Work Completed for Compliance with the 2008 Willamette Project Biological Opinion, USACE funding: 2011

LIFE-HISTORY CHARACTERISTICS OF JUVENILE SPRING CHINOOK SALMON REARING IN WILLAMETTE VALLEY RESERVOIRS

Prepared for
U. S. ARMY CORPS OF ENGINEERS
PORTAND DISTRICT – WILLAMETTE VALLEY PROJECT
333 S.W. First Ave.
Portland, Oregon 97204

Prepared by
Fred R. Monzyk
Jeremy D. Romer
Ryan Emig
Thomas A. Friesen

Oregon Department of Fish and Wildlife
Upper Willamette Investigations Program
Corvallis Research Lab
28655 Highway 34
Corvallis, Oregon 97333

Cooperative Agreement: W9127N-10-2-0008
Task Order Number: 0007

April 2012

Table of Contents

List of Tables

List of Figures

Executive Summary

We investigated several life-history characteristics of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) rearing in Detroit, Cougar and Lookout Point reservoirs to aid in the development of downstream passage options for Willamette Valley Project dams. The study objectives were to provide information on the longitudinal and vertical distribution of juvenile Chinook rearing in reservoirs, relative growth rate, predator/prey interactions, and other population characteristics such as parasitic copepod infection rates. In addition, we tested the feasibility of various gear types and techniques for sampling juvenile Chinook salmon rearing in the nearshore reservoir environment. Information on the smoltification dynamics of juveniles in reservoirs was also collected and will be presented in a separate report when analysis is complete.

Similar to 2010, the abundance of Chinook fry (<50 mm FL) was greatest near the head of the reservoirs. Fry catches in nearshore traps diminished the further away traps were set from the head of the reservoir. It appeared that the maximum distance fry dispersed along the reservoir shoreline from their natal stream was approximately 15 km under the current reservoir operations and environmental conditions. In Cougar and Lookout Point reservoirs, some fry travelled through the reservoirs and passed through the dams. We did not detect fry near Detroit Dam which is further from natal streams. We suspect factors that may influence fry dispersion through reservoirs include the amount of shoreline distance and the swimming ability of fry. There was no significant difference in fry abundance between habitat types measured at trap sites. Traps were set for a 24-hour period which was not conducive for detecting habitat preferences because fry occupy different habitats during the day than they do at night.

We did not detect a significant difference in relative abundance of larger juveniles (subyearling parr and yearlings) by reservoir section, indicating they were more evenly distributed longitudinally in the reservoir. There was, however, a shift in vertical distribution of subyearlings from summer to fall. In Detroit Reservoir the majority of subyearling Chinook occupied the water column from 4.6 to 13.7 m (15-45 ft) depth range in August. Beginning in September and continuing through October, fish continued to descend into deeper water with the majority occupying the 18.2 to 27.4 m (60-90 ft) depth range and they did not return closer to the surface until November. In Lookout Point Reservoir, subyearlings were not observed as deep as in Detroit Reservoir although low catch rates in Lookout Point Reservoir made comparisons difficult. During July and August, most subyearlings in Lookout Point Reservoir were captured in the 4.6 to 13.7 m (15-45 ft) depth range, similar to fish in Detroit Reservoir. By October and November subyearlings were evenly dispersed from the surface to 18.2 m (0-60 ft depth range).

Reservoir-rearing subyearlings grew more rapidly than juveniles rearing in streams above reservoirs. By November, natural-origin subyearlings in Detroit Reservoir were approximately 90 mm larger than subyearling collected above the reservoir. In Cougar Reservoir, subyearlings were approximately 40 mm larger by November than subyearlings collected in the trap above the reservoir. We were unable to collect stream-rearing juveniles above Lookout Point Reservoir to compare end of season growth to reservoir-rearing juveniles. It is likely that subyearlings rearing in Lookout Point Reservoir grew more rapidly than stream-rearing juveniles since they achieved the largest size by November compared to juveniles rearing in the other reservoirs. Subyearlings in Lookout Point Reservoir averaged 209 mm FL by November compared to 175 mm in Detroit Reservoir and 124 mm in Cougar Reservoir. The growth achieved by reservoir-rearing juveniles by August was comparable to that of juveniles rearing in the mainstem Willamette River below project dams.

We assessed copepod infection rates in juvenile Chinook above and below Cougar Reservoir from July through December. Infection rates for fish rearing above the reservoir ranged from 0 to 6.7%, whereas reservoir-rearing juvenile rates ranged from 12.8 to 89.1%. Monthly infection rates were correlated to average size of juveniles in the reservoir, however the effect of size was confounded with duration of time spent in reservoir. Larger fish were likely in the reservoir for a longer time and therefore likely experienced extended exposure to parasites.

Potential predators of juvenile Chinook salmon were captured in all reservoirs but salmonids in Lookout Point Reservoir were at greater risk of predation based on the number and type of predators. In Detroit Reservoir, four potentially piscivorous fish species were extant: rainbow trout (*Oncorhynchus mykiss*), cutthroat trout (*O. clarkii*), brown bullhead (*Ameirurus nebulosus*), and sculpin (*Cottus spp.*). We were only able to collect stomach samples from rainbow trout and bullhead. We documented two juvenile Chinook consumed among the 81 rainbow trout stomachs sampled. Rainbow trout were the most abundant predator species in Detroit Reservoir. Given the annual planting of hatchery rainbow trout in the reservoir and the large schools observed directly below the dam, rainbow trout would appear to have the greatest potential for predation on juvenile Chinook in Detroit and Big Cliff reservoirs. Five potentially piscivorous fish were observed in Cougar Reservoir: rainbow trout, cutthroat trout, bull trout (*Salvelinus confluentus*), largemouth bass (*Micropterus salmoides*), and sculpin. We did not sample bull trout diets. Largemouth bass were relatively rare and none were collected during electrofishing efforts to collect stomach samples. Rainbow trout fed mostly on zooplankton and macroinvertebrates with one dace (*Rhinichthys* spp.) found among the 16 stomach samples analyzed. Cutthroat trout also fed primarily on zooplankton and macroinvertebrates, but one of the three fish sampled consumed a dace. In Lookout Point Reservoir, ten piscivorous species were collected, including four non-native species: rainbow trout, cutthroat trout, sculpin, bullhead spp., largemouth bass, northern pikeminnow (*Ptychocheilus oregonensis*), walleye (*Sander vitreus*), and crappie (*Pomoxis spp.*). Northern pikeminnow, largemouth bass, and walleye had the highest occurrence of prey fish in their diet. Three juvenile Chinook were identified among the 75 northern pikeminnow sampled and four juvenile Chinook were found in the 24 walleye sampled. Based on preliminary data, walleye had a greater overall consumption rate of juvenile Chinook but northern pikeminnow were more abundant in Lookout Point Reservoir and likely present the greatest predation risk.

Introduction

The National Marine Fisheries Service concluded in the 2008 Willamette Project Biological Opinion (BiOp) that the continued operation and maintenance of the U.S. Army Corps of Engineers (USACE) Willamette Valley Project (WVP) would jeopardize the existence of Upper Willamette River spring Chinook salmon (*Oncorhynchus tshawytscha*) and Upper Willamette River steelhead (*O. mykiss*) (NMFS 2008). The BiOp concluded that lack of fish passage through WVP dams and reservoirs has one of the most significant adverse effects on both species and their habitat. Several Reasonable and Prudent Alternatives (RPA) to the action agencies' proposed actions were identified in the BiOp to address downstream fish passage concerns, notably, downstream fish passage structures (RPA 2.8; 4.8; 4.8.1; 4.9; 4.10; 4.12), head-of-reservoir juvenile collection facilities (RPA 4.9), and modifications to operational flows to improve conveyance of juvenile fish through the reservoirs. Assessing the feasibility of any of these proposed measures requires a baseline understanding of how juvenile salmonids use reservoir habitat.

Understanding juvenile Chinook life-history in WVP reservoirs will also inform other future management actions needed for population recovery. Currently, information regarding juvenile Chinook use of reservoirs, including life stage-specific entrance timing, distribution, migration rate, predator/prey interactions, and growth rates among other population characteristics is limited. In 2010, we began investigations in Cougar and Lookout Point reservoirs to further our understanding of these issues. In 2011, we expanded our scope of sampling to include Detroit Reservoir and refined our techniques to address the critical uncertainties. Several aspects of juvenile Chinook life-history were investigated in this report including; 1) longitudinal and vertical distribution of juvenile Chinook rearing in reservoirs; 2) relative growth rate compared to stream-rearing juveniles; 3) predator/prey interactions; and 4) parasitic copepod infection rates. Results from Detroit, Cougar, and Lookout Point reservoirs are included in this report.

Distribution- Improving downstream passage will depend on an understanding of when juvenile Chinook enter the reservoirs and their distribution at different life-stages while rearing in reservoirs. There are numerous reports that indicate the majority of juvenile Chinook enter WVP reservoirs at the fry life-stage (Bureau of Commercial Fisheries 1960, Monzyk et al. 2011a, Keefer et al. 2012) at an average fork length of 35 mm (Monzyk et al. 2011a). Although it is clear that the majority of juvenile Chinook enter the reservoirs as fry, less is known about their distribution within reservoirs. Given the poor swimming ability of newly emergent fry and the fact that the reservoirs are refilling when fry enter, we hypothesized that fry would be concentrated near the entrance of their natal stream. Limited snorkel surveys in 2010 suggested that fry in Cougar and Lookout Point reservoirs were more abundant in the upper end of the reservoirs near their natal stream and occupied shallow nearshore habitats (Monzyk et. al 2011b). Tabor et al. (2007, 2011) found a similar result with fall Chinook fry in Lake Washington, where fry abundance was highest near their natal stream in early spring. Fry in Lake Washington used shallow (<1 m) littoral habitat upon entering the lake system and only ventured into deeper waters as their size increased. This pattern has been observed in numerous studies in lotic environments (e.g., Lister and Genoe 1970; Dauble et al. 1989), including the lower Willamette River (Friesen et al. 2007). Water temperatures may also contribute to habitat shifts in reservoirs. Ingram and Korn (1969) showed that most gill net sampled juvenile Chinook from Cougar Reservoir were captured in the upper 30 feet of the water column during late spring. These authors reported that by summer, as surface temperatures increased, catches were greatest at 30-45 foot depth range. In November as surface temperatures cooled, the authors reported most juvenile Chinook were captured in the upper 15 feet of the water column. Our sampling in 2010 suggested a similar pattern. Parr catch rates in surface-oriented traps diminished as surface temperatures increased in summer (Monzyk et. al 2011b). Although parr were collected in all areas of the reservoirs in 2010, abundance during summer still tended to be in the upper end of the reservoirs (Monzyk et. al 2011b).

Risks and Benefits- The negative effects of reservoir residency in terms of increased predation risk and migration timing may be offset by superior growth rates that could impart a greater survival advantage to adulthood (ISRP 2011). Juvenile Chinook grow at a greater rate in reservoirs compared to their stream-rearing counterparts upstream of reservoirs (Monzyk et. al 2011b). Reservoir rearing may impart a survival benefit to juvenile Chinook via superior growth rates; however, reservoir rearing may also impose additional risks that extend beyond the obvious risks of delayed migration and dam passage mortality. Potential additional risks of reservoir rearing include increased predation and increased susceptibility to parasitic copepods. Further, the energetic costs of undergoing the physiological changes associated with smoltification with the inability to leave the reservoir are not known.

Predation in reservoirs by the numerous non-native and native piscivorous fish species that occur in WVP reservoirs may impart a greater population mortality rate than otherwise would occur if WVP dams did not exist. Predatory species include northern pikeminnow, bull trout, and exotics such as largemouth bass, walleye, and white crappie (*Pomoxis annularis*). The impact of predatory fish on juvenile Chinook depends on predator abundance, water temperature, size as well as mouth gape, spatial and temporal overlap in distribution in relation to juveniles, and growth rates of juvenile Chinook. In 2010, we initiated a pilot study in Cougar and Lookout Point reservoirs to determine the current fish community structure and diet of piscivorous fish species. In 2011, we expanded this effort to include Detroit Reservoir.

A related risk to delayed migration is the potential for juvenile Chinook to undergo the physiological changes associated with smoltification when they are unable to leave the reservoir. The migration delay associated with the reservoir residency could have possible negative effects on the smoltification process and their subsequent ability to transition to marine environments within the optimal ecological and physiological “smolt window” (McCormick 1994; Hoar 1988; Handeland et al. 2004). As part of this study, we tracked changes in smoltification through time using gill ATP-ase levels for juvenile Chinook that successfully exited Cougar Reservoir compared to juveniles that remained in the reservoir and stream-rearing migrants below the reservoir.

Our two primary areas of interest in this study were the distribution of juvenile Chinook in reservoirs and the relative risks and benefits of reservoir rearing. Objectives for the distribution portion of the study were to: 1) assess the longitudinal (head to dam) distribution of fry and parr in Detroit, Cougar and Lookout Point reservoirs; and 2) investigate temporal changes in the vertical distribution of parr in Detroit and Lookout Point reservoirs. Our objectives for the relative risks and benefits of reservoir rearing were to: 3) compare growth rates between stream-rearing and reservoir-rearing juvenile Chinook; 4) assess species composition, distribution, and diet of piscivorous fish in reservoirs, and 5) assess the temporal changes in smoltification of reservoir-rearing juvenile Chinook. We also assessed the prevalence of parasitic copepod (*Salmincola sp*.) infection in reservoir-rearing and stream-rearing juvenile Chinook.

Methods

We refined our sampling efforts in 2011 by determining which gear types best addressed our study objective of assessing fry distribution in nearshore habitat. We developed and compared the effectiveness of various trap designs for nearshore fry sampling (Appendix). Based on the results of this comparison, we selected a small floating box trap for nearshore fry sampling. The results we report here were from trapping efforts carried out with this design unless otherwise stated. For distribution of larger-sized parr, we used Oneida Lake traps for assessment of longitudinal distribution and gill nets for vertical distribution.

Distribution of Juvenile Chinook Salmon in Reservoirs

Fry Distribution- Our interest was in the distribution of fry-sized subyearlings, however traps frequently caught larger parr-sized subyearling Chinook, especially later in the season. Because there is no established criteria in the literature for distinguishing fry from parr, we chose a size of <50 mm fork length (FL) to designate fry.

Sampling efforts to assess fry distribution were conducted at a minimum of every three weeks in each reservoir (Detroit, Cougar, and Lookout Point) from April through July. To provide greater sample size and precision, weekly sampling was conducted during periods in May and June when personnel and equipment were available. Floating box traps consisted of a 0.61 x 0.61 x 0.91 m (W x H x L) PVC frame wrapped with 0.42 cm delta mesh. A 51 mm throat opening allowed fry to enter but excluded larger fish. Traps were placed perpendicular to shore with a 5 m lead net (0.91 m deep) extending from the shore to the trap opening. When water depths were greater than 0.61 m, we attached a ‘tongue’ fyke net below the trap opening to increase capture efficiency. Locations for daily trap placement were selected using a stratified random sampling design. Reservoirs were stratified into lower, middle, and upper thirds (forebay to head of reservoir). Within each section, random shoreline areas (approximately 0.4 km long) were selected for trap placement and a site was chosen within the 0.4 km area that would allow for easy attachment of the lead net to the bank. Each day, six areas were randomly selected in a reservoir (two per section) and traps fished overnight (approximately 24 h).

Trap coordinates were recorded for each set and used to estimate distance from the head of the reservoir to assess fry dispersion. Because fry are closely associated with nearshore habitat, we believed measuring fry dispersion in terms of shoreline distance was appropriate. Each bank of a reservoir was digitized using ArcGIS (measured at full pool). Depending upon which bank a trap was set, coordinates were overlaid on the appropriate digitized shoreline to calculate distance from the head of the reservoir to the trap site. Cougar and Lookout Point reservoirs have a single source river that serves as the natal stream for fry entrance. However, we could not determine if fry caught in Detroit originated from the Breitenbush River or the North Santiam River. For this reservoir, we chose the North Santiam arm near Hoover Campground to mark the head of the reservoir since most natural production occurs in this river (Cannon et al. 2011).

Fry Habitat- At each trap site, we characterized habitat based on substrate, vegetation and bank slope. Substrate was visually classified as silt/sand, gravel, or rock/cobble based on a modified Wentworth classification. Rock was considered as any substrate that was cobble-sized (64-256 mm diameter) and angular in shape. We also noted the presence or absence of vegetation. We calculated bank slope using depth (nearest cm) of the water column recorded at the trap mouth. Because traps were consistently placed 5 m from the shoreline, depth measurements served as an index for bank slope. Abundance of fry observed within substrate and vegetation categories were analyzed using a Kruskal-Wallis one way analysis of variance ($\alpha=0.05$). Relationships between bank slope and trap catch were analyzed with simple linear regression.

For each trap set, subyearlings were counted and fork lengths recorded to the nearest millimeter on a minimum of 15 randomly selected fish per trap. The number of fry in a trap was estimated by multiplying the proportion of measured Chinook that were <50 mm FL to total subyearling Chinook catch. Trap distance and environmental variables (trap depth, substrate type, and vegetation) were analyzed in relation to estimated fry.

Parr Longitudinal Distribution- We assessed the longitudinal distribution (forebay to head) of parr using floating Oneida Lake traps set at random locations along the shoreline. Oneida traps were set from April through October approximately every other week. The exception to this was at Cougar Reservoir in May and July where sampling was conducted weekly to increase sample sizes for gill ATP-ase collections and to provide natural-origin Chinook for other research projects occurring in the reservoir (e.g., the USGS JSAT study). The Oneida trap consisted of a 0.64 cm mesh holding box (2.4 m x 2.4 m x 2.4 m) with a lead net (34.1 m x 3.0 m) extending from shore to the box and two wings (7.2 m x 3.0 m, see Figure 1). Oneida traps are a passive capture gear type designed to intercept fish moving within 34.1 m along the shoreline and in the upper 3.0 m of the water column. Because Oneida traps capture and hold fish in the upper 3.0 m of the water column, they were not deployed if surface temperatures approached 20° C. Sites for trap deployment were selected with a stratified random sampling design and traps were fished for approximately 24 h. We counted all juvenile Chinook by year-class (based on relative size), checked for presence of passive integrated transponder (PIT) or other tags, and recorded fork length (mm). All previously untagged juveniles larger than 65 mm FL were PIT tagged for potential recapture. Differences in the catch per set of subyearlings and yearlings by reservoir section (lower, middle, upper) were analyzed separately with a Kruskal-Wallis one-way analysis of variance ($\alpha=0.05$). Yearlings and subyearlings were distinguishable by relative size differences.

Figure 1. Oneida Lake box trap used to capture juvenile Chinook salmon in Cougar Reservoir, 2011.

Parr Vertical Distribution- In 2011, we initiated a pilot study to assess vertical distribution of juvenile Chinook using gill nets deployed at specific depth intervals, similar to the methods of Ingram and Korn (1969). This effort occurred from July to November in Detroit and Lookout Point reservoirs but not in Cougar Reservoir where threatened bull trout (*Salvelinus confluentus*) were present. Gill nets were 18.3 m long by 4.6 m deep (60 x 15 ft), consisting of three 6.1 m panels with square mesh sizes of 9.5, 12.7, and 19.1 mm. Gill nets were set at 4.6 m (15 ft) depth intervals from the surface to a maximum depth of 27.6 m (six nets total). This resulted in nets deployed at 0-4.6 m, 4.6-9.2 m, 9.2-13.8 m, 13.8-18.4 m, 18.4-23 m, and 23-27.6 m depth intervals (Figure 2). Initially, we used bathymetry to locate the reservoir bottom and then deployed nets at the proper depths intervals. Bottom sets resulted in frequent tangling of nets on submerged structures, so we modified our methods to suspend nets off surface booms using ropes. In Detroit Reservoir, we used the forebay log boom beginning in mid-September. Similarly, we constructed a ‘rope boom’ in Lookout Point Reservoir extending perpendicular from the dam face to suspend nets beginning in mid-October.

Initially, nets were only deployed in the four upper depth intervals as described in Ingram and Korn (1969). Initial results indicated that juvenile Chinook were likely using greater depths (>18.4 m), therefore, we included the two additional depth intervals when we began suspending nets from booms. Also, initial results indicated juvenile Chinook in Lookout Point Reservoir grew rapidly through the summer and by October had likely outgrown the effective capture size of our largest gillnet mesh panel. Therefore, we added additional larger-mesh gill nets to the set in October consisting of an 18.3 m long by 2.4 m deep net (20 x 8 ft) of 25.4 mm square mesh.

We counted juvenile Chinook captured at each depth interval and recorded fork length for each fish. Fish were inspected for the presence of adipose fins to distinguish between hatchery and natural origin. Catch of Chinook at specific depth intervals were compared for each month to assess temporal changes in vertical distribution. Catch in the larger mesh gill nets (25.4 mm mesh) set in Lookout Point Reservoir were analyzed separately.

