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

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Summary

In this report we investigate several aspects of juvenile spring Chinook salmon *Oncorhynchus tshawytscha* life history and rearing in select Willamette Valley Project (WVP) reservoirs to aid in the development of downstream passage options. In the first section, we assess the distribution of juvenile Chinook salmon in reservoirs. We provide information on the longitudinal distribution (head-of-reservoir to dam) in the spring of subyearlings in Foster, Cougar, and Lookout Point reservoirs. We continued assessing subyearling parr distribution in Lookout Point Reservoir through the summer and fall. The second section compares fish size and growth rates between stream-rearing and reservoir-rearing subyearling Chinook salmon. We compare subyearling growth rates in Detroit, Cougar, Lookout Point, and Fall Creek reservoirs. In the third section, we compare the infection prevalence and intensity by the parasitic copepod *Salmincola californiensis* among salmonid species rearing in reservoirs and streams.

Distribution- The longitudinal distribution of Chinook salmon subyearlings in the spring was assessed with floating box traps and small Oneida Lake traps set in nearshore habitat of reservoirs. Subyearlings were collected in all nearshore areas but catch rates were greater in the upper ends of reservoirs where natal streams enter, especially early in the spring. In Foster Reservoir catch was greatest in the middle and upper portion of the reservoir, a different distribution than in 2013 when we observed greater catch in the lower third of the reservoir in the spring. Small sample sizes in both years may be one reason for the annual variability observed in Foster Reservoir. Juvenile steelhead *O. mykiss* in Foster Reservoir were more abundant in the lower reservoir, similar to 2013 results. Small subyearling Chinook salmon in Cougar Reservoir were more abundant in the upper reservoir throughout the spring but dispersed farther towards the dam each consecutive month from April – June, similar to previous years. In April, 79% of all subyearlings collected in Cougar Reservoir were in the upper third of the reservoir and only 7% in the lower. By June, the proportions in the upper and lower thirds of the reservoir were 43% and 40%, respectively. Most subyearlings caught in lower Cougar Reservoir were in the East Fork arm. The proportion of total monthly catch in the forebay was 1.5% in April and increased to 3.4% in June, similar to previous years. In Lookout Point Reservoir, subyearling Chinook salmon in the spring had a similar overall distribution as in Cougar Reservoir with most subyearlings located near the head of the reservoir. In May 79% of the subyearlings collected were in the upper reservoir and only 2% in the lower reservoir. In the summer (July-August), subyearling parr in Lookout Point Reservoir demonstrated a bimodal distribution pattern with greater catch in the forebay and near the upper reservoir. By the fall, subyearlings shifted their distribution towards the lower reservoir with the greatest catch in the forebay. Fall parr distribution was similar to that observed in 2013 and occurred prior to major changes to reservoir inflows or outflows, suggesting a natural downstream movement behavior in the fall that is common among spring Chinook populations.

Growth- Growth was more rapid for subyearling Chinook salmon rearing in reservoirs compared to streams. Fall parr in Lookout Point Reservoir were the largest, averaging 208 mm FL, but not significantly different from Fall Creek parr (Kruskal-Wallis one-way ANOVA on ranks; *P*>0.05). Fall parr were intermediate in size (mean=179 mm) in Detroit

Reservoir and significantly smaller than fish in Lookout Point and Fall Creek reservoirs. Fall parr in Cougar Reservoir were significantly smaller (mean=134 mm) than fish in all other reservoirs (Kruskal-Wallis one-way ANOVA on ranks; $P<0.05$). Mean size of fall parr in rivers (South Santiam, North Santiam, South Fork McKenzie, and Middle Fork Willamette) ranged from 81-101 mm. Growth rate for reservoir-rearing subyearlings was slowest in Cougar Reservoir at 0.61 mm/d and the fastest in Detroit Reservoir at 0.94 mm/d. Growth rate was 0.86 mm/d in Lookout Point and 0.71 mm/d in Fall Creek Reservoir, indicating that the larger size of subyearlings from these reservoirs is more a function of early reservoir entrance timing that allows more time for growth rather than a superior growth rate.

Copepod Infection- Trends in infection prevalence and intensity by the freshwater parasitic copepod *S. californiensis* among *Oncorhynchus* species rearing in reservoirs and streams were similar to results found last year, except for Fall Creek Reservoir where intensity was less. Parasitic copepods were more prevalent on reservoir-rearing fish than stream-rearing fish. Also, copepods tended to be more common in the brachial cavity of reservoir fish compared to stream-rearing fish. We observed an increase in prevalence each month (June-December) for reservoir-rearing subyearling Chinook salmon but the trend was not evident among other salmonid species in reservoirs or stream-rearing Chinook salmon. Copepod infection prevalence among reservoirs ranged from 74-94% in the fall for subyearling Chinook salmon. Infection intensity of reservoir-rearing Chinook salmon also increased each month. In previous years, subyearlings in Fall Creek Reservoir had the greatest infection intensity among WVP reservoirs by fall, but that was not evident in 2014. Copepod infection intensity of Chinook salmon in Fall Creek Reservoir (median=4) was similar to that in Detroit (median=5).

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 reservoirs and dams has one of the most significant adverse effects on both species and their habitat. The BiOp detailed specific actions, termed Reasonable and Prudent Alternative (RPA) measures that would "…allow for survival of the species with an adequate potential for recovery, and avoid destruction or modification of critical habitat". Several RPA measures 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 the life-history of juvenile Chinook salmon in WVP reservoirs will inform future management actions needed for population recovery. Currently, information is limited regarding juvenile Chinook salmon use of reservoirs, including seasonal distribution, migration rate, predator/prey interactions, growth rates, and the effect of reservoir rearing on parasites loads experienced by juveniles. In 2010, we began investigations in Cougar and Lookout Point reservoirs to further our understanding of these issues. In 2011 and 2012, we expanded our scope of sampling to include Detroit Reservoir and refined our techniques to address the critical uncertainties. In 2013, we included Foster Reservoir and investigated several aspects of juvenile Chinook salmon and steelhead life-history.

In this study, our objectives were to: 1) assess seasonal changes in the longitudinal distribution of juvenile Chinook salmon in reservoirs; 2) compare growth rates between stream-rearing and reservoir-rearing juvenile Chinook salmon; and 3) assess and compare the prevalence and intensity of infection by the parasitic copepod *Salmincola californiensis* in salmonid species rearing in reservoirs and streams. We report our findings of each of these objectives in separate sections of this report.

SECTION 1: JUVENILE CHINOOK SALMON DISTRIBUTION IN RESERVOIRS

Background

Improvements to downstream fish passage require an understanding of juvenile Chinook salmon entrance timing and distribution in reservoirs. Previous research demonstrated that the majority of juvenile Chinook salmon enter WVP reservoirs at the fry life-stage (Bureau of Commercial Fisheries 1960; Monzyk et al. 2011a; Keefer et al. 2012; Romer et al. 2012, 2013, 2014) at an average fork length (FL) of 35 mm (Monzyk et al. 2011a; Romer et al. 2012, 2013, 2014). Although it is clear that the majority of juveniles enter the reservoirs as fry, less is known about their distribution and dispersion patterns within reservoirs at different life stages. Habitat preferences, swimming ability of fish, and the location of natal streams all likely influence distribution patterns in reservoirs. Small subyearling "fry" (<50 mm FL) were closely associated with shallow nearshore habitat in the spring and not found in deeper waters until reaching a larger size (Monzyk et al. 2012). Tabor et al. (2007, 2011) found a similar result with fall Chinook salmon fry in Lake Washington; those fish were also found in shallow (<1 m) littoral habitat and only ventured into deeper waters as their size increased. This pattern was 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).

Small subyearlings in the spring were more abundant near the head of Cougar, Detroit, and Lookout Point reservoirs, where natal streams enter the reservoirs (Monzyk et al. 2011a, 2012, 2013). Subyearlings in Foster Reservoir showed an opposite pattern in 2013 with more fish in the lower portion of the reservoir (Monzyk et al. 2014). Foster Reservoir is smaller and shallower than other WVP reservoirs, with occasional reservoir-wide flow when pool elevations are still relatively low. These characteristics may aid in dispersing fry from the confluence of their natal stream towards the dam. In Cougar Reservoir, we observed greater dispersion towards the dam with each consecutive month from April – June (Monzyk et al. 2013, 2014). Given the poor swimming ability of newly emergent fry and the fact that reservoirs are refilling in the spring, it is not surprising that small subyearlings in large reservoirs would be more abundant near the entrance of their natal streams in early spring. Similar distribution patterns were observed for ocean-type Chinook fry in Lake Washington (Tabor et al. 2006). Fry dispersing further along the longitudinal axis of the reservoir through time would be expected as a function of random movements associated with feeding and improved swimming ability as fish grow.

The shift to deeper offshore habitat by parr is partly attributed to changes in water temperature through the year. Ingram and Korn (1969) observed that most juvenile Chinook salmon captured with gill nets in Cougar Reservoir were in the upper 9 m (30 ft) of the water column during late spring, but as surface temperatures increased in the summer, most fish were caught at depths of 9-14 m (30-45 ft). Fish returned to the upper 4.6 m of the water column in November as water temperatures decreased. We conducted similar gill netting efforts in Lookout Point and Detroit reservoirs from 2011-2013 and found similar patterns in vertical distribution. Most parr descended into deeper water in late summer when water temperatures reached a maximum and did not return to the surface until the fall when surface temperatures cooled (Monzyk et al. 2012, 2013, 2014).

In this report, we assessed longitudinal distribution of subyearlings in the spring, summer and fall. We continued our efforts to assess changes in longitudinal distribution along nearshore habitat during spring (March-June) in Foster, Cougar, and Lookout Point reservoirs. We compared subyearling nearshore distributions among years and analyzed interannual biological and environmental differences. We provide greater detail of subyearling Chinook distribution in the cul-de-sac of the Cougar Reservoir forebay as part of the Portable Floating Fish Collector (PFFC) evaluation. In addition, this year we assessed longitudinal distribution of parr in Lookout Point Reservoir during the summer and fall.

Methods

Distribution of subyearling Chinook salmon in nearshore habitat of reservoirs was assessed in the spring with floating box traps and small Oneida Lake traps. In the summer and fall, gill nets were used to assess distribution in the pelagic regions of Lookout Point Reservoir (Table 1-1).

Table 1-1. Sampling by gear type and location to assess juvenile Chinook salmon distribution in WVP reservoirs, 2014.

		Reservoir		
Gear type	Reservoir zone	Foster	Lookout Point	Cougar
Box trap	Nearshore	√	√	√[a]
Small Oneida	Nearshore	√	√	√
Gill net	Pelagic		√	

[a] Also conducted finer scale distribution assessment in cul-de-sac of forebay near PFFC.

Subyearling Nearshore Distribution

Sampling was conducted at least every two weeks from February-June in Foster Reservoir, March-June in Lookout Point Reservoir, and April-June in Cougar Reservoir in accordance with expected fry entrance in each reservoir (Romer et al. 2014). When possible, we conducted weekly sampling to increase sample sizes and precision.

Two trap types were used to capture subyearlings in nearshore habitat: floating box traps and small Oneida Lake traps. 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 (Figure 1-1). A 51-mm throat opening allowed fry and small parr to enter but excluded larger fish. We used a 5-m lead net (0.91 m deep) extending perpendicular from 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. Small Oneida Lake traps were larger and fished farther from shore. Small Oneida traps consisted of a 1.2 x 1.2 x 1.2 m net box constructed with 0.42-cm delta mesh with a 102-mm throat opening. A 20-m lead net (1.8 m deep, 0.42-cm delta mesh) extended from the shore to the throat opening and fykes on each side of the box redirected fish back to the throat opening (Figure 1-1). We initiated small Oneida traps sets when fish would be expected to begin moving farther offshore.

A stratified random sampling design was used for daily trap placement to ensure representative sampling throughout the reservoirs. Reservoirs were stratified into lower, middle, and upper sections (forebay to head of reservoir). For most reservoirs, section lengths were roughly a third of the longitudinal axis length. The exception was Foster Reservoir where the Middle and South Santiam arms comprised the upper section and accounted for roughly half the reservoir length at full pool. Within each reservoir section, random shoreline areas (approximately 0.4 km long) were selected for trap placement and a site was chosen within the area that would allow for easy attachment of the lead net to the bank. Nine areas were randomly selected each day (three per section) for placement of floating box traps and three areas were selected (one per section) for small Oneida trap placement. In Foster Reservoir, 10 floating box traps were set each day (three per section) with the additional trap set in the Middle Santiam arm. All traps were fished overnight for approximately 24 h. Captured subyearling Chinook salmon were anesthetized (50 mg/L tricaine methanesulfate [MS-222]) and enumerated for each trap. We measured fork length (nearest mm) on a minimum of 15 randomly selected fish per trap. Shoreline depth, substrate type (silt/sand, gravel, or cobble/rock), and presence of vegetation were recorded at each floating box trap location. Depth was measured at the mouth of the trap and categorized as shallow (0.5 to1.5 m) or deep (>1.5 m). Subyearling catches were compared among habitat categories with Kruskal-Wallis one-way ANOVA tests ($\alpha = 0.05$).

Coordinates were recorded for each trap set and used to estimate distance from the head of the reservoir. Because fry and small parr were closely associated with nearshore habitat in the spring, we believed measuring subyearling dispersion in terms of shoreline distance was appropriate. Each bank of a reservoir (at full pool) was digitized using ArcGIS and trap coordinates were overlaid on the appropriate digitized shoreline to calculate distance of the trap to the dam. Because of unequal shoreline lengths for each bank, trap distances were standardized as a percentage of total distance to the dam. The monthly distribution of subyearlings was evaluated by plotting the cumulative proportion of subyearlings caught in floating box traps to the shoreline distance to the dam.

