgelip Sucker	181	No Data	1.04 (0.07)
Common Carp	34	3.43-10.22	1.45 (0.16)
Channel Catfish	5	.50-1.22	0.75 (0.36)
Chinook	1474	0.769-1.3	0.99 (0.05)
Chislemouth	69	No Data	1.00 (0.07)
Coho	30	No Data	0.99 (0.16)
Sculpin	1	No Data	1.46 (NA)
Largescale Sucker	1753	No Data	0.99 (0.03)
Mountain Whitefish	189	1.35	0.84 (0.05)
Northern Pikeminow	126	0.8	0.82 (0.11)
Peamouth	1468	1.35-1.74 (SL)	0.90 (0.29)
Pumpkinseed	8	1.59-3.02	2.22 (0.23)
Redside Shiner	2	No Data	0.87 (0.10)
Smallmouth Bass	284	1.08-1.94	1.26 (0.18)
Sandroller	481	No Data	1.40 (0.30)
Steelhead	2	No Data	1.05 (0.04)
Walleye	8	0.4-2.1	1.06 (0.6)
White Crappie	3	0.55-2.31	1.71 (0.26)
Yellow Bullhead	4	1.05-1.44	1.62 (0.19)
Yellow Perch	12	No Data	1.21 (0.11)

Carlander (1969), Footts (2002, 2011), Stroud et al. (2010), Bellgraph et al. (2012), Onsoy et al. (2011)

Chinook salmon were selected for a more in-depth analysis of CF. Research has suggested shallow water habit created by dumping of dredging sediment may create feeding stations beneficial to juvenile salmonids (Bennett and Shrier 1986, Bennett et al. 1988, Bennett 1988a, Bennett 1988b, Curet 1994). If a benefit exists, CF should be higher at shallow water transects (2A, 2B, 3B, 6A, 7A, 7B, 10A, 11B, 12A, 12B), and lower at deeper transects (3A, 4A, 5A, 5B, 8A, 8B, 9B). If shallow water sites lead to higher CF in juvenile Chinook, this would indicate support for the above theory.

Condition Factor values for juvenile Chinook salmon at all transects were compared to test differences in CF between transects, with the null hypothesis of no difference between sampling transects. Juvenile Chinook captured at 1A had significantly higher condition factors than Chinook captured at 6B. This was the only significant difference. Transect 1A was a shallow transect, located in a free flowing stretch of river, while transect 6B was also a shallow transect, located in backwater section of Lake Bryan. Substrate was coarse at 1A, and consisted of silt and sand at 6B. This result provides no evidence that shallow habitat enhances condition factor, but may indicate that juvenile Chinook are able to feed more successfully in a lotic environment.

Differences between sampling trips were tested, with the null hypothesis of no difference between sampling dates. Significant differences (the null hypothesis was rejected) were detected between the sixth sampling trip (June 25, 2011) and the second (April 2, 2011), third (April 21, 2011) and fourth (May 12, 2011) trips. In addition, the fifth (June 2, 2011) sampling trip was significantly different than the fourth trip (Table 6). In all these cases, the trip later in the year resulted in a higher CF. Juveniles feeding in preparation for smolting likely increased in CF as the season progressed and more food sources became available. Assuming individuals with a higher CF have more storage of fat and protein, placement of dredge sediments should occur late in the season, when juvenile salmonids are at their maximum CF. This may help reduce any sediment placing related mortality, as fish with have greater energy stores to draw on during any feeding disruption.

Table 6. Comparison of the effect of sampling trip date on juvenile Chinook condition factor (Kruskal-WAllis ANOVA)*.

Comparison	Diff of Ranks	Q	P<0.05
Fifth vs Fourth	206.363	5.067	Yes
Sixth vs Fourth	455.95	7.511	Yes
Sixth vs Third	304.037	5.228	Yes
Sixth vs Second	264.229	4.198	Yes

* Table shows significant comparisons only. All other pairwise comparisons were not significant.

Species richness was used to compare sites in terms of species composition differences. In this case, species richness was defined as the number of distinct species captured at a site.

Sites were also sorted into categories for purposes of species richness comparisons. Four categories were identified: backwater, shallow mainstem, steep gradient mainstem, and free flowing river (Based on habitat evaluation conducted in Arntzen et al 2011). Groupings are shown in Table 7. Sites are shown in Figure 1 (Page 4). Since all sampling sites were identified as possible in-water disposal sites for dredging sediments, a variety of analyses were conducted to identify differences between sites, transects, and reservoirs. Data regarding differences may be identify areas that may benefit from the creation of shallow water habitat, as well as sensitive areas that may be disturbed by sediment disposal.

Table 7. Groupings of sampling sites based on bed slope and location within river.

Grouping	Site
Backwater	4A, 4B, 6B, 8A, 9A, 11A
Shallow Mainstem	2A, 2B, 3B, 6A, 7A, 7B, 10A, 10B, 11B, 12A, 12B
Steep Gradient	3A, 5A, 5B, 8B, 9B
Free Flowing River	1A, 1B

Species richness using the electrofishing data collected during the spring sampling period was used to test for differences between reservoirs. The null hypothesis was no difference between reservoirs. Lake West was found to have a significantly lower average species richness ($H = 10.819$, 3 df, $p=0.013$) than Lower Granite Lake. This is likely a sampling artifact due to the larger number of habitat types and transects that were sampled in Lower Granite Lake, as compared to Lake West. The two sites sampled in Lake West were dominated by silt and fine sediments, and are shallow sites. The five sites sampled in Lower Granite Lake include free flowing river, as well as several deep sites, and are predominately cobble with sand substrate. Sites were identified by the USACE as possible dredge sediment disposal sites, and are not indicative of the reservoir as a whole.

Differences in species richness between habitat categories were tested, with the null hypothesis of no difference between categories. If species richness was significantly higher in a particular reservoir, that reservoir may not be considered an optimal candidate for sediment disposal. No significant difference was found between habitat categories $F(3,119) = 0.684$, $p = 0.564$. This result may indicate that bathymetry and substrate size alone are poor indicators of species richness. Significant differences were found when a comparison of species richness was conducted between transects $F(23,119) = 1.915$, $p = 0.015$. Species richness was significantly lower at transect 9B when compared to 2A (p =

0.012), 2B (p = 0.001), and 8A (p = 0.033). The species richness over the spring sampling period ranged between 4 and 15 with the mean species richness ranged between 1.8 to 8.0 (Figure 2).

Shannon's index was used to assess diversity of fish collected during the spring sampling period via electrofishing (Shown in Figure 3). Calculated mean values ranged between 0.35 and 1.15 (Figure 3). No significant difference was found when comparing between reservoirs $F(3,114)=1.773$, $p = 0.156$ and no significant difference was found between habitat categories $F(3,114)=0.855$, $p = 0.467$. Significant differences were found when a comparison was conducted between sites $F(11,108)=3.258$, $p<0.001$. Site 9 had a significant decrease in diversity when compared with six other sites (Table 8). This indicates the construction of shallow water habitat via sediment disposal at Site 9 would not disturb an existing species rich community, and may benefit the species richness of the site.

Table 8. Results of Tukey test of comparison of diversity between sample sites.

Comparison	Diff of Means	P	q	p-Value
1 vs 9	0.689	12	5.327	0.021
3 vs 9	0.751	12	5.810	0.008
7 vs 9	0.781	12	6.041	0.005
8 vs 9	0.681	12	5.270	0.023
10 vs 9	0.672	12	5.198	0.026
11 vs 9	0.629	12	4.869	0.049

(Where "q" is critical value, and "P" is degrees of freedom)

Transects were compared, with a null hypothesis of no difference between transects. Significant differences were found when a comparison of Shannon index was conducted between transects $F(11,48)=2.777$, $p=0.007$. Transect 8A showed a significant increase in diversity when compared with four other transects and transect 9B had a significant decrease in diversity when compared with nine other transects (Table 9). In summary, transect 8A was shown to be one of the most diverse transects sampled, while transect 9B was one of the least diverse. This suggests that transect 8A should not be considered as a location for in water disposal of dredge sediments, to avoid disturbing the species richness of the area. Conversely, transect 9B may be an ideal candidate for sediment disposal.

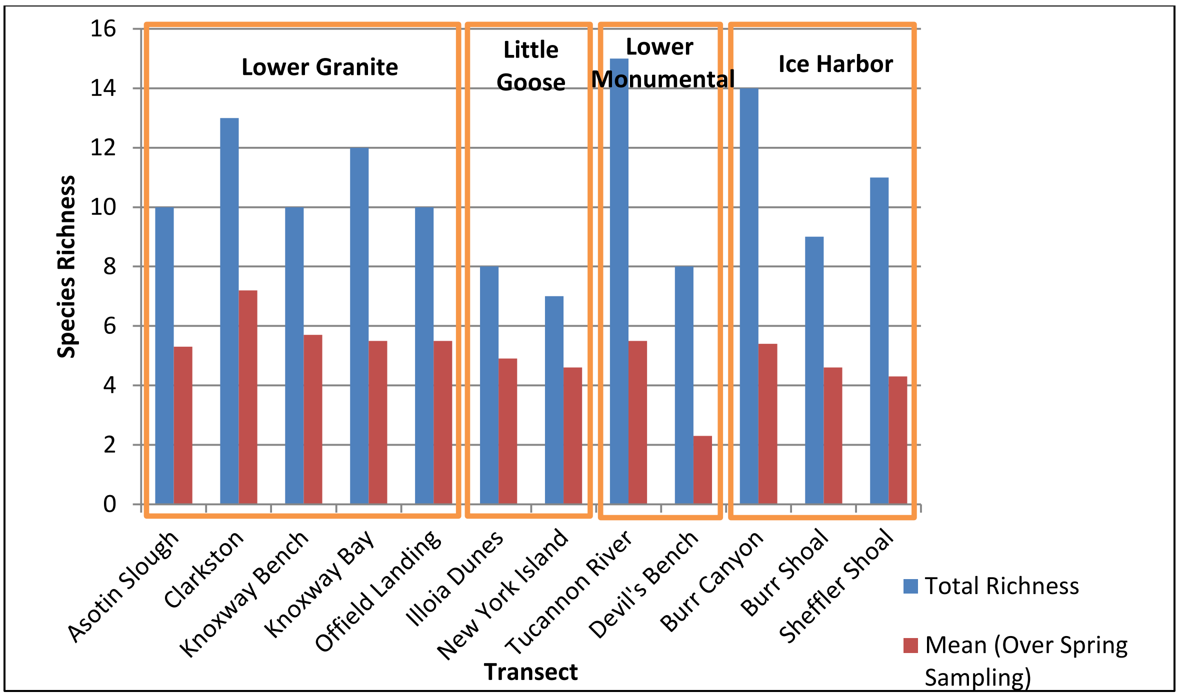

Figure 2. Total species richness and mean species richness based on electrofishing data during the entire sampling period.