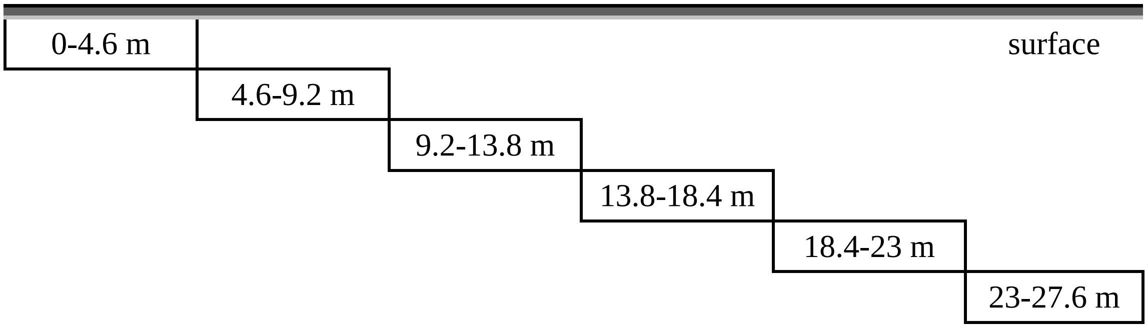

Figure 2. Depth intervals for gill nets set in Detroit and Lookout Point reservoirs, 2011. Each experimental gill net was 18.3 x 4.6 m and consisted of three mesh panels.

Risks and Benefits of Reservoir Rearing

Relative Growth- We used fish length data collected from screw traps and seining above the reservoirs to track cohort growth of subyearlings rearing in the streams. Seining was conducted in late summer at various locations in the South Fork McKenzie River above Cougar Reservoir, the North Fork Middle Fork Willamette River above Lookout Point Reservoir, and above Detroit Reservoir in the Breitenbush and North Santiam rivers. Fish lengths from seining efforts were compared to lengths from screw traps during the same time period using a t-test (α=0.05) to determine if fish sizes from screw trap collections were similar to the cohort rearing in the streams. If no differences in size were detected, we assumed that fish captured by the screw trap were representative of the stream rearing cohort. Screw trap length data represents a longer time series, and could be compared to lengths of fish collected during reservoir sampling, as well as fish collected in screw traps below the dams.

Parasitic Copepods- During our field collections in the reservoirs, we observed parasitic copepods attached to the gill filaments and fins of juvenile Chinook salmon. It is likely the copepod is *Salmincola californiensis*, as this is the only species known to infect Pacific salmon and trout (Kabata and Cousens 1973). To further understand the prevalence of copepod infection, we began recording the presence/absence of copepods on juveniles collected at rotary screw traps below Cougar Dam beginning in July. We also sampled stream-rearing juveniles above the reservoir for presence/absence of copepods during our seining efforts in the South Fork McKenzie during July and September. We continued monitoring this population with the screw trap above the reservoir in October and November. We compared the incidence rate of copepod infection between reservoir-rearing and stream-rearing juveniles. We also analyzed the relationship between the probability of infection to fish size and date of capture using multiple logistic regression (α=0.05).

Fish Community Structure- To limit the potential for gear selectivity and bias, we assessed fish species composition in reservoirs using a variety of gear types. In addition to incidental predator fish collections with the gears used primarily for juvenile Chinook (i.e., fry floating box traps, Oneida traps, gill nets), we used electrofishing and large-mesh gill nets to sample the fish community in reservoirs.

We conducted boat electrofishing in spring (May) and fall (October) in Cougar, Lookout Point, and Detroit reservoirs. The electrofisher settings were 850 V, 4 amps with a pulse width of 5 ms, and a frequency of 120 DC in Cougar and Lookout reservoirs (1000 V and 4.5 amps in Detroit Reservoir). Sampling occurred along two shoreline areas in each of the upper, middle, and lower sections of the reservoirs. Each transect was sampled for 30 minutes shock time, and areas sampled were chosen based on habitat potential for predatory fish.

We deployed gill nets to sample predator species during spring and fall in Lookout Point and Detroit reservoirs. No gillnetting was conducted in Cougar Reservoir due to the presence of threatened bull trout. The gill nets were experimental type nets that consisted of four 7.6 m x 3.0 m panels. Each panel contained a different size mesh, and the panels were sewn together with mesh size arranged from largest to smallest (7.6 cm, 6.4 cm, 5.1 cm, 3.8 cm). These mesh sizes were selected to avoid capturing subyearling Chinook and to target large predatory fish species. Gill nets were deployed approximately one to two weeks after electrofishing and were set overnight for approximately 24 h.

Predatory Fish Diet Analysis- Only predators sampled from gill nets or electrofishing were used for diet analysis. We conducted gill netting and electrofishing in the spring and fall because we hypothesized that juvenile Chinook would be more vulnerable in the spring due to their small size, whereas in the fall, juveniles would be less vulnerable after summer growth. We did not include predators in Oneida Lake traps and nearshore traps because we suspected these samples would be biased since prey fish were confined with predators in these traps.

We collected and analyzed stomach samples from all predatory fish >200 mm FL. We removed the stomach from crappie, bass, and walleye, and the entire digestive tract of northern pikeminnow, which lack a true stomach. Cutthroat and rainbow trout diet samples were non-lethally extracted using gastric lavage at Cougar and Lookout Point reservoirs. At Detroit Reservoir, we removed stomachs from trout because we did not want to return anesthetized trout to the fishery.

To remove stomachs, predator fishes were dispatched using a lethal dose of MS-222 (200 mg/L). An incision was made from the anus to the gills to expose the digestive tract. The stomach was isolated for removal using a hemostat to clamp the esophagus anterior to the stomach, and an additional hemostat clamped on the intestine posterior to the stomach (anterior to the anal vent in northern pikeminnow). The stomach was removed and placed in a Whirl Pak® and preserved with 95% ethanol at approximately a 20:1 ratio of fixative to tissue.

We used gastric lavage (Foster 1977) to non-lethally remove stomach contents from trout at Cougar and Lookout Point reservoirs with estimated removal efficiencies of approximately 98% (Light et al. 1983). Fish were anesthetized using standard MS-222 stock solution/water (50 mg/L MS-222 buffered with 125 mg/L $NaHCO_3$). A 500 ml wash bottle with the appropriate size hose attached (depending on fish size) was used for stomach flushing. Holding the water bottle upside down, the hose was inserted into the mouth of the fish, past the sphincter muscle in the throat and into the stomach. The water bottle was depressed, filling the stomach with water until regurgitation occurred. Diet samples were flushed directly from the stomach into a paper filter to strain off excess water. The entire filter (with diet sample) was then folded and placed in a Whirl Pak® and preserved with 95% ethanol.

We processed each diet sample by washing it through a 500 micron sieve and picking through the contents to remove soft tissue items (e.g., zooplankton, macroinvertebrates, etc.) and whole fish. All predator stomachs or digestive tracts were then chemically digested to reveal any fish bones that may have been missed during picking. The only exception were Detroit samples where only a subset of samples (~75%) were picked but all samples were chemically digested. Diet samples obtained via lavage were only chemically digested if prey fish items were found during the initial picking process.

After initial picking, any remaining unidentifiable fish portions along with the corresponding stomach/intestinal tract was kept for chemical digestion to remove excess stomach tissue and reveal bones that may have been missed during initial sorting. Fish items from lavage samples were kept for chemical digestion to isolate diagnostic bones.

Diet samples were chemically digested by adding 20-30 ml of a pancreatin and sodium sulfide nonahydrate solution. This solution will break down proteins and is mixed at a ratio of 20g of pancreatin and 10g of sodium sulfide nonahydrate per liter of water. The samples were then baked in a light bulb heated oven for 24 hours at a temperature of 46-49°C. After baking, we added 20 ml of a lye (NaOH) solution to each sample and shook the sample rigorously for about 10 seconds. Lye was used to digest fats from the stomach/fish portions of a sample. The lye solution was 30g of lye per liter of water. The sample was then washed in a 420 micron sieve and picked through to locate any bones. Bones tend to be heavier than other remaining debris in a sample so the sample can be "gold panned" in a small weight boat to separate the bones out of the sample. Bones were then stored in water with a label in a small plastic container for diagnostic evaluation.

Bones were emptied into a petri dish and placed under a microscope to distinguish diagnostic bones as described by Hansel et al. (1988), Frost (2000), and Parrish et al. (2006). Diagnostic bones included the dentaries (lower jaw bones), cleithra (pectoral bones), pharyngeal arches (gill arch bones), hyomandibulars, opercles, otoliths (ear bones), vertebrae, preopercles and spines of some species. For paired bones (dentaries, cleithra, hyomandibulars, opercles, otoliths, and pharyngeal arches), if one from each side was found they were counted as one fish. Two bones from the same side were counted as two fish.

After analysis, all diagnostic bones were placed in a vial with 95% ethanol for future reference.

Items found in diet samples (via picking and chemical digestion) were sorted into five taxonomic categories: fish, zooplankton, macroinvertebrates, crayfish, mollusks, and miscellaneous items. The miscellaneous category included amphibians, organic matter (e.g. vegetation), and inorganic matter (e.g. small pebbles, plastic, lures, etc). Intestinal parasites (e.g. tapeworms, round worms) were noted but not included as a diet item.

Diet composition analysis involved determining the presence/absence of each prey taxonomic category. For example, if a diet sample from a walleye contained only fish and macroinvertebrates, that individual sample was given a value of 1 for fish, 1 for macroinvertebrates, and zeros for all other prey groups. For each predator species, we summed each prey taxonomic category to determine the frequency of occurrence.

For diet samples containing fish items, we visually identified prey fish if whole. We also used diagnostic bones isolated from picking or chemical digestion to identify prey. Identification keys were utilized to identify prey fish to the lowest taxonomic group (usually family, genus, or species). We recorded the number of prey fish and measured fork lengths when possible.

Smoltification Dynamics

As part of our sampling within Cougar Reservoir, we conducted non-lethal gill biopsies to assess temporal changes in the smoltification process for juvenile Chinook rearing in the reservoir (McCormick 1994). We also collected gill filament samples from reservoir-reared and stream-reared juveniles at locations below Cougar Dam (Leaburg and Willamette Falls). Samples were submitted to Oregon State University (OSU) for processing to determine gill Na+ K+ ATP-ase levels. At this time we have not yet received all processed samples from OSU. These results will be included in a separate addendum report after all samples are received and analysis is complete.

Results and Discussion

Distribution of Juvenile Chinook Salmon in Reservoirs

Fry Distribution- We deployed nearshore fry traps of various designs in Detroit, Cougar and Lookout Point reservoirs from 07 April to 15 September 2011. A total of 474 sets were deployed and we collected 2,947 subyearlings (Table 1). Comparisons of subyearling catch among trap designs can be found in the Appendix.

Table 1. Number of subyearlings and estimated fry collected with floating box traps in Detroit, Cougar, and Lookout Point reservoirs, 2011. Fry were defined as the estimated proportion of catch < 50 mm FL.

	All traps			Floating box trap			
Reservoir	Sets	Total sub-yearling catch	Set dates	Sets	Total sub-yearling catch	Est. fry catch	Set dates
Detroit	210	2,157	13 Apr-18 Aug	101	301	256	24 May-18 Aug
Cougar	141	652	26 Apr-15 Sep	73	347	296	17 May-15 Sep
Lookout Point	123	138	07 Apr-05 Aug	67	35	15	02 Jun-05 Aug

The floating box trap design proved to be the best overall design for providing information on fry distribution and results from this design are reported below unless otherwise stated. Floating box traps were deployed on 241 overnight sets from 17 May to 15 September in the three reservoirs with a total of 683 subyearlings collected. We estimated 567 fry (<50 mm FL) were captured, primarily (~97%) in May and June (Table 1).

Most fry were collected in Cougar Reservoir (n=296) and Detroit Reservoir (n=256). In Lookout Point Reservoir, few fry were collected except at sites close to the natal stream at the head of reservoir. The low fry catch in Lookout Point Reservoir may be partially explained by an earlier reservoir entrance timing coupled with a rapid growth rate that may have resulted in juveniles moving into deeper habitat before we set floating box traps in the reservoir. Additionally, fry were collected in screw traps below Lookout Point Dam during a February high flow event (Greg Taylor, USACE, personal communication). If substantial numbers of fry exited the reservoir in February, this may have also contributed to low catch rates in the reservoir in the spring. Because of the low catch rates, analysis of distribution and habitat variables was not conducted for this reservoir.

Catch of spring Chinook fry in floating box traps was greatest in the upper end of all reservoirs where natal streams enter the reservoirs (Figure 3). Seventy-five percent of all fry collected were within the upper 5 km of the reservoir (Figure 4). We attempted to analyze the relationship of fry catch to shoreline distance with simple linear regression but the assumptions of residual normality could not be met with data transformations due to the high variance in catch. However, very few fry were caught in traps located >15 km of shoreline distance (measured from the head of reservoir) in both Detroit and Cougar reservoirs (Figures 3 and 4). Additional testing is needed to determine if 15 km is the upper range that fry are able to disperse along the shoreline under current reservoir refill rule-curves. Total shoreline distance in Cougar Reservoir is less than 15 km along the west shoreline, indicating fry can travel the entire length of the reservoir. We regularly collect fry in screw traps located below Cougar Dam (Romer et al. 2012). The minimum shoreline distance in Detroit is approximately 18 km (north shore) and we did not collect fry in a screw trap below Detroit Dam in 2011. Fry enter reservoirs when the pool is refilling or at full-pool levels. We hypothesize that if pool elevations were maintained at or near low conservation pool levels during the period of fry entry, the maximum extent of fry dispersal in the reservoirs may increase and a greater number of fry could exit through the dams.

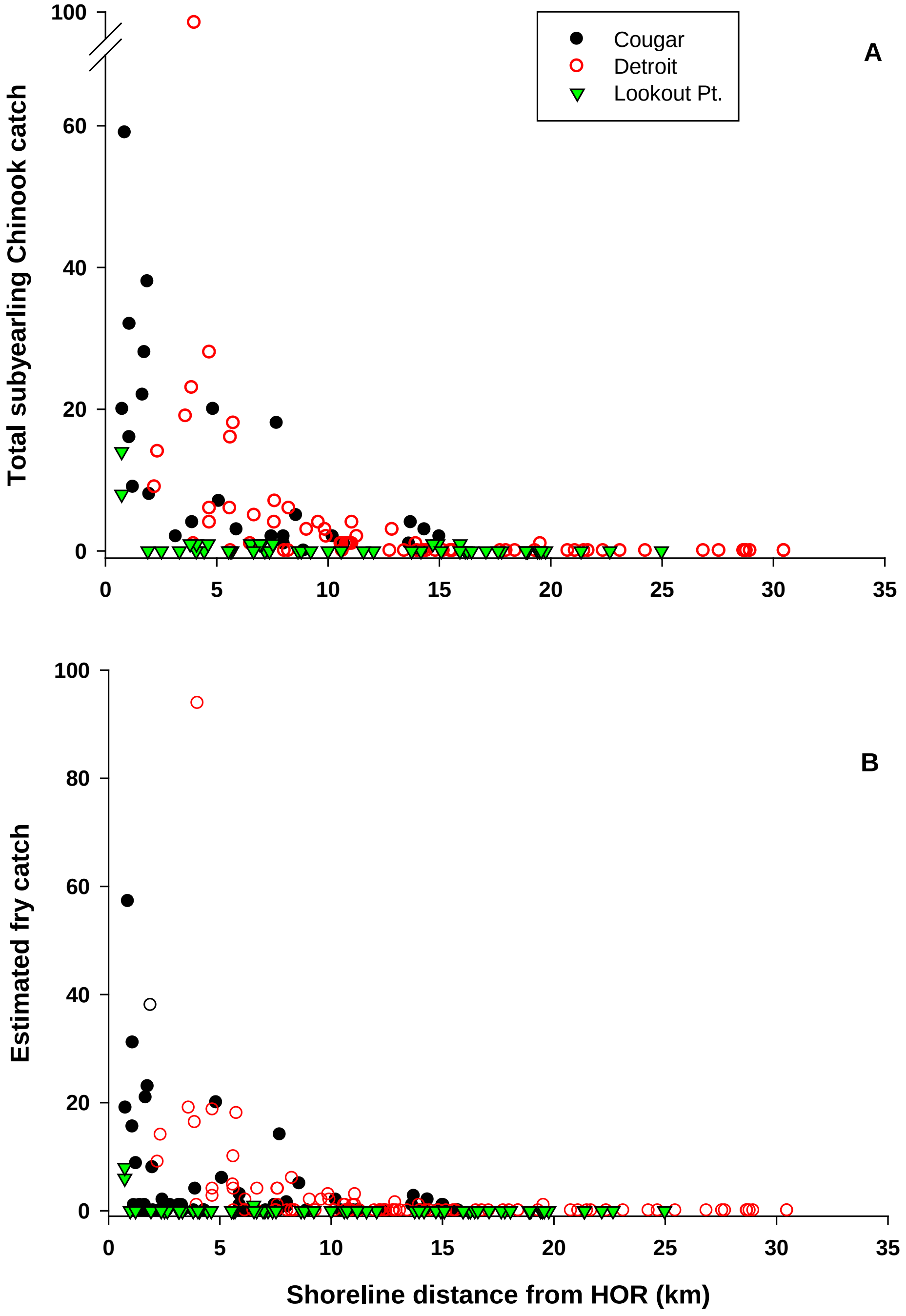

Figure 3. Relationship between juvenile Chinook salmon catch in floating box traps and shoreline distance from the head of the reservoir (HOR), 2011. Catch represented as all subyearling Chinook salmon caught in nearshore traps (A) and estimated number of fry (B) based on the proportion of subyearlings that were <50 mm FL.

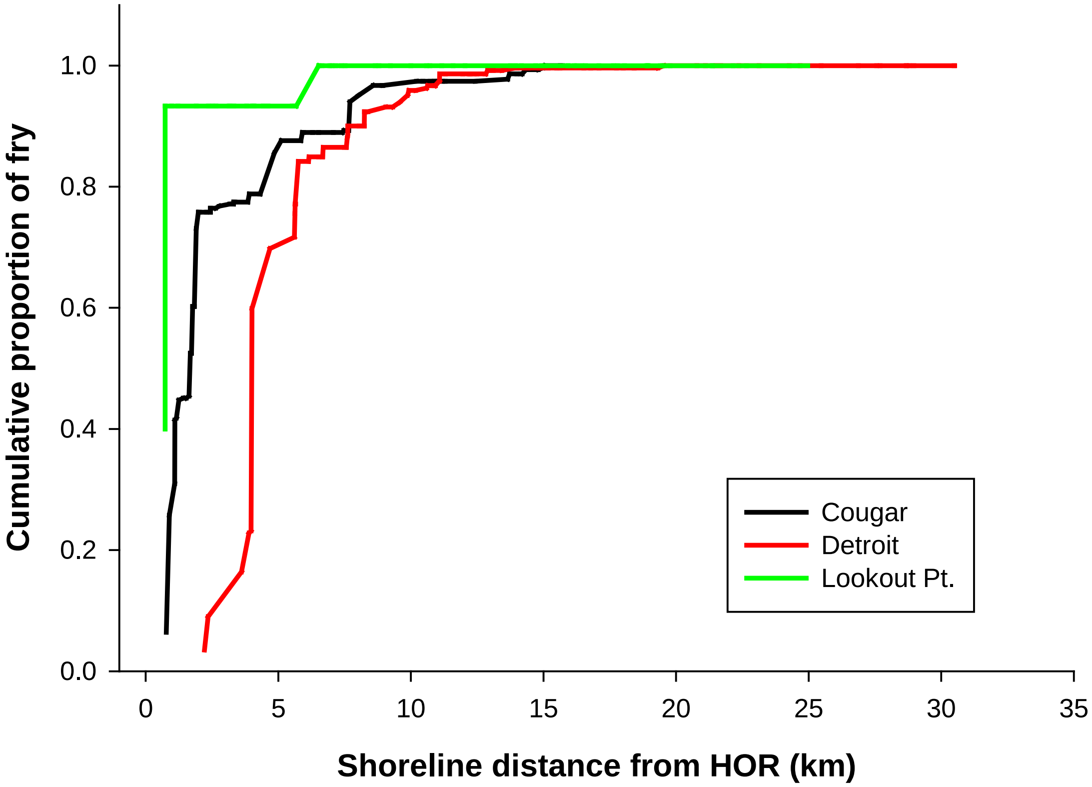

Figure 4. Cumulative proportion of fry catch from nearshore floating box traps in relation to shoreline distance from the head of the reservoir (HOR), 2011.

Fry Habitat- We did not detect consistent fry habitat preferences based on catch rates and the habitat variables measured at trap locations. Depth at the trap location and number of fry captured could not be analyzed with simple linear regression due to non-normality of residuals. However, when catch was plotted by depth categories, no clear trend was evident (Figure 5). For both Detroit and Cougar reservoirs, we observed a bimodal pattern with higher catch in both shallow (0.5-1.5 m) trap sets and deep sets (>4 m).