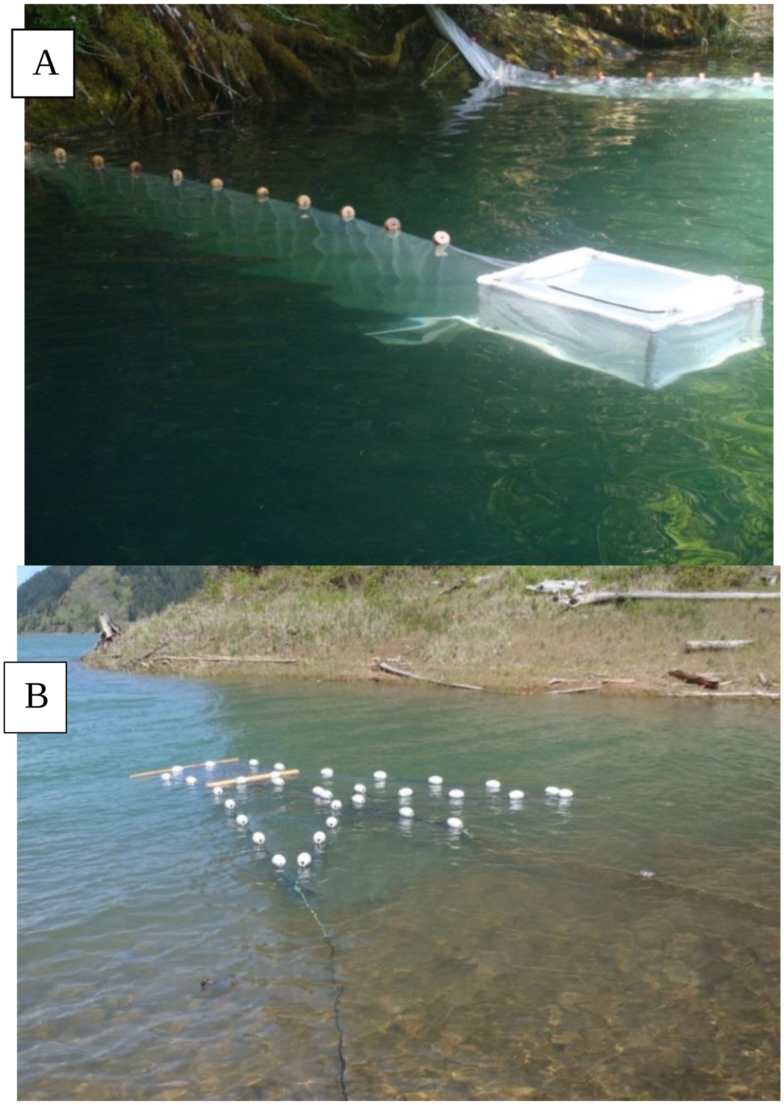

Figure 1-1. Floating box trap (A) and small Oneida Lake trap (B) used to collect subyearling Chinook salmon in reservoirs, 2014.

Cougar Forebay Monitoring.-We estimated the proportion of total monthly catch that occurred within the forebay of Cougar Reservoir to provide an estimate of number of subyearlings potentially available for downstream passage through the dam. The forebay was defined as the shoreline within the boat-restricted zone (log boom). Because we randomly placed traps in the reservoir, the proportion of monthly trap sets that occurred within the forebay was not always equal to the proportion of total shoreline length comprised by the forebay. Therefore, we standardized the percent of forebay catch as:

$$F = \frac{C_f}{C_T}\left(\frac{\rho_f}{\rho_s}\right) \times 100$$

Where C_f is the monthly catch in the forebay, C_T is the total monthly catch, ρ_f is the proportion of total shoreline length comprised by the forebay, and ρ_s is the proportion of total monthly trap sets occurring in the forebay.

We set additional floating box traps in the cul-de-sac of the forebay from 22 April-27 June to monitor distribution of subyearlings around the Portable Floating Fish Collector (PFFC). Nets were set at fixed nearshore locations around the PFFC: one each on the east and west side of the Water Temperature Control tower and one on the east side of the island located in front of the tower. Beginning in May we set an additional trap on the west side of the island. The traps were fished daily. All juvenile Chinook salmon captured in these traps were marked and released for possible recapture in the PFFC. Fish <65 mm FL were caudal fin-clipped and fish ≥ 65mm FL were PIT-tagged. For this report, we summarize the catch per unit effort by month for each trap.

Parr Longitudinal Distribution

We evaluated longitudinal distribution of Chinook salmon parr during the summer (July-August) and fall (October-November) in Lookout Point Reservoir. Gill nets were set at six sampling areas evenly spaced apart by approximately three km from the head-of-reservoir to the dam (Figure 1-2). Two nets approximately 170 m apart were set off the dam face in area A1. In each remaining area (A2-A6) one gill net was set at a fixed location. To increase sample sizes, we supplemented sampling in these areas beginning in October by systematically setting a 'rover' net across the reservoir from the fixed location. We selected an area for placement of the 'rover' net each day, ensuring nearly equal supplemental sampling in each area each month (Figure 1-2).

Gill nets were 24.4 m long by 4.6 m deep (80 x 15 ft), consisting of four 6.1-m panels with square mesh sizes of 9.5, 12.7, 19.1, and 25.4 mm. All nets were set off of steep banks to mimic the bank slope of the dam face. The depth we set nets each month was based on water temperatures and juvenile Chinook salmon vertical distribution patterns we previously assessed (Monzyk et al. 2014). During July and August, nets were set with the top (float line) 9.1 m (30 ft) deep using net suspension methods of Ingram and Korn (1967). In October we started the month with nets at 15.2 m and transitioned to the surface as water temperatures decreased. In November all nets were set on the surface. Nets were deployed mid-month and fished for 24 h during approximately eight overnight sets per month. Each day we attempted to set nets at the same depth. However, in areas where depths were insufficient (usually in the shallower upper reservoir), we identified the deepest location and set nets near the bottom.

We counted juvenile Chinook salmon captured in each net and measured fork length to the nearest mm. Fish were inspected for the presence of adipose fins to distinguish between hatchery and natural origin (adipose-clipped hatchery Chinook salmon were released in the forebay and head-of-reservoir on 05 June). To determine if distribution differed between natural and hatchery parr, we compared their proportional catch among areas each season with goodness-of-fit tests ($\alpha = 0.05$) and if no differences were detected, data were combined for further analysis. Differences in catch among the reservoir sampling areas were compared each season with Kruskal-Wallis one-way ANOVA on ranks, with Dunn's multiple comparison test (α = 0.05). We compared size of parr among sampling areas with one-way ANOVA, with Tukey's multiple comparison test (α = 0.05).

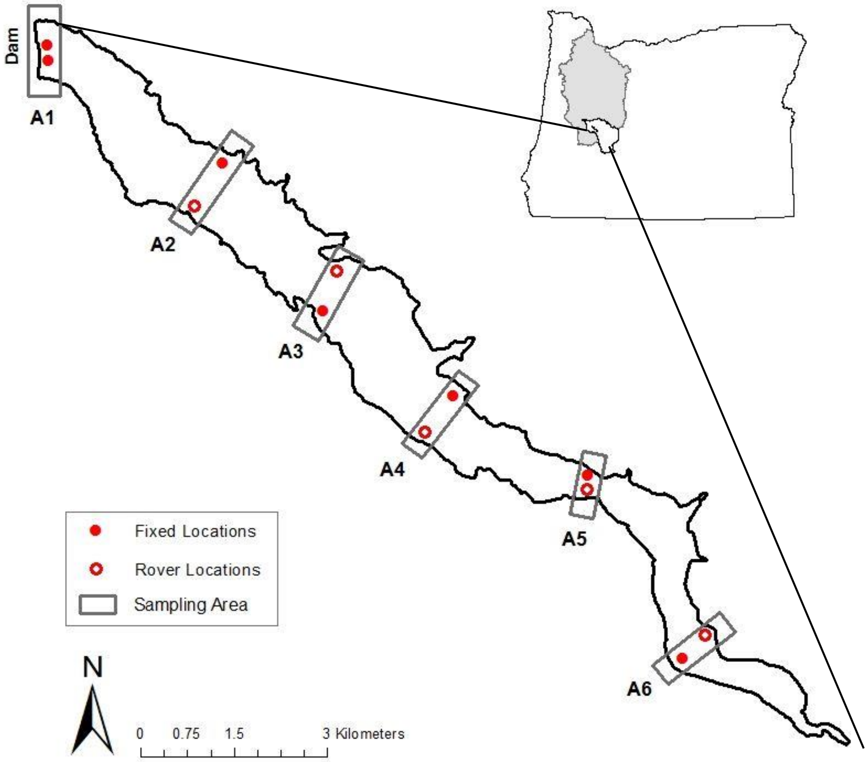

Figure 1-2. Location of gill net sets in Lookout Point Reservoir, 2014. Closed circles were fixed locations. Open circles represent locations for a single 'rover' net that was systematically set at one of the locations on a daily basis beginning in October.

Results

Subyearling Nearshore Distribution

Trapping effort to assess distribution was similar among reservoirs, but catch of subyearling Chinook salmon differed (Table 1-2). In Foster Reservoir we deployed 526 traps from 19 February to 12 June and captured 498 subyearlings. No Chinook salmon were caught in June (24 sets), so we were only able to assess distribution from February-May. Total catch was over an order of magnitude higher in Cougar Reservoir with 5,761 subyearlings captured from 492 trap sets from 01 April to 27 June. In Lookout Point Reservoir, 444 traps were deployed from 05 March to 20 June with 1,697 subyearlings collected. Several incidental species were also captured in nearshore traps in each reservoir (Appendix Table A-1).

Table 1-2. Number of nearshore trap sets in each reservoir, 2014. Number of subyearling captured in parentheses.

	Reservoir		
Gear type	Foster	Cougar	Lookout Point
Box trap	406 (288)	423 (3,835)	390 (650)
Small Oneida	120 (210)	69 (1,940)	54 (1,047)

Subyearlings were collected throughout the nearshore habitat of reservoirs. With the exception of Foster Reservoir, trap catches were greater in the upper end of reservoirs where natal streams enter, especially early in the spring (Figure 1-3). Subyearlings were smaller in the upper reservoir due to the continued influx of newly emergent fry from upstream (Table 1-3). Small Oneida Lake traps fished farther offshore and generally caught larger subyearlings than floating box traps (Table 1-3).

Table 1-3. Mean fork length (SE) of subyearling Chinook caught in floating box traps and small Oneida traps by month and reservoir section for Cougar, Foster, and Lookout Point reservoirs, 2014.

			Reservoir Section		
Reservoir	Month	Gear type	Lower	Middle	Upper
Cougar	April	Box trap	37.8 (0.48)	36.2 (0.26)	36.2 (0.1)
	May	Box trap	41.2 (0.49)	41.5 (0.4)	40.1 (0.2)
		Small Oneida	52.1 (1)	45.8 (0.81)	45.0 (0.68)
	June	Box trap	50.7 (0.75)	46.2 (1.04)	46.9 (0.39)
		Small Oneida	60.0 (0.62)	54.6 (0.58)	54.9 (0.54)
Foster	February	Box trap	38.1 (0.49)	36.9 (0.57)	36.8 (0.66)
		Small Oneida			
	March	Box trap	41.8 (0.9)	41.9 (0.68)	40.2 (0.68)
		Small Oneida	39.0	45.5 (2.7)	37.7 (1.76)
	April	Box trap	44.9 (3.19)	44.8 (1.74)	38.5 (0.65)
		Small Oneida	48.9 (2.11)	53.6 (2.47)	53.1 (1.6)
	May	Box trap	42.4 (1.21)	41.7 (2.03)	45.8 (2.12)
		Small Oneida	70.2 (3.87)		47.3 (1.33)
Lookout	March	Box trap	40.6 (0.84)	38.4 (0.61)	39.2 (0.61)
	April	Box trap	49.6 (2.06)	41.6 (0.80)	38.5 (0.4)
		Small Oneida	53.1 (2.7)	48.4 (3.28)	43.0 (0.77)
	May	Box trap	45.5 (6.5)	44.0 (1.94)	43.9 (1)
		Small Oneida	58.9 (5.98)	54.6 (1.12)	53.5 (1.65)
	June	Small Oneida	71.5 (1.5)		

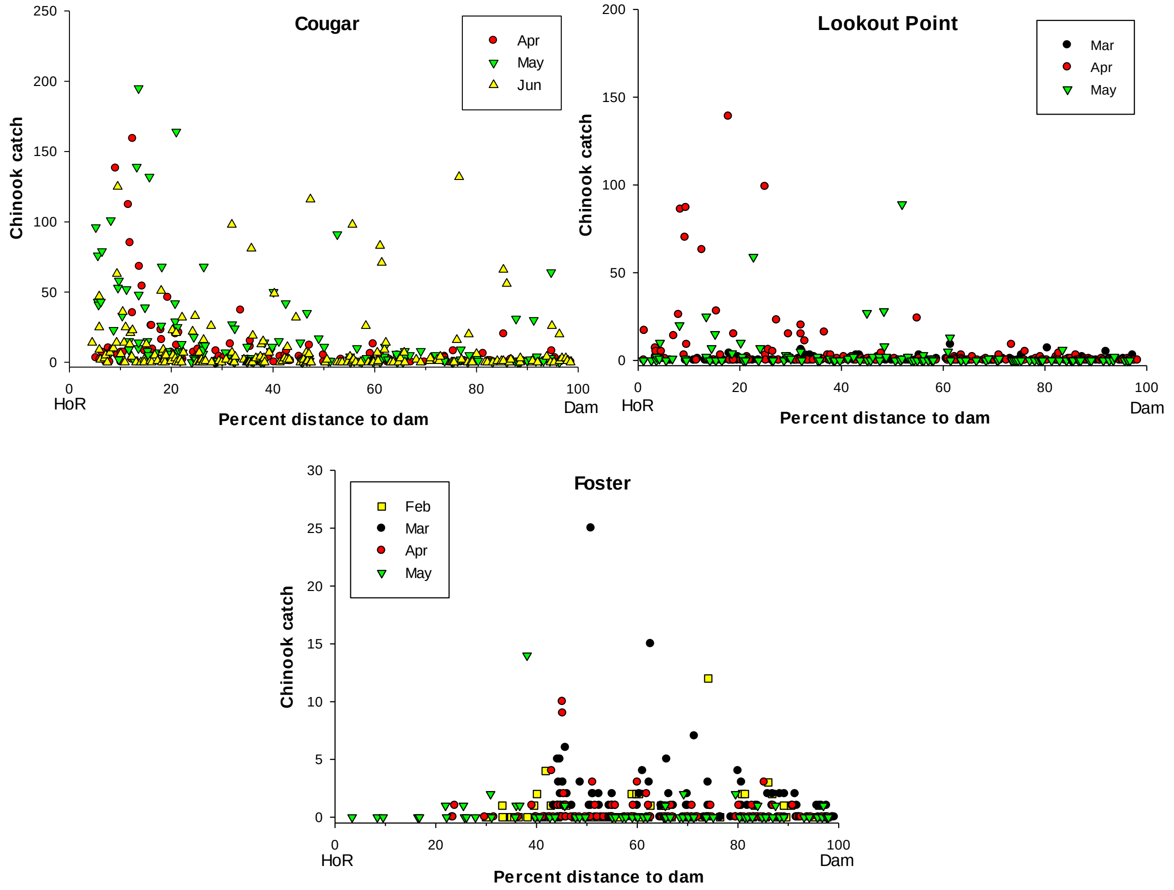

Figure 1-3. Subyearling Chinook salmon catch in nearshore traps in relation to shoreline distance for Cougar, Lookout Point, and Foster reservoirs, 2014. Includes all subyearling Chinook salmon caught in floating box traps and small Oneida traps. For clarity, the Lookout Point graph does not show a May catch of 337 subyearlings at 28% distance to dam and Foster graph does not show an April catch of 81 subyearlings at 51% distance to dam (South Santiam arm).