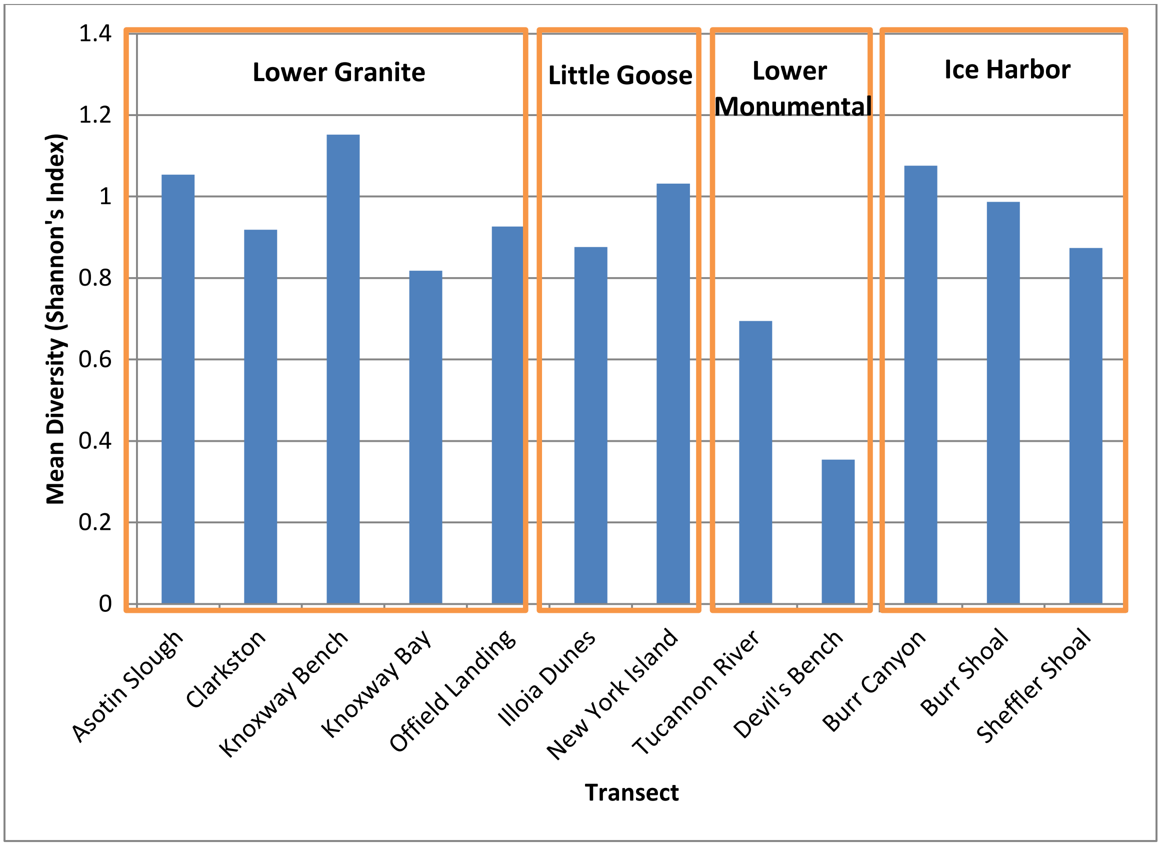

Figure 3. Mean Shannon Index values based on data collected during electrofishing.

Table 9. Results of Tukey test on comparison of diversity between sample transects.

Comparison	Diff of Means	P	q	p-Value
8A vs 6A	0.891	24	6.113	0.008
8A vs 9A	0.914	24	6.275	0.005
8A vs 9B	1.241	24	8.082	<0.001
8A vs 12A	0.783	24	5.374	0.043
1B vs 9B	0.952	24	6.533	0.003
3A vs 9B	0.982	24	6.737	0.002
3B vs 9B	0.899	24	6.172	0.007
5A vs 9B	0.846	24	5.808	0.016
6B vs 9B	0.978	24	6.714	0.002
7A vs 9B	0.95	24	6.517	0.003
10A vs 9B	0.955	24	6.555	0.003
11B vs 9B	0.849	24	5.828	0.016
12B vs 9B	0.865	24	5.935	0.012

(Where "q" is critical value, and "P" is degrees of freedom)

Stomach Content Analysis

A total of 139 stomach samples were collected from potentially piscivorous fish. Table 10 shows the number of each species sampled by reservoir.

Table 10. Species and location distribution of collected stomach samples.

	Reservoir				
Species	**Sacajawea**	**Herbert G. West**	**Bryan**	**Lower Granite**	**Total**
Channel Catfish	1	1	0	3	**5**
Smallmouth Bass	28	19	6	78	**131**
Walleye	1	2	0	0	**3**
Total	**30**	**22**	**6**	**81**	**139**

The majority (94%) of samples were collected from smallmouth bass. Smallmouth bass were found in every reservoir, and were the only potentially piscivorous fish found in Lake Bryan. Of the 284 SMB collected via electrofishing, 20 were below the size threshold of 150 mm, 133 SMB stomachs were empty, and 131 contained prey items. Every walleye and channel catfish caught was sampled for stomach contents. Only 3 out of 8 walleye sampled contained prey items. Every channel catfish sampled contained prey items. The majority of stomach samples were collected from Lower Granite Lake (n=81), followed by Lake Sacajawea (n=30), Lake Herbert G. West (n=22), and Lake Bryan (n=6).

Diet Habits By Species

Smallmouth bass diet habits are described in Figure 4, and listed in Table 11.

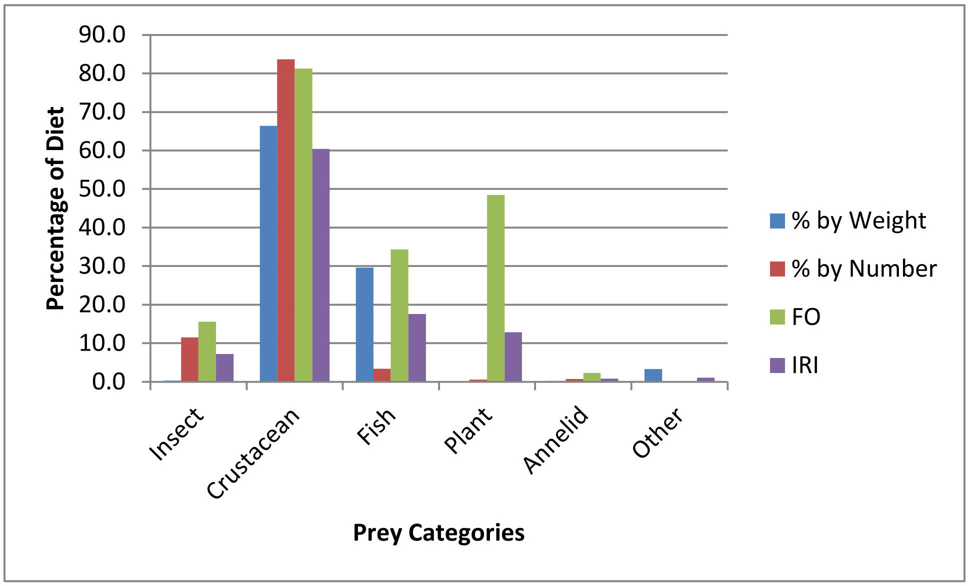

Figure 4. Smallmouth bass diet habits in the Lower Snake River.

Table 11. Smallmouth bass diet habits in the Lower Snake River (n=131).

Prey Type	#	Wt.	FO	% by Weight	% by Number	IRI
Insect	188	0.9	15.6	0.4	11.5	7.2
Crustacean	1365	153.2	81.3	66.4	83.6	60.4
Fish	56	68.3	34.4	29.6	3.4	17.6
Salmonid	6	3.8	4.7	1.6	0.4	
Plant	10	0.3	48.4	0.1	0.6	12.8
Annelid	12	0.5	2.3	0.2	0.7	0.9
Other	1	7.6	0.8	3.3	0.1	1.1

Smallmouth bass fed primarily on crustaceans, including the native Signal Crayfish (*Pacifastacus leniusculus*), *Gammarus*, Mysid shrimps and the invasive Siberian Prawn (*Exopalaemon modestus*) (Haskell 2006). Of the fish prey found in SMB stomachs, over 35% (by weight) were sandrollers (*Percopsis transmontana*), followed by peamouth at 19.5% (*Mylochelius caurinus*) and chislemouth at 18.9% (*Acrocheilus alutaceus*). Salmonids composed less than 6% of the fish prey, and less than 2% of the total diet by weight was composed of salmonid species. Of salmonid species identified in the stomachs, only Chinook salmon (*Onchorhyncus tshawytscha*), could be identified to species. Table 12 shows smallmouth bass fish prey with calculated metrics.

Table 12. Fish prey found in smallmouth bass stomach.

Fish Prey	#	Wt. (g)	FO	% by Weight	% by number	IRI
Chislemouth	3	12.9	5.4	18.9	5.4	10.2
Pikeminnow	2	1.0	3.6	1.4	3.6	2.9
Peamouth	10	13.3	16.1	19.5	17.9	18.3
Ictalurid	1	2.1	1.8	3.0	1.8	2.3
Chinook	1	0.8	1.8	1.2	1.8	1.6
Salmonid	6	3.2	10.7	4.7	10.7	9.0
Sandroller	13	24.1	21.4	35.2	23.2	27.4
Smallmouth	3	3.6	5.4	5.3	5.4	5.5
Non-Salmonid	12	7.1	19.6	10.3	21.4	17.7
Unidentified	4	0.3	7.1	0.4	7.1	5.0

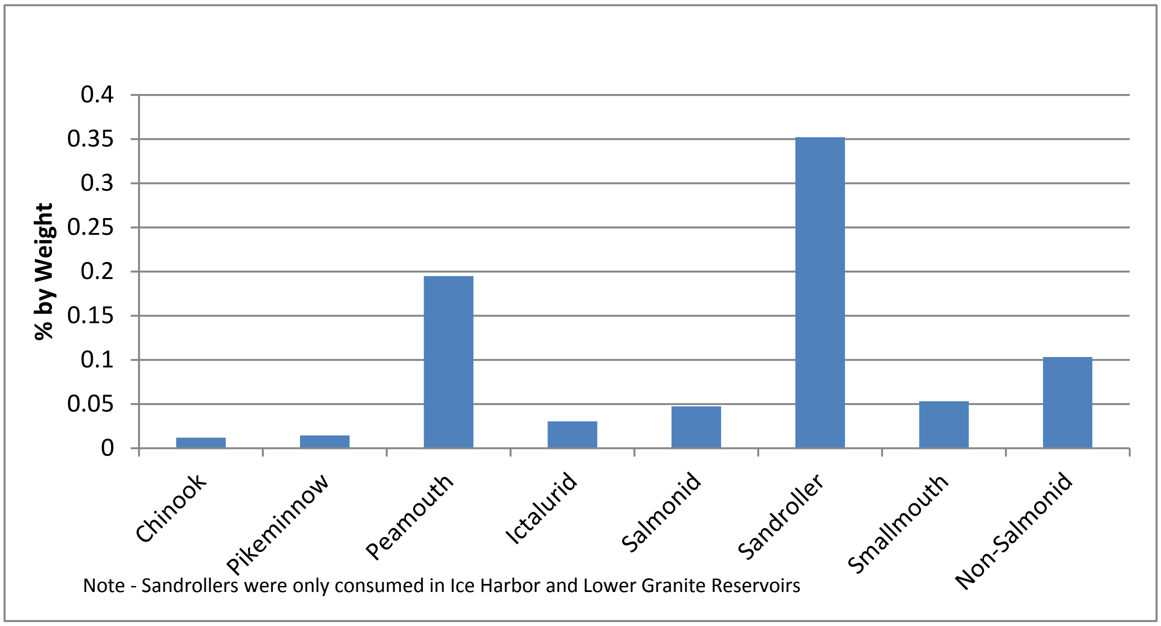

Figure 5. Fish prey found in smallmouth bass stomach samples from Lower Snake River.

Channel catfish (n=5) and walleye (n=3) were both found to consume sandrollers, and one channel catfish stomach sample was found to contain an unidentified salmonid. One channel catfish stomach contained a large number of wheat grains (*Triticum* sp.). Diet habits of channel catfish and walleye are summarized below in Tables 13 and 14 respectively.

Table 13. Channel catfish diet habits in the Lower Snake River (n=5).

Prey Type	#	Wt. (g)	FO	% by Number	% by Weight	IRI
Plant	294	19.4	60	92.5	43.7	37.3
Annelid	0	0	0	0	0	0
Mollusk	4	0	20	1.3	0.1	4.1
Crustacean	3	3.2	60	0.9	7.3	13
Insect	13	1.2	40	4.1	2.7	8.9
Fish	2	20.4	40	0.6	46	16.5
Salmonid	1	14.3	20	<0.1	32.2	9.9
Sandroller	1	6.1	20	<0.1	13.8	6.4
Other	2	0.1	20	0.6	0.2	4

Walleye consumed mostly fish prey, with fish prey items occurring in 100% of stomach samples collected. By weight, fish prey contributed over 99% of the diet by weight.