There was also no clear pattern between fry catch and other habitat variables in the reservoirs. In Detroit Reservoir, significantly more fry were captured at sites with sand/silt substrate than cobble/rock but the presence of vegetation was not significantly associated with greater fry catch (Figure 6). However, in Cougar Reservoir the opposite pattern was evident, with no significant difference between fry catch and substrate type but significantly more fry caught at sites with submerged vegetation (Figure 7). These seemingly contradictory results can be explained by the different habitat characteristics present at the head of each reservoir. All fry entering reservoirs from natal streams occupy the head of the reservoirs for some period of time during their reservoir residence regardless of the habitat characteristics. In Detroit, the head of the reservoir can be characterized as containing very little submerged vegetation or rocky substrate. However, the head of Cougar Reservoir contains large areas of submerged vegetation and a mixture of substrate types (Figure 8). The results reported here reflect substrate type and vegetation habitat characteristics at the head of each reservoir rather than fry habitat preferences. In addition, traps were set overnight allowing for the capture of fry that likely moved between preferred daytime and nighttime habitat. Tabor et al. (2011) observed Chinook fry in Lake Washington exhibiting different habitat preference for substrate type and overhead vegetation between daytime and nighttime surveys. Our study was designed to investigate longitudinal fry distribution in reservoirs. An unbiased investigation of fry habitat preferences would require a sampling design specific to that objective.

In several studies, fry preferred shallow shoreline areas with silt/sand substrate (Tabor and Piaskowski 2002, Garland et al. 2002, Tiffan et al. 2002). The availability of this type of habitat was generally limited in Detroit and Cougar reservoirs that had steep, rocky shorelines except near the head of the reservoirs. Lookout Point was not as steep and contained more gradual sloping, sand/silt habitat than either Cougar or Detroit reservoirs.

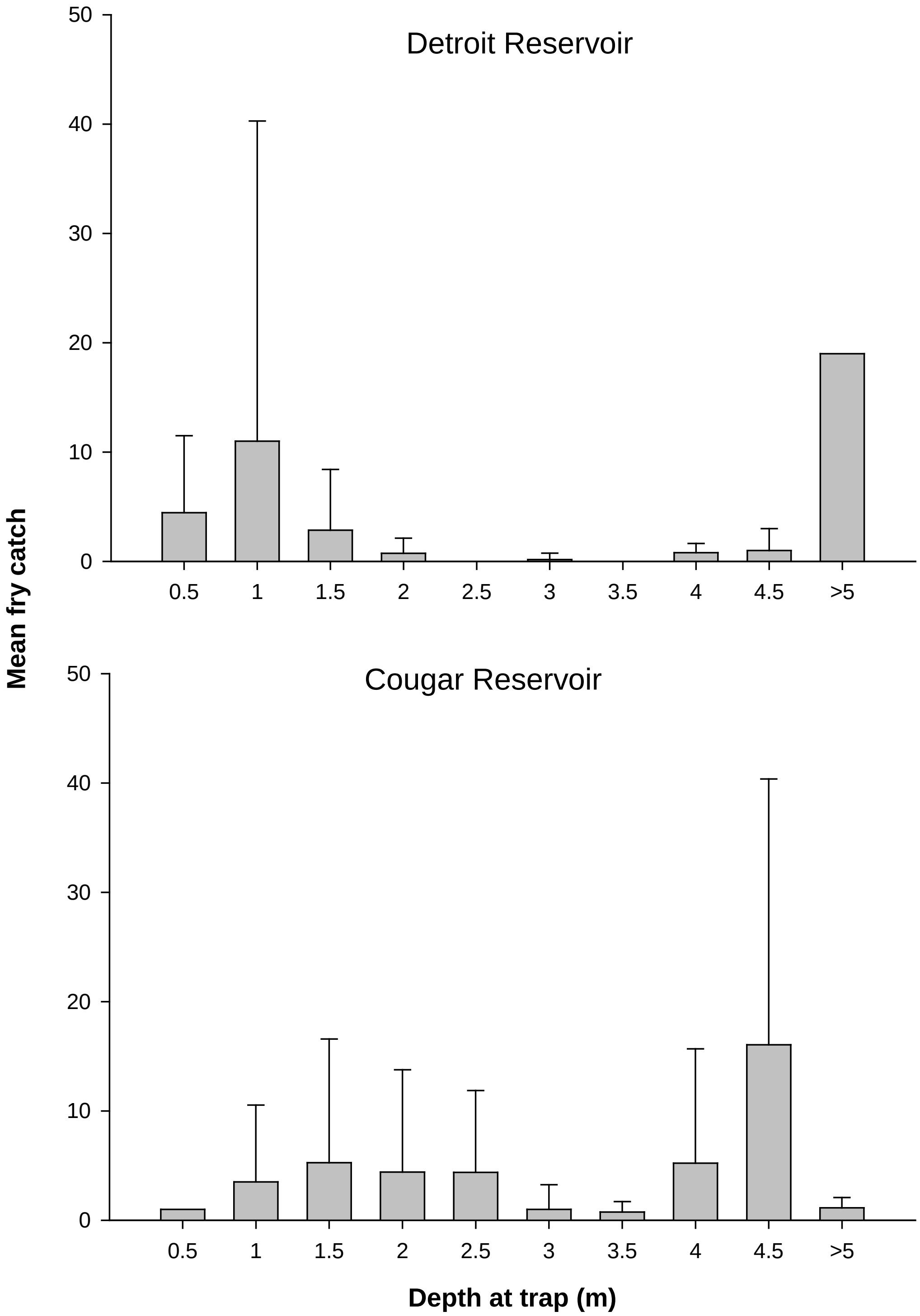

Figure 5. Relationship between mean fry catch (SE) and water depth at floating box traps in Cougar and Detroit reservoirs, 2011. Depth was categorized in 0.5 m bins. All trap depths were measured 5 m from shore.

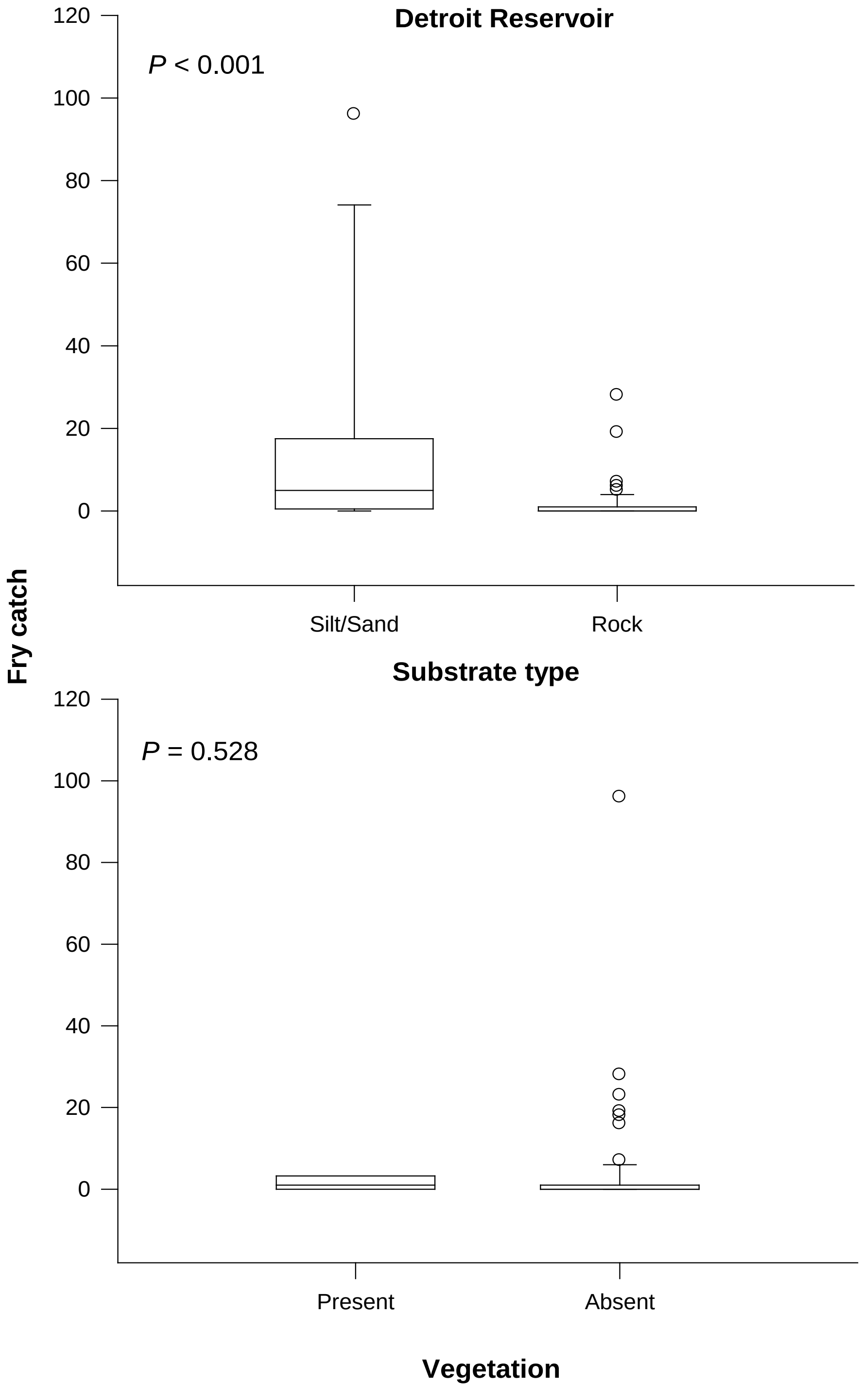

Figure 6. Box plots showing relationships of subyearling catch and habitat variables in Detroit Reservoir, 2011. Boxes represent the 25th and 75th percentiles and the horizontal line in each box is the median. Error bars indicate 90th and 10th percentiles. Open circles represent outliers. *P*-value from Kruskal-Wallis Rank Sum Test shown for each plot.

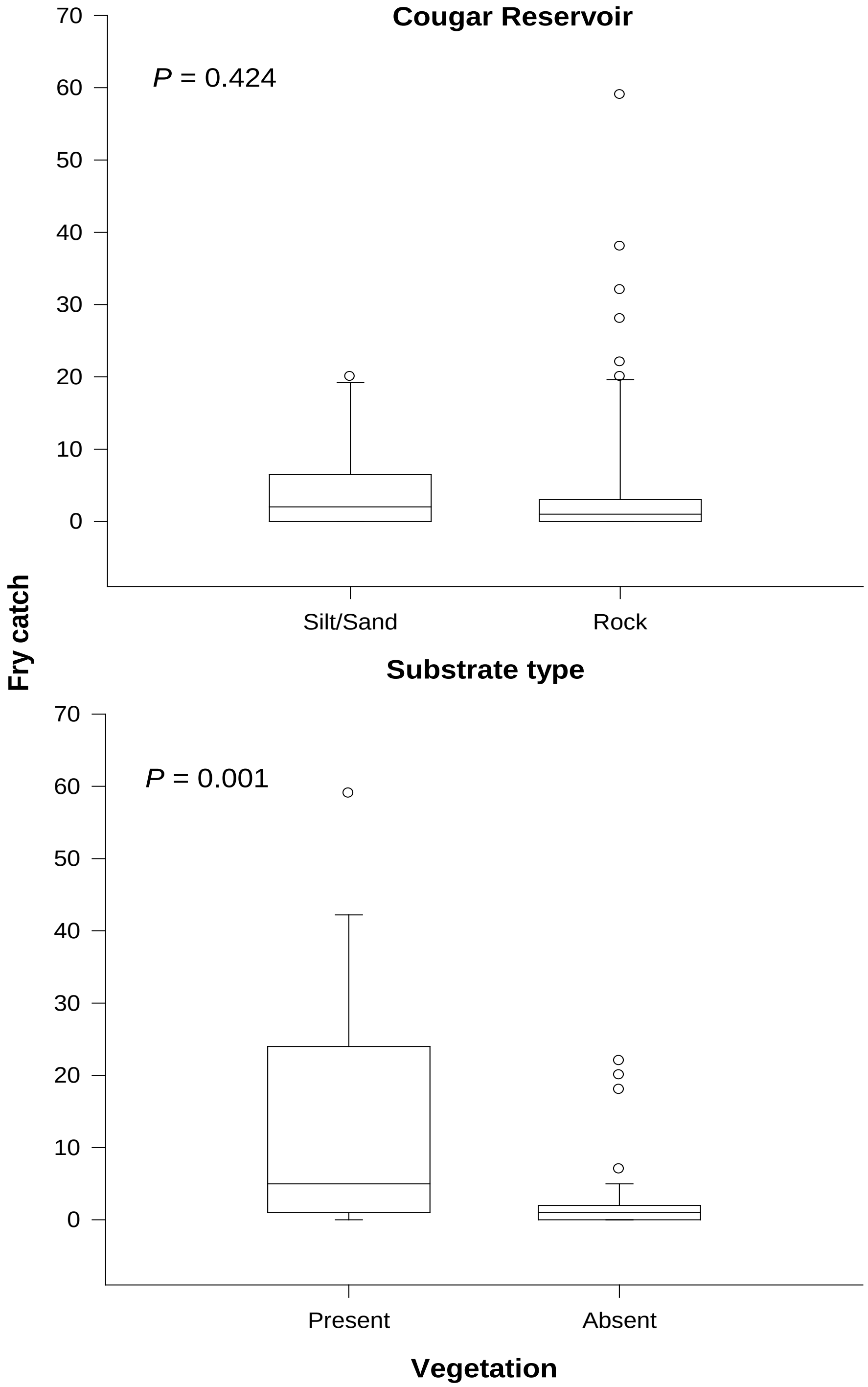

Figure 7. Box plots showing relationships of subyearling catch and habitat variables in Cougar Reservoir, 2011. Box represents 25th and 75th percentile and line in box represents median. Error bars indicate 90th and 10th percentiles. Open circles represent outliers. *P*-value from Kruskal-Wallis Rank Sum Test shown for each plot.

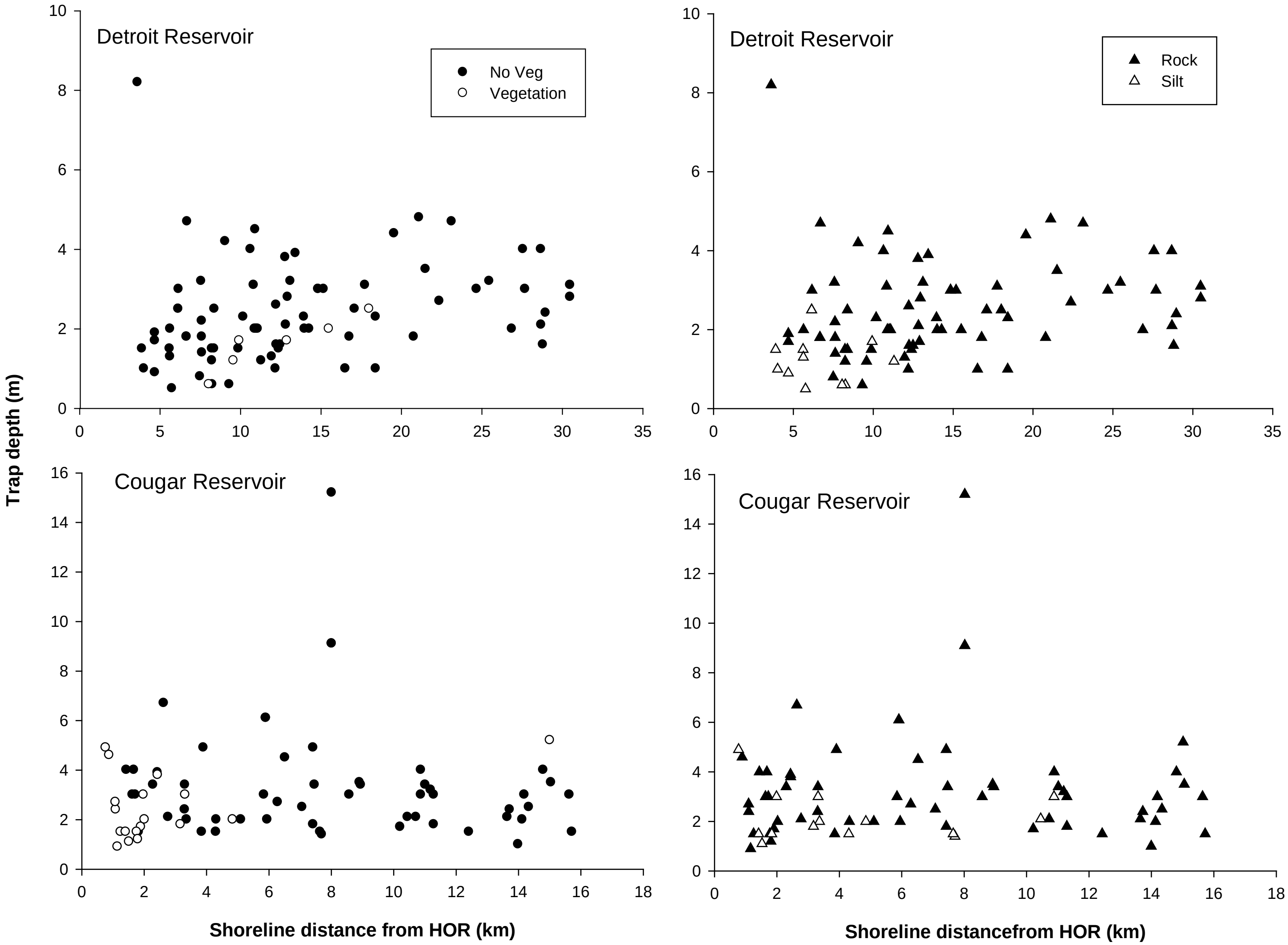

Figure 8. Relationship between shoreline distance, habitat variables, and depth at trap locations in Cougar and Detroit reservoirs, 2011. Shoreline distance was measured from the head of the reservoir.

Size- Subyearlings collected in floating box traps averaged 42.3 mm FL in Detroit Reservoir and 41.8 mm FL in Cougar Reservoir. In both reservoirs, subyearlings demonstrated considerable variability in size (Figure 9). Subyearlings collected in May were <50 mm FL. By June subyearlings demonstrated a greater range of sizes with some larger parr-sized fish (i.e., >50mm FL). The wide range of sizes of subyearlings collected near the head of the reservoirs suggest that some juveniles likely rear in these areas after reservoir entrance. However, fry were present at all locations where juvenile Chinook were collected suggesting that some are able to disperse a considerable distance along the shoreline despite the lack of flow and their relative poor swimming ability compared to larger fish.

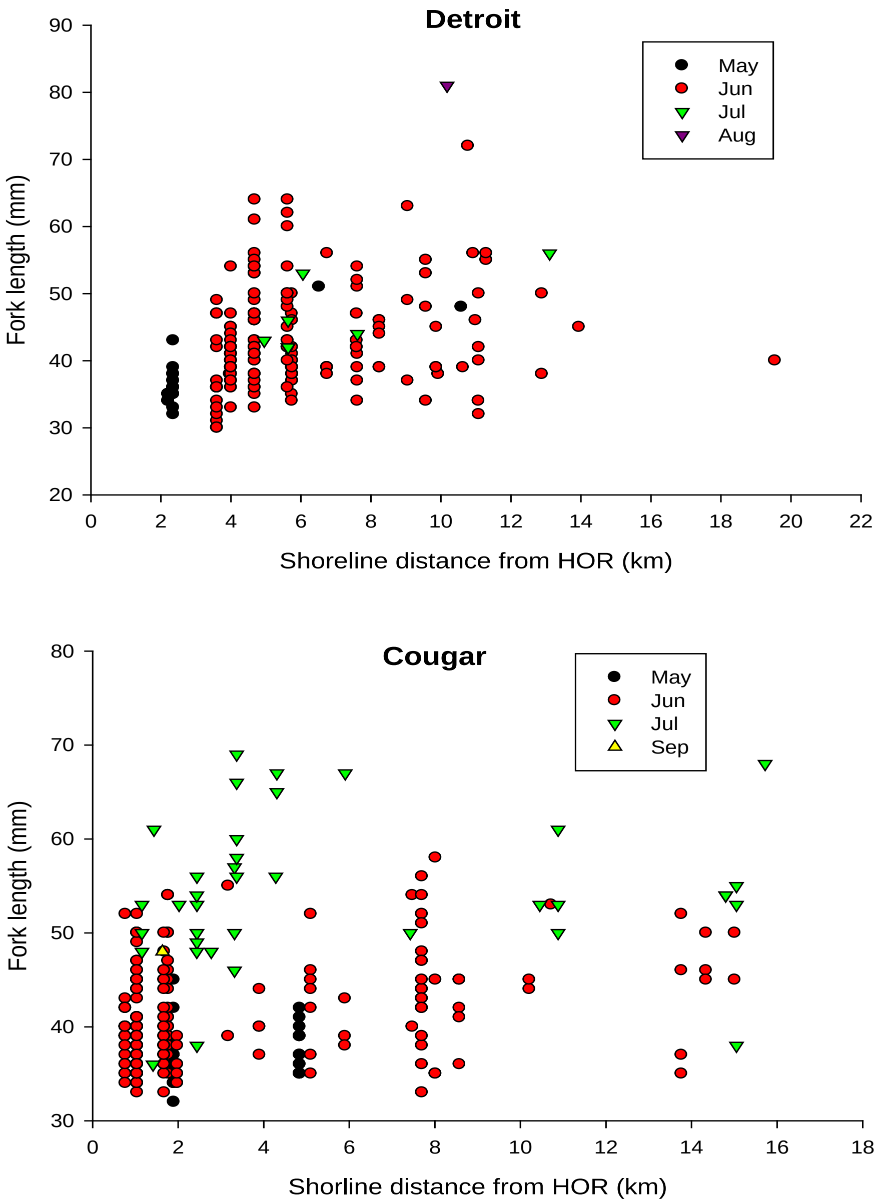

Figure 9. Fork lengths of juvenile Chinook salmon collected in nearshore floating box traps in Detroit and Cougar reservoirs in relation to shoreline distance and month of collection, 2011.