Foster Reservoir.-Catch of subyearling Chinook salmon in Foster Reservoir was greater in the middle section and the lower end of the South Santiam arm of the reservoir. Less than 2% of the cumulative catch in Foster Reservoir occurred in the upper third of the reservoir, compared to >66% of the catch for other reservoirs (Figure 1-4). The distribution observed in Foster Reservoir may be influenced by the atypical shape and size of the reservoir. Foster Reservoir was the shortest and shallowest of the reservoirs we sampled (see Appendix Table A-3) with the upper half comprised of the Middle and South Santiam arms (see Figure 1-5). The South Santiam arm functions as a transition zone between the river and reservoir with most of the arm characteristic of a slow-moving river during periods of low pool elevation and high inflows. This may explain why few fish were collected in the upper arm if they could easily move downstream with the current. Lentic conditions were not

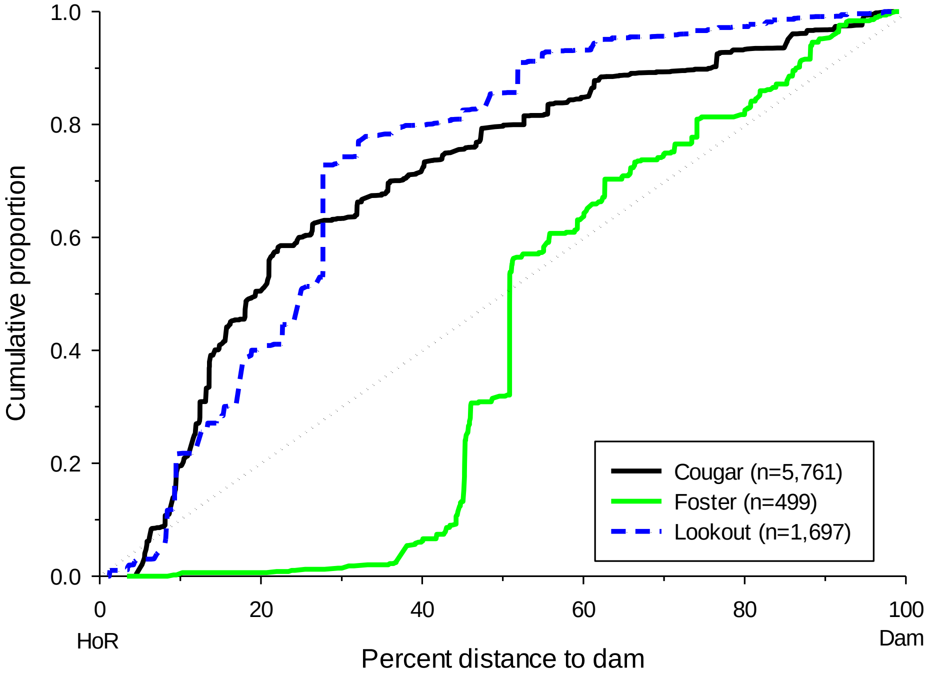

Figure 1-4. Cumulative proportion of all subyearling Chinook salmon caught during spring in relation to percent of shoreline distance to dam, by reservoir in 2014. Dotted line represents the cumulative proportion of a theoretical population that is evenly distributed throughout the reservoir.

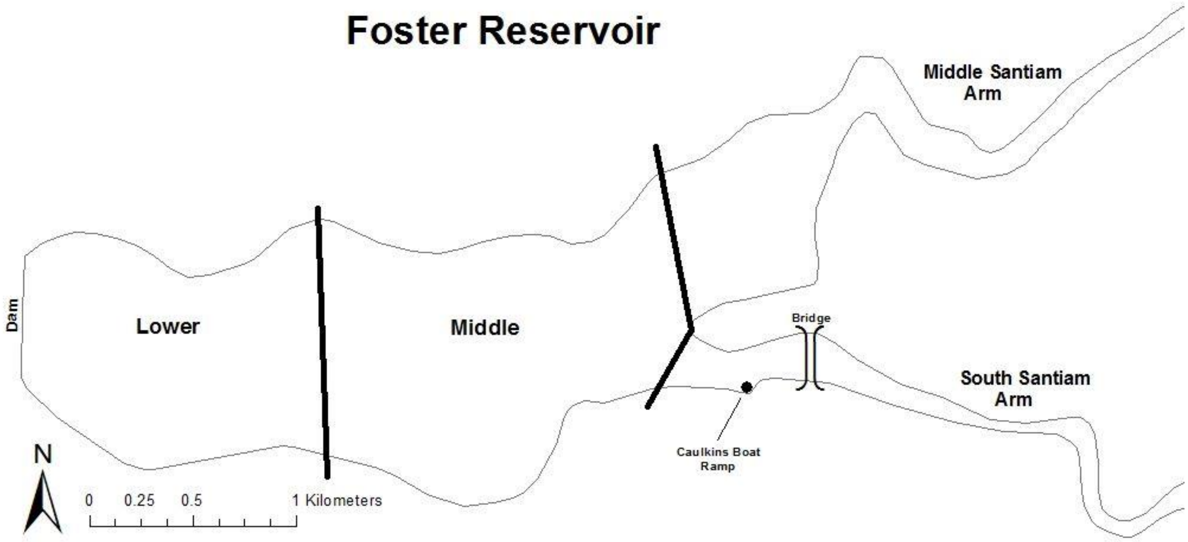

Figure 1-5. Foster Reservoir sections used for sampling fish in 2014. The upper reservoir section was divided into the Middle Santiam and South Santiam arms.

evident until just upstream of the bridge near Calkins boat ramp. Within the South Santiam arm, catch per unit effort (CPUE) was 0.3 fish/set upstream of the bridge and 2.4 fish/set downstream of the bridge. Overall, few fish were collected in the Middle Santiam arm (CPUE = 0.3 fish/set) with most collected from areas closest to the South Santiam.

Monthly distribution patterns of subyearling Chinook salmon differed between 2013 and 2014. In 2014, subyearlings were more evenly distributed in February-March but by April-May the majority of fish were caught in the upper reservoir section below the bridge (Table 1-4). In 2013 the majority of fish were caught in the lower and middle reservoir each month in the spring. In 2014, most subyearlings (52%) were caught in the South Santiam arm downstream of the bridge but this area only comprised 8% of total catch in 2013.

Catch rates of subyearlings in the reservoir tended to be greater in shallower habitats. In the middle and lower reservoir sections CPUE was greater along the shallower north bank (0.9 fish/set) compared to the south bank (0.4 fish/set), similar to 2013. Significantly more subyearlings were caught at shallow (≤ 1.5m) sites than deep (> 1.5 m) sites (Kruskal-Wallis one-way ANOVA on ranks; $P \leq 0.001$). We could not detect differences in catch between substrate types or vegetation presence/absence.

Juvenile steelhead were more abundant in the lower reservoir in both 2013 and 2014 (Table 1-5). Steelhead in 2014 were comprised mostly of age-1 fish (based on their length) with a mean size of 110 mm FL. Most of these fish would have entered the reservoir the previous summer/fall as subyearlings (see Romer et al. 2014).

Table 1-4. Proportion of subyearling Chinook salmon captured by reservoir section and month, 2014. Pool range bounds were the minimum (0%) and maximum conservation pool (100%) and reported ranges were only for the days we sampled.

			Proportion of total catch			
Reservoir	Month	n	Lower	Middle	Upper	Pool range (% full)
Foster	Feb	46	0.295	0.477	0.227	0-29
	Mar	173	0.212	0.376	0.412	0-10
	Apr	205	0.159	0.158	0.683	0-43
	May	74	0.365	0.050	0.584	90-99
Cougar	Apr	1,219	0.071	0.139	0.790	81-94
	May	2,565	0.120	0.135	0.745	100-100
	Jun	1,977	0.402	0.172	0.426	87-100
Lookout Point	Mar	87	0.310	0.332	0.359	52-71
	Apr	894	0.041	0.064	0.895	71-81
	May	713	0.015	0.267	0.718	81-86

Table 1-5. Proportion of juvenile steelhead captured in Foster Reservoir by reservoir section during spring, 2013-2014. Proportion adjusted for the number of trap sets in each reservoir section.

Year	Section	Number caught	Sets	Proportion of catch
2014	Lower	116	155	0.490
	Middle	98	166	0.387
	Upper	39	207	0.123
2013	Lower	79	72	0.621
	Middle	30	69	0.246
	Upper	28	119	0.133

Cougar Reservoir.- The high catch per unit effort of small subyearling Chinook salmon in Cougar Reservoir allowed for more detailed analysis of monthly distribution. Subyearlings dispersed farther into the reservoir towards the dam each month from April through June (Figure 1-6), similar to patterns observed in 2012 and 2013. For instance, in April the upper third of the reservoir comprised 79% of the monthly total catch and the lower third comprised 7%. By June, catch in the upper third decreased to 43% of the monthly total and the lower third increased to 40% (Table 1-4).

The proportion of subyearlings caught in the lower reservoir in June (40%) was more than previously observed in 2012-13 (range: 26-30%), however the greatest catch rates occurring in the East Fork arm. The proportion captured in the forebay did not differ between years (Table 1-6). For the last two years, the proportion of total monthly catch from forebay sets was about 1% in April and increased to 3% in June.

Although catch numbers were low, subyearling Chinook salmon were in all areas of the forebay. From late April through June, average catch was 3.5 fish/set (range 0-26) for the floating box traps set at random locations in the forebay. For the four cul-de-sac traps set at fixed locations around the PFFC, we collected a total of 483 subyearling Chinook with an average catch of 3.6 fish/set. In general, catch rates in May and June were greater for traps near the tower compared to the island (Table 1-7) This trend was driven by relatively large catches of fish (>20 fish/trap) in a short window of time between 29 May-06 June.

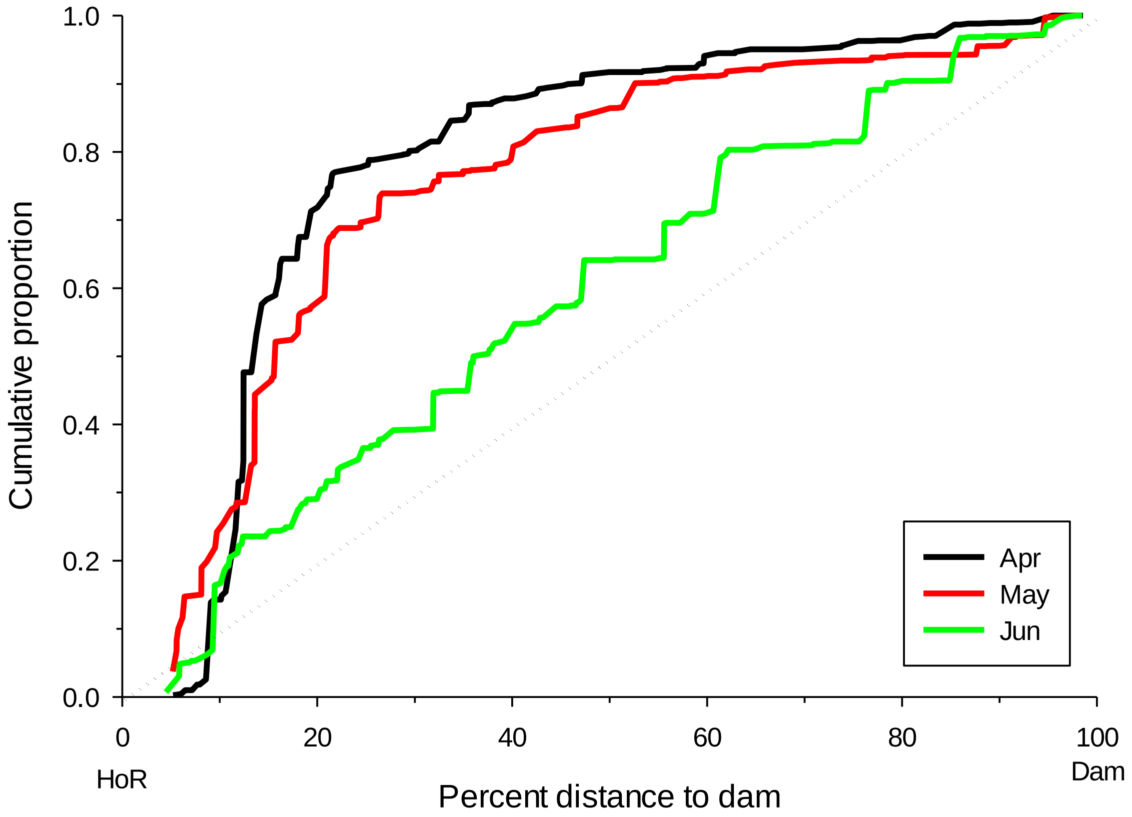

Figure 1-6. Monthly cumulative proportions of subyearling Chinook salmon catch in nearshore floating box traps and small Oneida Lake traps in relation to percent of shoreline distance to Cougar Dam, 2014. Dotted line represents the cumulative proportion of a theoretical population that is evenly distributed throughout the reservoir.

Table1-6. Percent of total nearshore catch occurring in the forebay of Cougar Reservoir by month and year.

	Percent of total catch in forebay		
Year	April	May	June
2012	0.2	2.5	2.3
2013	1	2.5	3.4
2014	1.5	3.8	3.4

Table 1-7. Catch per unit effort of subyearling Chinook salmon in the cul-de-sac of the Cougar Reservoir forebay, 2014. Numbers in parentheses are the total number of subyearlings caught.