Table 14. Walleye diet habits in the Lower Snake River (n=3).

Prey Type	#	Wt. (g)	FO	% by Number	% by Weight	IRI
Plant	0	0	0	0	0	0
Annelid	0	0	0	0	0	0
Mollusk	0	0	0	0	0	0
Crustacean	1	0.001	33.3	16.7	0	10.6
Insect	0	0	0	0	0	0
Fish	4	19.473	100	66.7	99.5	56.5
Sandroller	1	10.587	33.3	16.7	54.1	22.1
Other	1	0.105	33.3	16.7	0.5	10.7

It is clear that crustaceans are the most important food items to smallmouth bass in the Lower Snake River. When smallmouth bass did consume fish prey, less than 6% by weight were salmonids. Walleye consumed the highest proportion of fish by weight, at >99% of the diet. However, three walleye contained food items when sampled, and five of the eight walleye sampled had empty stomachs. Additionally, only eight walleye were collected over the entire study period, which indicated a low walleye population. Walleye may have been using deeper water and could not be accessed using electrofishing. We were not allowed to use other sampling gear (such as gill nets) that could have answered this question.

Smallmouth bass collected in the Lower Snake River above the potentially pisvicorous threshold of 170 mm were aged from 1+ to 6+, with the majority of fish at age 3+. Age distribution is shown in Figure 6. Scales were collected from smallmouth bass prior to gastric lavage, so fish with empty stomachs were aged, as well as fish containing prey items. Smallmouth bass age distribution and status of stomach is shown in Figure 6.

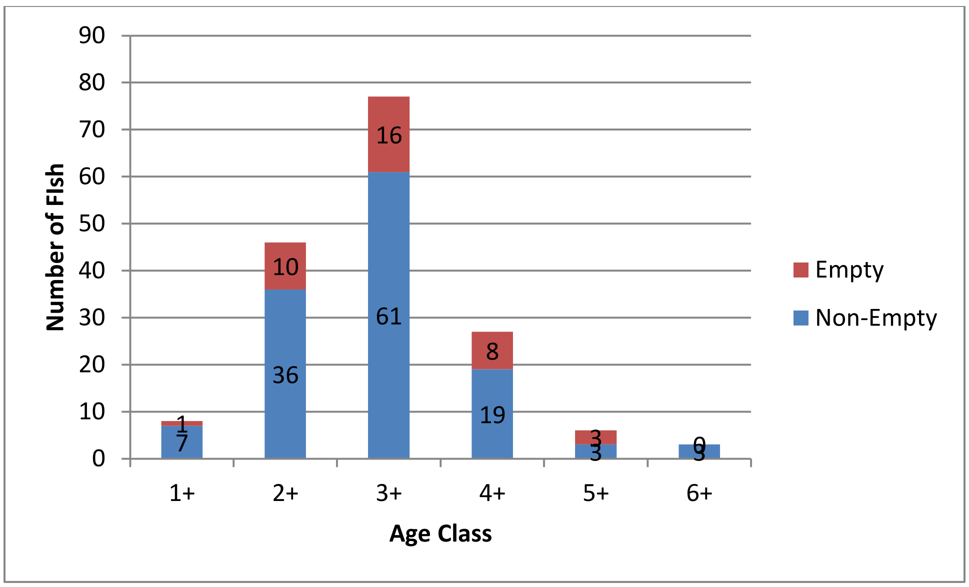

Figure 6. Smallmouth bass age distribution on the Lower Snake River. n for each category is displayed above each bar.

For non-empty smallmouth bass, an ANOVA was used to test for differences between age groups of smallmouth bass in both the proportion (by weight) of salmonids and total proportion of fish prey found in stomach samples, with the null hypothesis of no age effect. No discernible effect of age on the proportion of fish found in smallmouth bass stomachs was found $F(5,123) = 1.057$, $p = 0.388$. By extension, there was no effect by age of the proportion of salmonids found in stomach samples $F(5,123) = 1.361$, $p = 0.244$. Additionally, no salmonids were consumed by age 5+ and 6+ smallmouth bass, the two oldest groups sampled. Figure 7 shows the proportion of salmonid and all fish prey consumed by smallmouth bass along with standard error.

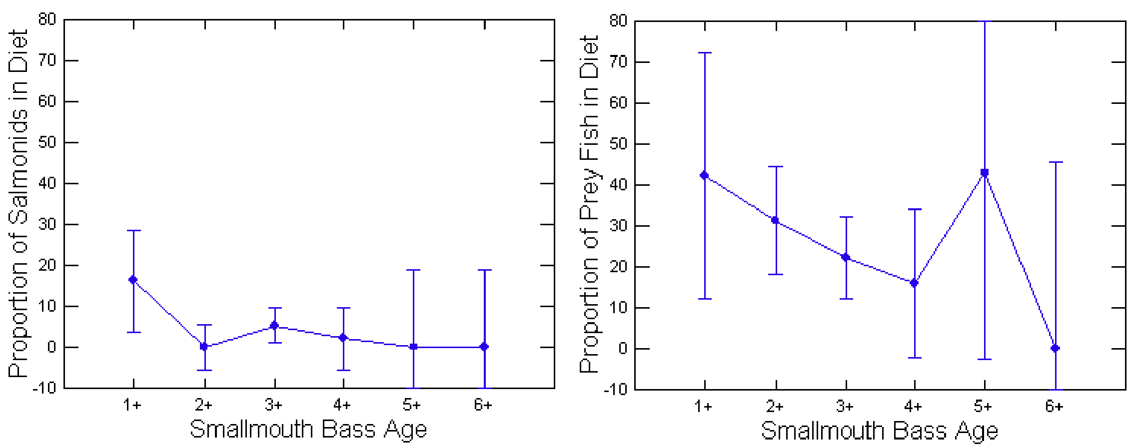

Figure 7. Proportion by weight of salmonid prey found in smallmouth bass stomachs by age (Figure 7a). Proportion of all fish prey found in smallmouth bass stomachs (Figure 7b).

Proportion by weight of all fish prey, and salmonid fish prey found in the stomach contents of smallmouth bass is shown in Figure 8. While catch rates of smallmouth bass varied between reservoirs, if consumption rates varied between reservoirs, then management efforts could be focused on particular sites. Sites were separated into five categories, including the four lakes formed by the dams, and sites 1A and 1B which were located upstream of the influence of Lower Granite Lake. An ANOVA was used to test for differences, with the null hypothesis of no difference.

No significant reservoir effect was found on the proportion of salmonid or all fish prey found in stomach samples $F(4,124) = 0.275$, $p = 0.894$.

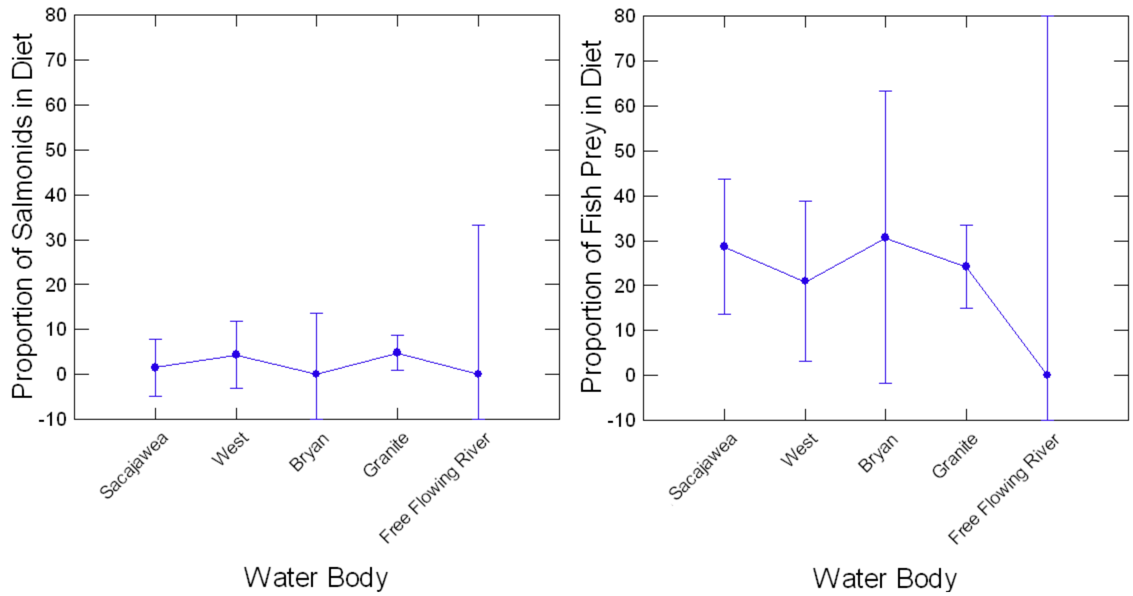

Figure 8. Proportion by weight of salmonid prey found in smallmouth bass stomachs by reservoir (Figure 8a). Proportion of all fish prey found in smallmouth bass stomachs (Figure 8b).

Turbidity Trials

The number of kokanee fry consumed in each trial varied widely, from no prey fish consumed, to consumption of all prey fish involved in the trial. As expected, the proportion of replications with 100% consumption was much higher during trials with lower numbers of prey items. See Table 15 and Figure 9.

Table 15. Average number of prey items consumed in each trial (n=4 for each trial).

	# Prey Items				
NTUs	**1**	**2**	**4**	**8**	**16**
0	0.75	0.75	2.25	5.75	8.50
0.5	0.75	1.00	1.50	4.25	11.50
5	0.25	1.50	3.50	5.25	4.50
10	1.00	0.75	0.58	2.75	7.00

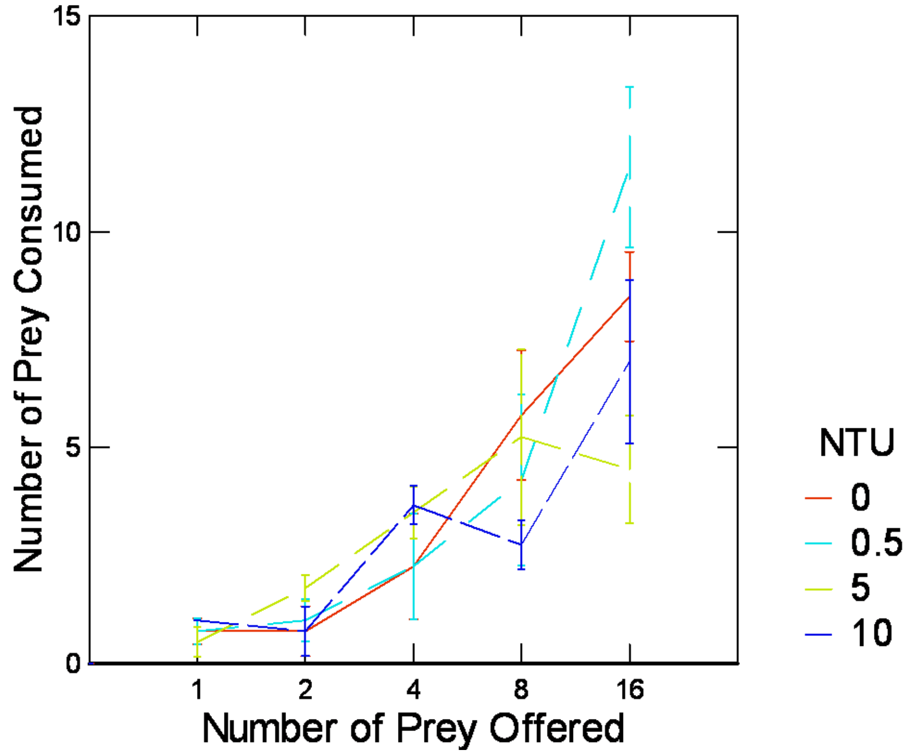

Figure 9. Summary graph of turbidity feeding trials. Error bars are Standard Error.