Parr Longitudinal Distribution- We assessed the distribution of Chinook subyearling parr and yearlings from the forebay to head of reservoir with Oneida traps. We collected a total of 103 yearlings and 850 subyearlings in the three reservoirs with a total of 180 Oneida trap sets from 05 April to 03 November (Table 2). Most fish were collected in Cougar Reservoir due, in part, to extra sampling effort (to provide fish for USGS) and because of a higher catch per unit effort in this reservoir (Table 2).

Most yearling Chinook (91%) were caught in April and May, and none were caught after June. For this reason, we only included catch from April through June in our analysis of yearling distribution. There was no significant difference in yearling catch among reservoir sections (lower, middle, upper) in any reservoir (Kruskal-Wallis test; $P>0.05$), indicating that yearlings were evenly distributed throughout the reservoirs. This observation is supported by the JSAT study conducted by USGS, which showed tagged yearlings repeatedly travelling back and forth in the reservoir during spring (John Beeman, USGS, personal communication).

With the exception of Lookout Point Reservoir, subyearlings were not collected in large numbers until June (Figure 10), corresponding to when we observed decreased catch in nearshore fry traps. For analysis of subyearling distribution, we excluded data from April and May in Detroit and Cougar reservoirs. There appeared to be a general trend of greater catch of subyearlings in the upper section of the reservoirs but we did not detect a significant difference for any reservoir (Kruskal-Wallis test $P>0.05$) (Table 3). Small sample sizes may have precluded our ability detect significant differences in catch by reservoir section. Greater catch in the upper section of a reservoir in early summer would not be unexpected given that fry distribution was skewed to the upper reservoir section in April-May (see *Fry Distribution*), and our highest Oneida trap catches occurred soon after this period in June-July. Catch rates tended to decrease later in the summer and parr appeared to be more evenly distributed after this period (Figure 10).

Oneida traps have limited ability to assess longitudinal distribution because they were only efficient at capturing fish moving within 34.1 m of shore and in the top 3.0 m of the water column. As fish descend into deeper, cooler water further offshore during the summer, trap efficiency becomes limited. Because of these limitations, Oneida traps may not provide adequate late-season distribution information for parr.

Table 2. Number and dates of Oneida traps sets and catch of juvenile Chinook salmon in Detroit, Cougar, and Lookout Point reservoirs, 2011.

Reservoir	Number of trap sets	Set dates	Yearlings	Subyearlings	Subyearling CPUE
Detroit	48	19 Apr-13 Oct	6	68	1.4
Cougar	80	05 Apr-03 Nov	85	728	9.1
Lookout Point	52	05 Apr-03 Nov	12	54	1.0

Table 3. Summary statistics for subyearling parr catch in Oneida trap sets by reservoir section in Detroit, Cougar, and Lookout Point reservoirs, 2011. *P*-values listed are for Kruskal-Wallis test comparing catch among reservoir sections.

		Reservoir section			
Reservoir		Lower	Middle	Upper	*P*
Detroit	mean	1.4	1.9	3.8	
	median	0	1	2	0.321
	range	0-10	0-10	0-9	
	sets (n)	14	13	6	
Cougar	mean	9.8	13.8	16.9	
	Median	5	4	10	0.238
	Range	0-51	0-97	0-68	
	sets (n)	17	16	20	
Lookout Point	mean	0.3	1.4	1.7	
	median	0	0	0.5	0.177
	range	0-2	0-12	0-12	
	sets (n)	19	21	12	

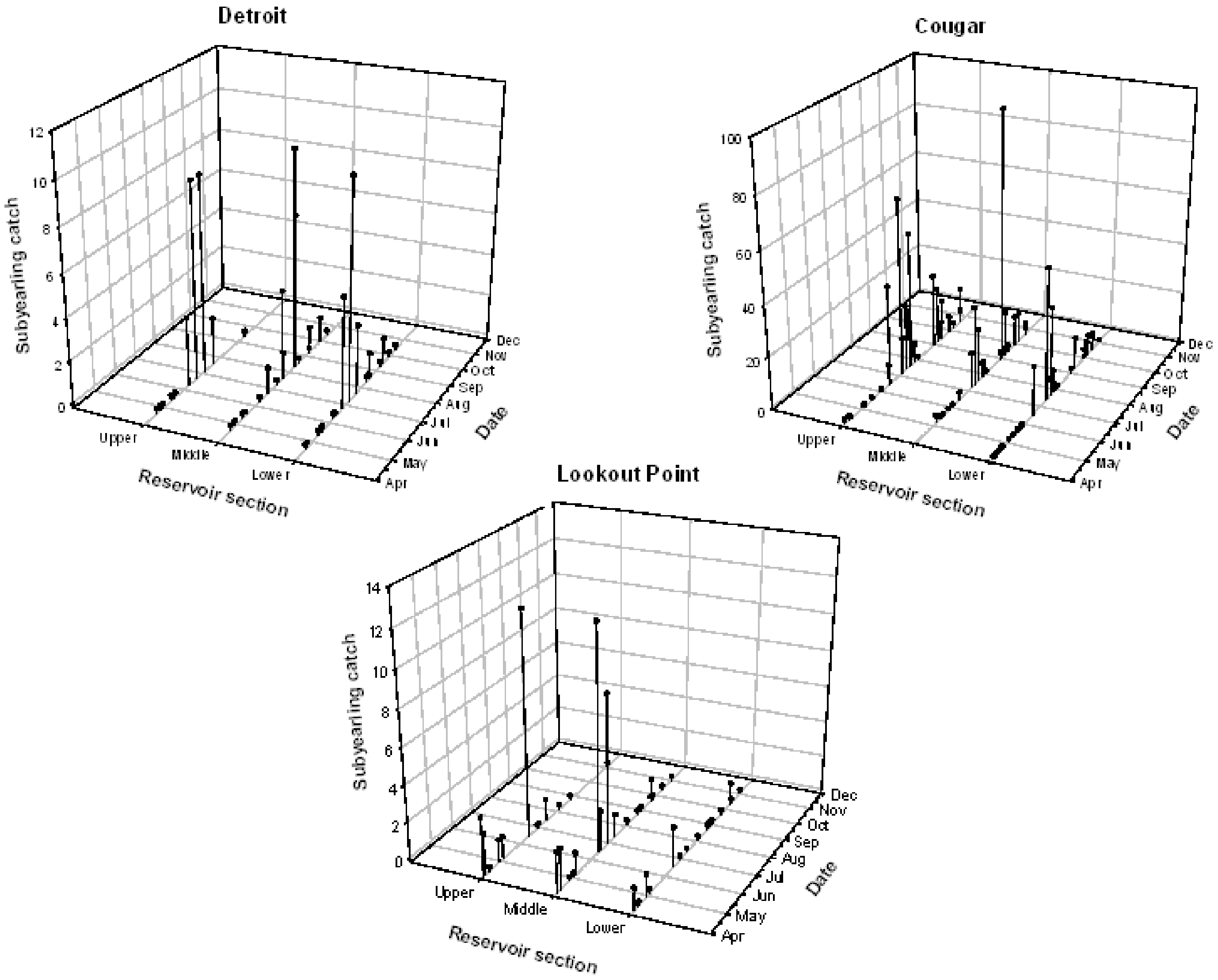

Figure 10. Subyearling parr catch in Oneida traps in relation to reservoir section and date for Detroit, Cougar and Lookout Point reservoirs, 2011.

Parr Vertical Distribution- We assessed vertical distribution of parr from July through November in Detroit and Lookout Point reservoirs with gill nets set at specific depth intervals. We performed 33 gill net sets (4-6 nets/set) in Detroit Reservoir from 03 August to 17 November and caught 1,073 juvenile Chinook (425 natural-origin subyearling, 1 natural-origin yearling, and 647 hatchery subyearlings). In Lookout Point Reservoir, we performed 26 gill net sets from 20 July to 04 November and caught 80 juvenile Chinook (27 natural-origin subyearlings, 53 hatchery subyearlings). Because of the low catch rate in Lookout Point we pooled July and August catch together to assess vertical distribution in the summer and we pooled October and November to assess fall distribution.

Hatchery and natural-origin juvenile Chinook demonstrate similar patterns of vertical distribution in Detroit and Lookout Point reservoirs. Catch at any particular depth interval was a mixture of both groups, suggesting that hatchery fish behaved the same as their natural-origin counterparts. We combined both groups when analyzing temporal changes in vertical distribution.

Results from Detroit Reservoir showed that the majority of juvenile Chinook were distributed in the 4.6 to 13.7 m (15-45 ft) depth range in August (Figure 11). Temperatures at this depth range during our sampling period in August averaged 16.1°C with a range of 11.7-18.45°C (based on USACE temperature string at 20, 30, and 40 ft depths). Beginning in September and continuing through October, fish continued to descend into deeper water with the majority occupying the 18.2 to 27.4 m (60-90 ft) depth range. USACE temperature information is incomplete for this time period but based on the available data, it appears juvenile Chinook were mainly occupying water less than 15ºC. Although surface temperatures had decreased by October (Figure 12), juvenile Chinook did not return closer to the surface until November (Figure 11).

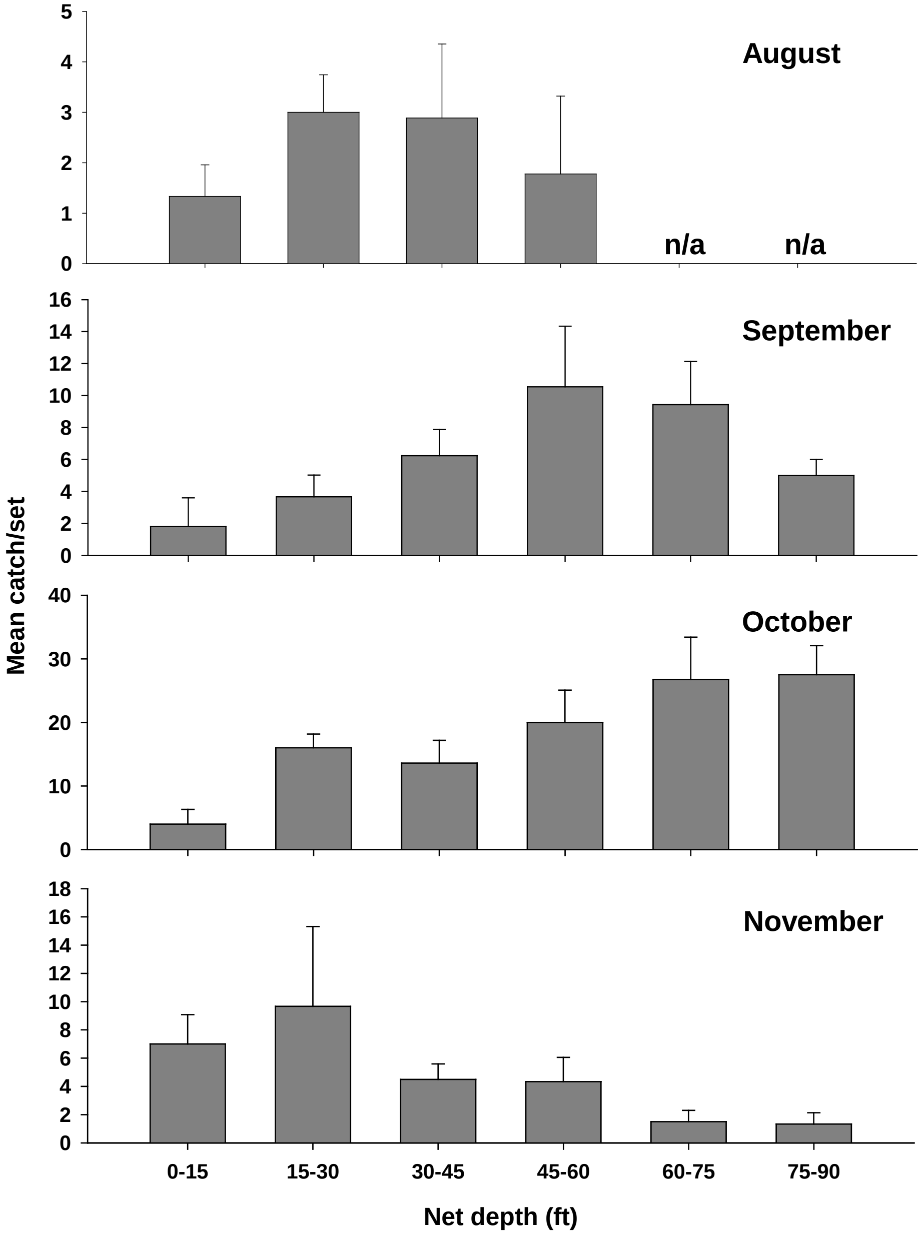

Figure 11. Mean catch/set (SE) of subyearling Chinook salmon (hatchery and natural origin) at specific depth intervals in Detroit Reservoir from August to November 2011.

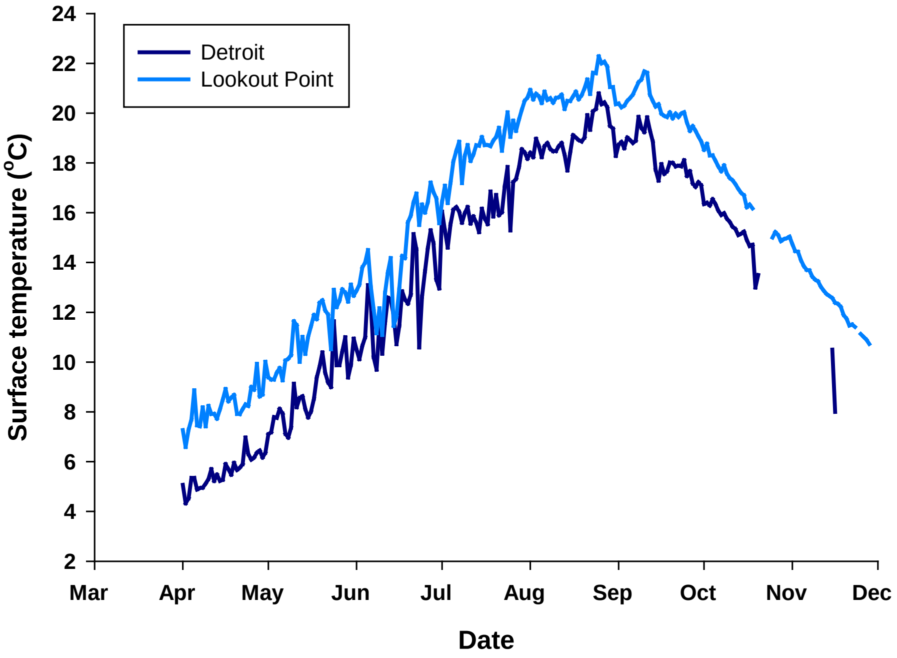

Figure 12. Surface temperatures recorded for Detroit and Lookout Point reservoirs from April through December, 2011. Temperatures used were those recorded at 12:00PM each day by USACE temperature strings located in reservoir forebays.

In Lookout Point Reservoir, juvenile Chinook did not descend as deep as they did in Detroit Reservoir although low catch rates in Lookout Point made comparisons to Detroit difficult. During July/August, most fish in Lookout Point were in the 4.6 to 13.7 m (15-45 ft) depth range, similar to fish in Detroit (Figure 13). Most of Lookout Point fish captured during this period were captured in July (27 of 31) when temperatures in this depth range averaged 14.6°C with a range of 12.2-19.5°C (based on USACE temperature string @ 20,30, and 40 ft depths). By October/November juvenile Chinook were evenly dispersed from the surface to 18.2 m (0-60 ft depth range).

Ingram and Korn (1969) reported similar results for juvenile Chinook in Cougar Reservoir, although these authors did not deploy nets below 45 ft in the summer and fall. Their results showed most fish caught in their deepest sets (30-45 ft) during August and September, whereas in November, most fish were caught in the 0-15 ft depth range.

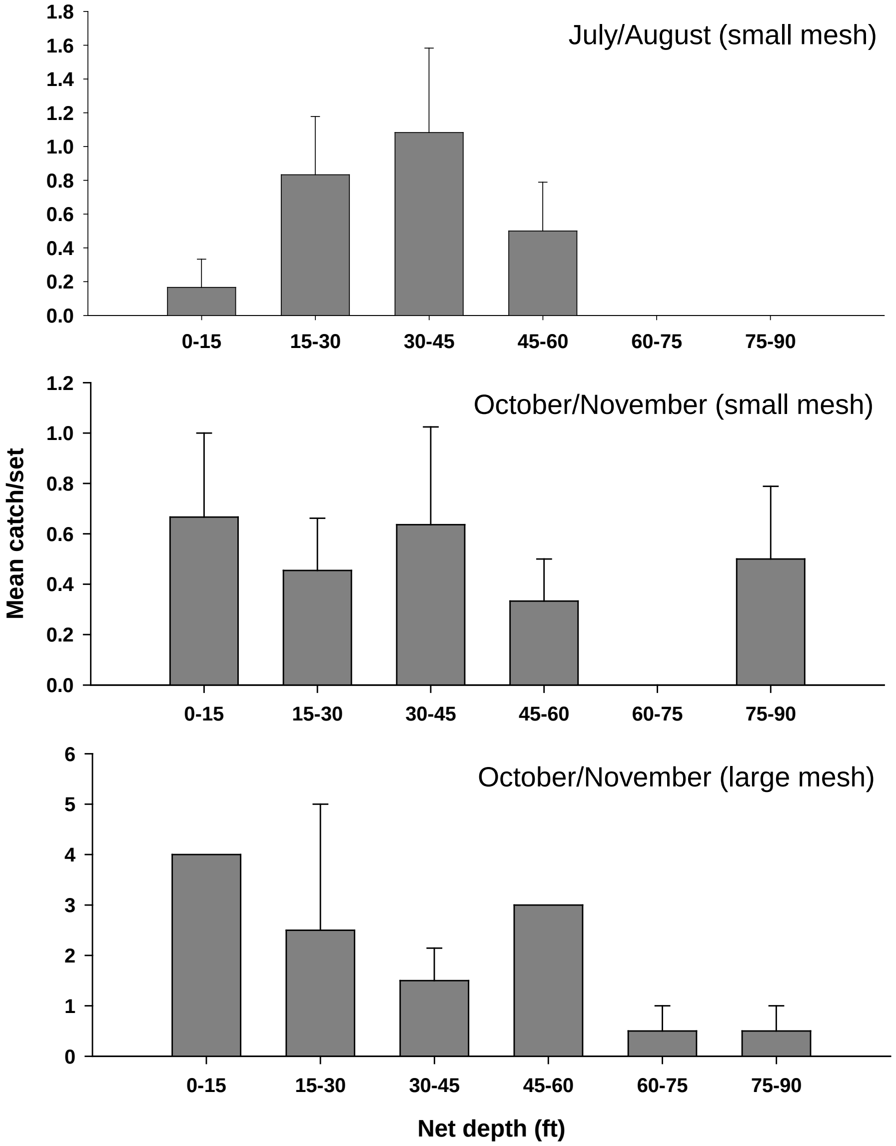

Figure 13. Catch of subyearling Chinook salmon (hatchery and natural) at specific depth intervals in Lookout Point Reservoir during July-August and October-November, 2011. No fish were caught with small mesh in September. Beginning in October nets were set off a rope boom in the forebay. Larger mesh nets were also used at this time. Error bars represent one standard error.

Although USACE temperature strings did not provide information at the specific depth intervals we used, in general, it appears fish were occupying areas of the water column that were approximately 15°C or less. This is consistent with temperature preference for juvenile Chinook reported by Richter and Kolmes (2005), who found juvenile salmonids generally prefer temperatures from 11.7 to 14.7ºC. Optimal rearing temperatures at natural feeding regimes for juvenile Chinook are 12.2 to14.8ºC (Hicks 2000), and The Independent Science Group (1996) determined optimal rearing for juvenile Chinook is between 12–17ºC, with most optimal at 15ºC.