Trap location	April	May	June
W. Island	--	2.8 (39)	1.5 (24)
E. Island	4.3 (17)	1.9 (29)	1.7 (27)
W. Tower	4.3 (17)	3.7 (56)	4.9 (79)
E. Tower	1.0 (4)	8.3 (125)	4.1 (66)

Subyearlings were evenly distributed on both sides of Cougar Reservoir. CPUE was 11.8 fish/set on the east bank and 11.6 fish/set on the west bank. We did not detect a significant difference in subyearling catch between shallow and deep trap sites (Kruskal-Wallis one-way ANOVA on ranks; $P>0.05$). Only 7% Cougar Reservoir sites were shallow (compared to 24% in Foster) and any preference for this habitat type may have been masked by its relative unavailability and the high subyearling abundance. Substrate in Cougar Reservoir was predominately rock or sand/silt and there was no significant difference in trap catch between substrate categories (Kruskal-Wallis one-way ANOVA on ranks; $P>0.05$). There was significantly greater catch at sites with nearshore vegetation (Kruskal-Wallis one-way ANOVA on ranks; $P\leq0.001$), however this result may be biased because vegetated sites were generally found at the head of the reservoir. When only the middle and lower section were used in analysis, we did not detect a significant difference in catch between sites with and without vegetation. We note that our traps were designed to intercept subyearlings actively swimming along the shoreline and, as such, may not accurately reflect habitat preferences of small subyearling Chinook salmon when not actively moving.

Lookout Point Reservoir- Subyearling Chinook salmon in Lookout Point demonstrated a similar overall distribution as in Cougar Reservoir with most subyearlings located near the head of the reservoir (Figure 1-4). However, fish captured in March (n=87) were evenly distributed throughout the reservoir (Table 1-4), unlike 2013 when most were in the upper reservoir. Inflows in March 2014 (mean=6,403; range 2,180-18,470 cfs) were substantially greater than in March 2013 (mean=2,519; range 1,910-3,420) and may have contributed to the greater dispersion observed in 2014. In April and May, after most fish had entered, abundance was greater in the upper reservoir. Shallow sites were relatively common in the reservoir (30% of all sites) but we did not detect differences in catch between shallow and deep sites (Kruskal-Wallis one-way ANOVA on ranks; $P>0.05$). We also did not detect differences in catch between substrate type and vegetation presence/absence (Kruskal-Wallis one-way ANOVA on ranks; $P>0.05$).

Parr Longitudinal Distribution

We assessed subyearling Chinook salmon distribution in Lookout Point Reservoir in the summer (July-August) and fall (October-November). We caught 1,090 subyearling parr (552 natural- and 538 hatchery-origin) from 282 gill net sets in the six pre-established reservoir sampling areas from 08 July through 26 November (Table A-2). Only three parr were caught from 20 sets in area A6 (see Figure 1-2) during the summer and by fall this area was dewatered, so we excluded it from further analysis. Area A6 was relatively shallow (maximum depth of 11 m) and water temperature was >17˚C throughout the water column in the summer. These environmental conditions were likely the reason few Chinook salmon used this upper reservoir area in summer. The remaining areas had greater depth (> 20 m) with cooler temperatures in the lower water column.

In the summer, proportional catch differed between hatchery and natural-origin parr (Chi-square; $P\leq0.001$), so we analyzed their distribution separately. However, in the fall we did not detect a proportional catch difference between hatchery and natural-origin parr, so data were combined for this season.

Distribution of parr differed between seasons. During summer, significantly more natural-origin parr were caught at A1 and A5 than other areas (Figure 1-7) (Kruskal-Wallis one-way ANOVA on ranks; $P \leq 0.001$). Hatchery-origin parr showed a similar bimodal pattern during the summer but with more fish at A1, near the dam (Kruskal-Wallis one-way ANOVA on ranks; $P \leq 0.001$). During fall, significantly more fish were collected lower in the reservoir at A1 and A2 (Figure 1-8) (Kruskal-Wallis one-way ANOVA on ranks; $P \leq 0.001$), suggesting a seasonal shift in parr distribution towards the forebay in the fall. The fall distribution was similar to the distribution observed in November 2013 when 47% of the parr were captured in the net set closest to the dam (Monzyk et al. 2014).

Although there was considerable overlap in the size of parr collected in each area, fish in the lower reservoir (A1) were larger on average than in the upper reservoir (A5) during the summer (Table 1-8). Mean fork length of natural-origin parr captured in A1 were nearly 20 mm larger than fish captured in A5 (ANOVA; $P \leq 0.001$) and generally increased in size from the upper to lower reservoir (Table 1-8). Hatchery fish released at the Hampton boat ramp (head-of reservoir release group) were also larger in A1 compared to A5 (ANOVA; $P \leq 0.001$) but we did not detect a size difference between areas for the forebay release group (Table 1-8).

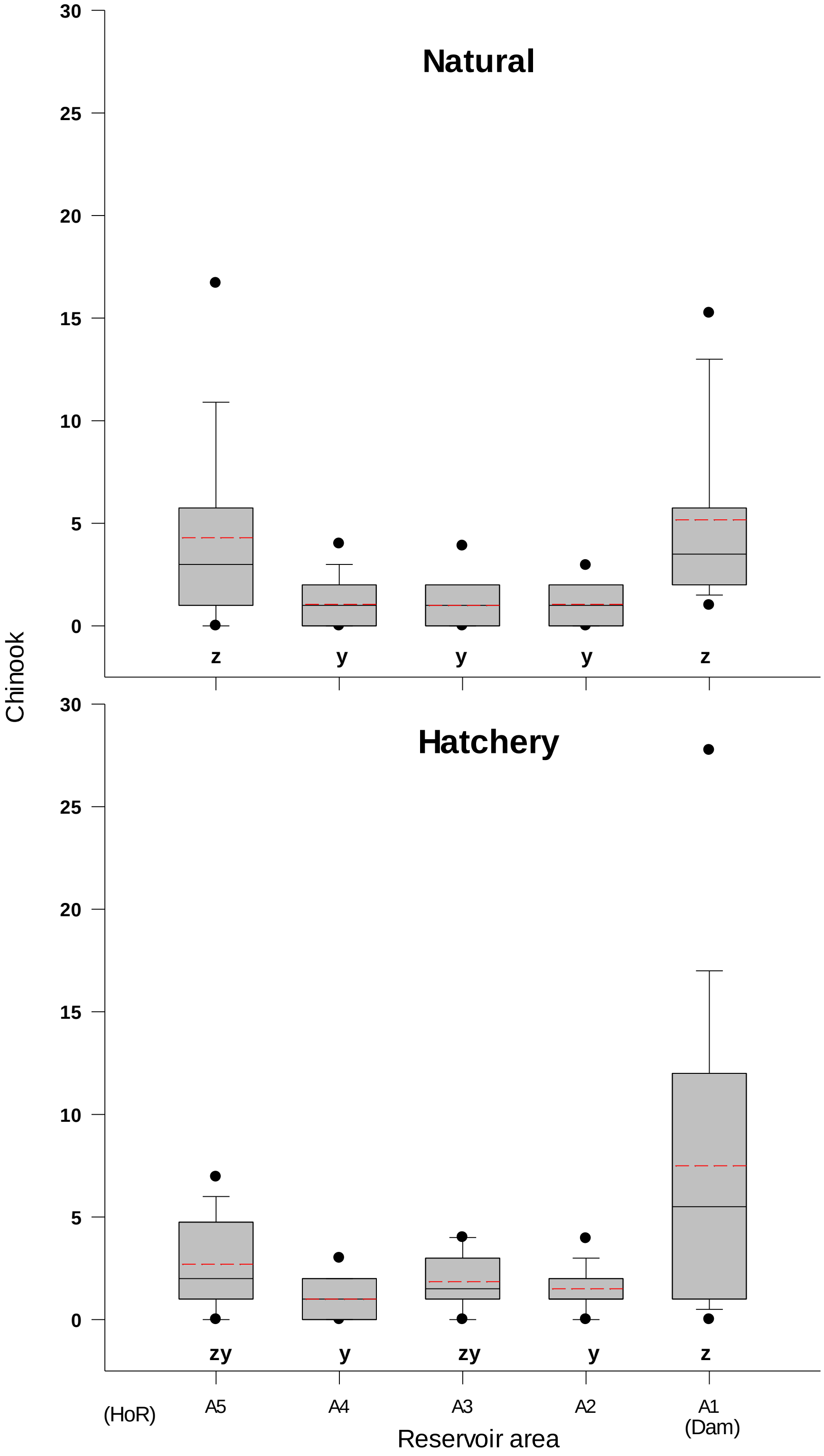

Figure 1-7. Number of natural- and hatchery-origin Chinook parr caught during the summer in five areas of Lookout Point Reservoir, 2014. Solid lines denote medians, red dashed lines denote means, the box represents 25th-75th percentiles, whiskers are the 10th -90th percentile and circles are outliers. Areas sharing the same letter are not significantly different (*P*>0.05).

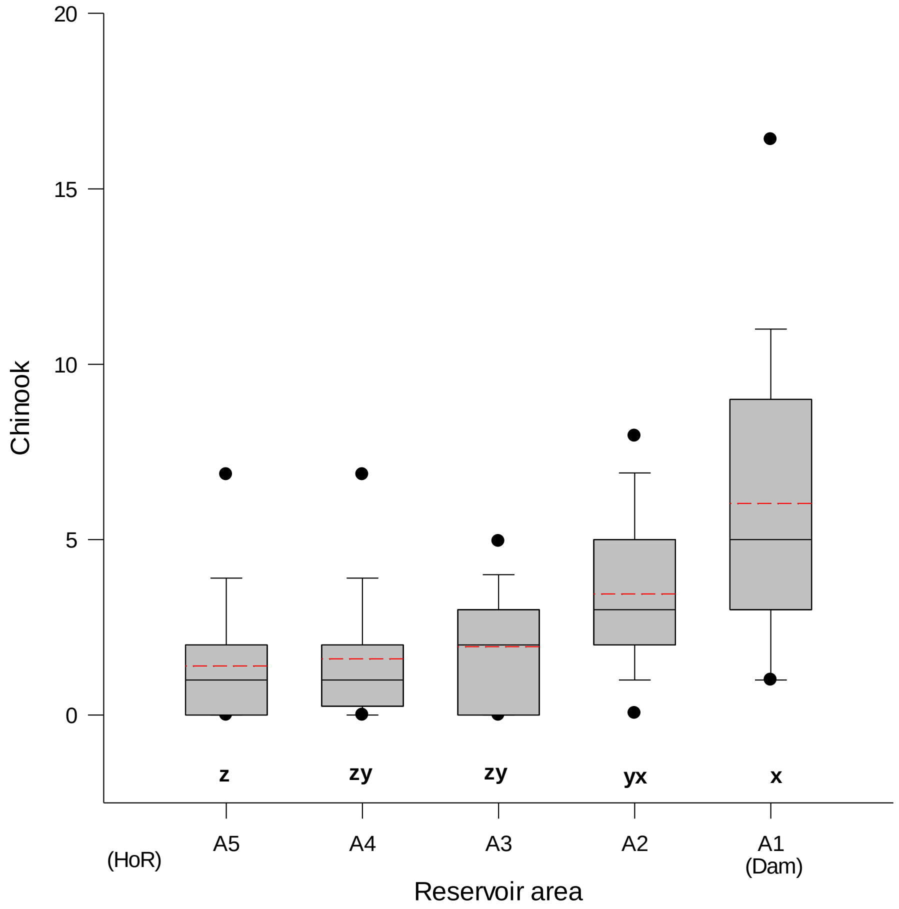

Figure 1-8. Number of Chinook parr (hatchery and natural combined) caught during the fall in five areas of Lookout Point Reservoir, 2014. Solid lines denote medians, red dashed lines denote means, the box represents 25th-75th percentiles, whiskers are the 10th -90th percentile and circles are outliers. Areas sharing the same letter are not significantly different (*P*>0.05).

Table 1-8. Size of natural- and hatchery-origin Chinook salmon parr captured by area in Lookout Point Reservoir in the summer, 2014. Hatchery Chinook salmon are comprised of the Hampton boat ramp (head-of-reservoir) and forebay release groups. Means values sharing the same letter are not significantly different between areas by Tukey's multiple comparison test (*P*>0.05).

	Natural			Hatchery releases					
				Hampton			Forebay		
Area	N	Mean FL		N	Mean FL		N	Mean FL	
A1	123	143	z	63	152	z	106	146	z
A2	21	134	zy	8	146	zy	22	130	z
A3	19	138	zy	17	142	zy	18	146	z
A4	20	127	yx	8	143	zy	10	139	z
A5	82	124	x	34	135	y	10	146	z

Discussion

Subyearling Chinook salmon in reservoirs demonstrated seasonal shifts in their longitudinal distribution. In the spring small subyearling ‘fry’ were most abundant near the head of reservoirs. In the summer, parr were bimodally distributed, with greater abundance at both the upper reservoir and in the forebay. By the fall, most parr were found in the reservoir forebay.

Subyearling distribution in the spring has been consistent among years for Cougar and Lookout Point reservoirs but more variable in Foster Reservoir (Appendix Figure A-1). We did not observe greater abundance in the lower section of Foster Reservoir in 2014 as we did in 2013. It is unclear why distribution differed between years. River inflows were greater and reservoir elevation was lower in 2014 (Appendix Figure A-2), which should have theoretically aided fry dispersion towards the dam, but that was not evident from our data. The disparity between years may be an artifact of relatively small number of fish collected each year (n < 500) compared to other reservoirs and, as such, our distribution assessment can be highly influenced by a large catch in a single trap. Given that our screw trap catch below Foster Dam was dominated by fry each year (Romer et al. 2015), one hypothesis for the relatively low catch rates in the reservoir is that many subyearlings are able to pass the dam in the spring. Given the low catch rates, additional years of sampling would be required to accurately assess distribution in this reservoir. Another unique characteristic of Foster Reservoir is the long and narrow South Santiam arm where few subyearlings were collected and water currents appeared to be sufficient to flush fish into the main body of the reservoir.

Monthly distribution patterns in Cougar Reservoir suggested that subyearlings were dispersing farther into the reservoir each month during spring, a pattern observed in past years (Monzyk et al. 2012, 2013). We have speculated that by late spring and early summer, subyearlings would approach an even distribution throughout the reservoir. If our results in Lookout Point Reservoir apply to other reservoirs, then instead of an even distribution by summer, fish would have a bimodal distribution with greater abundance in the forebay and near the upper end of the reservoir where water depths were sufficient to contain cool temperatures. The very upper end of Lookout Point Reservoir (from Hampton boat ramp to approximately 4 km downstream) was too shallow and warm in the summer and did not hold many subyearlings.