To test for a turbidity effect, I used a two-factor ANOVA (See Table 16), with NTU and number of prey offered as the factors. Absolute counts of prey consumed were used as the dependent variable. See Figure 10. Turbidity negatively affected the number of prey items consumed during a trial, while prey density positively affected the number of items consumed. See Figures 10 and 11, respectively. An interaction effect between NTU and prey density did exist $F(12,78) = 2.843$, $p = 0.004$ (See Table 16).

Table 16. ANOVA Table for Turbidity Results

Source	DF	SS	MS	F	P
NTU	3	11.113	3.704	1.041	0.381
Prey Density	4	542.938	135.734	38.15	<0.001
Interaction	12	121.362	10.114	2.8473	0.004
Residual	59	209.917	3.558		
Total	78	887.215	11.375		

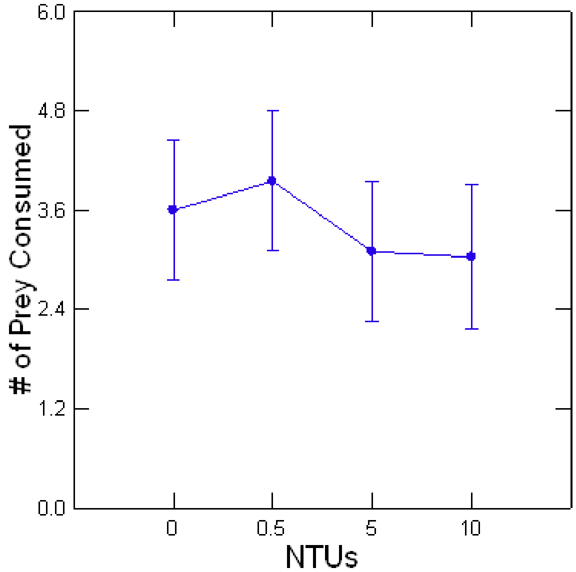

Figure 10. Effect of increased turbidity on number of prey items consumed.

The number of prey items offered did have an effect, $F(4,78) = 38.150$, $p < 0.001$, on the number of prey items consumed. While this result may not be surprising, it does indicate that the smallmouth bass were taking advantage of increased prey numbers. See Figure 11.

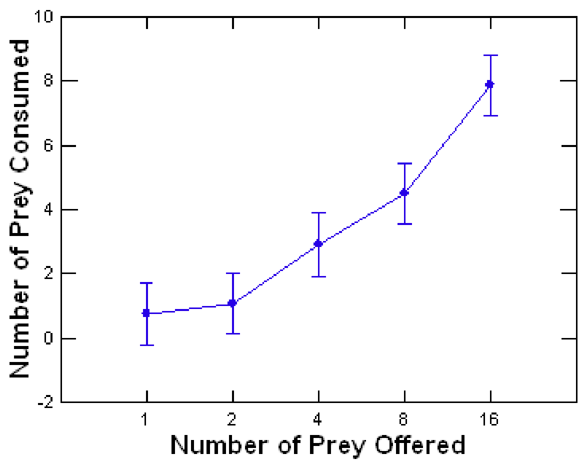

Figure 11. Average number of prey consumed at prey density levels.

Based on this result, I conducted another ANOVA on the results from the trials involving 16 prey fish.

At a prey density of 16, predation was significantly higher, $F(3,15) = 5.074$, $p = 0.017$, in the 0.5 NTU treatment than the 5 or 10 NTU treatments. See Figure 12 below.

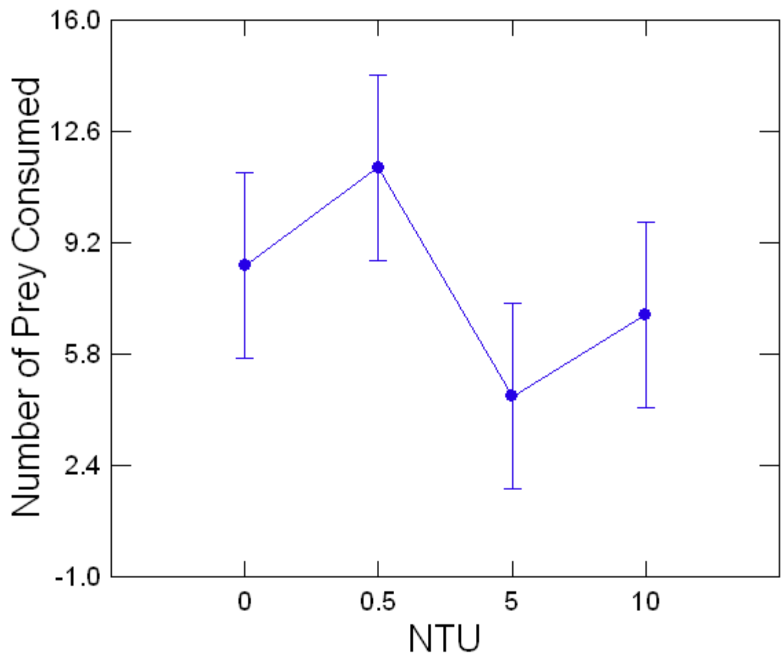

Figure 12. Average number of prey consumed during trial with 16 prey items.

To test for a body length effect on number of fish consumed, I used a linear regression to test for a relationship between the number of fish consumed during a trial, and the predator length. The relationship was significant ($p = 0.036$), and positive. Larger smallmouth bass tended to consume more fish during a trial (See Figure 13). However, the proportion of prey fish consumed in a trial did not ($p = 0.294$) scale significantly with predator size (See Figure 14). Additionally, since fish were randomly assigned to a treatment tank during the trials, any bias added by predator size would be randomly distributed through the trials.

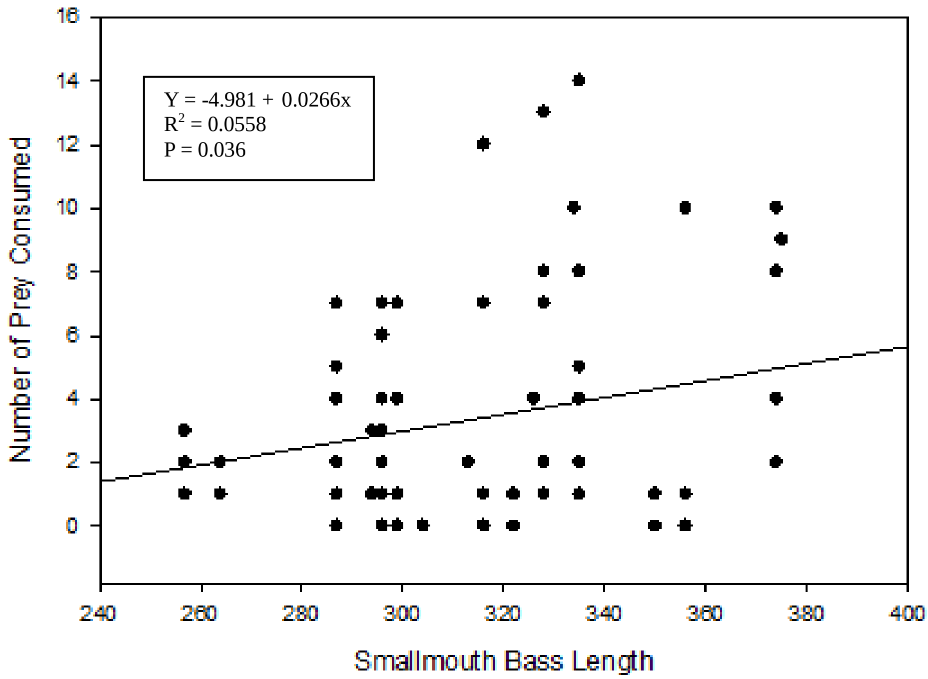

Figure 13. Linear regression shows increase in number of prey consumed with increasing predator size.

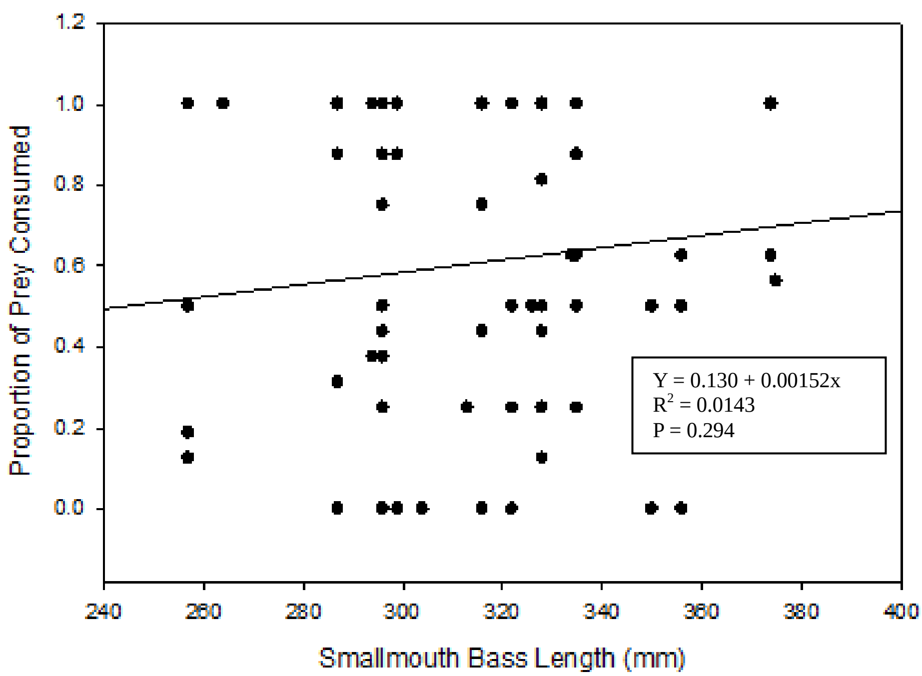

Figure 14. Linear regression shows no effect of predator length on the proportion of prey consumed.

Discussion

Community Structure

Sandrollers (*Percopsis transmontana*) were found in large numbers during this study. Earlier studies of fish community structure in the Snake River found no sandrollers in 1979 or 1995 (Bennett et al. 1983, Bennett et al. 1999). Sandrollers were found in low numbers (n<100) during sampling in 2008 and 2009 (Seybold and Bennett 2010). Smallmouth bass and centrarchids composed a much larger percentage of the catch during past sampling events. Our sampling in 2011 found a larger percentage of native fishes, including peamouth, sandrollers, and suckers. See Table 16 for details.

High flows and colder temperatures may have accounted for part of the community structure shift. Lower Snake River flows in 2008-2009 were higher than the 10-year average, as were 2010-2011 flows (Arntzen et al. 2011). Sandrollers are reported to prefer heavy cover (Wydoski and Whitney 2003); high flows may have flushed sandrollers into the mainstem from tributary streams such as the Tucannon and Palouse rivers. Most sandroller captures occurred in open water.

Devil's Bench (Transect 9B) was found to have less diversity than several of the other sites. This area is bordered by steep basalt cliffs, and had a steep bed slope, which may make this transect an ideal candidate for sediment disposal. There was no detectable correlation, $F(3,120) = 0.684$, $p = 0.564$, between diversity and habitat categories: backwater (sites 8A, 8B, and 6B), shallow mainstem (sites 3B, 7A, 10B, 11B, and 12B), steep gradient mainstem (sites 3A and 5A), and free flowing (site 1B).

Table 17. Relative Abundance values from 2011 sampling and comparison with past sampling events.