It appears juvenile Chinook in Cougar Reservoir would not have to descend as deep to find preferred water temperatures as they would in Detroit and Lookout Point reservoirs. Fish in Detroit and Lookout Point reservoirs would need to descend to approximately 40 ft depth in mid-summer to find an optimal temperature of 15 ºC, whereas in Cougar Reservoir these temperatures occur at a depth of approximately 20 ft (Figure 14). Detroit and Lookout Point reservoirs also appear to remain warmer later into the year than Cougar Reservoir. In Cougar Reservoir, temperatures of 15 ºC could be found near the surface in October, whereas in Detroit and Lookout Point reservoirs, fish would need to descend to a depth below 40 ft.

However, temperature may not be the only factor that drives Chinook vertical distribution. Mysid shrimp were present in Detroit Reservoir and generally occupy water temperatures <10°C (Boscarino et al. 2010) which would correspond to >100 ft deep in Detroit Reservoir in October. This may explain why we caught most juvenile Chinook at the 75-90 ft depth range despite optimal temperatures occurring at shallower depths. A more thorough understanding of the seasonal changes in vertical distribution of juvenile Chinook in Detroit and other reservoirs would greatly aid the development of downstream passage designs that are surface oriented.

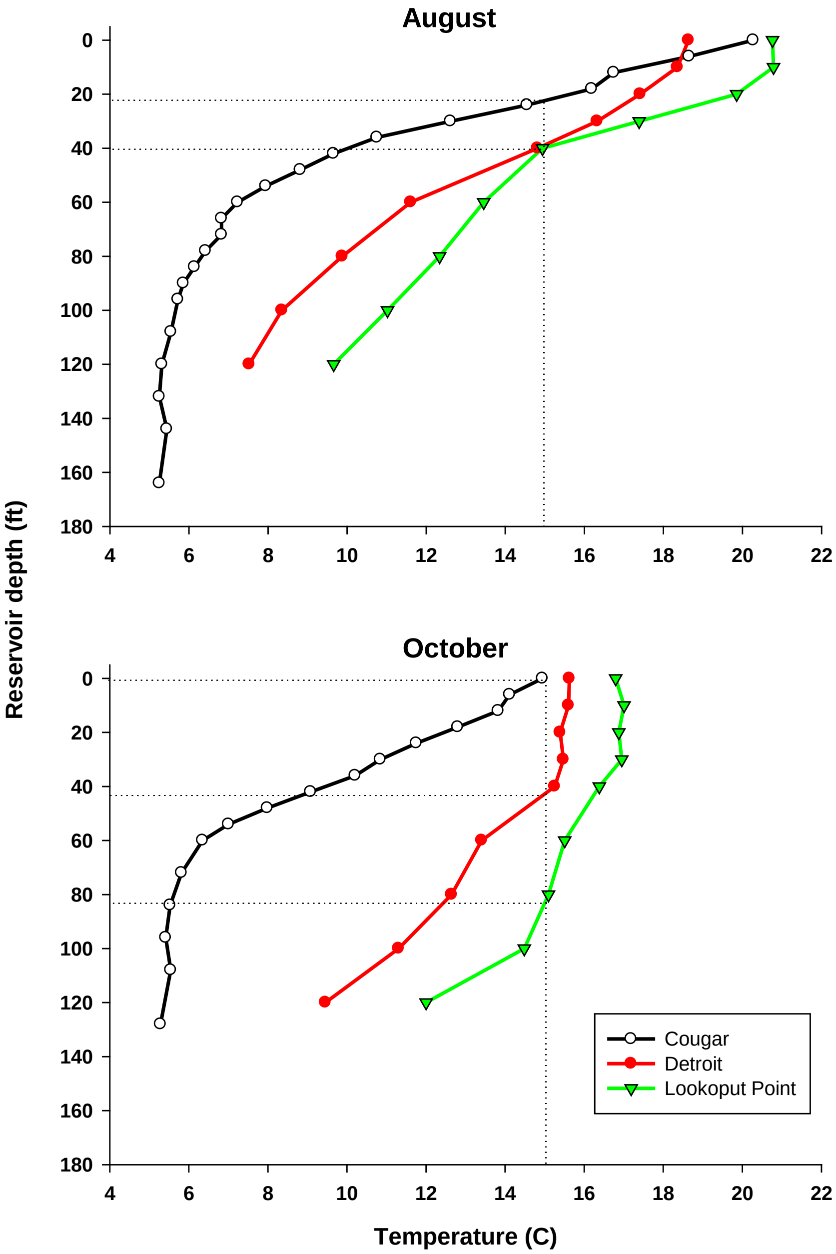

Figure 14. Temperature profiles for Detroit, Cougar, and Lookout Point reservoirs in August and October, 2011. Temperatures represent means for the entire month of August and October up to 19 October when temperature strings stopped functioning. Dotted reference lines mark depth at 15°C for each reservoir. Data courtesy of the U.S. Army Corps of Engineers.

Risks and Benefits of Reservoir Rearing

Relative Growth- Based on fork length data, at least two year-classes of juvenile Chinook were present in the reservoirs (Figure 15). Scales were collected on a subset of fish to verify age classification but have not yet been analyzed. We used the American Fisheries Society aging convention for assigning age to juveniles (Devries and Frie 1996). Juveniles that hatched in spring 2011 were classified as subyearlings (age 0). Yearlings (age 1) were fish that hatched the previous year and remained in the reservoir after 01 January. Most yearling and older juveniles were caught early in the season (April through June) with very few collected later in the year.

We used only natural-origin subyearlings to compare relative growth between stream- and reservoir-rearing juveniles. Fork lengths of seine captured subyearlings rearing in streams above reservoirs during the summer were not significantly different from fork lengths of fish collected at screw traps above reservoirs during the same time period (t-test; $P>0.05$). Therefore, we used screw trap fish lengths as a measure of stream-rearing growth to have a longer time-series to compare with reservoir-rearing subyearlings.

Reservoir-rearing subyearlings grew more rapidly than juveniles rearing in streams above reservoirs by the end of their first year of growth (Figure 16). By November, natural-origin subyearlings in Detroit Reservoir were approximately 90 mm larger than subyearlings collected above the reservoir. In Cougar Reservoir, subyearlings were approximately 40 mm larger by November than subyearlings collected in the trap above the reservoir. This is comparable to the 30 mm size difference we observed between groups above and within Cougar Reservoir during 2010 (Monzyk et al. 2011b). We did not collect any subyearlings in traps above Lookout Point Reservoir after September so end-of-year growth comparisons were not possible for this reservoir. However, subyearlings rearing in Lookout Point tended to achieve a larger size by November compared to fish in other reservoirs. Subyearling fork lengths in Lookout Point, Detroit, and Cougar reservoirs averaged 209, 175, and 124 mm, respectively. The larger size achieved in Lookout Point Reservoir could be attributed to better growing conditions or that the earlier entrance timing of subyearlings to the reservoir allowed more time for growth to occur.

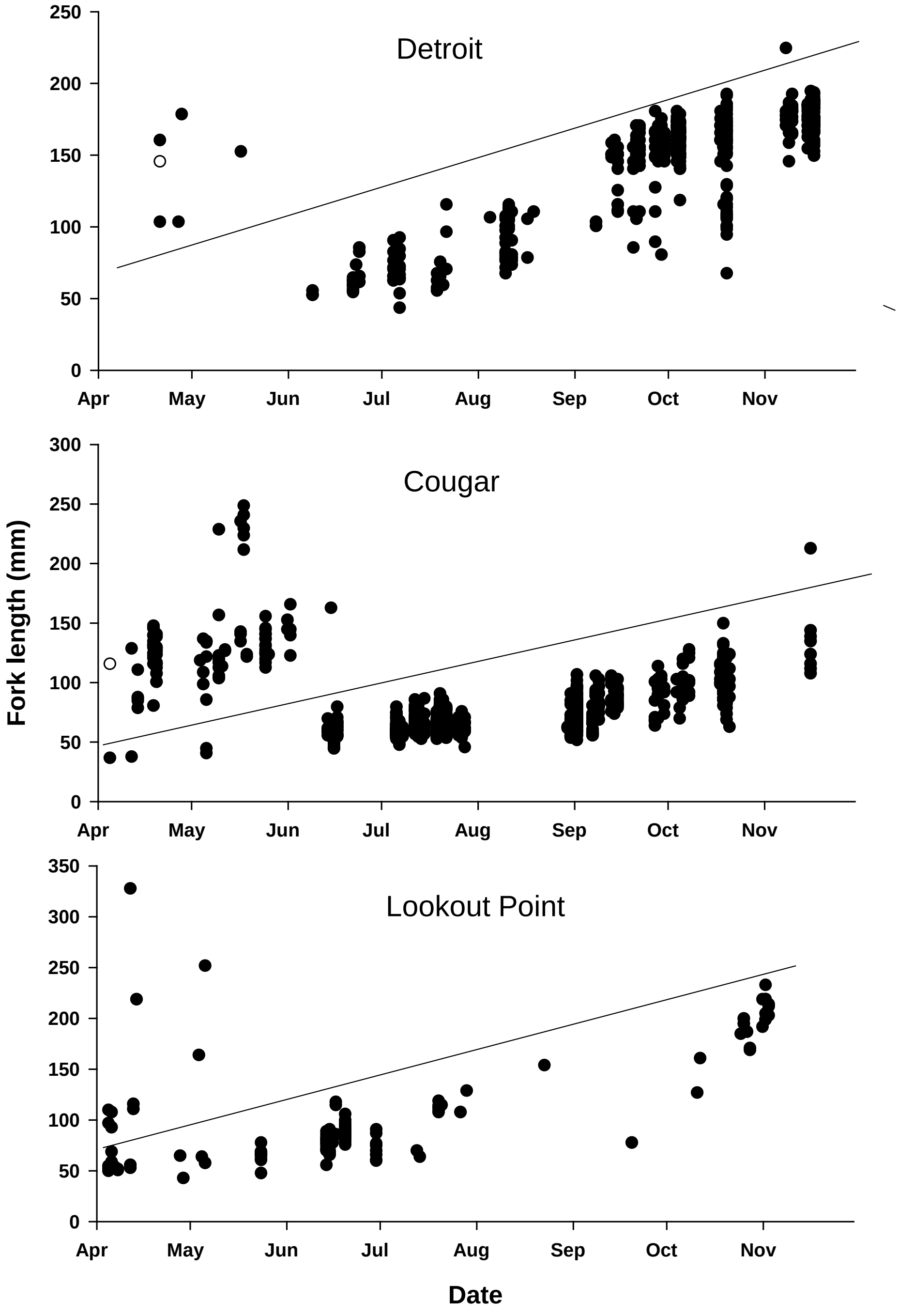

Figure 15. Fork lengths of juvenile Chinook salmon collected in Detroit, Cougar, and Lookout Point reservoirs, 2011. Subyearlings were classified as any fish falling below the diagonal line. Fish above the line were yearling or older fish.

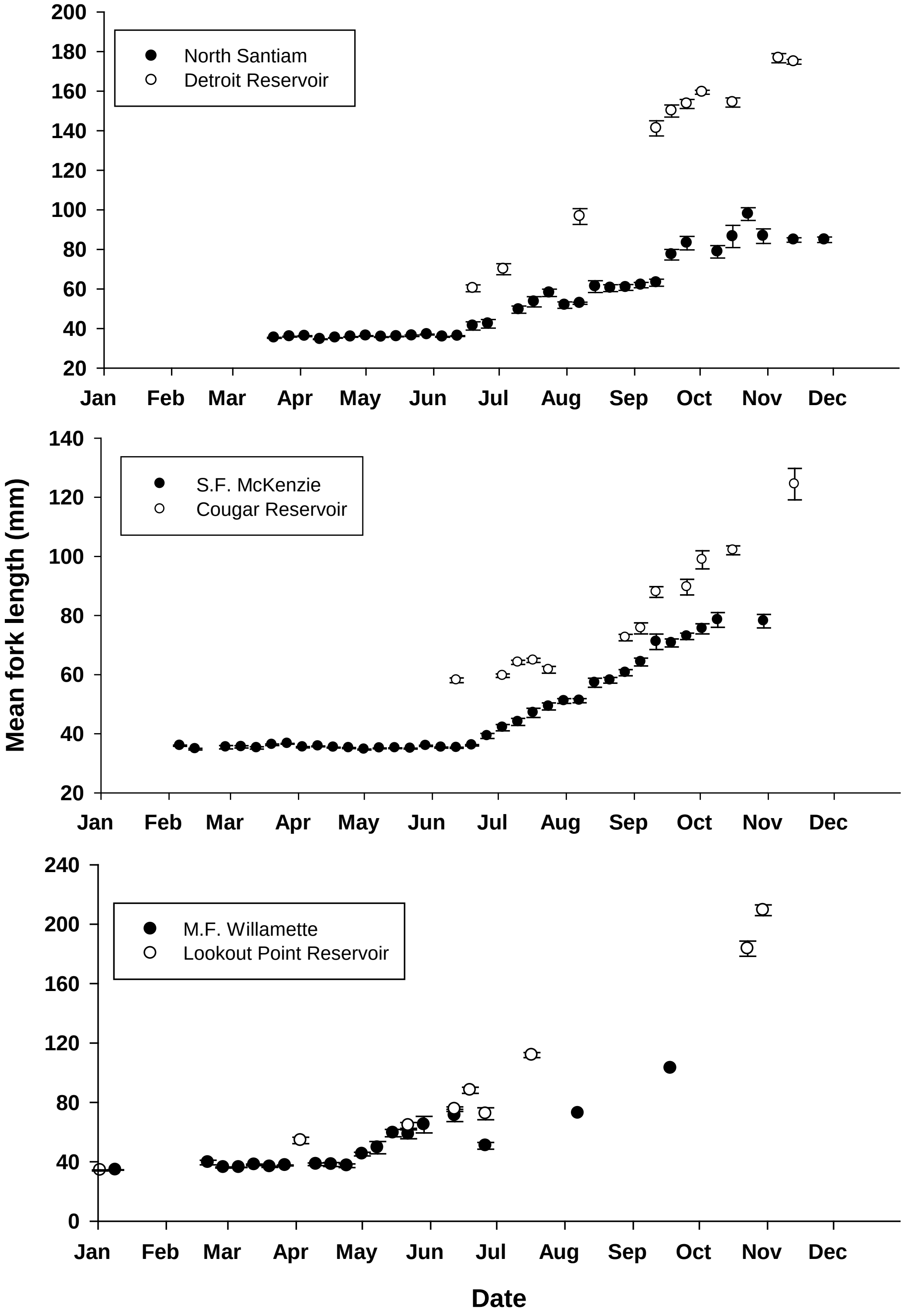

Figure 16. Comparison of size between natural-origin subyearlings rearing above and within Detroit, Cougar, and Lookout Point reservoirs, 2011. Error bars represent standard error.

Although growth of reservoir-rearing juveniles was greater than juveniles rearing in streams above reservoirs, their growth appeared similar to individuals rearing below WVP dams. Juvenile Chinook rearing in the upper Willamette River (between the McKenzie and Santiam river confluences) averaged 101 mm FL in August (Luke Whitman, ODFW, personal communication). This was similar to the size juveniles achieved in Detroit Reservoir by August (95 mm FL), whereas in Cougar Reservoir juvenile tended to be smaller (63 mm FL). No juveniles were collected in or below Lookout Point Reservoir in August, but by July juveniles averaged 104 mm FL (Figure 16).

Copepod Infection- Although juvenile Chinook grew rapidly in the reservoirs, this growth appeared to be associated with high rates of infection by the parasitic copepod *Salmincola californiensis*. The prevalence of copepod infection was greater for juvenile Chinook collected below the dam compared to fish rearing above the reservoir in the South Fork McKenzie (Table 4). Fish in the South Fork McKenzie had low overall infection levels that increased only slightly from 0.0 to 6.7 % during July through November while fish exiting the reservoir during the same months generally had infection rates that were at least an order of magnitude greater.

Table 4. The proportion of juvenile Chinook salmon infected by the parasitic copepod *Salmincola californiensis* in Cougar Reservoir and in the South Fork McKenzie River above the reservoir, 2011. Cougar Reservoir fish were collected in traps directly below the dam.

	Cougar Reservoir		South Fork McKenzie	
Month	N	Proportion infected (%)	N	Proportion Infected (%)
July	28	57.1	60	0
August	39	12.8	-	-
September	22	31.8	417	1.9
October	92	70.7	51[a]	3.9
November	995	66.1	15 [a]	6.7
December	128	89.1		

[a] *Fish were collected at rotary screw trap above reservoir.*

The infection rate was positively correlated (r=0.92) with average fish size from July through December (Figure 17). Numerous studies have shown that the degree of infection by *Salmincola* is related to fish size (Poulin et al. 1991, Amundsen et al. 1997, Nagasawa and Urawa 2002, Barndt and Stone 2003). Poulin et al. (1991) demonstrated in a laboratory study that fish size was the best predictor of copepod infection. The authors concluded that larger fish have a greater surface area for larval copepod attachment, and also circulate more water over their gills than smaller fish, thereby bringing more free-swimming parasites into contact with them. This size relationship was evident with fish from Cougar Reservoir as well (Figure 17), although in our case, the effect of size was confounded with duration of time spent in reservoir. Larger fish were likely in the reservoir for a longer time and therefore likely experienced extended exposure to parasites. When we compared the probability of infection to fish size for just the month of November, when most fish were leaving the reservoir, we could not detect a significant difference (logistic regression, *P*=0.120). The probability of infection was high, regardless of the size of fish.

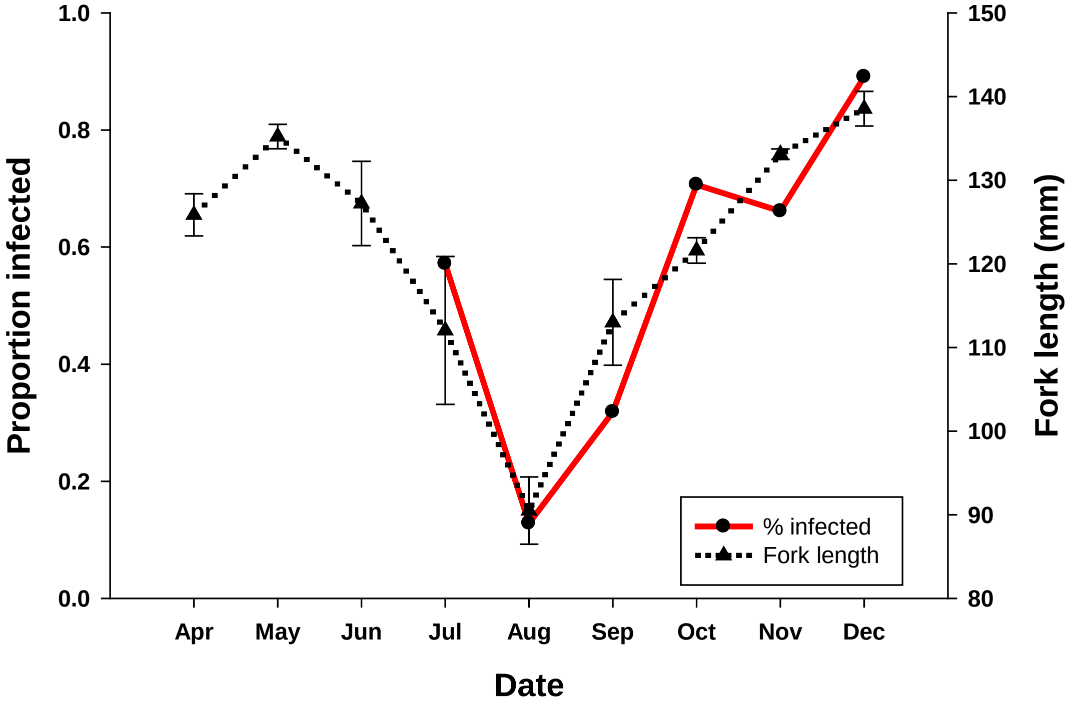

Figure 17. Relationship of infection rate of parasitic copepods and average size of juvenile Chinook salmon collected directly below Cougar Dam, 2011. April through July catch comprised mostly of yearlings while August through December catch was mostly subyearlings.

The relationship between copepod infection and reservoir residence does not appear to be isolated to Cougar Reservoir. Juvenile Chinook in Detroit Reservoir also appears to have a high prevalence of infection with approximately 58% of fish collected below the dam in December infected with copepods. Fish seined above Detroit Reservoir in September had a low infection rate (2.5%), comparable to fish from the South Fork McKenzie during the same month. Whether large juvenile Chinook that rear in the Willamette River are just as highly infected is unknown.

We did not quantify the intensity of copepod infection, but it was not uncommon to observe fish with numerous copepods attached to gills (Figure 18). Although copepod infection has not been shown to be lethal, gill tissue damage caused by infection has been shown to have sublethal effects. Pawaputanon (1980) demonstrated reduced swimming ability and anemic conditions in sockeye salmon (*O. nerka*) with high levels of infection. Vaughan and Coble (1975) reported reduced resistance to high temperatures but did not detect increased vulnerability to predation in infected brook trout (*Salvelinus fontinalis*). Juvenile Chinook leaving WVP reservoirs in the fall or spring would likely be undergoing smoltification in preparation for marine residence. The effect of gill damage caused by copepod infection on this process, especially the physiological changes in chloride cells in the gill filament, is unknown but could have negative consequences in the ability for smolts to adapt to their new environment.