A plausible theory to explain the summer bimodal distribution in Lookout Point Reservoir must take into account the current state of knowledge about Chinook salmon movement in reservoirs. Hatchery subyearlings tagged with Juvenile Salmon Acoustic Telemetry System (JSATS) tags in other reservoirs repeatedly traversed the reservoir’s length in the summer (Beeman et al. 2013). Reservoir-wide movement in Lookout Point was evident from PIT-tag recoveries of hatchery fish released in the forebay and the Hampton boat ramp in June. The forebay release group comprised 23% of the summer PIT-tag recoveries from A5 (near the head of the reservoir) and the equally-sized Hampton release group comprised 38% of the tagged fish collected at A1 (near the dam), suggesting that it was common for fish from both groups to traverse the reservoir’s length at least once. The bimodal distribution of subyearlings in the summer could be explained if fish traverse the reservoir and then mill when arriving at a barrier (the dam at one end and shallow/warm water at the other). This movement pattern would result in more fish at the two ends of the reservoir at any given point in time. The hatchery release groups could have also influenced the distribution and behavior of natural-origin fish. An additional year of study is needed in this reservoir to determine if the distribution pattern observed among natural-origin fish is repeated when there are no hatchery releases.

Natural-origin parr and hatchery parr released at the head-of-reservoir were larger on average in the forebay than in the upper reservoir. For natural-origin fish, a trend of larger fish in the lower reservoir was already evident in the spring. This could be partially explained if subyearlings that had dispersed to the lower reservoir by spring had entered the reservoir earlier and had more growth opportunity. However, this would not explain why hatchery fish released as a batch at the head-of-reservoir would show the same trend. There are at least two possible explanations for the size trend we observed for this release group: larger hatchery fish are more likely to move downstream; or smaller fish may be more vulnerable to predation as they move downstream, resulting in a greater proportion of larger fish reaching the forebay. However, the lack of a similar trend for the forebay hatchery release group confounds these possible explanations.

Chinook salmon parr in Lookout Point Reservoir shifted their distribution in the fall with most fish caught in the forebay. It is interesting to note that the distribution shift began prior to major increases in stream inflow or dam outflow, suggesting a mechanism other than discharge levels was responsible. Downstream movement from upper rearing areas to overwinter habitat is common among stream-rearing spring Chinook salmon pre-smolts (Bjornn 1971; Favrot et al. 2012) including in the Willamette River (Zakel and Reed 1984). Our results showed that fish were abundant in the forebay and available for passage as early as October. However, under current conditions peak dam passage at Lookout Point occurs in January after the reservoir is drawn down to annual lows and access to deep-water passage routes are improved (Keefer et al. 2011).

SECTION 2: RELATIVE SIZE AND GROWTH OF JUVENILE CHINOOK SALMON IN RESERVOIRS AND STREAMS

Background

The negative effects of reservoir residency due to increased dam passage mortality, delays in migration, and extended exposure to parasites and predation may be offset by superior growth rates that would impart a greater survival advantage to adulthood (ISRP 2011). It is well documented that juvenile Chinook salmon rearing in reservoirs grow larger than in streams (Korn and Smith 1971; Monzyk et al. 2011b, 2012, 2013, 2014). Reservoir subyearlings change vertical position in the water column with changes in water temperatures throughout the year (Monzyk et al. 2013, 2014), thereby thermo-regulating for optimal growth. Chinook salmon in Fall Creek, Foster, and Lookout Point reservoirs were larger by fall than in Detroit and Cougar reservoirs (Monzyk et al. 2013, 2014). Differences in fish size among reservoirs are likely influenced by two factors: length of time fish rear in reservoirs (i.e., fry entrance timing) and growth rate differences (Monzyk et al. 2014). Reservoirs with later fry entrance timing are generally located at higher elevations, and consequently have cooler water temperatures that may decrease growth rate. Cougar Reservoir is the highest in elevation (Appendix Table A-3) and Chinook salmon consistently had slower estimated growth rates than juveniles in other WVP reservoirs (Monzyk et al. 2014).

In this report, we continued our assessment of subyearling growth in streams and WVP reservoirs and evaluated if size differences of fall parr among reservoirs were consistent between years. Knowledge of growth rate and size juveniles attain while rearing in reservoirs will aid in designing appropriate downstream fish passage that can accommodate the full range of fish sizes present in reservoirs.

Methods

Length information from reservoir-rearing Chinook salmon was collected using a variety of sampling methods including nearshore box traps, small and large Oneida Lake traps, electrofishing and gill nets. Information on the location and duration of the various sampling methods in Foster, Cougar, and Lookout Point reservoirs can be found in the other sections of this report. Length data were also collected from rotary screw traps sampling below dams using methods described in Romer et al. (2015). Length information for Fall Creek Reservoir subyearlings was provided by USACE personnel operating a screw trap and fish evaluator below the dam (courtesy Todd Pierce, USACE). Fork length was measured to the nearest millimeter for all natural-origin fish.

Fork length of stream-rearing subyearlings was measured from screw traps and seining captures above reservoirs. Seining occurred in late summer at various locations in the South Fork McKenzie River above Cougar Reservoir and the South Santiam River above Foster

Reservoir. Previous analyses showed fish lengths from seining efforts were not significantly different from lengths of fish collected in screw traps during the same period (Monzyk et al. 2010), so data were combined for analyzes.

Age of fish was estimated from length-frequency analysis (DeVries and Frie 1996). Yearling and subyearling Chinook salmon generally maintained a clear size difference throughout the year. For each reservoir and stream, we plotted individual fish size by date and assigned age based on visual separation of modes (Appendix Figure A-3). Juveniles hatched in spring 2014 were classified as subyearlings (age 0) and yearlings (age 1) were fish that hatched the previous year and remained in the reservoir or stream after 01 January. We believe the aging technique accurately assigned age for most fish and any assignment errors would not greatly affect results.

Subyearling parr size in the fall (October-December), after summer growth, was compared among reservoirs with Kruskal-Wallis one-way ANOVA tests (α=0.05) and Dunn's pairwise multiple comparisons.

Growth Rate – We used two methods to estimate growth rate, depending on available data. In Cougar Reservoir, we estimated subyearling growth rate using length data from individual fish that were PIT tagged and subsequently recaptured. Growth rate (mm/d) was calculated as the fork length at recapture minus length at tagging divided by the number of days between events. In 2014, we tagged subyearlings >60 mm FL that were caught in the reservoir or in the upstream screw trap and presumed to have immediately migrated into the reservoir. We only used fish tagged between April and July and recaptured at least two weeks after tagging to calculate growth rates. Recaptures reported in the PTAGIS database came from collection in the reservoir, screw traps below the dam, or the Leaburg bypass juvenile fish collector.

PIT tag sample sizes were generally small and limited to specific reservoirs, so we also estimated subyearling growth rates in all reservoirs using differences in mean size in the spring and fall. Mean size in spring was based on the month of peak fry emigration into individual reservoirs: March in Fall Creek; April in Lookout Point; and May in Cougar and Detroit reservoirs. Mean size in the fall was based on length data collected in October because previous sampling efforts showed most summer growth occurred by this month. We estimated growth rate as mean size in October minus mean size in the spring month divided by the number of days between months. The number of days between months was calculated as the difference in the mean date of capture each month.

Results

Both yearling and subyearling Chinook salmon were present in WVP reservoirs but subyearlings were more common (Appendix Figure A-3). In this report we limited our growth analyses to the subyearling cohort.

As observed in previous years, reservoir-rearing subyearlings grew more rapidly than juveniles rearing in streams above reservoirs (Figure 2-1). Mean fork length in the fall (October-December) ranged from 134-208 mm in Cougar, Lookout Point, and Detroit reservoirs and 81-101 mm in the South Fork McKenzie, Middle Fork Willamette and North Santiam rivers. Mean weekly length of Foster Reservoir subyearlings was more variable later in the year and was likely attributable to small sample sizes and the presence of stream-rearing fish that had recently entered the reservoir. For this reason, we did not include Foster Reservoir in growth rate comparisons.

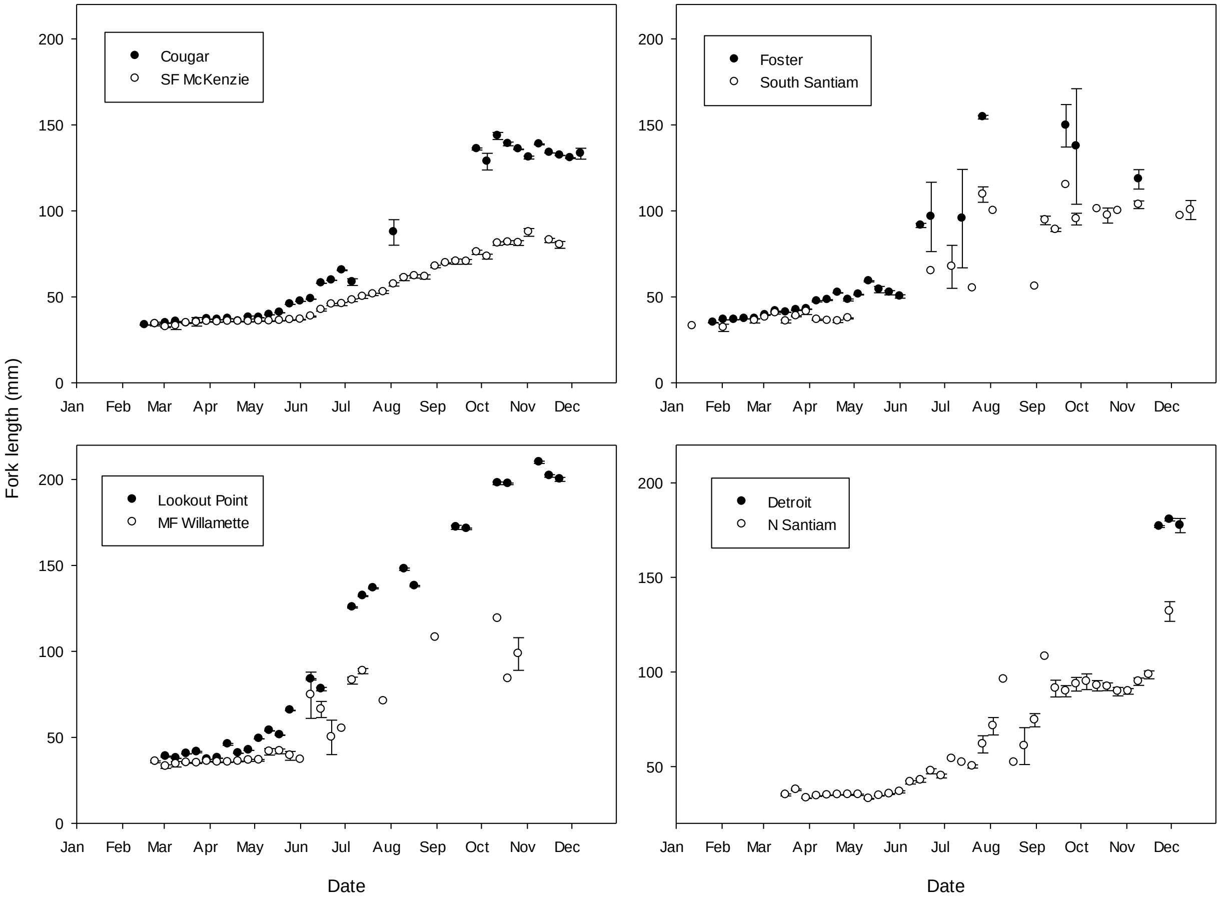

Figure 2-1. Mean weekly fork lengths of subyearling Chinook salmon captured in WVP reservoirs and streams above reservoirs, 2014. Error bars are standard error. For clarity, only weeks with two or more fish collected are shown.

Differences in fall parr size among reservoirs were consistent with results from 2012 and 2013 (Appendix Figure A-4). In 2014, fall parr in Lookout Point Reservoir were the largest, averaging 208 mm FL (Figure 2-2), but not significantly different from Fall Creek parr (Kruskal-Wallis one-way ANOVA on ranks; $P>0.05$). Fall parr were intermediate in size (mean=179 mm) in Detroit Reservoir and significantly smaller than fish in Lookout Point and Fall Creek reservoirs. Fall parr in Cougar Reservoir were significantly smaller (mean=134 mm) than fish in all other reservoirs (Kruskal-Wallis one-way ANOVA on ranks; $P<0.05$).

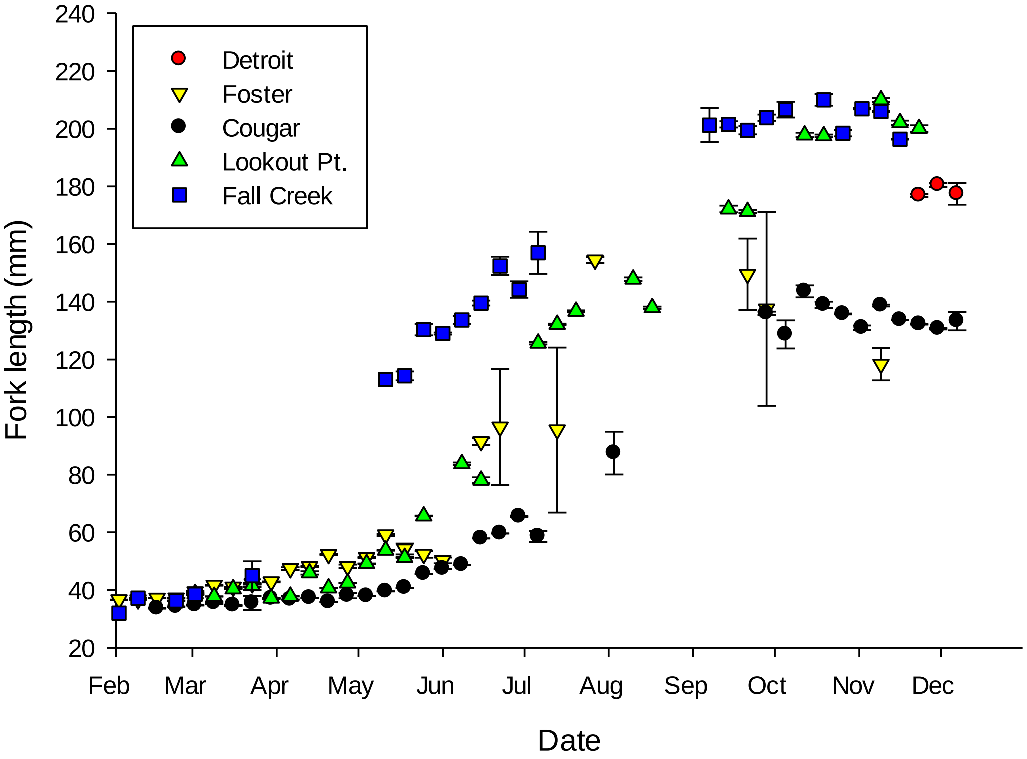

Figure 2-2. Mean fork length by week of natural-origin subyearling Chinook salmon in WVP reservoirs, 2014. Error bars are the standard error. For clarity, only weeks with two or more fish collected are shown.