	Lake Sacajawea				Lake West				Lake Bryan				Lower Granite							
	1979-1980		2011		1979-1980		2011		1979-1980		2011		1979-1980		1989		1994-1995		2011	
Species	**N**	**RA**	**N**	**RA**	**N**	**RA**	**N**	**RA**	**N**	**RA**	**N**	**RA**	**N**	**RA**	**N**	**RA**	**N**	**RA**	**N**	**RA**
Brown Bullhead	20	0.52	0	0.02	31	0.66	1	0.25	629	1.56	0	0.00	36	1.72	110	0.64	26	0.18	0	0.00
Black Crappie	141	3.68	0	0.02	129	2.75	1	0.25	1672	4.16	0	0.00	79	3.78	84	0.49	44	0.31	0	0.00
Bluegill	21	0.55	1	0.07	5	0.11	1	0.25	1218	3.03	0	0.00	12	0.57	11	0.06	40	0.28	2	0.06
Bull Trout	0	0.00	0	0.02	0	0.00	1	0.25	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Bridgelip Sucker	402	10.49	8	2.95	490	10.44	14	3.48	3808	9.47	6	0.71	274	13.11	155	0.91	1397	9.73	153	4.74
Common Carp	256	6.68	7	0.55	187	3.98	2	0.50	1057	2.63	10	1.18	120	5.74	207	1.21	3	0.02	15	0.46
Channel Catfish	218	5.69	1	0.08	118	2.51	1	0.25	1152	2.86	0	0.00	7	0.33	234	1.37	0	0.00	3	0.09
Chinook	2	0.05	142	24.00	3	0.06	38	9.45	75	0.19	231	27.18	4	0.19	4982	29.10	284	1.98	1063	32.90
Chislemouth	99	2.58	0	1.12	408	8.69	22	5.47	1456	3.62	4	0.47	310	14.83	914	5.34	836	5.82	43	1.33
Coho	0	0.00	7	0.49	0	0.00	2	0.50	0	0.00	2	0.24	0	0.00	0	0.00	0	0.00	19	0.59
Sculpin	38	0.99	0	0.02	80	1.70	0	0.00	201	0.50	0	0.00	0	0.00	6	0.04	0	0.00	1	0.03
Large Scale Sucker	1257	32.79	325	28.55	849	18.08	226	56.22	7972	19.83	128	15.06	255	12.20	5379	31.42	4089	28.48	1074	33.24
Mountain Whitefish	10	0.26	8	3.08	2	0.04	0	0.00	39	0.10	1	0.12	2	0.10	11	0.06	27	0.19	180	5.57
Northern Pikeminnow	347	9.05	61	2.05	823	17.53	15	3.73	2510	6.24	24	2.82	354	16.94	749	4.38	365	2.54	26	0.80
Peamouth	23	0.60	944	23.90	25	0.53	26	6.47	76	0.19	135	15.88	2	0.10	46	0.27	52	0.36	363	11.23
Pumpkinseed	70	1.83	1	0.13	145	3.09	3	0.75	1926	4.79	0	0.00	16	0.77	246	1.44	350	2.44	4	0.12
Redside Shiner	553	14.43	2	0.03	219	4.66	0	0.00	3847	9.57	0	0.00	246	11.77	49	0.29	3	0.02	0	0.00
Smalllmouth Bass	106	2.77	64	4.62	301	6.41	31	7.71	2104	5.23	15	1.76	218	10.43	2391	13.97	5459	38.03	174	5.39
Sandroller	0	0.00	79	7.83	0	0.00	3	0.75	0	0.00	293	34.47	0	0.00	0	0.00	0	0.00	106	3.28
Steelhead	6	0.16	1	0.03	22	0.47	0	0.00	172	0.43	0	0.00	4	0.19	744	4.35	761	5.30	1	0.03
Walleye	0	0.00	1	0.13	0	0.00	7	1.74	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
White Crappie	118	3.08	0	0.05	440	9.37	0	0.00	7011	17.44	0	0.00	68	3.25	619	3.62	482	3.36	3	0.09
Yellow Bullhead	1	0.03	2	0.07	22	0.47	1	0.25	240	0.60	0	0.00	15	0.72	0	0.00	64	0.45	1	0.03
Yellow Perch	145	3.78	4	0.20	396	8.43	7	1.74	3046	7.58	1	0.12	68	3.25	182	1.06	74	0.52	0	0.00

(1979-1980 from Bennett et al.(1983), 1989 from Bennett et al. (1991), 1994-1995 from Bennett et al. (1999))

The area sampled via electrofishing in Site 9B was consistently deeper than any of the other sites sampled. Electrofishing is effective to about three meters. Nearly all of site 9B greatly exceeded this depth. Due to high flows during the spring sampling, visibility in the water was extremely low. There may have been fish that were at the edge of the shocking field which were not captured due to water quality. Over the entire spring sampling only four different species (juvenile Chinook, large scale suckers, small mouth bass, and peamouth) were collected at site 9B. This richness value of four was the highest of all the sampling trips at this site in the spring. On three sampling trips only one species was collected, and on one trip no fish were collected at this site. It is possible water quality and the depth of the site were contributing factors that limited the number of fish collected. If the low species richness values are accurate, transect 9B may be a good location for in-water disposal of dredge sediments.

Chinook sampled in this study had a K_{TL} 0.95 ± 0.29 (SD) and a K_{FL} of 1.386 ± 0.255 (SD) (Conversion from Ramseyer 1995). Several previous studies have calculated K_{TL} for young Chinook salmon, with values ranging from 0.769 to 1.111 (Foott and Fogerty 2011) and 0.98 to 1.09 (Foott et al 2002) for Californian stocks. Conner et al (2004) found K_{FL} values ranging from 1.088 to 1.228 for yearling and subyearling Chinook in the Snake River. This suggests that the young Chinook sampled in the winter and spring of 2011 were in a similar or better condition to the Snake River Chinook sampled in 2004. Chinook sampled during this study were of similar condition to other Pacific Chinook stocks.

Condition factor was significantly lower for juvenile Chinook captured at 6B than for Chinook captured at site 1A. Condition factor comparisons between all other pairs of sites were not significant. Transect 6B, Illia Dunes Lower, is a backwater section in Lake Bryan, with a gradual bed slope composed of sand and silt. Transect 1A (Asotin Slough Upper) is located in a free flowing section of the Snake River upstream of the confluence with the Clearwater River, and was classified as a free-flowing stretch. The bed slope was also gradual, but substrate size was coarse. Studies have shown that growth and survival of juvenile salmonids tend to be negatively correlated with increased amounts of fine < 2 mm sediments (Crouse et al. 1981, Suttle et al. 2004). Flow and substrate differences may account for condition factor differences, but more research would be necessary to identify the most ideal juvenile salmonid habitat. In the Snake River basin specifically, researchers (Bennett 1988a, Bennett 1988b, Curet 1994) have noted increased juvenile salmonid presence at sites with low gradient shorelines, suggesting bathometry may be a more important factor.

Transect 8A was found to have higher diversity than many other transects, with a total species richness value of 15. This transect (Tucannon River Upper) is located at the upstream mouth of the Tucannon River. The area has a rapid bed slope comprised of talus and cobbles, but is uniformly shallow at < 4 m deep.

My study found that smallmouth bass in the Lower Snake River consume low numbers of juvenile salmonids, at less than 2% of the diet by weight. Other researchers have found variable rates of predation on juvenile salmonids. Bennett et al. (1999) found that in 1994, for smallmouth bass in the size range of 250-389 mm, 62.1% of the diet by weight was composed of juvenile salmonids in Lower Granite Reservoir (study conducted April to November). However, in the next year, salmonids made up less than 20% of the diet by weight for smallmouth bass in the same size range, with the sampling period from May to November. Bennett and Shrier (1986) found that 26% of the smallmouth bass diet was composed of salmonids during field sampling during the spring and summer of 1985, then found no evidence of predation on salmonids a year later during sampling from January to April in 1986, although this sampling window probably missed predation during outmigration which occurs primarily during April through August (Bennett and Shrier 1987).

Early studies conducted in the Lower Snake River (Bennett et al. 1983) collected smallmouth bass as well as channel catfish. SMB were collected (n = 484) between April 1979 to November 1980 in Lake Bryan, at a size range of 57 to 470 mm. Empty stomachs occurred in 96 fish (18.8%). Crayfish accounted for 72% of the diet by volume, and occurred in 64% of samples. Fish prey accounted for 25.4% of the diet by volume, and were found in 32% of stomachs. Of 95 prey fish consumed, only two were identified as salmonids (Chinook). Insects were of minor importance, with terrestrial insects composing 1.8% of the total volume and occurring in 7% of samples, and aquatic insects 0.3% of the total volume and occurring in 6.4% of samples.

Stomach samples (n = 452) were collected from channel catfish, 92-649 mm TL, in the same area and timeframe. Empty stomachs occurred in 149 (33%) fish, and 303 (67%) contained foot items. Fish prey accounted for 80.4% of the total volume of food items, and occurred in 28.1% of stomachs. Chinook were consumed most abundantly (n = 47), followed by steelhead (n = 31). Crayfish accounted for 5.4% of the total volume of food items, and occurred in 17.5% of the stomach samples. Wheat grains occurred in 8.5% of the stomachs, and accounted for 4.3% of the total volume. Aquatic insects (Chironomidae) composed 4.3% of the diet by volume, and were found in 21.1% of samples.

A later study was conducted to quantify the rate of predation of salmonid prey specifically: SMB (n = 184) were collected from Lake Bryan in April and May of 1980 (timeframe which coincided with downstream migration of Chinook and steelhead salmon), at an average size of 249 mm (135-467 mm). Food items were present in 153 (83.2%) of these samples, in which only two juvenile Chinook salmon were found. Frequency of occurrence of Chinook salmon was less than 2%. Channel catfish (n = 83) were collected at the same time, with a mean length of 526 mm (365- 635 mm). Food items occurred in 73 (88%) of these samples, of which Chinook and steelhead salmon were the most abundant food items at 66.5% of the total number of food items, and 85.5% of the diet by volume.

Channel catfish were captured in high numbers during sampling in 1979-1980, when 218 were captured in Lake Sacajawea, 118 in Lake West, 1,152 in Lake Bryan, and 234 in Lower Granite (Bennett et al. 1983). In 1989, 234 CC were captured in Lower Granite Lake (Bennett et al. 1991). Channel catfish were captured in low numbers (n = 11) in the Lower Snake River in 2008-2009 (Seybold and Bennett 2010). My sampling in 2011 yielded five channel catfish. While not comprehensive, this data may indicate a decrease in channel catfish population. Channel catfish predation on salmonids may be common, and should be investigated in light of both PDO changes favoring salmonid production, and recent high flow and low temperature events in the Lower Snake River. Electrofishing may not be sufficient to capture these fish, other methods (traps, Fyke nets, beach seining) may provide a more comprehensive estimate of the population.

Anglea (1997) found that salmonids composed 89% of the diet of smallmouth bass in 1994, and 56% of the diet by weight in 1995, during sampling from April to June in Lower Granite Lake. However, salmonids were absent from the diet during sampling in August through November, suggesting that SMB were opportunistically feeding on a seasonably available food source, and that timing of diet studies may be a large source of bias.

Poe et al. (1991) found that, on average, 4% of the diet of SMB was composed of juvenile salmonids during sampling in the Columbia River during April through August in 1983-1986. Additionally, consumption of salmonids was undetected in April, but increased to 6% of the diet by August, when subyearling Chinook and SMB habit overlapped.

Tabor et al. (1993) examined SMB diets in the Columbia River, during May and June of 1990, during outmigration of juvenile salmonids. Salmonids were found in 65% of SMB stomach samples, and composed 59% of the diet by weight. This study did not address salmonid consumption throughout the rest of the year.

Naughton et al. (2004) found a low incidence of predation by smallmouth bass on salmonids in Lower Granite Lake during sampling from April to August in 1996 and 1997. Juvenile salmonids comprised 11% of smallmouth bass diet by weight in the forebay of the dam, and only 5% of SMB diet in the free flowing section above the dam. The study cited high flows and high turbidity during sampling as a possible contributing factor to the low predation rates.

The proportion of salmonids in the diet of SMB was seasonally highly variable, with additional variation added by yearly conditions such as flow, turbidity, water temperature, and the number of juvenile salmonids available as forage. Curet (1994) estimated a 3.8% loss of the juvenile Chinook during sampling in May 1992 to SMB predation in Lower Granite Lake. Additional mortalities undoubtedly occurred in the other Lower Snake River reservoirs, as well as reservoirs in the Columbia river during outmigration.