Figure 18. Adult parasitic copepods (*Salmincola californiensis*) attached to gill filaments of a juvenile Chinook salmon.

Fish Community Structure- In Detroit Reservoir, nine species other than Chinook were captured in 2011. We captured four potentially piscivorous fish species: rainbow trout, cutthroat trout, brown bullhead, and sculpin (Table 5). Rainbow trout comprised 87.8% of the predatory fish captured in Detroit Reservoir and were more abundant in this reservoir compared to other reservoirs. Rainbow trout included both hatchery and natural-origin fish. Hatchery rainbow trout and kokanee are released in Detroit Reservoir annually for a recreational sport fishery. Non-predatory species were dominated by dace (n=14,079) and pumpkinseed (*Lepomis gibbosus*) (n=5,297), most of which were captured alongside Chinook fry in nearshore fry traps.

We collected seven fish species other than Chinook in Cougar Reservoir in 2011. Five of the seven were piscivores and only one (largemouth bass) was non-native (Table 5). Rainbow and cutthroat trout comprised 90% of the piscivorous species. Bull trout were not as abundant as rainbow and cutthroat trout but were the largest predator collected. Largemouth bass were first documented in 2010, but were likely introduced several years prior and have established a spawning population, as evidenced by the various size classes observed. Similar to Detroit Reservoir, dace were the most abundant non-predatory fish species found in Cougar Reservoir. We captured about 29,000 dace with most (94%) captured in nearshore traps.

Table 5. Relative abundance and length (mm) range of each species collected in Lookout Point, Cougar and Detroit reservoirs, 2011. Fish were captured using Oneida box traps, hoop nets, boat electrofishing, hook and line, and gill netting. Asterisks denote non-native (exotic) species.

	Lookout Point	Cougar	Detroit
	Number captured (Fork length range; mm)		
Piscivorous species			
Cutthroat Trout *(Oncorhynchus clarkii)*	198 (99-394)	132 (67-330)	1 Not measured
Rainbow Trout *(Oncorhynchus mykiss)*	39 (36-440)	73 (76-367)	1,880 (38-350)
Bull Trout *(Salvelinus confluentus)*	0	12 (215-657)	0
Northern Pikeminnow *(Ptychocheilus oregonensis)*	577 (33-590)	0	0
Sculpin *(Cottus* spp.*)*	53 Not measured	4 Not measured	5 Not measured
Largemouth Bass* *(Micropterus salmoides)*	160 (30-475)	8 (46-224)	0
Walleye* *(Sander vitreus)*	26 (187-755)	0	0
White Crappie* *(Pomoxis annularis)*	271 (47-380)	0	0
Black Crappie* *(Pomoxis nigromaculatus)*	6 (75-290)	0	0
Brown Bullhead* *(Ameiurus nebulosus)*	89 (183-395)	0	254 (25-300)
Yellow Bullhead* *(Ameiurus natalis)*	10 (120-260)	0	0
Non-piscivorous species			
Mountain Whitefish *(Prosopium williamsoni)*	1 (330)	158 Not measured	13 (147-187)
Redside Shiner *(Richardsonius balteatus)*	357 Not measured	0	0
Dace *(Rhinichthys* spp.*)*	62 Not measured	28,707 Not measured	14,079 Not measured
Largescale Sucker *(Catostomus macrocheilus)*	527 Not measured	0	0
Pumpkinseed *(Lepomis gibbosus)*	3 (Not measured)	0	5,297 Not measured
Bluegill* *(Lepomis macrochirus)*	11 (53-170)	0	127 Not measured
Kokanee *(Oncorhynchus nerka)*	0	0	400 Not measured

In Lookout Point Reservoir, 16 species other than Chinook salmon were captured in 2011. Unlike Detroit and Cougar reservoirs, predatory fish were abundant and dace were rare (Table 5). Lookout Point Reservoir contained 10 piscivorous species, six of which were non-native. Potential predators of juvenile Chinook included cutthroat trout, rainbow trout, sculpin, bullhead spp., northern pikeminnow, walleye, largemouth bass and crappie spp. Northern pikeminnow were the most numerous predator found in Lookout Point Reservoir. Overall, non-piscivorous species in Lookout Point Reservoir were generally present in much smaller numbers compared to Cougar and Detroit reservoirs. Dace numbers were especially low (n=62) compared to the thousands found in the other reservoirs (Table 5). Largescale suckers (*Catostomus macrocheilus*) were present in Lookout Point Reservoir but not in the other reservoirs.

In 2010, we captured >10,000 young-of-year crappie (presumably white crappie) during late summer and fall, but in 2011 we captured very few young-of-year crappie (<100) despite increased sampling effort. The major difference between these years was the early reservoir drawdown that occurred in 2010. In most years, reservoir elevation was >274 m (900 ft) by mid-July. Lookout Point was drawn down to about 259 m (850 ft) elevation by mid-July 2010. This may have provided a greater expanse of preferred shallow spawning habitat in July/August in the upper section of the reservoir that otherwise would not have been available. Interestingly, in 2007, when reservoir elevation was also lower in mid-July (~268 m or 880 ft), USACE personnel that operate a trap below Lookout Point Dam reported high young-of-year crappie abundance (Todd Pierce, USACE-personal communication). It is unclear whether crappie abundance and reservoir elevation during these years was coincidental or somehow related.

Numerous factors likely drive the present-day fish community structure in the three reservoirs. Lookout Point Reservoir is located at a lower elevation (287 m at full pool) compared to Detroit Reservoir (481 m) and Cougar Reservoir (518 m) and subsequently has a warmer temperature profile that likely contributes to the persistence of introduced warm-water piscivorous species as well as northern pikeminnow. We did not capture northern pikeminnow in Detroit or Cougar reservoirs in 2011, but they were abundant in Lookout Point Reservoir (Table 5). A spawning population of northern pikeminnow was likely present in the Middle Fork Willamette River before the completion of Lookout Point Dam in 1954. Hasselman and Garrison (1957) collected numerous pikeminnow in the reservoir soon after its completion. Northern pikeminnow prefer a temperature range of 16-22°C (Brown and Moyle 1981) and a minimum spawning temperature 13.9°C (Wydoski and Whitney 2003). Temperatures suitable for northern pikeminnow spawning do not occur in the river or tributaries above present-day Detroit and Cougar reservoirs. However, in the Middle Fork Willamette above Lookout Point Reservoir, stream temperatures often exceed the minimum spawning temperatures required for pikeminnow.

Both speckled (*Rhinichthys osculus*) and longnose dace (*R.. cataractae*) were captured in reservoirs but were in markedly lower abundance in Lookout Point Reservoir compared to Detroit and Cougar reservoirs despite similar trapping effort in all reservoirs (Table 5). The reason for the low relative abundance is unclear. Dace generally tolerate warmer temperatures and tend to be habitat generalists (Wydoski and Whitney 2003). In addition, dace populations appear to be strong in streams that feed into Lookout Point as well as streams and sloughs above the reservoir (Paul Scheerer,ODFW, personal communication). Predatory species in this reservoir are likely a limiting factor for dace populations.

Diet Composition of Predator Fish – We collected 160 diet samples in the spring from 24 May through 10 June and 149 samples in the fall from 11 October through 03 November. Of the 309 samples, 22% contained no diet items leaving 240 used for diet composition analysis. Most samples came from predators in Lookout Point Reservoir (Table 6).

Table 6. The total number of diet samples collected and percent empty by reservoir and predator species, 2011.

				Spring		Fall	
Reservoir	Species	Total samples	% empty	Samples	% empty	Samples	% empty
Detroit	Rainbow trout	81	21.0%	40	22.5%	41	19.5%
	Brown bullhead	6	16.7%	4	25.0%	2	0.0%
Cougar	Rainbow trout	16	6.3%	6	0.0%	10	10.0%
	Cutthroat trout	3	0.0%	1	0.0%	2	0.0%
Lookout Point	Rainbow trout	21	4.8%	11	9.1%	10	0.0%
	Cutthroat trout	3	0.0%	1	0.0%	2	0.0%
	Bullhead spp.[a]	10	30.0%	8	37.5%	2	0.0%
	Sculpin	1	0.0%	-	-	1	0.0%
	Crappie spp.[b]	46	23.9%	32	28.1%	14	14.3%
	Largemouth bass	23	52.2%	13	46.2%	10	60.0%
	Walleye	24	29.2%	10	30.0%	14	28.6%
	N. pikeminnow	75	21.3%	34	14.7%	41	26.8%

[a] *Includes both brown and yellow bullhead*
[b] *Includes both white and black crappie. Most samples were from white crappie.*

In Detroit Reservoir the only potential Chinook predator species collected for diet analyis were rainbow trout (n=81) and brown bullhead (n=6). Both of these species were likely opportunistic piscivores based on the variety of items found in their diet. Of the taxonomic groups found in rainbow trout stomachs, macroinvertebrates (both aquatic and terrestrial) had the highest overall frequency of occurrence at 63% (Figure 19). Zooplankton occurred approximately 13% of the time, while fish occurred only 4% of the time. Overall, the frequency of occurrence of the different prey taxon change little from spring to fall (Figure 19). Only three of the 64 rainbow trout that had food items in their stomachs contained fish. Of the identifiable prey fish, two were identified as a juvenile Chinook (one was approxiamtely 115 mm FL), both found in a 325-mm FL hatchery rainbow trout collected in the fall. The only other identifiable prey fish was a juvenile pumpkinseed in a 221 mm FL rainbow trout collected in the spring.

The length frequency of rainbow trout in Detroit Reservoir was skewed heavily toward large fish, undoubtedly the result of stocking efforts (Figure 20). In addition to the large rainbow trout in the reservoir, numerous (>1,000) individuals were observed schooling in the Detroit Dam tailrace and some were observed feeding on hatchery Chinook released in the tailrace as part of a screw trap efficiency test. Diet samples were not collected from rainbow trout below the dam but the possibility exists that they prey on juvenile Chinook passing through the dam. Given the documented consumption of juvenile Chinook by rainbow trout and their sheer numbers in the reservoir, this species is likely to have the greatest predation impact on juvenile Chinook in Detroit Reservoir.

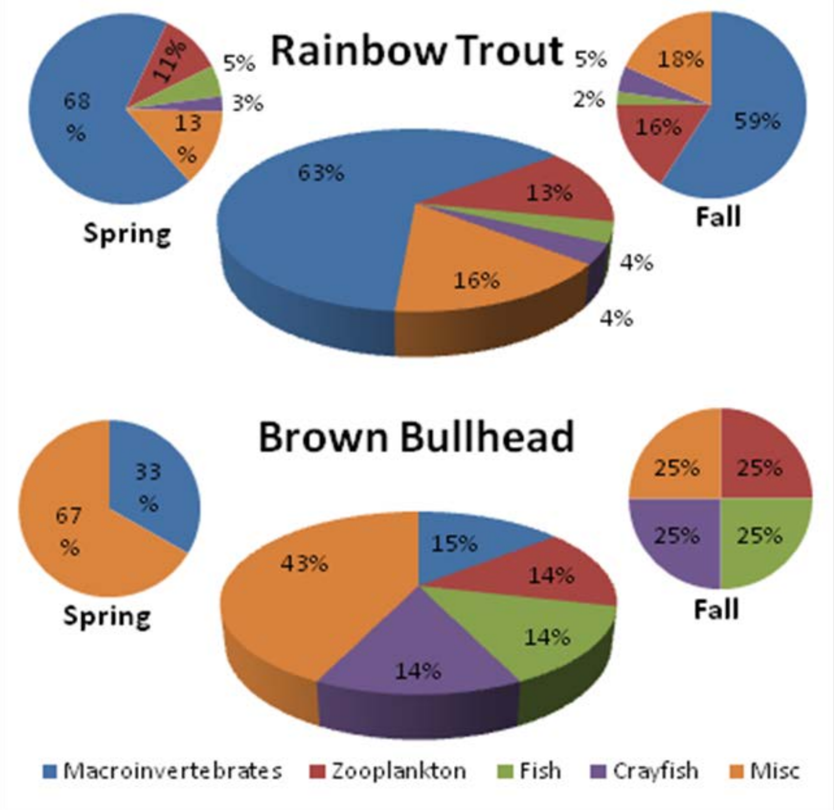

Figure 19. Diet composition of rainbow trout and brown bullhead in Detroit Reservoir, 2011. Percentages are the frequency of occurrence of prey taxon.

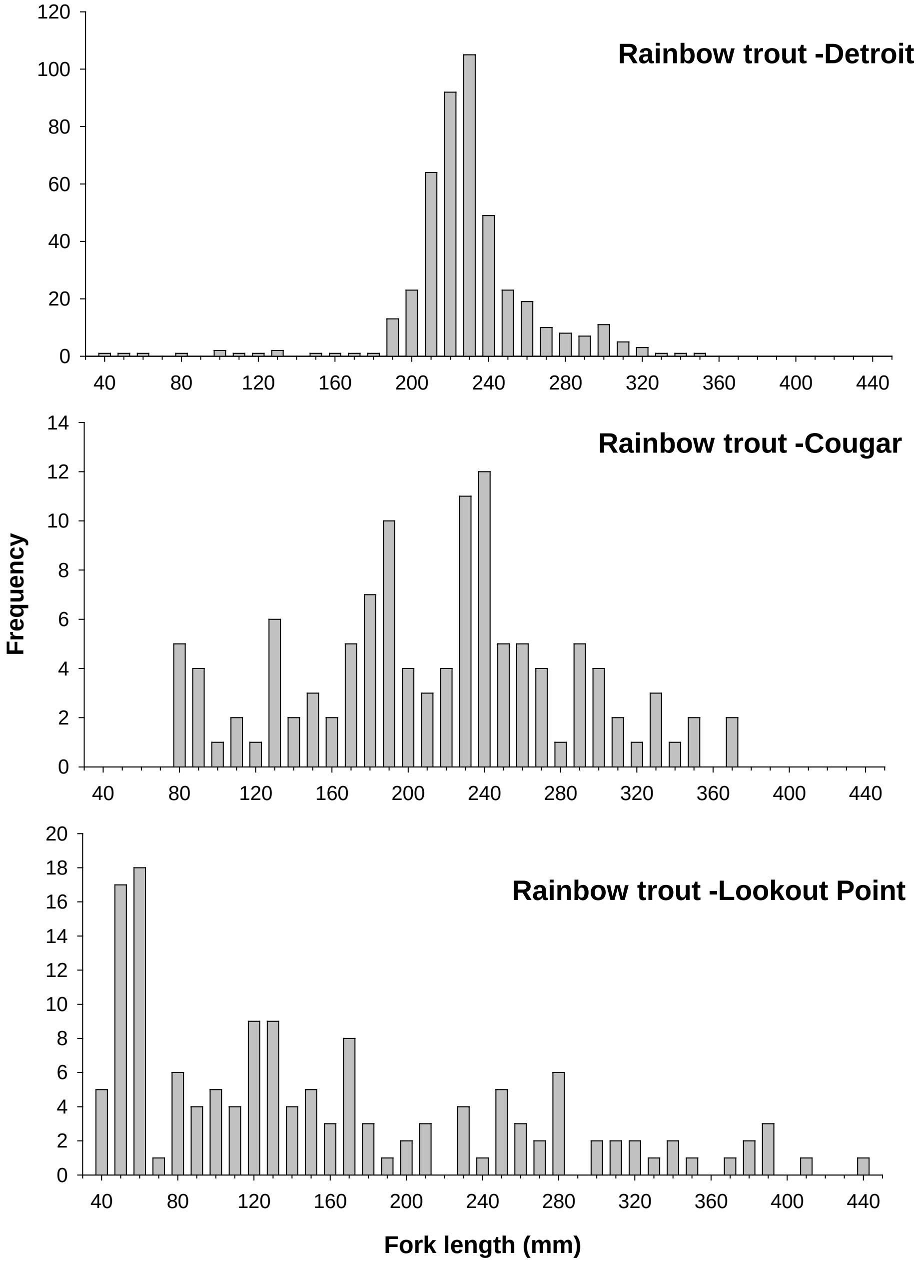

Figure 20. Length frequency of rainbow trout collected in Detroit, Cougar, and Lookout Point reservoirs, 2011. Rainbow trout in Detroit Reservoir include both hatchery and natural-origin fish.

Brown bullheads also appeared to be opportunistic piscivores in Detroit Reservoir. Bullheads are typically benthic feeders, so it is not surprising that most prey items found in stomachs were benthic in nature (Figure 19). In bullhead stomachs, crayfish, macroinvertebrates, zooplankton and fish (a sculpin) occurred equally (14-15% of the time). Rocks and aquatic vegetation made up the majority of items found in their stomachs (43% of occurrence). These results should be viewed with some caution since few bullheads were collected for diet analyis. We would not expect bullheads to be major predators given their omnivorous diet (Wydoski and Whitney 2003), however bulheads often preyed on juvenile Chinook when captured with them in nearshore traps (this study). Bullhead are nocturnal in their feeding activity and are benthic oriented. Tabor et al (2011) reported that Chinook fry were inactive at night and located near the bottom of nearshore areas in Lake Washington. We hypothesize that if bullheads were to have a significant impact on juvenile Chinook, it would likely be on juvenile Chinook fry in the early spring.

Cougar Reservoir predator fish included rainbow trout, cutthroat trout, and bull trout. We did not sample bull trout stomachs. Only three cutthroat were sampled for diet analysis along with 16 rainbow trout (Table 6). All three cutthroat trout samples contained macroinvertebrates and one also contained a dace. As with Detroit Reservoir, Cougar Reservoir rainbow trout were largely insectivorous and diet composition changed little between spring and fall (Figure 21). Macroinvertebrates occurred most frequently (70%) followed by zooplankton (15%). Only one fish (a dace) was found in the diet samples (5% occurrence). Although sample sizes were small, cutthroat trout appear to have a higher prey fish comsumption rate (1/3) compared to rainbow (1/16). Cutthroat trout are reported to be more piscivorous than ranibow trout (Baldwin et al. 2000), and they are the most abundant predator in the reservoir (Table 5).

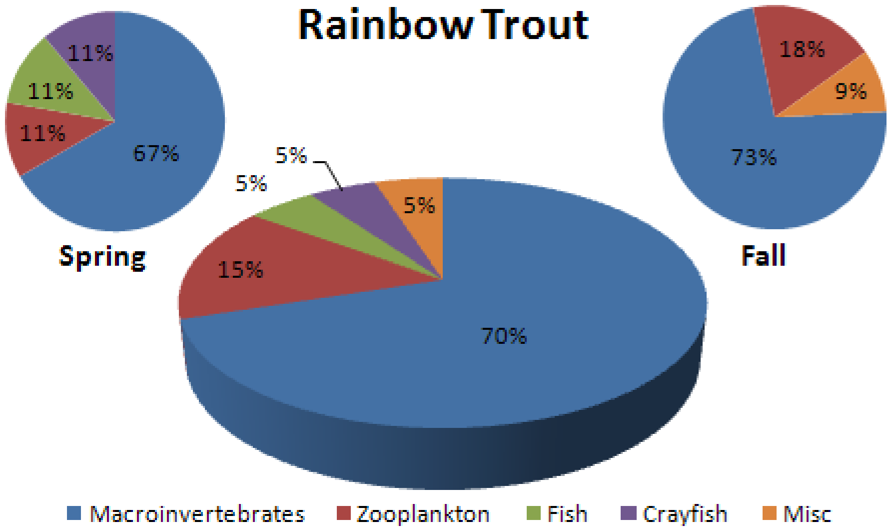

Figure 21. Diet composition of rainbow trout in Cougar Reservoir, 2011. Percentages were frequency of occurrence of prey taxon categories.

In Lookout Pont Reservoir, we collected stomach from 10 species that could be potential predators of juvenile Chinook. For analysis we combined brown bullheads (n=6) and yellow bullheads (*A. natalis*) (n=6) into a single group. We also combined black crappie (*P. nigromaculatus*; n=4) with white crappie (n=42). The other species analyzed for diet composition were rainbow trout, cutthroat trout, sculpin, northern pikeminnow, largemouth bass, and walleye.

Only three cutthroat trout were sampled, one of which contained a fish that could not be identified to species but was not a salmonid. Rainbow trout in Lookout Point Reservoir appeared to feed exclusively on macroinvertebrates and zooplankton, 47% and 53% occurrence, respectively (Figure 22). The frequency of occurrence of zooplankton in Lookout Point rainbow trout stomachs was greater than the other reservoirs. Warmer conditions in Lookout Point may support greater phytoplankton and subsequent zooplankton densities with rainbow trout responding to zooplankton availability.