Growth Rates – Differences in fall parr size among reservoirs is partially explained by growth rate differences. Chinook salmon in Cougar Reservoir had a slower growth rate than other reservoirs. Eight subyearling Chinook salmon PIT-tagged from June-July in Cougar Reservoir and recaptured in November in screw traps below the dam had a mean growth rate of 0.45 ±0.02 mm/d (SE), similar to estimates from 2013 (0.42 ±0.02). This growth rate estimate may be biased low because it did not include the spring growth period and includes the late fall period when growth would be slower. We estimated a growth rate of 0.61 mm/d based on difference in mean fish size between May and October, consistent with estimates from previous years (Table 2-1). This later estimate accounted for growth occurring in the spring and did not include the slow growth period in late fall.

Subyearling growth rates in other WVP reservoirs were calculated from mean fork lengths in spring and fall and ranged from 0.71-0.90 mm/d (Table 2-1). Growth rates in Detroit and Lookout Point reservoirs were similar to each other and greater than other reservoirs (Table 2-1). Given the rapid growth rate estimated in Detroit Reservoir, the intermediate size of fall parr in this reservoir is likely the result of less growth opportunity due to a later fry entrance timing compared to Fall Creek or Lookout Point reservoirs.

Table 2-1. Growth rate of subyearlings in WVP reservoirs calculated from mean fork length in the spring and fall.

	Growth rate (mm/d)			
Reservoir	2011	2012	2013	2014
Detroit	0.73	0.78[a]	0.84	0.90[a]
Foster	n/a	n/a	0.80	n/a
Cougar	0.52	0.55	0.52	0.61
Lookout Point[b]	0.61	0.86	0.84	0.86
Fall Creek			0.84[c]	0.71

[a] Mean fork length in May estimated from screw trap above reservoir.
[b] Growth rate calculated as mean size differences between April and October.
[c] Fish size in March not available. Growth rate estimate based on assumed mean length on 15 March of 34 mm (from Keefer et al. 2011).

Discussion

Greater growth of subyearling Chinook salmon in reservoirs compared to streams was likely attributable to the greater primary and secondary productivity in reservoirs and temperature regimes that allowed for optimal growth. Subyearlings in reservoirs experience optimal rearing temperatures of 12.2 to14.8ºC (Hicks 2000) earlier in the year than streams, thereby allowing subyearlings more time for optimal growth. As surface water temperatures continued to warm in the summer, fish could shift their vertical position to maintain optimal growth conditions.

The differences in fall parr size among reservoirs in 2014 were consistent with 2012-2013 results. Lookout Point and Fall Creek reservoirs had the largest fall parr, Detroit subyearlings were intermediate in size, and Cougar Reservoir had the smallest parr. Differences in fish size among reservoirs were likely a function of fry entrance timing and reservoir-specific growth rates. Compared to other WVP reservoirs, growth rates in Cougar Reservoir were lower and fry entrance timing was later in the year. Detroit Reservoir had similar fry entrance timing to Cougar Reservoir but growth rate was high. The large size of fall parr in Lookout Point and Fall Creek reservoirs is partly the result of both high growth rate and early fry entrance timing. Other factors may also influence the size fish reach by fall. Growth rates in Cougar Reservoir were slower than the other WVP reservoirs for the last three years. Subyearling catch per unit effort in the reservoir was consistently higher each year compared to other reservoirs, suggesting greater fish densities. The slower growth rate in Cougar Reservoir may be the result of density-dependent compensation.

The most rapid growth rate estimated this year was nearly one mm/d for subyearlings in Lookout Point and Detroit reservoirs. Our growth rate estimates based on mean size could be biased high if differential mortality due to predation on smaller individuals occurs in reservoirs, leaving a greater proportion of larger fish available for capture in the fall. However, this would likely only be a problem in Lookout Point Reservoir as we believe predation in Detroit Reservoir is minimal (Monzyk et al. 2011b). Growth rates exceeding one mm/d have been reported for juvenile fall Chinook salmon in the Snake River (Connor and Burge 2003). Similarly, summer growth rates for juvenile Chinook salmon rearing in the mainstem Willamette River were estimated between 0.5-1.0 mm/d (Schroeder et al. 2013).

SECTION 3: PARASITIC COPEPOD INFECTION PREVALENCE AND INTENSITY

Background

In recent years, several researchers working in WVP reservoirs noted high infection levels by the parasitic copepod *Salmincola californiensis* on juvenile Chinook salmon, prompting interest in monitoring infection levels given the potential negative health effects on juvenile salmonids. The copepod parasitizes Pacific salmon and trout of the genus *Oncorhynchus* (Kabata and Cousens 1973) and the life cycle consists of several stages involving a single host fish (Figure 3-1). Adult females carry two large egg sacs that require approximately one month to hatch. The free-swimming infectious copepodid (~0.69 mm in length) can survive for about two days after hatching in their attempt to find a host (Kabata and Cousens 1973). The copepodid attaches externally to the host and undergoes several chalimus stages ending with the adult stage within weeks after hatching.

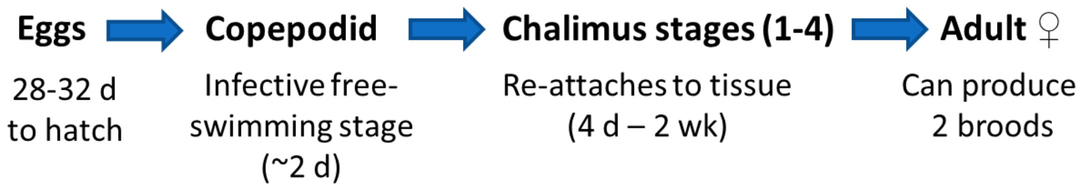

Figure 3-1. Life cycle of female *Salmincola californiensis.*

In the fourth chalimus stage, the female copepod re-attaches to the host by excavating a cavity into host tissue and implanting a bulla for anchorage (Kabata and Cousens 1973). Attachment location is believed to be host size-dependent with preferred attachment to pectoral and pelvic fin bases on smaller fish and within the brachial cavity, including gill filaments, of larger fish (Kabata and Cousens 1977; Black 1982). In previous assessments, we observed attachment within the brachial cavity to be more common for reservoir-rearing Chinook salmon than those rearing in streams (Monzyk et al. 2013, 2014). It is unclear if this is due to the larger size of reservoir fish or if environmental conditions in reservoirs are more conducive for copepod attachment in the brachial cavity.

The prevalence and intensity of *S. californiensis* infection increases with host body length (Nagasawa and Urawa 2002; Barndt and Stone 2003). We observed a positive correlation between copepod prevalence and juvenile Chinook salmon fork length for fish rearing in reservoirs (Monzyk et. al 2012). However, larger fish (yearlings) were in reservoirs for a longer period of time and therefore experienced extended parasite exposure. The highest infection prevalence and intensity among subyearlings was in late fall (Monzyk et al. 2013, 2014). We observed significantly higher infection prevalence and intensity for juvenile Chinook salmon rearing in reservoirs compared to streams, with some reservoir juveniles infected with >20 copepods in the brachial cavity (Monzyk et al. 2013, 2014).

The negative impact of parasitic copepod on the health of the fish depends on the severity of infection. Low-level infections observed in stream-rearing fish are generally not believed to be lethal. However, high intensity infections in the brachial cavity of reservoir-rearing fish can cause gill tissue destruction (Kabata and Cousens 1977; Sutherland and Wittrock 1985) resulting in anemia and high mortality during saltwater transition (Sutherland and Wittrock 1985; Pawaputanon 1980). In addition, a surface lesion can be an 'open gate' to secondary infection (Kabata and Cousens 1977). Beeman et al. (2015) noted higher tagging mortality and reduced reservoir swimming activity for juvenile Chinook salmon with more than four copepods in the brachial cavity. In 2012 and 2013, we observed high intensity infection in Fall Creek Reservoir Chinook salmon (i.e., >20 copepods on gills) that could potentially cause high mortality during saltwater transition. Anecdotal information suggests Chinook salmon in Hills Creek Reservoir are also highly infected. In this report, we describe the prevalence and intensity of copepod infection through time for reservoir- and stream-rearing juvenile Chinook salmon and other salmonids. We also compare infection trends from previous years.

Methods

In 2014 we assessed infection by *S. californiensis* among *Oncorhynchus* spp. rearing in WVP reservoirs and streams above reservoirs. We sampled salmonids in the following reservoirs and streams: Detroit Reservoir and the North Santiam River, Foster Reservoir and the South Santiam River, Cougar Reservoir and the South Fork McKenzie River, and Lookout Point Reservoir and the Middle Fork Willamette River, including the North Fork Middle Fork Willamette River. In addition, USACE personnel provided data from a trap below Fall Creek Reservoir. The salmonids assessed included natural-origin juvenile Chinook salmon, rainbow trout *O. mykiss*, cutthroat trout *O. clarkii*, and kokanee *O. nerka*. Adipose-clipped hatchery Chinook salmon were present in Lookout Point and Detroit reservoirs and adipose-clipped rainbow trout were present in Foster, Detroit, and Lookout Point reservoirs. Unclipped *O. mykiss* from Foster Reservoir and the South Santiam River were likely progeny of steelhead outplanted above the dam.

We assigned fish as stream- or reservoir-rearing based on collection location. Reservoir-rearing fish were collected from gill nets, nearshore nets, and Oneida nets set in the reservoirs as well as rotary screw traps located below dams. Stream-rearing fish were collected by seining in streams during August and September and rotary screw traps operated above reservoirs throughout the year.

Captured fish were anesthetized (50mg/L MS-222), examined for an adipose fin clip, and measured (fork length; mm). The fins and brachial cavity of each fish were macroscopically examined for the presence of gravid adult female copepods. We counted copepods at each attachment location from a subset of the fish collected each day (minimum of five fish/species/day/gear type). Only gravid adult female copepods were assessed since this life stage was easily visible during field examinations. Age-class of juvenile Chinook salmon was determined by length-frequency analysis (see Section 2).

We assessed both the prevalence and intensity of copepod infection. Prevalence was defined as the percentage of fish infected with at least one copepod. We compared prevalence between reservoir- and stream-rearing subyearlings collected between October-November (z-test; $\alpha=0.05$), the period when sample sizes are generally the largest for both rear groups. Hatchery fish may differ from natural-origin fish in size and duration of rearing in reservoirs; therefore we analyzed hatchery fish separately when they were distinguishable from naturally-produced fish.

To control for the influence of fish size on infection differences between reservoir and stream fish, we categorized subyearlings into 5-mm size groups (e.g., 65-69 mm) and compared infection prevalence and attachment location between rearing locations for each size group. For this analysis we used data collected from Cougar Reservoir and the South Fork McKenzie River from 2012-2014.

Intensity was defined as the number of copepods per infected fish. Sample sizes of subyearling Chinook salmon in Lookout Point Reservoir were large enough to compare intensity each month from July-November with Kruskal-Wallis one-way ANOVA on ranks, with Dunn's multiple comparison test ($\alpha=0.05$). We also compared intensity between subyearlings and yearlings in reservoirs when sampled during similar periods (Mann-Whitney rank sum test,$\alpha=0.05$). We also compared copepod intensity in the early fall (Oct-Nov) between reservoir- and stream-rearing subyearling Chinook salmon with the Mann-Whitney rank sum test ($\alpha=0.05$). We compared intensity among reservoirs in late fall (Nov-Dec) using Kruskal-Wallis one-way ANOVA on ranks, with Dunn's multiple comparison test ($\alpha=0.05$). For all intensity comparison in reservoirs, we used only copepod counts in the brachial cavity since this attachment location is most detrimental to fish.

Results

We macroscopically examined 10,044 salmonids for infection by *S. californiensis* throughout 2014. None of the kokanee examined (n=732) were infected. Infection level varied for the other species depending on time of year and rearing location, but Chinook salmon in reservoirs had higher infection levels overall, especially late in the year. Infection prevalence was <10% for cutthroat trout in both reservoirs and streams. Prevalence was <25% for rainbow trout in all locations, with the exception of Lookout Point Reservoir in late summer (August-October) where mean prevalence among trout examined was 74% (n=62).

With the exception of cutthroat trout, copepods were more common in the brachial cavity instead of on fins for salmonids rearing in reservoirs (Table 3-1). For instance, 81.4% of all copepods attached to reservoir-rearing Chinook salmon were in the brachial cavity compared to 38.8% for stream-rearing Chinook salmon. This was similar to the proportions observed in previous years between reservoir- and stream-rearing Chinook salmon (range: reservoir 75-84%; stream 24-30%). The larger mean size of reservoir fish may have contributed to greater likelihood of attachment in the brachial cavity. However, greater likelihood of brachial cavity attachment for reservoir fish was evident even when comparing fish of similar size between Cougar Reservoir and the South Fork McKenzie River (Table 3-2). For all size groups, reservoir subyearlings had a greater percentage of copepods in the brachial cavity even though they were generally captured earlier in the year and therefore exposed to copepods for less time. The smallest fish with copepods attached within the brachial cavity was 56 mm FL in the reservoir and 81 mm in the river.

Table 3-1. Percent of *Salmincola californiensis* attached in the brachial cavity and on fins of infected Pacific salmonids by rearing location in the Willamette basin, 2014.

			Copepods		
			Brachial cavity		Fins
Rearing location/ Species	Number of fish	Mean fork length (mm)	Number adult ♀	Percent of total	Number adult ♀
Reservoir	**6,886**	**128.3**	**8,546**	**82.4**	**1,830**
Chinook	4,316	112.2	6,961	81.4	1,588
Hatchery Chinook	700	169.1	1,324	94.2	82
Rainbow/Steelhead[a]	975	134.1	170	59.4	116
Hatchery Rainbow	58	279.5	82	74.5	28
Cutthroat	102	134.0	9	36.0	16
Kokanee	732	163.5	0	--	0
Stream	**2,211**	**74.7**	**40**	**45.5**	**48**
Chinook	1,331	70.4	19	38.8	34
Rainbow/Steelhead[a]	1,719	93.1	1	25.0	3
Cutthroat	49	135.1	20	64.5	11

[a] *O. mykiss from the South Santiam River were likely juvenile steelhead.*

Table 3-2. Infection prevalence and percent of total copepods attached in the brachial cavity by size group of subyearling Chinook salmon in Cougar Reservoir and the South Fork McKenzie River, 2012-2014. Numbers in parentheses are total number of copepods counted on fish.