Total loss of salmonids depends on predator population; a large walleye population in Lake Roosevelt has contributed to recruitment failure of a stocked kokanee population. Baldwin et al (2003) estimated that up to 15% of hatchery released kokanee were consumed within 41 days of release, based on a population estimate of 16,610 walleyes.   Walleye population in the reservoir is high, comprising 30% of the total fish relative abundance in the 1980's (Beckman et al. 1985).   Stroud et al. (2010) expanded on this research in the Sandpoil arm of the reservoir, using bioenergetics modeling along with walleye population estimates, that walleye were capable of consuming nearly all of the juvenile rainbow trout and kokanee that entered the study area.

Fritts and Pearsons (2004) estimated an average consumption of over 200,000 juvenile salmonids from March to June (1998-2001) in the Lower Yakima River. This was based on a bass population that increased from 3,347 in March to 19,438 by late June. 47% of the diet was composed of juvenile Chinook salmon, with estimated daily consumption peaking in 1998 at over 16,000 juvenile Chinook.

Quantification of individual fish diets provides a limited amount of useful data, and should be combined with population data for the predator in question. While my study suggested that the proportion of smallmouth bass diets composed of salmonids is low, the population of smallmouth bass is a large unknown. Walleye diets in my study (n = 3) were composed 100% of fish prey, albeit no salmonids were present. If piscivore populations increase, so will total loss of juvenile salmonids.

Smallmouth bass, and other introduced fish are obviously sources of juvenile salmonid mortality in the Lower Snake River. Large variations in SMB diets, percentage of diet composed of juvenile salmonids, between studies are likely caused by variable river conditions. The number of outmigrating salmonids, water flow, turbidity, and water temperature are all important factors.

During our sampling year (2011) river flows were high, as was turbidity. Discharge during our sampling period was significantly higher than the mean daily discharge during the previous 10 years (Arntzen et al. 2011). Peak discharges were not only higher, but lasted longer during 2011. Increased discharge likely leads to increased turbidity (Lawler et al. 2006, Anderson and Potts 1987), as well as leading to lower temperatures, particularly in the late spring to early summer (See Figure 15).

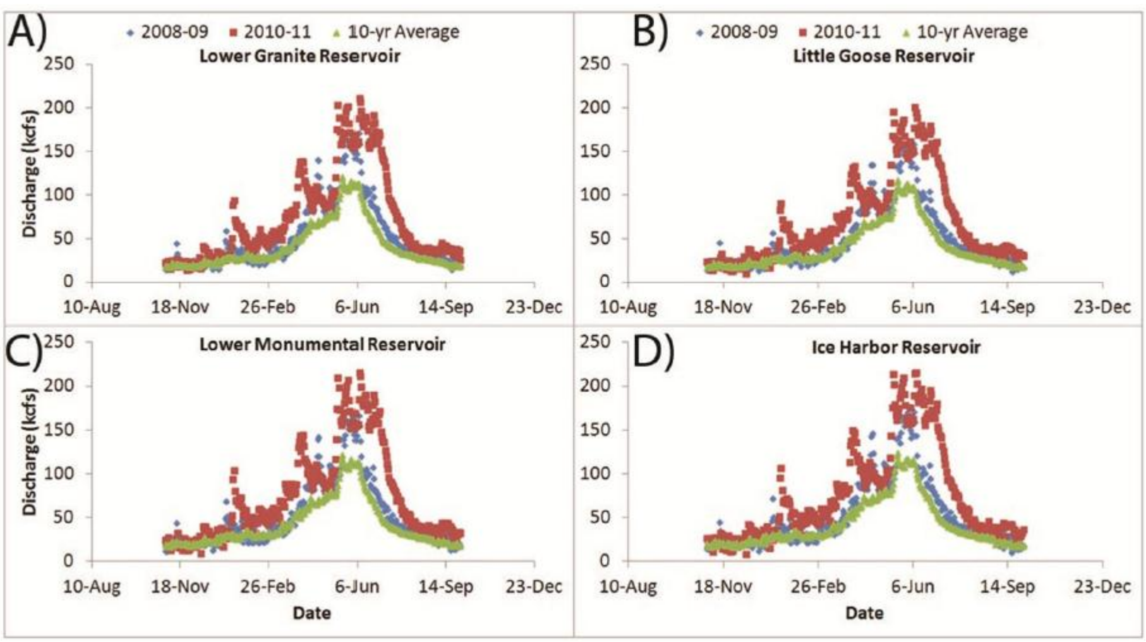

Figure 15. Mean daily discharge (cfs x 1000) for the four Lower Snake River reservoirs during 2010-2011, 2008-2009, 2001-2010 periods. Figure from Arntzen et al. 2011.

As the graphs in Figure 15 illustrate, peak flows in early June were much higher than during the previous decade, with some daily averages nearly twice historical daily averages. Water temperatures, particularly during the summer months, were lower than the previous 10 years. See Figure 16 for mean daily reservoir temperatures.

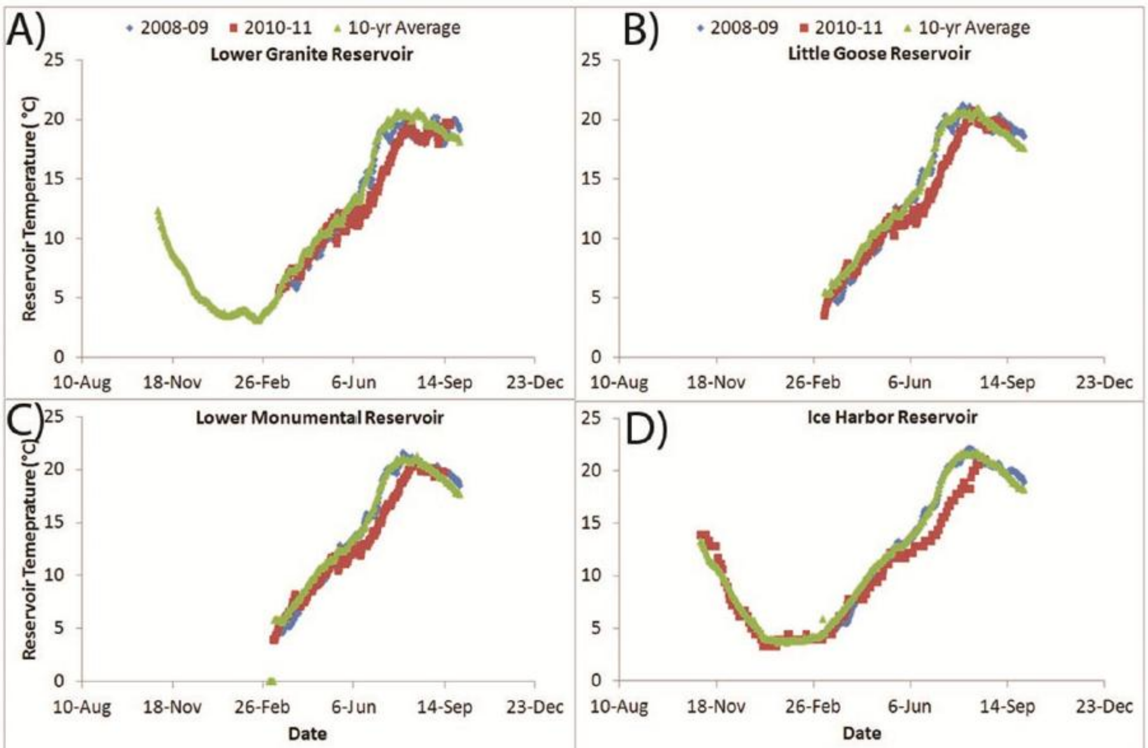

Figure 16. Mean daily reservoir temperature (°C) over the 2010-2011 study period. 2008-2009 and 2001-2010 10-year average included for comparison. From Arntzen et al. 2011.

It is likely that the combination of high flows and low temperatures, combined with high turbidity, lowered predation rates on juvenile salmonids during our sampling during 2011. High flows would have moved juvenile salmonids more quickly downstream, leading to reduced temporal habitat overlap. Lower temperatures lower piscivorous fish metabolism, leading to lower rates of feeding (Vigg et al. 1991). As smallmouth bass are highly visual predators, relying on visual detection of prey items, elevated turbidity likely reduced the number of successful detection events, and thus reduced predation.

Turbidity Trials

My results do suggest that turbidity levels may affect smallmouth foraging ability on juvenile salmonids. The interaction effect between turbidity and prey density was highly significant ($p = 0.004$). Increased turbidity decreased prey consumption, increased prey density increased prey consumption. In a prey rich environment, such as the 16 prey trials, I saw a reduction in consumption rates in the 5.0 NTU trials as compared to the 0.5 NTU trials. Variation was too high to detect any potential significant difference between the 5.0 and 10.0 NTU levels.

Predator size did have an effect on the number of prey consumed during a trial, but did not have any significant effect on the proportion of prey consumed. This would seem to indicate that the random sorting of predators to trials may have resulted with larger smallmouth bass assigned to trials with larger numbers of prey items. However, the presence of a larger predator in any given trial did not increase the proportion of prey consumed in that trial. A regression showed no relationship ($p = 0.665$) between predator length and the trial to which the predator was assigned.

Possible contributions to the high amount of variance during the study include the low sample size (n=4) for each trial. This constraint was introduced by the number of tanks available at the facility. Additional trials could have been completed over a greater period of time, but the continued growth of the kokanee would have introduced an additional source of error. The random assignment of predators to both trials and replicates lead to large predator size disparities between tanks, with over 120 mm difference between the smallest and largest smallmouth bass. As larger predators are able to eat more prey than smaller predators in a given amount of time, this may have been another source of variation, as discussed earlier. Future trials could control this variation by using several slot groupings of predator size, and using predator size as an experimental treatment.

Increased turbidity may lead to behavioral changes in prey species (Abrahams and Kattenfeld 1997). A study using fathead minnows (*Pimephales promelas*) as prey items, and yellow perch as the predator, found a reduced predator avoidance response under increased turbidity levels. The smaller minnows were selectively preyed upon under clear water conditions, but size selectivity disappeared under turbid conditions. These results suggest that the increased swimming speed and thus predator avoidance behavior of the larger minnows was negated under the turbid conditions. As a result, turbidity did not have an effect of the proportion of minnows consumed.

Similar behavioral alterations may occur within the salmonids under similar conditions. Gregory and Leavings (1996) conducted trials that compared the ability of adult coastal cutthroat trout (*Oncorhynchus clarkii clarkii*) to forage on a selection of juvenile salmonids prey under two treatments – additional turbidity and the addition of vegetative cover. The researchers found that the presence of cover had a significant effect on predation rate, the effect of turbidity alone was not significant. An interesting interaction effect also appeared. Predation rates were actually lower in the trials with vegetation alone than in the trials that combined turbidity and vegetation. The authors suggest that any turbidity effects may be driven by a change in the rate of encounter, not in the rate of capture or attack.

Gregory (1993) conducted a study in which juvenile Chinook were exposed to both bird and fish predators under clear water and turbid conditions. The juvenile salmonids tended to distribute at the bottom of the enclosure during clear water conditions, and distributed randomly during turbid conditions. When exposed to predators, both the clear water and turbid treatments altered their distribution to orient deeper in the enclosure. However, the responses in turbid conditions were of a shorter vector and of a shorter duration. This research provides additional evidence that altered (increased) turbidity affects both predator and prey behavior.

Two factors appear to be affected by the addition of turbidity to waters containing both juvenile salmonids and their predator: the encounter rate of predators and the behavior of the prey, in this case, juvenile salmonids. As turbidity levels have the potential to affect predation impacts on native salmonids, the influence of anthropogenic alterations of turbidity levels should be studied in depth. Human endeavors such as the damming of the Snake River system, as well as subsequent dredging, alter the natural flow of sediments, and thus turbidity. The USACE plan to dispose of sediments collected by dredging, by creating shallow water habitat via in-river-disposal, may serve several purposes. In addition to creating feeding stations for out- migrating salmon smolts, the addition of fine sediments will help mimic the river's natural function. Increasing flow would provide a host of other benefits to outmigrating juvenile salmonids, including reducing water temperature, reducing temporal/spatial overlap with predators, and increasing turbidity. Summer flow augmentations (by managed releases from Dworshak Dam) should be continued. Returning the Snake River flow regime to a pattern that mimics flow conditions prior to the construction of the hydrosystem would likely be the most direct way to positively influence juvenile salmonid survival.