Bullhead diet samples from Lookout Point Reservoir contained primarily macroinvertebrates in both the spring and the fall samples (Figure 22). Bullheads were one of only two predators to have mollusks found in their stomachs, the other being northern pikeminnow. We captured a single sculpin (223 mm FL) in a gill net in October and its diet was comprised entirely of zooplankton.

Crappie diets were largely comprised of zooplankton, especially in fall samples (Figure 22). Macroinvertebrates also had a high frequency of occurrence (50%) in the spring. Fish occurred in about 10% of the total identifiable items, with a higher frequency in fall samples (Figure 22). Diet studies of white crappie suggest the species is opportunistic, feeding on the most available food (Mathur 1972). Five of the 35 crappie sampled had fish in their stomach although none of the prey fish could be identified to species or family. It is likely that predation on Chinook juveniles would only occur in the spring while they are still small enough for the mouth gape of crappie.

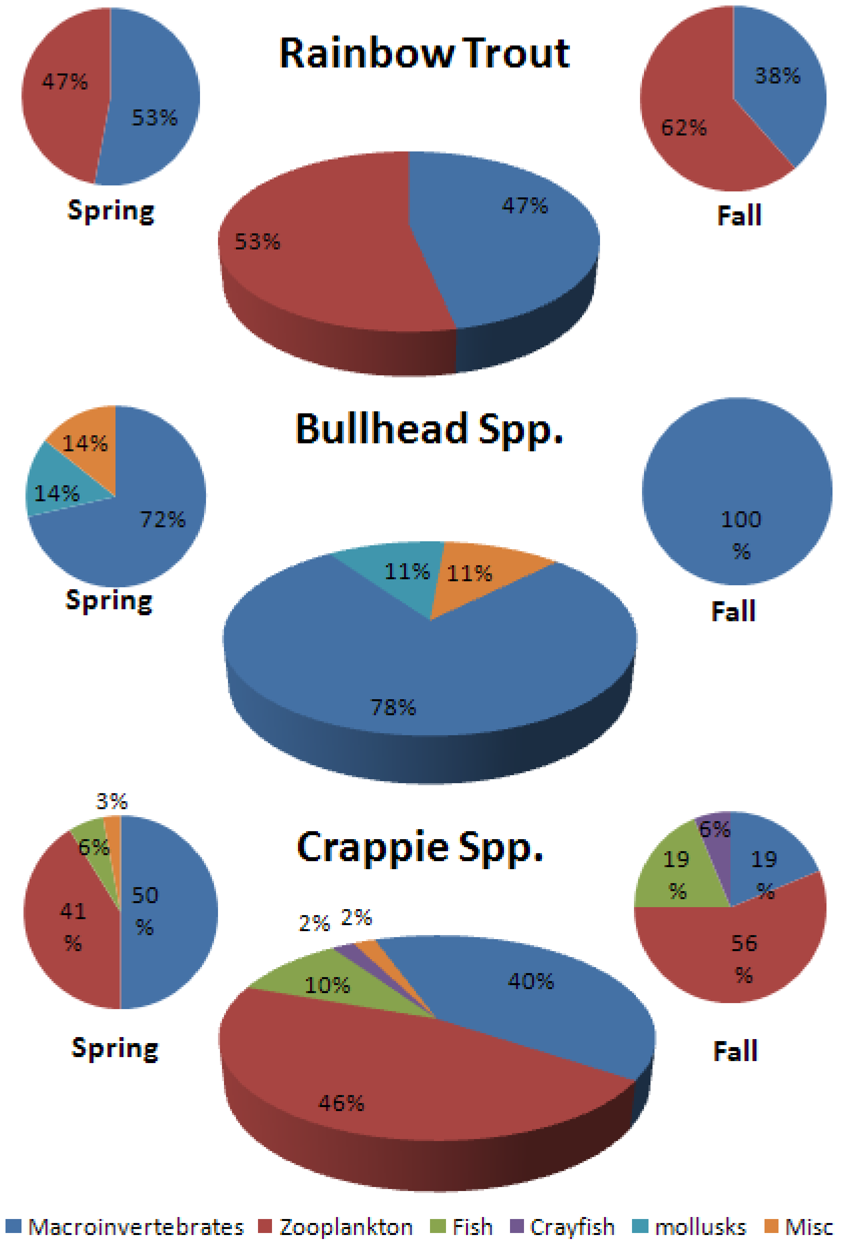

Figure 22. Diet composition of rainbow trout, bullhead spp., and crappie spp. in Lookout Point Reservoir, 2011. Percentages were the frequency of occurrence of each prey taxon category.

Northern pikeminnow, largemouth bass, and walleye diet samples in Lookout Point Reservoir contained the greatest number of fish (Table 7). Although northern pikeminnow had a diversity of prey items in their diet, fish occurred most frequently (46%), and few differences in their diet were apparent between spring and fall (Figure 23).

Table 7. The number of individual prey fish by species/group found in the diet samples of piscivorous fish in Lookout Point Reservoir, 2011.

Prey Species	Piscivorous Species					
	Cutthroat trout	White crappie	Black crappie	Bass spp.	Northern pikeminnow	Walleye
Chinook salmon					3	4
Rainbow trout				1	2	1
Salmonid spp.					3	2
Sucker				2	8	7
Sculpin				4	9	2
Bass spp.					1	
Brown bullhead				2	1	
Dace					1	
Northern pikeminnow						1
Cyprinid spp.						1
Non-salmonid spp.	1	1		1	4	4
Unknown fish spp.		3	1	3	17	2
Total	**1**	**4**	**1**	**13**	**49**	**24**

Of the 59 northern pikeminnow that contained prey items in their digestive tracts, 38 contained at least one prey fish. Suckers, sculpins, and salmonids comprised most of the consumed fish (Table 7). Three juvenile Chinook were among the prey fish identified, all from the same 387 mm FL northern pikeminnow. One of the Chinook was 72-mm FL and was of hatchery origin. Three juvenile Chinook found in a single pikeminnow is not surprising given that Petersen and DeAngelis (1992) reported northern pikeminnow predation on Chinook occurs during distinct 'feeding bouts' rather than random feeding occasions on individual prey over long periods of time. The largest prey fish found in the diet samples of pikeminnow was a 200-mm FL largescale sucker in a 590-mm FL Northern pikeminnow. The large size of prey fish consumed by northern pikeminnow suggest they are capable of preying on juvenile Chinook throughout the year in Lookout Point Reservoir.

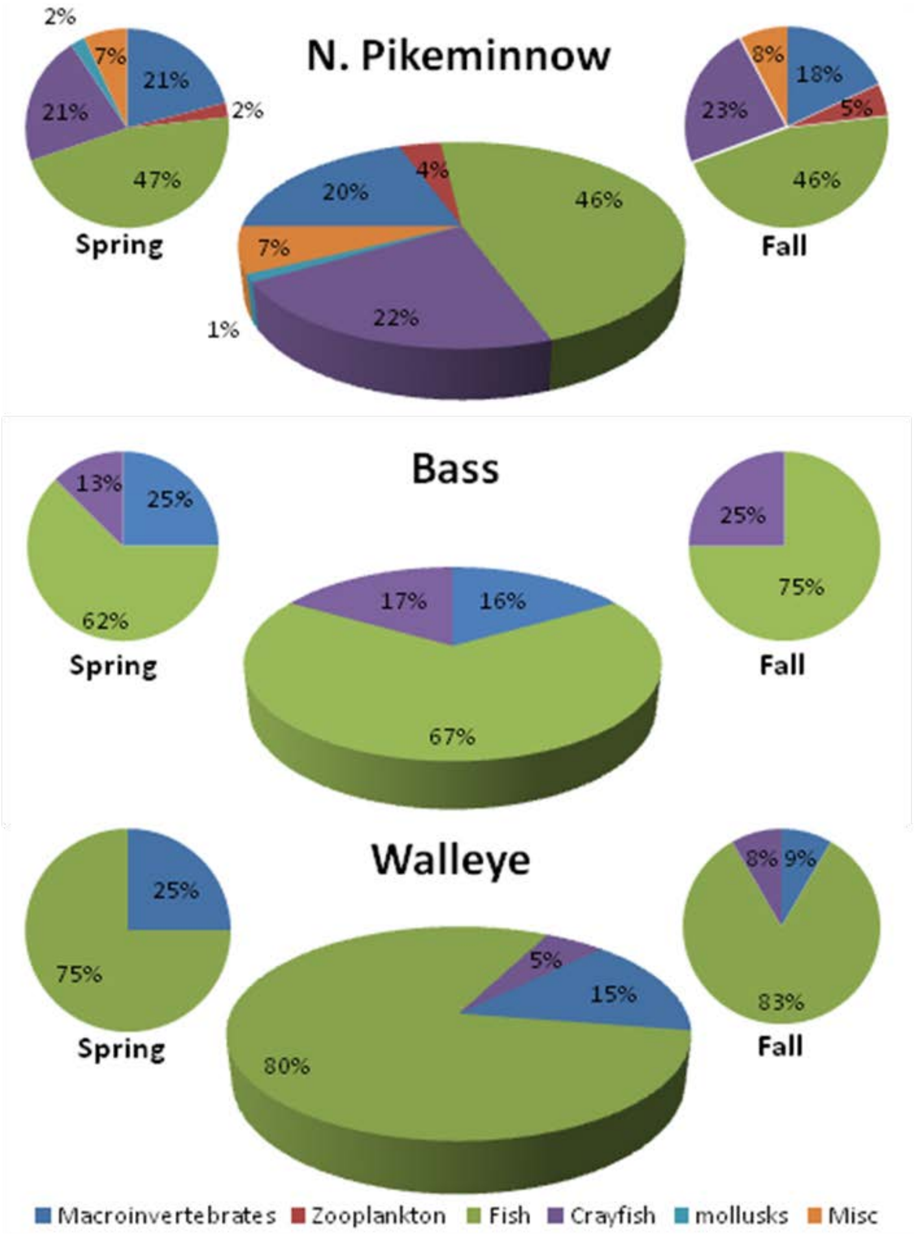

Figure 23. Diet composition of warm water species and northern pikeminnow in Lookout Point Reservoir, 2011. Percentages were the frequency of occurrence of each ptey taxon category.

Largemouth bass had the second highest frequency of occurrence of fish in diet samples (67%) in Lookout Point Reservoir (Figure 23). Fall diet samples from bass contained roughly 10% more fish prey items, as a portion of total prey items found, than spring samples. Macroinvertebrates and crayfish were the remaining items found in bass stomachs. A total of 11 bass contained at least one prey item in their digestive tracts; eight contained prey fish and none were juvenile Chinook. The largest prey item was a 155-mm FL sucker found in the stomach of a 470-mm largemouth bass.

Walleye had the highest portion of fish items (80%) in their stomachs (Figure 23). Like bass, walleye had more fish prey items in the fall than in the spring. Macroinvertebrates (15%) and a small portion of crayfish also occurred in walleye stomachs. Of the 17 walleye that contained at least one item in its stomach, 16 contained prey fish. Suckers and salmonids were the most frequent prey fish consumed (Table 7). A total of four juvenile Chinook were identified, the largest was 80 mm FL and found in a 740-mm FL walleye. The lengths of walleye that contained fish in their diet ranged from 490-740 mm FL. Walleye were the largest predator collected in the reservoir (Figure 24). The age-class for walleye appeared to be skewed toward older fish as only one walleye collected was less than 450 mm FL. However, this may be an artifact of the gear we used to collect walleye and the habitat used by younger age classes.

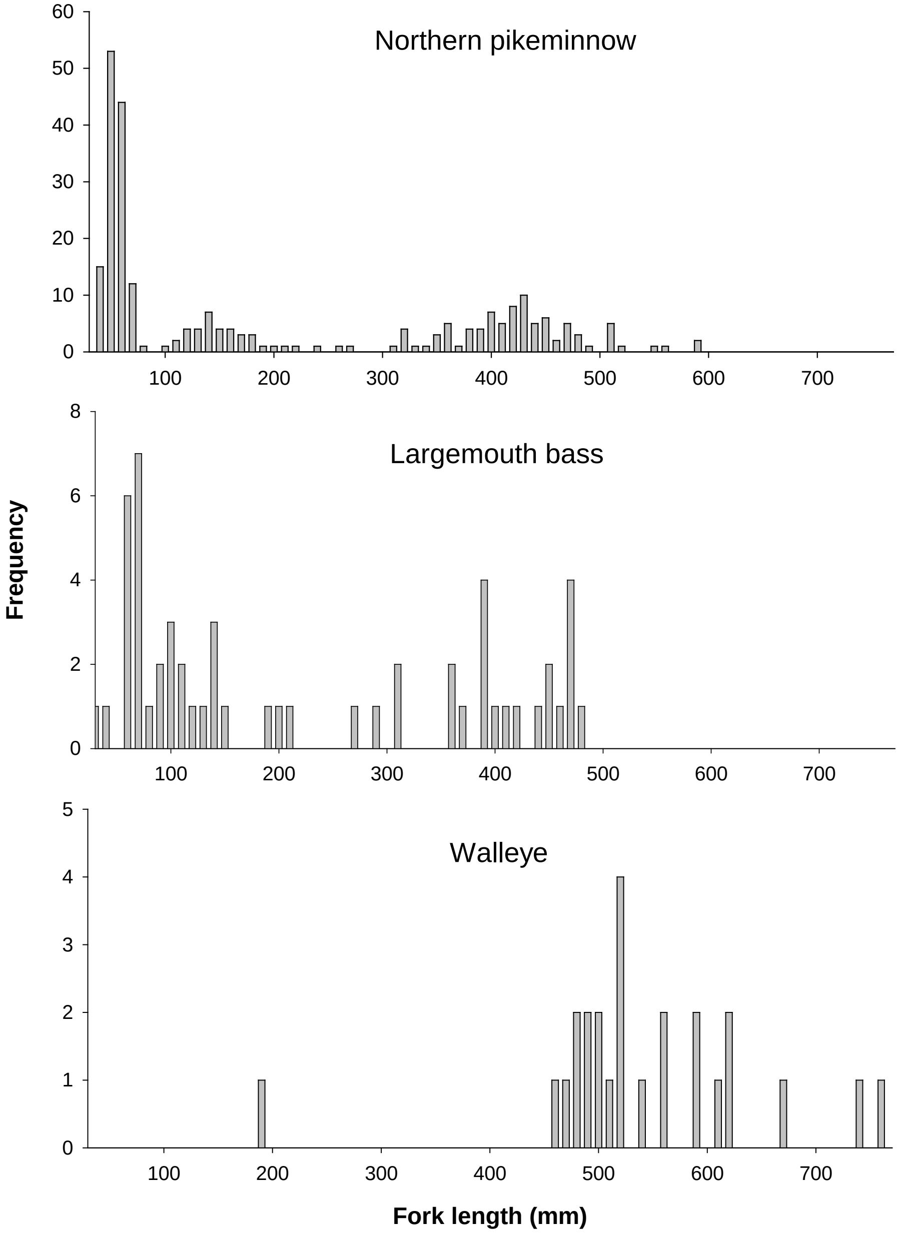

Figure 24. Length frequencies of northern pikeminnow, largemouth bass, and walleye collected with various gear types in Lookout Point Reservoir, 2011.

The total consumption of juvenile Chinook by predators in the reservoirs depends on numerous factors such as spatial and temporal overlap in predator-prey habitat, prey diversity, and predator abundance. Estimates of predator abundance in reservoirs were not available but northern pikeminnow appeared to have a high relative abundance in Lookout Point Reservoir based on our sampling efforts, whereas the relative abundance of walleye was low (Table 5). Consumption rates for predator species (number of Chinook prey/predators sampled) were highest for walleye (4/24 or 16.7%) compared to northern pikeminnow (3/75 or 4%), however, the relatively high abundance of northern pikeminnow in Lookout Point Reservoir suggest this species is the greatest predator of juvenile Chinook in the reservoir.

Other studies have found high salmonid consumption rates by northern pikeminnow in lentic habitats (Brown and Moyle 1981, Beamesderfer and Rieman 1991, Poe et al. 1991, Tabor et al. 1993, Zimmerman 1999). Northern pikeminnow were found to be the major predator of juvenile Chinook in John Day Reservoir when compared to walleye and smallmouth bass (Poe et al. 1991, Vigg et al. 1991). The highest consumption rate of all predators in that reservoir occurred in July (Vigg et al. 1991). Tabor et al. (2007) reported largemouth and smallmouth bass predation on juvenile Chinook in Lake Washington but concluded that the impact on salmonid populations was minimal.

Bass can prey on juvenile salmonids when both species occupy littoral areas that correspond to preferred bass habitat (Gray and Rondorf 1986; Tabor et al. 2007). From our distribution data, this would correspond to the time period when fry enter the reservoirs (February) to when they begin residence in deeper water (June). There is evidence that exotic black bass species have already contributed to declines in salmonid populations in Oregon (Reimers 1989) and Washington (Fritts and Pearsons 2004). The literature emphasizes that proportions of juvenile salmonids in predatory fish diet are highly variable, and dependant on abundance, water temperature, habitat utilization, and size of both predator and juvenile salmonids.

Our diet analysis may underreport the actual incidence of Chinook consumed since samples were only collected during two distinct time periods (May-June and October-November) using just two gear types that may have resulted in Chinook predation being underreported. A slightly higher percentage of fish were found in diet samples collected in the fall than in the spring. The sample size of diet samples was similar for spring (n=123) and fall (n=116), as well as sample size per predator species (except for crappie which had half as many samples in the fall as the spring). Although the difference in the proportion of prey fish items consumed between spring and fall diet samples was not statistically significant (z-test, P= 0.457, z = 0.744), we suspect smaller fish in the spring would be more likely to be missed during the processing of diet samples. The smaller size of juvenile Chinook in the spring could result in more rapid digestion by predator fish. Furthermore, our chemical digestion process can dissolve the fine bones from small fish likely biasing our sample towards larger size prey. Another potential bias was the use of gill nets for collecting predator diet samples. Predator species caught in gill nets are known to evacuate their stomach contents partially or completely while entangled in the nets (Treasurer 1998, Sutton et al. 2004). There was a significantly greater proportion of empty stomach samples from gill net samples compared to electrofishing samples (z-test, P = 0.001, z = 3.229). For these reasons, the amount of juvenile Chinook predation reported here should be considered a conservative estimate.

Conclusion and Recommended Future Directions

Chinook fry (<50 mm FL) comprise the vast majority of downstream migrants from spawning areas upstream of WVP dams (Romer et al. 2012). Historically, most fry from spawning areas above present-day dam sites would have migrated in the spring to lower river reaches, including the mainstem Willamette River, with some entering the Columbia Estuary as subyearlings (Bureau of Commercial Fisheries 1960, Zakel and Reed 1984, Mattson 1962, Schroeder et al. 2007). Currently, most fry that are progeny of adults outplanted above the dams now rear in the reservoirs for a period of approximately seven months until reservoir drawdown in the fall. The purpose of this study was to provide information on juvenile Chinook use of reservoirs and the risks and benefits of reservoir rearing to aid management decisions on future adult outplanting strategies and juvenile downstream passage.

One benefit of reservoir rearing was the rapid summer growth compared to stream-rearing juveniles and the survival advantage to adulthood larger size imparts (ISRP 2011). However, before the rearing potential of reservoirs can be fully realized, risks of reservoir rearing will need to be mitigated. Current passage conditions at WVP dams are poor (Duncan 2011) and larger fish appear to incur a higher mortality rate (Taylor 2000, Keefer et al. 2011, Zymonas et al. 2012 *in prep*). In a retrospective analysis of balloon-tag studies conducted at Columbia/Snake river dams, Skalski et al. (2002) found that as fish size increased, so did turbine passage mortality. Time spent rearing in reservoirs was also accompanied by an increase incidence of parasitic copepod infections. The effect of gill tissue damage associated with infection on the ability of juveniles to transition to a saltwater environment is currently unknown but could be detrimental to survival. We recommend this aspect of copepod infection be more fully assessed. Reservoirs also contained predator populations including non-native species, hatchery rainbow trout, and northern pikeminnow. The impact of predation on the juvenile Chinook populations has not been quantified but likely varies among reservoirs depending on the predator species present. In some reservoirs, predation is likely greater than it would otherwise be in free-flowing river reaches. This is likely the case in Lookout Point Reservoir that contains many non-native predators and northern pikeminnow. Brown and Moyle (1981) showed that northern pikeminnow predation on salmonids is much greater in lake environments compared to lotic environments. Viggs et al. (1991) reported northern pikeminnow predation to have a major impact on juvenile Chinook populations in the John Day Reservoir.

Currently, efforts are underway to improve passage survival for juvenile Chinook of all sizes through operational or structural modifications at dams. These improvements will likely take several years to accomplish. In the interim, passage survival could be improved by passing fish at a smaller size earlier in the year. This management strategy would also mitigate for the potential downside risks of copepod infection and predation associated with reservoir rearing until the impact of these risks are better known.