	Cougar				South Fork McKenzie			
Size group	n	Prevalence	% in brachial cavity	Mean capture week	n	Prevalence	% in brachial cavity	Mean capture week
50-54	972	0.017	0.0 (17)	24.0	375	0.003	0.0 (1)	29.4
55-59	789	0.019	12.5 (16)	24.4	437	0.011	0.0 (5)	31.7
60-64	466	0.047	8.3 (24)	24.9	505	0.022	0.0 (12)	34.1
65-69	352	0.037	7.7 (13)	25.3	614	0.036	0.0 (23)	35.0
70-74	283	0.078	3.6 (28)	26.5	553	0.049	0.0 (27)	35.8
75-79	172	0.157	8.8 (34)	28.2	370	0.027	0.0 (10)	37.1
80-84	168	0.262	26.9 (67)	32.6	233	0.052	6.3 (16)	38.5
85-89	161	0.441	35.0 (117)	37.6	119	0.076	20.0 (10)	39.9
90-94	171	0.491	43.5 (161)	40.2	39	0.128	33.3 (6)	40.5
95-99	207	0.652	50.5 (301)	42.0	11	0.182	0.0 (3)	40.7

Prevalence

Copepod infection prevalence was greater for subyearling Chinook salmon rearing in reservoirs compared to streams (z-test *P*<0.05; Table 3-3). Prevalence in the fall for stream-rearing subyearlings was <10% but >74% in reservoirs. Sample size in Foster Reservoir was too small in the fall (n=2) for comparison with stream fish.

Only Lookout Point Reservoir had sufficient sample sizes of subyearling Chinook salmon each month to assess changes in prevalence and intensity through the year. As observed in previous years, prevalence increased each month (Figure 3-2). We observed greater summer prevalence in 2014 compared to previous years. In all years, prevalence was >75% by fall.

Similar to previous years, hatchery Chinook salmon in Lookout Point Reservoir had greater prevalence in November (z-test, *P*<0.01) and were larger than unclipped fish (unclipped prevalence=77%, mean FL=204 mm; ad-clipped prevalence=100%, mean FL=227 mm).

Table 3-3. Copepod prevalence between reservoir- and stream-rearing subyearling Chinook salmon, October-November 2014.

	Reservoir		Stream		
Location	Prevalence	n	Prevalence	n	*P* (z-test)
Cougar / South Fork McKenzie	0.937	1,282	0.086	163	<0.001
Detroit / North Santiam	0.895	38	0.029	139	<0.001
Lookout Point / MF Willamette	0.745	192	0.000	4	0.006

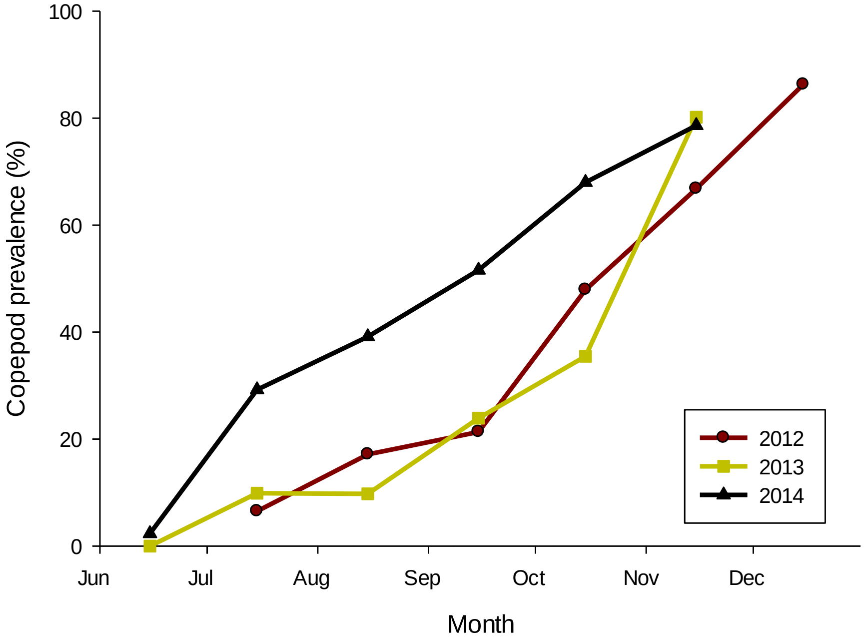

Figure 3-2. Proportion of subyearling Chinook salmon with copepods present by month in Lookout Point Reservoir, 2012-2014.

Intensity

Infection intensity within the brachial cavity of subyearling Chinook salmon from Lookout Point Reservoir increased through the year with significantly greater intensity in the fall (Kruskal-Wallis one-way ANOVA on ranks, $P<0.001$) (Figure 3-3). This was consistent with results from previous years in other reservoirs. Intensity continued to increase for fish that remain in reservoirs an additional year. Yearlings in Lookout Point and Cougar reservoirs had significantly greater infection intensity than subyearlings (Mann-Whitney rank sum test, $P<0.001$) (Figure 3-4).

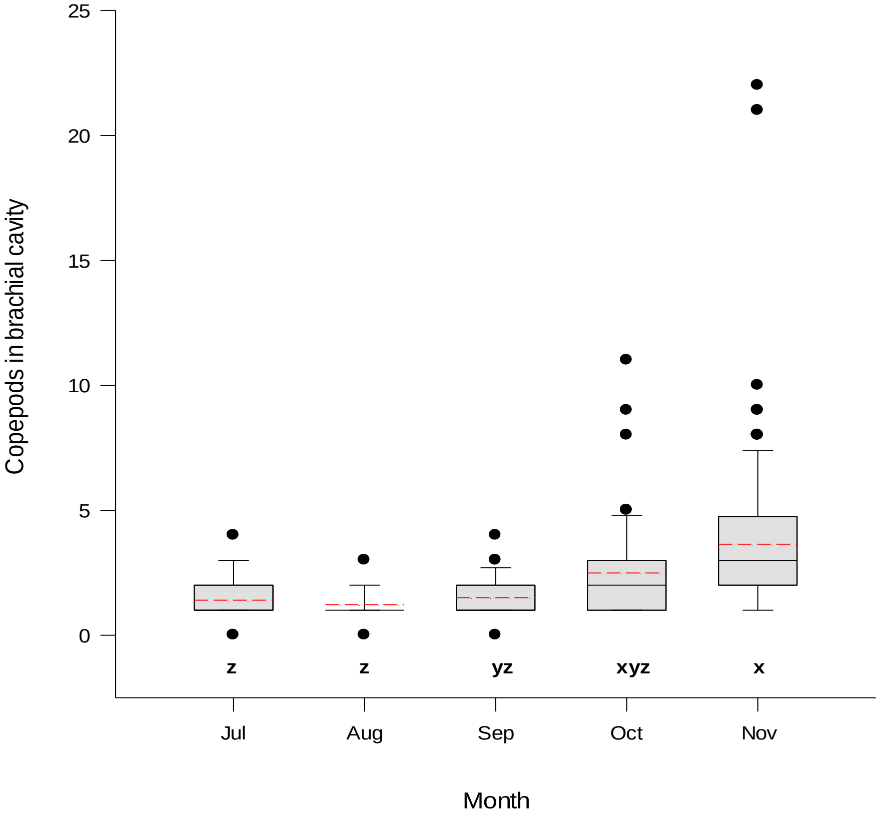

Figure 3-3. Number of copepods in the brachial cavity of infected subyearling Chinook salmon by month in Lookout Point Reservoir, 2014. Solid lines denote medians, red dashed lines denote means, the box represents 25th-75th percentiles, whiskers are the 10th -90th percentile and circles are outliers. Areas sharing the same letter are not significantly different (Dunn's multiple comparison test; $P<0.05$)

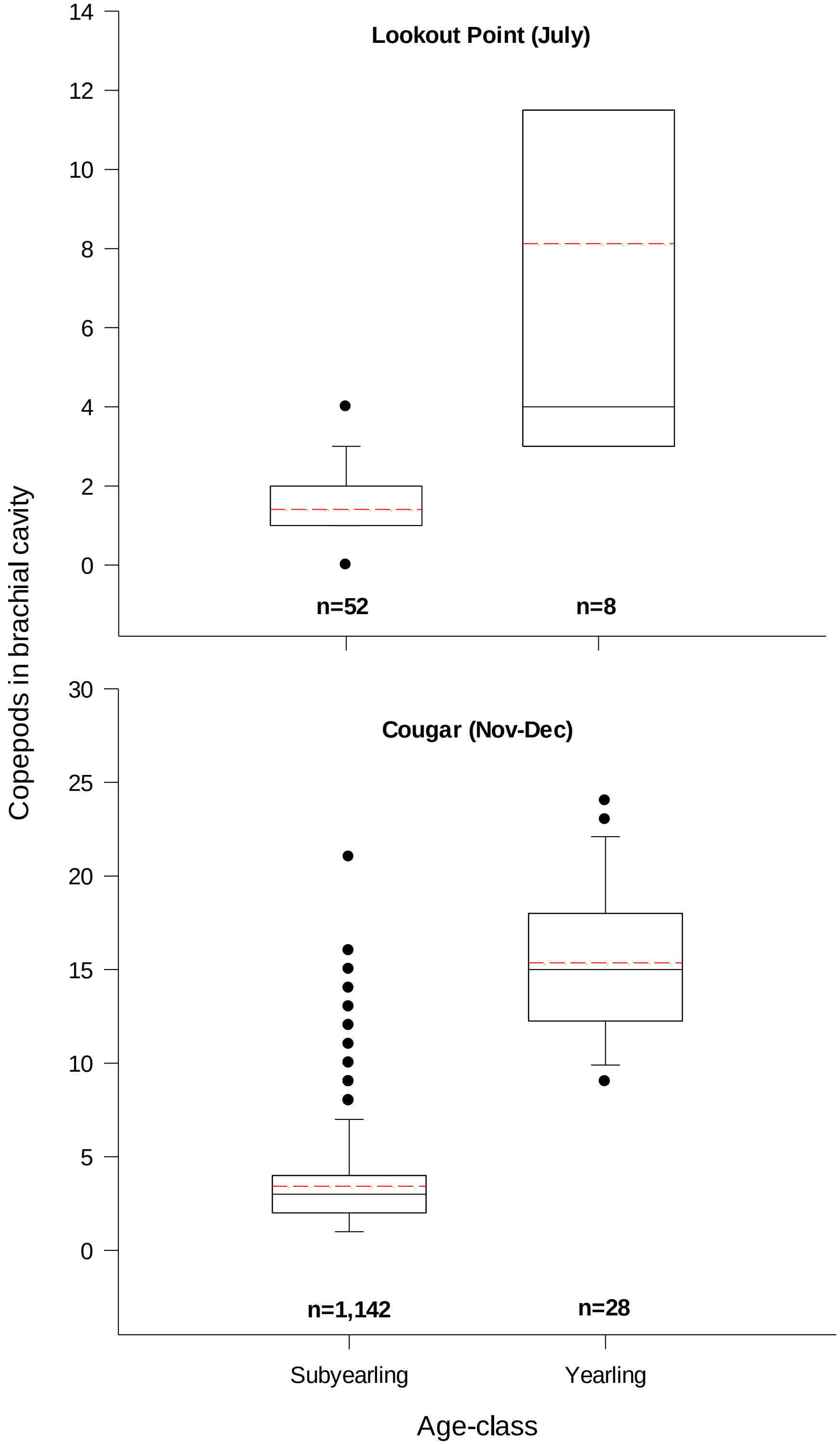

Figure 3-4. Number of copepods within the brachial cavity of infected subyearling and yearling Chinook salmon in Lookout Point and Cougar reservoirs, 2014. Solid lines denote medians, red dashed lines denote means, the box represents 25th-75th percentiles, whiskers are the 10th -90th percentile and circles are outliers. Comparisons were in July for Lookout Point and Nov-Dec for Cougar, periods when sample sizes for both age-classes were sufficient for comparisons (n ≥ 8).

As with prevalence, infection intensity in the fall was greater for reservoir subyearlings compared to streams (Mann-Whitney rank sum test, *P*<0.001) (Figure 3-5). The majority of infected stream-rearing subyearlings (83%) had just one copepod, generally attached to a fin, while most reservoir-rearing fish had multiple parasites (median=3) usually attached within the brachial cavity.

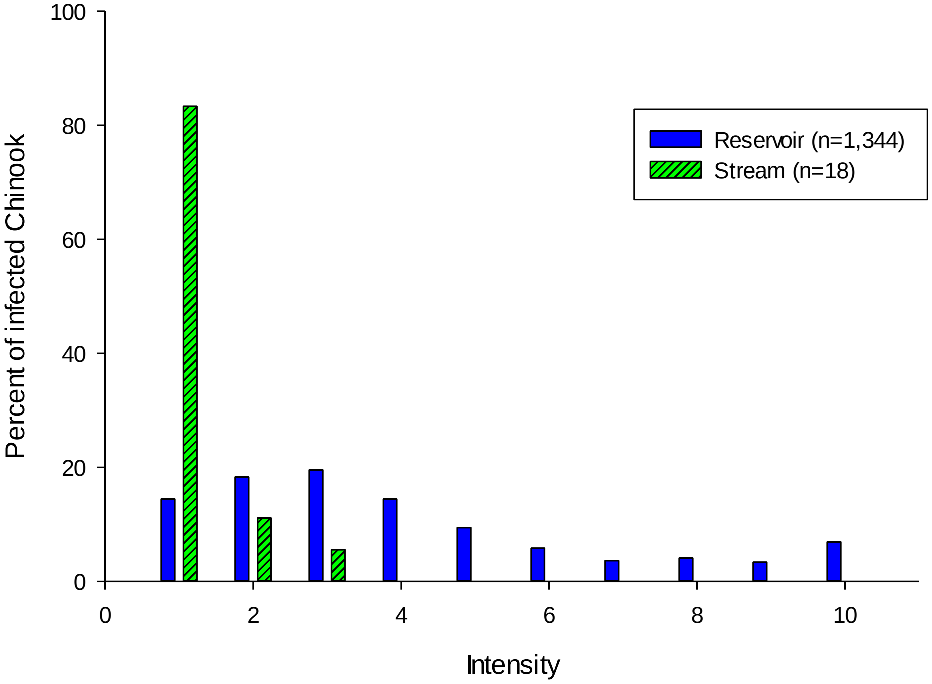

Figure 3-5. Copepod intensity among reservoir- and stream-rearing subyearling Chinook salmon collected in October-November, 2014. Copepod attachment location includes both brachial cavity and fins.