Literature Cited

Abrahams, M., M. Kattenfeld. 1997. The role of turbidity as a constraint on predator-prey intereactions in aquatic environments. Behavioral Ecology and Sociobiology. 40: 169-174

Adult Salmon Annual Totals. 2008 Fish Passage Center. <http://www.fpc.org/adultsalmon/adulthistory/YTD-IHR.html>

Anderson, B., D.F. Potts. 1987. Suspended sediments and turbidity following road construction and logging in Western Montana. Journal of the American Water Resources Association. **23**: 681-690

Anglea, S. M. 1997. Abundance, food habits, and salmonid fish consumption of smallmouth bass and distribution of crayfish in Lower Granite Reservoir, Idaho-Washington. Masters Thesis. University of Idaho.

Arntzen, E. V., K.J. Klett, B.L. Millter, R.P. Mueller, R.A. Harnish, M.A. Nabelek, D.D. Dauble, B.B. James, A.T. Scholz, M.C. Paluch, D. Sontag, G. Lester. 2011. Habitat Quality and Fish Species Composition/Abundance at Selected Shallow Water Locations in the Lower Snake River Reservoirs. Draft Report. Prepared for U.S. Army Corps of Engineers by Battelle, Pacific Northwest Division. Contract W912EF-08-D-0004

Baldwin, C. M., J. G. McLellan, M. C. Polacek, K. Underwood. 2003. Walleye predation on hatchery releases of kokanees and rainbow trout in Lake Roosevelt, Washington. North American Journal of Fisheries Management. **23**: 660-676

Beckman, L. G., Novotny, J. F., Persons, W. R. and Terrell, T. T. 1985. Assessment of the fisheries and limnology in Lake F. D. Roosevelt, 1980–1983, Report of the U.S. Fish and Wildlife Service for the U.S. Bureau of Reclamation, FWS-14-06-009-904 Seattle

Bellgraph, B.J., R.A. Harnish, L.A. Ortega, M.C. Paluch, D.M. Sontag, A.T. Scholz, A.R. Black, C.O. Price. 2012. Evaluation of Fish Assemblages and Piscivore Diets in Developed and Undeveloped Littoral Area of Lake Pend Oreille. Prepared for U.S. Army Corp of Engineers, Walla Walla District. Contract W912EF-08-D-0004

Bennett, D.H., P.M. Bratovich, W. Knox, D. Palmer, H. Hansel. 1983. Status of the Warmwater Fishery and the Potential of Improving Warmwater Fish Habitat in the Lower Snake Reservoirs. Final Report. Prepared for U.S. Army Corp of Engineers, Walla Walla District. Contract DACW68-79-C0057

Bennett, D. H., J. A. Chandler, G. Chandler. 1991. Lower Granite Reservoir in-water disposal test: results of the fishery, benthic and habitat monitoring program – year 2 (1989). Planning Environmental Resources Branch: Fishery Library Publication #721

Bennett, D. H., T. J. Dresser Jr., T. S. Curet, K. B. Lepla, M. A. Madsen. 1993. Lower Granite Reservoir in-water disposal test: Results on the fishery, benthic and habitat monitoring program – year 4 (1991). Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., T. J. Dresser Jr., and M. A. Madsen. 1994. Effects of reservoir operations at minimum pool and regulated inflows of low temperature water on resident fishes in Lower Granite Reservoir. Draft. Department of Fish and Wildlife. College of Forestry, Wildlife and Range Sciences. University of Idaho. Moscow, ID 83843

Bennett, D. H., L. K. Dunsmoor, J. A. Chandler, and T. Barila. 1988. Use of dredged material to enhance fish habitat in Lower Granite Reservoir, Idaho-Washington. Planning Environmental Resources Branch: Fishery Library Publication #750

Bennett, D. H., L. K. Dunsmoor, and J. A. Chandler. 1988a. Fish and benthic community abundance at proposed in-water disposal sites, Lower Granite Reservoir (1987). Completion Report with Addendum. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., L. K. Dunsmoor, and J. A. Chandler. 1988b. Fish and habitat evaluation of shallow water habitats in Lower Granite Reservoir. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., M. A. Madsen, S. M. Anglea, T. Cichosz, T. J. Dresser Jr., and M. Davis. 1999. Fish interactions in Lower Granite Reservoir, Idaho-Washington. Final Completion Report to USACE. Projects: #14-45-0009-1579 w/o 21 and #14-16-0009-1579 w/o 32

Bennett, D. H., and F. C. Shrier. 1986. Effects of sediment dredging and in-water disposal on fishes in Lower Granite Reservoir. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., and F. C. Shrier. 1987. Monitoring sediment dredging and overflow from land disposal activities on water quality, fish and benthos in Lower Granite Reservoir, Washington. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bickford, S. A., and J. R. Skalski. 2000. Reanalysis and interpretation of 25 years of Snake-Columbia River juvenile salmonid survival studies. North American Journal of Fisheries Management. **20**: 53-68

Bratovich, P. M. 1985. Reproduction and early life histories of selected resident fishes in lower Snake River reservoirs. Masters Thesis. University of Idaho.

Budy, P., G. P. Thiede, N. Bouwes, C. E. Petrosky, and H. Schaller. 2002. Evidence linking delayed mortality of Snake River salmon to their earlier hydrosystem experience. North American Journal of Fisheries Management **22**:35-51

Bugert, R. M. 1985. Microhabitat selection of juvenile salmonids in response to stream cover alteration and predation. Master of Science Thesis, University of Idaho, Moscow.

Busbee, R.L. 1968 Piscivorous activities of the channel catfish. The Progressive Fish Culturalist. January 32-34

Cada, G. F., M. D. Deacon, S. V. Mitz, and M. S. Bevelheimer. 1997. Effects of water velocity on downstream migrating juvenile salmon and steelhead: a review with emphasis on the Columbia River basin. Reviews in Fisheries Science **5**:131-183

Carey, M.P., B.L. Sanderson, T.A. Friesen, K.A. Barnas, J.D. Olden. 2011. Smallmouth bass in the Pacific Northwest: A threat to native species; a benefit for anglers. Reviews in Fisheries Science. **19**: 305-315

Carlander, K.D. 1969. Handbook of Freshwater Fishery Biology, volume 1. The Iowa State University Press, Ames. Iowa

Carlander, K. D. 1977. Handbook of freshwater fishery biology, volume 2. Life history data on centrarchid fishes on the United States and Canada. Iowa State University Press, Ames.

Carlander, K. D. 1982. Standard intercepts for calculating lengths from scale measurements for some contrarchid and percid fishes. Transactions of the American Fisheries Society. **111**: 332-336.

Carter, M.W., D.E. Shoup, J.M. Dettmers, D.H. Wahl. 2010. Effects of Turbidity and Cover on Prey Selectivity of Adult Smallmouth Bass. Transactions of the American Fisheries Society **139**: 353-361

Connor, W. P., H. L. Burge, and D. H. Bennett. 1998. Detection of PIT-tagged subyearling Chinook salmon at a Snake River Dam: implications for summer flow augmentation. North American Journal of Fisheries Management **18**:530-536

Connor, W. P. 2001. Juvenile life history, downstream migration rate, and survival of wild Snake River fall Chinook salmon. Master of Science Thesis, University of Idaho, Moscow.

Connor, W.P., S.G. Smith, T. Anderson, S.M. Bradbury, D.C. Burum, E.E. Hockersmith, M.L. Schuck, G.W. Mendel, R.M. Bugert. 2004. Postrelease Performance of hatchery Yearling and Subyearling Fall Chinook Salmon Released into the Snake River. North American Journal of Fisheries Management. 24: 545-560

Craig, J. A. and R. L. Hacker. 1940 The history and development of the fisheries of the Columbia River. Fisheries Bulletin **49**:133-216

Crouse, M.R., C.A. Callahan, K.W. Malueg, and S.E. Dominquez. 1981. Effects of fine sediments on growth of juvenile coho salmon in laboratory streams. Transactions of the American Fisheries Society. **110**: 281-286

Curet, T. S. 1994. Habitat use, food habits, and the influence of predation of subyearling Chinook salmon in Lower Granite and Little Goose reservoirs, Washington. Master of Science Thesis. University of Idaho, Moscow.

Distefano, R. J., M. J. Roell, B. A. Wagner, and J. J. Decoske. 1994. Relative performances of four preservatives on fish and crayfish. Transactions of the American Fisheries Society. **123**: 817-823

Devries, D. R., and R. V. Frie. 1996. Determination of age and growth. Pages 483-512 in B. R. Murphy and D. W. Willis, editors. Fisheries Techniques, 2nd Edition. American Fisheries Society. Bethesda, Maryland, USA

Dunsmoor, L. K. 1990. Relative prey importance and availability in relation to smallmouth bass growth in Brownlee Reservoir, Idaho, with notes on dietary indices. Master of Science Thesis. University of Idaho, Moscow.

Fritts, A. L., and T. N. Pearsons. 2006. Effects of predation by nonnative smallmouth bass on native salmonid prey: the role of predator and prey size. Transactions of the American Fisheries Society **135**: 853-860

Foott, J.S. and R. Fogerty. 2011. FY2011 Technical Report: Juvenile Stanislaus River Chinook salmon pathogen and physiology assessment: January – May 2011. U.S. Fish & Wildlife Service California – Nevada Fish Health Center, Anderson, CA. http://www.fws.gov/canvfhc/reports.asp

Foott J.S., T. Martinez, R. Harmon, K. True, B. McCasland, C.Glace, R. Engle. 2002. FY2001 Investigational Report: Juvenile Chinook Health Monitoring in the Trinity River, Klamath River, and Estuary. June – August 2001. U. S. Fish and Wildlife Service, California – Nevada Fish Health Center, Anderson, CA.

Fulton, L. A. 1968. Spawning areas and abundance of chinook salmon, *Oncorhynchus tshawytscha*, in the Columbia River Basin--Past and present. U.S. Fish. Wildl. Serv. Spec. Sci. Rep.--Fish. 571, 26 p.

George, E. L., and W. F. Hadley. 1979. Food and habitat partitioning between rock bass (*Ambloplites rupestris*) and smallmouth bass (*Micropterus dolomieui*) young of the year. Transactions of the American Fisheries Society **108**: 253-261

Goodstein, E. and L. Matson. 2007. Climate change in the pacific northwest: Valuing snowpack loss for agriculture and salmon.” In J.D. Erickson and J.M. Gowdy, eds., *Frontiers in Ecological Economic Theory and Applications.* Northampton, MA: Edward Elgar.

Gregory, R.S. 1993. Effect of turbidity on the predator avoidance behavior of juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences **50**: 241-246

Gregory, R.S., and C.D. Levings. 1996. The effects of turbidity and vegetation on the risk of juvenile salmonids, Oncohynchus spp., to predation by adult cutthroat trout, O. clarkii. Environmental Biology of Fishes. **47**: 279-288

Gregory, R. S., and C. D. Levings. 1998. Turbidity reduces predation on migrating juvenile Pacific salmon. Transactions of the American Fisheries Society **127**: 275-285

Hankin, D. G., and J. Richards. 2000. The northern pikeminnow management program: An independent review of program justification, performance, and cost-effectiveness. Northwest Power Planning Council. 04 April 2000

Hansel, H. C., S. D. Duke, P. T. Lofy, and G. A. Gray. 1988. Use of diagnostic bones to identify and estimate original lengths of ingested prey fishes. Transactions of the American Fisheries Society **117**: 55-62

Hare, S.R., N.J. Mantua, and R.C. Francis. 1999. Inverse production regimes: Alaskan and West Coast Salmon. Fisheries **24**: 6-14

Harley, S. J., R. A. Myers, and A. Dunn. 2001. Is catch-per-unit-effort proportional to abundance? Candian Journal of Fisheries and Aquatic Sciences. **58**: 1760-1772

Haskell, C.A., R.D. Baxter, K.F. Tiffan. 2006. Range Expansion of an Exotic Siberian Prawn to the Lower Snake River. Northwest Science **80**: 311-316

Helvoigt, T. L., and D. Charlton. 2009. The economic value of Rogue River salmon. Save the Wild Rogue Campaign.