Acknowledgments

We would like to thank Michele Weaver from the ODFW Northern Pikeminnow Management Program for helpful details, citations, fish bone identification keys, and advice regarding diet sampling; Randy Wildman of Oregon State University for assistance with electrofishing, and; Chris Abbes, Dave Metz, Khoury Hickman, David Duckett, Kris Clemons, Shelly Goff, Mario Minder, John Elliott, and Greg Gilham, who diligently collected much of the field data. We also thank Jeff Ziller (ODFW) for the use of his boat and gear for much of the sampling this year. Chad Helms, Greg Taylor and Doug Gartletts of the U.S. Army Corps of Engineers provided access and assistance while sampling in the reservoirs. Stephanie Miller provided helpful comments on an earlier draft of this report.

References

Amundsen, P.-A., R. Kristoffersen, R. Knudsen, and A. Klemetsen. 1997. Infection of *Salmincola edwardsii* (Copepoda: Lernaeopodidae) in an age-structured population of Arctic charr—a long-term study. Journal of Fish Biology 51:1033–1040.

Baldwin, C. M., D. A. Beauchamp, and J. J. Van Tassell. 2000. Bioenergetic assessment of temporal food supply by salmonids in the Strawberry Reservoir food web. Transactions of the American Fisheries Society 129:429-450.

Barndt, S. and J. Stone. 2003. Infestation of *Salmincola californiensis* (Copepoda: Lernaeopodidae) in wild coho salmon, steelhead, and coastal cutthroat trout juveniles in a small Columbia River tributary. Transactions of the American Fisheries Society, 132,1027-1032.

Beamesderfer, R. C., and B. E. Rieman. 1991. Abundance and distribution of northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:439-447.

Boscarino, B. T., L. G. Rudstam, M. A. Minson, and E. E. Freund. 2010. Laboratory-derived light and temperature preferences of juvenile mysid shrimp, *Mysis diluviana*. Journal of Great Lakes Research 36:699-706.

Brown, L. R., and P. B. Moyle. 1981. The impact of squawfish on salmonid populations: a review. North American Journal of Fisheries Management 1:104-111.

Bureau of Commercial Fisheries. 1960. Downstream Migrant Studies South Fork McKenzie River 1957, 1959, 1960. Department of Interior Bureau of Commercial Fisheries, Portland, Oregon.

Cannon, B., R. Emig, T. A. Friesen, M. Johnson, P. Olmsted, R. K. Schroeder, C. S. Sharpe, C. A. Tinus, and L. Whitman. 2011. Work completed for compliance with the 2008 Willamette Project Biological Opinion, USACE funding:2010. Task Order: NWPPM-10-FH-05. Annual Report of Oregon Department of Fish and Wildlife (ODFW) to U.S. Army Corps of Engineers, Portland, Oregon.

Dauble, D. D., T. L. Page, and R. W. Hanf Jr. 1989. Spatial distributions of juvenile salmonids in the Hanford Reach, Columbia River. Fishery Bulletin 87:775-790.

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.

Duncan, J. P., 2011. Characterization of fish passage conditions through a Francis turbine and regulating outlet at Cougar Dam, Oregon, using sensor fish, 2009-2010: Pacific Northwest Laboratory report PNNL-20408, 172 p.

Foster, J. R. 1977. Pulsed gastric lavage; an efficient method of removing the stomach contents of live fish. The Progressive Fish Culturist 39:166-169.

Friesen, T. A., J. S. Vile, and A. L. Pribyl. 2007. Outmigration of juvenile Chinook salmon in the lower Willamette Rivier, Oregon. Northwest Science 81:173-190.

Fritts, A. L., and T. N. Pearsons. 2004. Smallmouth bass predation on hatchery and wild salmonids in the Yakima River, Washington. Transactions of the American Fisheries Society. 133: 880-895.

Frost, C. N. 2000. A key for identifying preyfish in the Columbia River based on diagnostic bones. U.S. Geological Survey, Cook, WA..

Garland, R. D., K. E. Tiffan, D. W. Rondorf, and L. O. Clark. 2002. Comparison of subyearling fall Chinook salmon's use of riprap revetments and unaltered habitats in Lake Wallula of the Columbia River. North American Journal of Fisheries Management 22:1283-1289.

Gray, G. A., and D. W. Rondorf. 1986. Predation of juvenile salmonids in Columbia basin reservoirs. Pages 178-185 *in* G.E. Hall and M.J. VanDenAvyle, editors. Reservoir Fisheries Management: Strategies for the 80s. American Fisheries Society, Southern Division, Reservoir Committee, Bethesda, Maryland.

Handeland, S. O., Wilkinson, E., Sveinsbø, B. , McCormick S.D. and Stefansson, S.O. 2004. Temperature influence on the development and loss of seawater tolerance in two fast-growing strains of Atlantic salmon Aquaculture 233:513-529.

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.

Hasselman, R., and R. Garrison. 1957. Studies on the squawfish *Ptychocheilus Oregonense* in Lookout Point and Dexter reservoirs, 1957. U.S. Fish and Wildlife Service report. 41 p.

Hicks, M. 2000. Evaluating standards for protecting aquatic life in Washington's surface water quality standards. Draft discussion paper and literature summary. Revised 2002. Washington State Department of Ecology, Olympia, WA..

Hoar, W.S., 1988. The physiology of smolting salmonids. *In* Hoar, W. S. Randall, D. J., editors. Fish Physiology, Bol. XIB. Academic Press, NY, pp.

Independent Science Group (ISG). Return to the River Report. 1996. Document number 96-6, Northwest Power Planning Council Independent Scientific Advisory Board, Portland, OR.

Independent Scientific Review Panel (ISRP). 2011-26. Review of the Research, Monitoring, and Evaluation Plan and Proposals for the Willamette Valley Project. Northwest Power and Conservation Council, Portland, Oregon. http://www.nwcouncil.org/library/report.asp?d=648.

Ingram P., and L. Korn. 1969. Evaluation off fish passage facilities at Cougar Dam on the South Fork McKenzie River in Oregon. Fish Commission of Oregon, Research Division, Portland.

Kabata, Z., and B. Cousens. 1973. Life cycle of *Salmincola californiensis* (Dana 1852) (Copepoda: Lernaeopodidae). Journal of the Fisheries Research Board Canada. 30: 881-903.

Keefer, M.L., G.A. Taylor, D.F. Garletts, C.K. Helms, G.A. Gauthier, T.M. Pierce, and C.C. Caudill. 2011. Reservoir entrapment and dam passage mortality of juvenile Chinook salmon in the Middle Fork Willamette River. Ecology of Freshwater Fish. pp. 1-13.

Keefer, M. L., G. A. Taylor, D. F. Garletts, C. K. Helms, G. A. Gauthier, T. M. Pierce and C. C. Caudill. 2012. High-head dams affect downstream fish passage timing and survival in the Middle Fork Willamette River. River Research and Applications: online publication DOI: 10,1002/rra.1613.

Light, R. W., P. H. Adler, and D. E. Arnold. 1983. Evaluation of gastric lavage for stomach analyses. North American Journal of Fisheries Management. 3:81-85.

Lister, D. B., and H. S. Genoe. 1970. Stream habitat utilization by cohabitating underyearlings of chinook (*Oncorynchus tshawytscha*) and coho (*O. kisutch*) in the Big Qualicum River, British Columbia. Journal of the Fisheries Research Board of Canada 27:1215-1224.

Mathur, D. 1972. Seasonal food habits of adult white crappie, Pomoxis annularis Rafinesque, in Conowingo Reservoir. American Midland Naturalist, 87:236-241.

Mattson, C. R. 1962. Early life history of Willamette River spring Chinook salmon. Fish Commission of Oregon Report, Portland, Oregon.

McCormick, S.D., 1994. Loss of smolt characteristics in hatchery and stream-reared Atlantic salmon. In: Mackinlay, D.D. (Ed.), High Performance Fish, Proceedings of an International Fish Physiology Symposium, Vancouver, Canada, 16-21 July, 1994, pp. 51-56.

Monzyk, F. R., J. D. Romer, R. Emig, and T. A. Friesen. 2011a. Pilot head-of-reservoir juvenile salmonid monitoring. Annual Report of Oregon Department of Fish and Wildlife (ODFW) to U.S. Army Corps of Engineers, Portland, Oregon.

Monzyk, F. R., J. D. Romer, R. Emig, and T. A. Friesen. 2011b. Life-history characteristics of juvenile spring Chinook salmon rearing in Willamette Valley reservoirs. Annual Report of Oregon Department of Fish and Wildlife (ODFW) to U.S. Army Corps of Engineers, Portland, Oregon.

Nagasawa, K, and S. Urawa. 2002. Infection of Salmincola californiensis (Copepoda: Lernaeopodidae) on juvenile Masu salmon (*Oncorhynchus masou*) from a stream in Hokkaido. Bulletin of the National Salmon Resources Center 5:7-12.

NMFS. 2008. 2008-2023 Willamette River Basin Project Biological Opinion. NOAA’s National Marine Fisheries Service, Northwest Region, Seattle, WA. F/NWR/2000/02117.

Parrish, J. K., K. Haapa-aho, W. Walker, M. Stratton, J. Walsh, and H. Ziel. 2006. Small-bodied and Juvenile Fishes of the Mid-Columbia Region Including Keys to Diagnostic Otoliths and Cranial Bones. Draft Version, March 2006. University of Washington, Seattle WA.USA.

Pawaputanon, K. 1980. Effects of parasitic copepod, *Salmincola californiensis* (dana, 1852) on juvenile sockeye salmon, *Oncorhynchus nerka*. Dissertation. The University of British Columbia. Vancouver.

Petersen, J. H., and D. L. DeAngelis. 1992. Functional response and capture timing in an individual-based model: predation by northern squawfish (*Ptychocheilus oregonensis*) on juvenile salmonids in the Columbia River.

Poe, T. P., H. C. Hansel, S. Vigg, D. E. Palmer, and L. A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:405-420.

Poulin, R., M. A. Curtis, and M. E. Rau. 1991. Size, behaviour, and acquisition of ectoparasitic copepods by brook trout, *Salvelinus fontinalis*. Oikos 61:169-174.

Richter A., and S. A. Kolmes. 2005. Maximum temperature limits for Chinook, coho, and chum salmon, and steelhead trout in the Pacific Northwest. Reviews in Fisheries Science 13:23-49.

Reimers, P. E. 1989. Management of wild and hatchery coho salmon in the Tenmile Lakes system. Oregon Department of Fish and Wildlife, Information Report 89-5, Portland.

Romer, J. D., F. R. Monzyk, R. Emig, and T. A. Friesen. 2012. Juvenile salmonid outmigration monitoring at Willamette Valley Project reservoirs. Annual Report of Oregon Department of Fish and Wildlife (ODFW) to U.S. Army Corps of Engineers, Portland, Oregon.

Schroeder, R.K., K.R. Kenaston, and L.K. McLaughlin. 2007. Spring Chinook salmon in the Willamette and Sandy rivers. Oregon Department of Fish and Wildlife Progress Reports 2006-2007, Project Number F-163-R-11/12, Fish Division, Salem.

Skalski, J. R., D. Mathur, and P. G. Heisey. 2002. Effects of turbine operating efficiency on smolt passage survival. North American Journal of Fisheries Management 22: 1193-1200.

Sutton, T. M., M. J. Cyterski, J. J. Ney and M. C. Duval. 2004. Determination of factors influencing stomach content retention by striped bass captured using gillnets. Journal of Fish Biology, 64: 903–910.

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.

Tabor, R. A., and R. M. Piaskowski. 2002. Nearshore habitat use by juvenile Chinook salmon in lentic systems of the Lake Washington Basin, annual report, 2002. U.S. Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Lacey, Washington.

Tabor, R. A., B. A. Footen, K. L. Fresh, M. T. Celedonia, F. Mejia, D. L. Low, and L. Park. 2007. Smallmouth bass and largemouth bass predation on juvenile Chinook salmon and other salmonids in the Lake Washington Basin. North American Journal of Fisheries Management 27:1174-1188.

Tabor, R. A., K. L. Fresh, R. M. Piaskowski, H. A. Gearns, and D. B. Hayes. 2011. Habitat use by juvenile Chinook salmon in the nearshore areas of Lake Washington: effects of depth, lakeshore development, substrate, and vegetation. North American Journal of Fisheries Management 31:700-713.

Taylor, G. 2000. Monitoring of Downstream Fish Passage at Cougar Dam in the South Fork McKenzie River, Oregon 1998-00 Final Report, Oregon Department of Fish and Wildlife, Springfield OR. pp.1-9.

Tiffan, F., R. D. Garlands, and D. W. Rondorf. 2002. Quantifying flow-dependent changes in subyearling fall Chinook salmon rearing habitat using two-dimensional spatially-explicit modeling. North American Journal of Fisheries Management 22:713-726.

Treasurer, J. W. 1988. Measurement of regurgitation in feeding studies of predatory fishes. Journal of Fish Biology 33:267–271.

US Army Corps of Engineers. 2000. Biological assessment of the effects of the Willamette River Basin Flood Control Project on listed species under the Endangered Species Act. Final document, submitted to National Marine Fisheries Service, U.S. Fish and Wildlife Service.

US Army Corps of Engineers. 2010. Water temperature string reports by project. Available: http://www.nwd-wc.usace.army.mil/tmt/documents/ops/ temp/string_by_project.html (February 2010).

Vaughan, G. E., and D. W. Coble. 1975. Sublethal effects of three ectoparasites on fish. Journal of Fish Biology 7:283-294.

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.

Wydoski, R. S., and R. L. Whitney. 2003. Inland fishes of Washington, 2nd edition. University of Washington Press, Seattle, WA.

Zakel, J. C., and D. W. Reed. 1984. Downstream migration of fish at Leaburg Dam, McKenzie River, Oregon, 1980 to 1983. Oregon Department of Fish and Wildlife Information Reports 84-13. Fish Division, Research and Development Section, Corvallis.

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

Zymonas, N.D., J.V. Tranquilli, and M. Hogansen. 2012 *in prep*. Monitoring and evaluation of impacts to bull trout (Salvelinus confluentus) and spring Chinook salmon (*Oncorhynchus tshawytscha*) in the South Fork McKenzie River from construction of water temperature control facilities at Cougar Dam, Oregon. Final Report to U.S. Army Corps of Engineers, Portland, Oregon. Oregon Department of Fish and Wildlife, Corvallis.

Appendix

Six nearshore trap designs were compared in the reservoirs from April through July, 2011 (Table A-1). Traps were located in a series approximately 20 m apart in a randomly selected shoreline area in the upper end of reservoirs. We re-arranged the sequence traps were placed along the shoreline (upstream/downstream) to avoid potential bias. Criteria for the most efficient design was based on both catch rates of subyearling Chinook and the efficiency of deploying traps in all habitat types encountered in reservoirs.

Table A-1 shows the dimensions, materials, and other characteristics of the various trap designs. All traps were made with 1/8" mesh material and were fished with a 3' deep lead net set perpendicular to shore leading from the bank to the trap opening. Trap catches were non-normally distributed so comparisons of fry catch were made with a Kruskal-Wallis test with Tukey tests for multiple comparisons ($\alpha = 0.05$). The initial four trap designs we compared from late April to mid-May were a large PVC frame, a sinking rebar frame, sinking rebar V-slot trap, and a floating wood-frame V-slot trap. The large PVC trap caught significantly more fry than the rebar (non-V-slot) and wood trap designs (Table A-2). Other trap designs were incorporated into the study as new designs were developed. These included a floating box trap made with a PVC frame with a bottom fyke (tongue) net attached to the mouth. We could not detect a significant difference between this trap design and the Large PVC trap design (P=0.520). We also compared a small version of an Oneida trap (with fyke and a lead nets) to the PVC tongue and could not detect a significant difference (P=0.058) between the floating box trap and the mini-Oneida. Based on these results and the efficiency of deploying floating box traps, this design was chosen for further assessment of fry distribution in the reservoirs.

Table A-1. Description of trap designs used in comparison of fry catch in nearshore habitat.

Trap type	Dimension (WxDxL) in meters	Frame material	Mesh material	Opening	Set type
Large PVC	3x3x4	PVC	Nylon	3" circle	Sink
Rebar	2x2x3	rebar	Polyethylene	2" circle	Sink
Rebar V-slot	2x3x2	rebar	Polyethylene	2" slot	Sink
Wood	2x3x2	wood	metal screen	2" slot	Float
Mini Oneida	4x4x4	none	Nylon	3" circle	Float
Floating box trap	3x3x4	PVC	Nylon	2" circle	Float

Table A-2. Results of pairwise multiple comparisons procedure (Tukey Test) for the first round of trap comparisons showing Large PVC trap with significantly better catch compared to other designs. Overall Kruskal-Wallis test was significant at *P*=0.003.

Comparison	Diff of Ranks	q	*P*<0.05
Large PVC vs Rebar	194.5	4.565	Yes
Large PVC vs Wood	158	3.709	Yes
Large PVC vs Rebar V-slot	119.5	2.805	No
Rebar V-slot vs Rebar	75	1.76	No
Rebar Vslot vs Wood	38.5	0.904	Do Not Test
Wood vs Rebar	36.5	0.857	Do Not Test

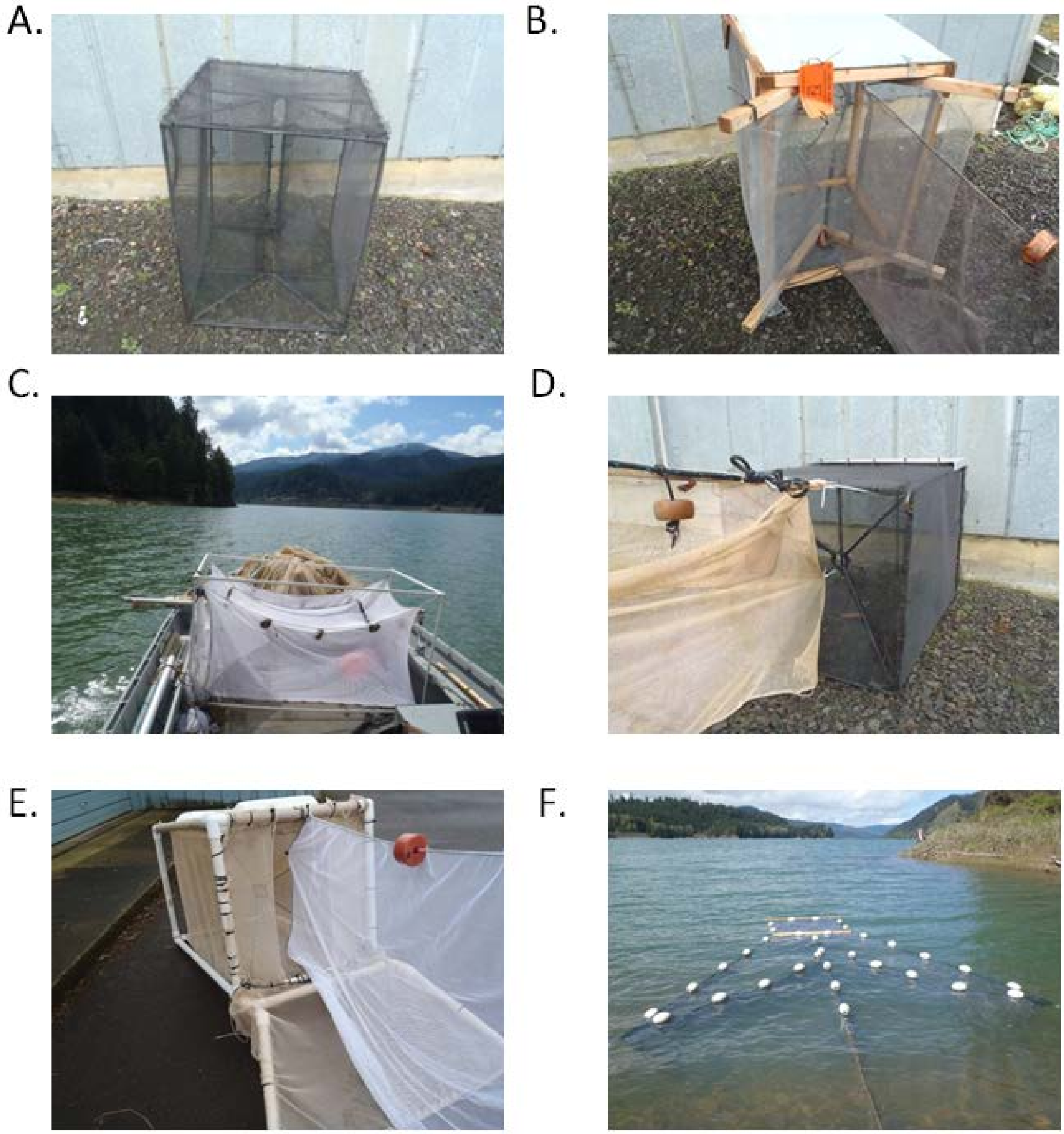

Figure A-1. Trap designs used to compare fry catch in reservoirs, 2011. Traps are Rebar V-slot (A), Floating Wood (B), Large PVC (C), Rebar (D), Floating box trap (E), and miniature Oneida (F).