Hassemer, P. E., S. W. Keifer, and C. E. Petrosky. 1997. Idaho's salmon: can we count every last one? Pages 113-125 in D. G. Stouder, P. A. Bisson, and R. J. Naiman, editors. Pacific salmon and their ecosystems: Status and future options. Chapman and Hall, London.

Idaho Fish and Game. 2005. Chinook salmon conservation status and conservation. Idaho Conservation Data Center. <http://fishandgame.idaho.gov/cms/tech/CDC/cwcs_appf >

Isermann, D. A., J. R. Meerbeek, G. D. Scholten, and D. W. Willis. 2003. Evaluation of three different structures used for walleye age estimation with emphasis on removal and processing times. North American Journal of Fisheries Management. **23**: 625-631

Kammerer, J. C. 1990. Water fact sheet: Largest Rivers in the United States. United States Geological Survey. 1992 O: 334-338

Kareiva, P., Marvier, M. and McClure, M. 2000. Recovery and management options for spring/summer chinook salmon in the Columbia River basin. Science 290:977–979.

Keating, J. F. Jr. 1970. Growth rates and food habits of smallmouth bass in the Snake, Clearwater and Salmon Rivers, Idaho, 1965-1967. Master of Science Thesis. University of Idaho.

Knox, W. J. 1982. Angler use, catch and attitudes on lower Snake River reservoirs, with emphasis on Little Goose Reservoir. Master of Science Thesis, University of Idaho, Moscow.

Landry, C.J. 2003. The wrong way to restore salmon: Few results at $400 per fish. Property and Environmental Research Center. Vol. 21, No. 2

Lawler, D.M., G.E. Petts, I.D. Foster, S. Harper. 2006. Turbidity dynamics during spring storm events in an urban headwater river system: the Upper Tame, West Midlands, UK. Science of the Total Environment. **3**: 109-126

Ligon, F. K., W. E. Dietrich, and W. J. Trush. 1995. Downstream ecological effects of dams. Bioscience. **45**: 183-192

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific decadal climate oscillation with impacts on salmon. Bulletin of the American

Meteorological Society **78**:1069–1079.

Martinson, R., G. Kovalchuk, D. Ballinger. 2009. Columbia River Basin Juvenile Fish Field Guide Including Common Injuries, Diseases, Tags, and Invertebrates – 6th Edition. Pacific States Marine Fisheries Commission Smolt Monitoring Program Staff. The Dalles, OR

Marzolf, R. C. 1955. Use of pectoral spines and vertebrae for determining age and rate of growth of the channel catfish. Journal of Wildlife Management. **19**: 243-248

Matthews, G. M., and R. S. Waples. Status review for Snake River spring and summer Chinook salmon. NOAA Tech Memo NMFS F/NWC-200. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center. Seattle, WA, USA.

McMahon, T. E., and D. H. Bennett. 1996. Walleye and northern pike: boost or bane to northwest fisheries? Fisheries. **8**: 6-13

Muir, W. D., D. M. Marsh, B. P. Sandford, S. G. Smith, J. G. Williams. 2006. Post-Hydropower system delayed mortality of transported Snake River stream-type Chinook Salmon: Unraveling the mystery. Transactions of the American Fisheries Society. **135**: 1523-1534

Naughton, G. P., D. H. Bennett, K. B. Newman. 2004. Predation on juvenile salmonids by smallmouth bass in the Lower Granite Reservoir system, Snake River. North American Journal of Fisheries Management. **24**: 534-544

Nelle, R. D. 1999. Smallmouth bass predation of juvenile fall Chinook salmon in the Hells Canyon Reach of the Snake River, Idaho. Masters Thesis. University of Idaho.

Nickelson, T. E. 1986. Influences of upwelling, ocean temperature, and smolt abundance on marine survival of coho salmon (Oncorhynchus kisuch) in the Oregon production area. Canadian Journal of Fisheries and Aquatic Sciences **43**: 527-535

Nilsson C., A. Ekblad, M. Gardfjell, and B. Carlberg. 1991. Long-term effects of river regulation on river margin vegetation. Journal of Applied Ecology. **23**:963-987

NMFS (U.S. National Marine Fisheries Service). 2000. Biological opinion of the Federal Columbia River power system including the juvenile fish transportation program and the U.S. Bureau of Reclamation's 31 dams including the entire Columbia basin project. NMFS, Seattle, WA.

Paulsen, C. M. and T. R. Fisher. 2001. Statistical relationship between parr-to-smolt survival of Snake River spring-summer Chinook salmon and indices of land use. Transactions of the American Fisheries Society. **130**:347-358

Piaskowski, R. M. 1998. Distribution and movements of northern squawfish and smallmouth bass during operation of a surgace bypass and collection system for juvenile salmonids at Lower Granite Dam. Masters Thesis. University of Idaho.

Pinkas, L., M. S. Oliphant, and I. L. K. Iverson. 1971. Food habits of albacore, bluefin tuna, and bonito in Californian waters. California Fish and Game **152**:1-105

Porter, R. 2011. Report on the predation index, predator control fisheries, and program evaluation for the Columbia Basin experimental northern pikeminnow management program. 2011 Annual Report. Bonneville Power Administration

Raborn, S.W., L.E. Miranda, and M.T. Driscoll. 2003. Modeling predation as a source of mortality for piscivorous fishes in a southeastern U.S. reservoir. Transactions of the American Fisheries Society. **132**: 560-575.

Ramseyer, L.J. 1995. Total length to fork length relationships of juvenile hatchery-reared coho and Chinook salmon. The Progressive Fish-Culturist. Vol 57, Iss. 3

Rieman, B. E., R. C. Beamesderfer, S. Vigg, and T. P. Poe. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia River reservoir: part IV. Estimated total loss and mortality of juvenile salmonids to northern squawfish, walleye, and smallmouth bass. Pages 249-273 in Poe and Rieman (1988)

Rieman, B. E., R. C. Beamesderfer, S. Vigg, and T. P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day reservoir, Columbia River. Transactions of the American Fisheries Society **120**: 448-458

Sanderson, B.L., K.A. Barnas, A.M. Wargo Rub. 2009. Nonindigenous species of the Pacific Northwest: An overlooked risk to endangered salmon? Bioscience. **59**: 245-256

Schaller, H. A., C. E. Petrosky, O. P. Langness. Contrasting patterns of productivity and survival rates for stream-type Chinook salmon (*Oncorhynchus tshawytscha*) populations of the Snake and Columbia Rivers. Canadian Journal of Fisheries and Aquatic Sciences **56**: 1031-1045

Scheuerell, M. D. and J. G. Williams. 2005. Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*). Fisheries Oceanography **14**: 448-457

Schindler, D. E., M. D. Scheuerell, J. W. Moore, S. M. Gende, T. B. Francis, and W. J. Palen. 2003. Pacific salmon and the ecology of coastal ecosystems. Frontiers in Ecology and the Environment. **1**: 31-37

Schoener, T. W. 1971. Theory of feeding strategies. Annual Review of Ecology and Systematics **2**:369-404

Scholz, A.T., H.J. McLellan. 2009. Field Guild to the Fishes of Eastern Washington. Eagle Printing. Cheney, WA November 2009

Scholz, A.T., H.J. McLellan. 2010. Fishes of the Columbia and Snake River Basins in Eastern Washington. Eagle Printing. Cheney, WA October 2010

Seybold, W.F., D.H. Bennett. 2010. Inventory and Impact/Benefit Analyses of Sediment Disposal for Salmonid Fishes at Selected Sites in the Lower Snake River Reservoirs, Washington.

Shively, R. S., T. P. Poe, and S. T. Sauter. 1996. Feeding response by northern squawfish to a harchery release of juvenile salmonids in the Clearwater River, Idaho. Transactions of the American Fisheries Society. **125**: 230-236

Smith, S. H. 1954. Method of producting plastic impressions of fish scales without heat. The Progressive Fish-Culturist. **16**: 75-78

Sneed, K. E. 1951. A method for caluculating the growth of channel catfish, *Ictalurus lacustris punctatus*. Transactions of the American Fisheries Society. **80**: 174-183

Stroud, D.H.P, A.O. Black, G.C. Claghorn, B. Nine, S.Wolvery, and A.T. Scholz. 2010. Salmonid consumption in the Sanpoil River Arm of Lake Roosevelt by smallmouth bass and walleye using bioenergetic modeling. United States Department of Energy, Bonneville Power Administration, Portland, Oregon. Project No. 1995-001-00. Contract No. 45289, 185 pp.

Suttle, K.B., M.E. Power, J.M. Levine, C. McNeely. 2004. How fine sediments in riverbeds impairs growth and survival of juvenile salmonids. Ecological Applications. **14**: 969-974

Sweka, J.A., and K.L. Hartman. 2001. Influence of Turbidity on Brook Trout Reactive Distance and Foraging Success. Transactions of the American Fisheries Society. **130**: 138-146

Sweka, J. A. and K. J. Hartman. 2003. Reduction of reactive distance and foraging success in smallmouth bass, *Micropterus dolomieu*, exposed to elevated turbidity levels. Environmental Biology of Fishes **67**: 341-347

Tabor, R. A., R. S. Shively, and T. P. Poe. 1993. Predation on juvenile salmonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. North American Journal of Fisheries Management **13**:831-838

Teasdale, Gregg N. 2010. Sediment load, transport, and accumulation in Lower Granite Reservoir on the Snake River. 2nd Joint Interagency Conference, Las Vegas, NV, June 27-July 1, 2010

Public Affairs Division of the Northwest Power and Conservation Council. Twenty Years of Progress: 20th Anniversary Review of The Columbia River Basin Fish and Wildlife Program, Council Document 2003-20

U.S. Army Corps of Engineers, 2003, Supplemental environmental analysis for the purposes of 2003-2004 dredging (Lower Snake and Clearwater Rivers, Washington and Idaho): U.S. Army Corps of Engineers, Walla Walla District, 100 p.

Vigg, S., T. P. Poe, L. A. Prendergast, and H. C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society. **120**: 421-438

Ward, D. L., J. H. Petersen, and J. J. Loch. 1995 Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River and in the Lower Snake River. Transactions of the American Fisheries Society. **124**:321-

334

Ward, D. L., and M. P. Zimmerman. 1999. Response of smallmouth bass to sustained removals of northern pikeminnow in the lower Columbia and Snake rivers. Transactions of the American Fisheries Society. **128**: 1020-1035

Wydoski, R.S., and R.R. Whitney. 1979. Inland fishes of Washington. University of Washington Press, Seattle, WA.

Wydoski, R.S., and R.R. Whitney. 2003. Inland fishes of Washington. Second edition. University of Washington Press, Seattle, WA.

Zabel, R. W. and J. G. Williams. 2002 Selective mortality in Chinook salmon: What is the role of human disturbance? Ecological Applications **12**: 173-183

Zimmerman, M.P. 1999. Food habits of smallmouth bass, walleyes, and northern pikeminnow in the lower Columbia River basin during outmigration of juvenile anadromous salmonids. Transactions of the American Fisheries Society. **128**: 1036-1054

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Bellgraph, B.J., R.A. Harnish, L.A. Ortega, M.C. Paluch, **D.M. Sontag**, A.T. Scholz, A.R. Black, C.O. Price. 2012. Evaluation of Fish Assemblages and Piscivore Diets in Developed and Undeveloped Littoral Area of Lake Pend Oreille. Prepared for U.S. Army Corp of Engineers, Walla Walla District. Contract W912EF-08-D-0004. 64 Pages + Appendices

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