Fall Creek Reservoir in previous years exhibited much greater infection intensity than other reservoirs, but that was not evident in 2014 (Figure 3-6). Median intensity within the brachial cavity for fish in Fall Creek (median=4, range: 2-10) and Detroit (median=5, range: 1-21) were not significantly different, but were greater than Cougar (median=3, range: 1-21) and Lookout Point (median=3, range: 1-22) reservoirs (Kruskal-Wallis one-way ANOVA on ranks, *P*<0.001, with Dunn's multiple comparison test).

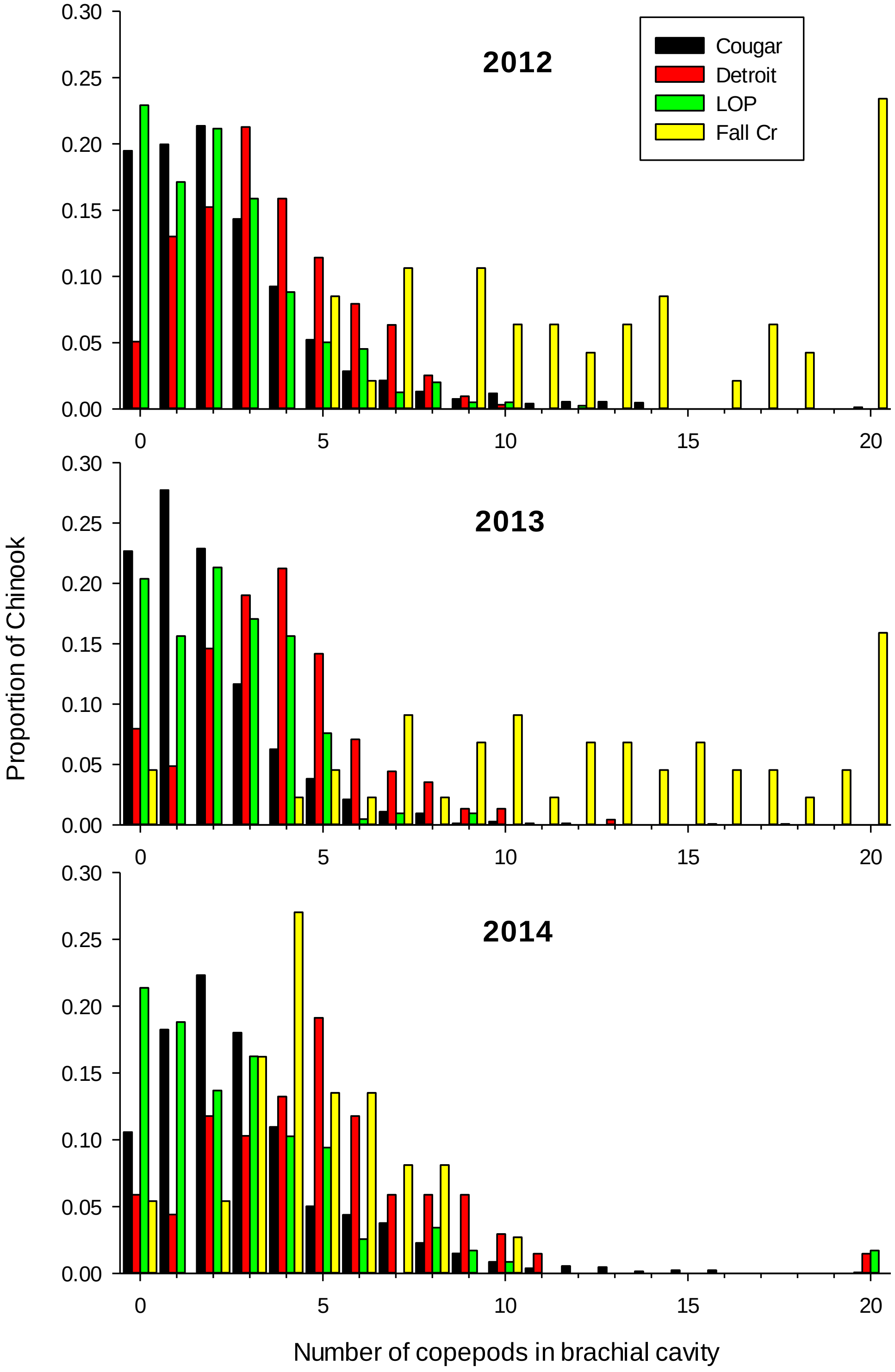

Figure 3-6. Copepod intensity within the brachial cavity of subyearling Chinook salmon from four WVP reservoirs in late fall (Nov-Dec), 2012-2014. Chinook salmon from Lookout Point (LOP) were collected primarily from gill nets in the reservoirs. Cougar and Fall Creek samples were from screw traps below dams. Fall Creek data courtesy of USACE.

Discussion

The greater infection prevalence and intensity of reservoir fish compared to stream fish can partly be attributed to the larger size of fish in reservoirs. Several studies have attributed host size to infection prevalence (Nagasawa and Urawa 2002; Barndt and Stone 2003; Amundsen et al. 1997). Poulin et al. (1991) demonstrated in a laboratory study that a closely related copepod species, *S. edwardsii*, was more likely to infect larger brook trout *Salvelinus fontinalis*, possibly due to the greater host surface area and water volume circulated over the gills. We also observed a greater propensity for reservoir-rearing fish to be infected within the brachial cavity, which is consistent with results from Kabata and Cousens (1977) and Black (1982), who reported that the gills were the preferred attachment location on larger fish. However, we also demonstrated that even after controlling for fish size, reservoir fish were more likely to have greater infection prevalence and copepod attachment within the brachial cavity than stream rearing fish. This suggests that reservoir environmental conditions and/or fish behavior are responsible for the greater infection levels. One mechanism may be related to low water flows (or lack thereof) in reservoirs. During the copepodid stage, the copepod crawls along the host body in search of a suitable attachment location (Kabata and Cousens 1973). Lack of water currents in reservoirs may provide better conditions for copepods to seek out the gills for attachment. McGladdery and Johnston (1988) suggested that copepodids may be retained in the gills if water flow rates in hatcheries are insufficient to flush copepodid eggs out of the opercular cavity, thereby allowing copepodids to re-infect the same host. The relationship between higher transmission rates and low flow environments has also been noted in wild salmon (Friend 1941). Given that it takes a female copepod about 1.5 months to produce copepodids, re-infection could explain the intensity increase we observed in the fall from subyearling Chinook in Lookout Point Reservoir. Chinook salmon schooling behavior in reservoirs may increase the likelihood of copepod lateral transmission. Feeding behavior may also contribute to the greater infection prevalence. Daphnia appear to be the main food item selected by juvenile Chinook salmon in WVP reservoirs (Monzyk et al. 2010). Rondorf et al. (1990) observed subyearling Chinook salmon in reservoirs occasionally consuming daphnia that were approximately 0.7 mm in length, similar to the mean length of the free-swimming copepodids. If juvenile Chinook salmon in reservoirs feed on copepodids, this could explain the greater prevalence in the brachial cavity.

In the previous two years (2012 and 2013) USACE personnel observed very high infection intensity for Chinook salmon in Fall Creek Reservoir, but not in 2014. It is unclear why copepod intensity declined in 2014. In previous reports, we hypothesized that infected adult steelhead and Chinook salmon may be the main source of copepods in reservoirs. We do not know what the infection levels were among outplanted adults in 2014, since copepod monitoring is not part of current protocols. If copepod infection in reservoirs is episodic, low infection intensity in Fall Creek could continue but infection outbreaks could occur in other reservoirs.

Pawaputanon (1980) demonstrated that juvenile sockeye salmon *O. nerka* with mean infection intensity of 23 copepods experienced 90% mortality during salinity tolerance tests compared to 10% mortality for non-infected control fish (an 80% mortality rate). In previous years, 16-20% of Chinook salmon from Fall Creek Reservoir exceeded infection levels reported to cause high mortality during saltwater transition (Pawaputanon 1980). In 2014, no fish in Fall Creek reached this level. However, no studies have been conducted on smolt survival at intermediate infection levels commonly observed in WVP reservoirs. The effects of intermediate infection levels on juvenile Chinook salmon survival during saltwater transition is not currently known but merits further investigation. If infection intensity observed in WVP reservoirs is shown to cause mortality to smolts, then measures can be taken to reduce infection. One possible management option would be treatment of infected adults with hydrogen peroxide before transporting above dams to reduce the potential for infection of juveniles.

Conclusions and Recommended Future Directions

The conditions juvenile spring Chinook salmon currently encounter while rearing in freshwater is vastly different from what existed before construction of WVP dams. 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 the fall. The purpose of this study was to provide information on juvenile Chinook salmon use of reservoirs and the risks and benefits of reservoir rearing to aid management decisions on future adult outplanting strategies and juvenile downstream passage. The one benefit of reservoir rearing is the rapid growth compared to stream-rearing fish and the survival advantage to adulthood this growth would likely impart, assuming dam passage mortality can be reduced below current high levels. The large size at ocean entry of reservoir-rearing Chinook salmon could result in younger age of maturity of returning adults (Hankin et al. 1993; Neilsen and Geen 1986; Claiborne et al 2011).

Heavy parasitic copepods infection on the gills of reservoir-rearing fish may also negate the benefit of rapid growth given that high infection levels likely results in mortality as smolts transition to saltwater. In summer, subyearling population start to become infected with parasitic copepods and by late fall, the majority of fish were infected with intensity varying between individuals and reservoirs. The degree copepod infection influences smolt fitness is an area that deserves further research. If current levels of infection prove detrimental to Chinook salmon populations in reservoirs, management strategies would need to be implemented to reduce the risk. One possible management action could be the treatment of adult salmonids transported above dams, assuming these fish are a key source of copepods in the reservoir systems.

We studied several life-history characteristics of juvenile Chinook salmon rearing in WVP reservoirs. Generally, juveniles entered the head of reservoirs in early spring as fry. Fry were more concentrated in the upper end of the reservoirs in the spring. In larger reservoirs only a very small proportion of fry-sized Chinook salmon (<60 mm FL) reached the dams by spring. By October, most Chinook salmon parr in Lookout Point Reservoir were in the forebay and available for dam passage. If distribution in Lookout Point is indicative of other WVP reservoirs, then parr may congregate in the forebay during the fall irrespective of reservoir operations as part of a natural downstream movement to overwintering habitat.

Despite the risks that parasitic copepods and predation impart on juvenile Chinook rearing in reservoirs, the greatest current risk is mortality associated with dam passage. Current passage conditions at WVP dams are poor (Duncan 2011) and larger fish appear to incur a higher mortality rate (Taylor 2000; Normandeau 2010; Keefer et al. 2011; Zymonas et al. 2014. In a retrospective analysis of balloon-tag studies conducted at Columbia and Snake river dams, Skalski et al. (2002) found that turbine passage mortality increased with fish size. Currently, efforts are underway to improve passage survival for juvenile Chinook salmon of all sizes through operational or structural modifications at dams. These improvements will likely take several years to accomplish. In the interim, overall passage survival for a cohort could be improved by passing more fish at a smaller size earlier in the year. This management strategy would also hedge against the potential risks of copepod infection and predation associated with reservoir rearing until the impact of these risks are better known.

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Appendix

Table A-1. Species composition collected in nearshore traps in three WVP reservoirs, 2014.

Species/rear	Cougar	Foster	Lookout Point
Chinook subyearlings *(Oncorhynchus tshawytscha)*	5,761	498	1,697
Hatchery Chinook *(O. tshawytscha)*	0	0	1
Dace *(Rhinichthys spp.)*	25,051	304	110
Rainbow trout *(O. mykiss)*	150	253	101
Hatchery rainbow trout *(O. mykiss)*	0	4	0
Cutthroat trout *(O. clarkii)*	60	4	26
Sculpin *(Cottus spp.)*	0	115	121
Northern pikeminnow *(Ptychocheilus oregonensis)*	0	2,769	87
Redside shiner *(Richardsonius balteatus)*	0	107	225
Brown bullhead *(Ameiurus nebulosus)*	0	8	14
Yellow bullhead *(A. natalis)*	0	73	14
Largemouth bass *(Micropterus salmoides)*	16	0	1
Smallmouth bass (*M. dolomieu*)	0	40	0
White crappie *(Pomoxis annularis)*	0	2	12
Bluegill *(Lepomis macrochirus)*	2	512	46
Yellow perch *(Perca flavescens)*	0	112	0
Mountain whitefish *(Prosopium williamsoni)*	0	1	1
Suckers *(Catostomus spp.)*	0	272	13
Western brook lamprey (*Lampetra richardsonii)*	3	20	1
Rough-skinned newt *(Taricha granulosa)*	212	620	526

Table A-2. Number of gill net sets and subyearling Chinook salmon caught by month and area in Lookout Point Reservoir, 2014.

		Number of subyearling Chinook salmon	
Area[a]	Sets	Natural	Hatchery
July			
A1	12	93	106
A2	12	16	22
A3	12	13	22
A4	12	18	12
A5	12	43	33
August			
A1	12	31	74
A2	8	5	8
A3	8	7	15
A4	6	2	7
A5	8	43	21
September			
A1	14	16	40
A2	8	6	1
A3	8	13	9
A4	9	31	15
A5	9	3	1
October			
A1	16	34	43
A2	10	19	18
A3	10	7	7
A4	10	8	3
A5	10	16	5
November			
A1	16	68	48
A2	10	25	7
A3	10	16	9
A4	10	15	6
A5	10	3	4

[a] Data does not include area A6 at head of the reservoir. Area A1 in at the dam.

Table A-3. Dimensions of select Willamette Valley Project reservoirs at full and low conservation pool.

				Depth (m)		Length (km)	
Reservoir	Year completed[a]	Dam height (m)[a]	Elevation above sea level (m)	Full pool[a]	Low pool	Full pool	Low pool
Foster	1967	38.4	214	37.5	~30	7.4	5.6
Fall Creek	1965	62.5	256	55.2	~23	9.2	4.1
Lookout Point	1953	84.1	287	73.8	~43	21.0	10.9
Detroit	1953	141.1	481	110.9	~79	14.4	10.3
Cougar	1964	158.2	518	142.3	~94	9.7	5.2
Hills Creek	1962	103.9	472	96.6	~68	12.2	7.1

[a] Data from National Performance of Dams Program (Stanford University)

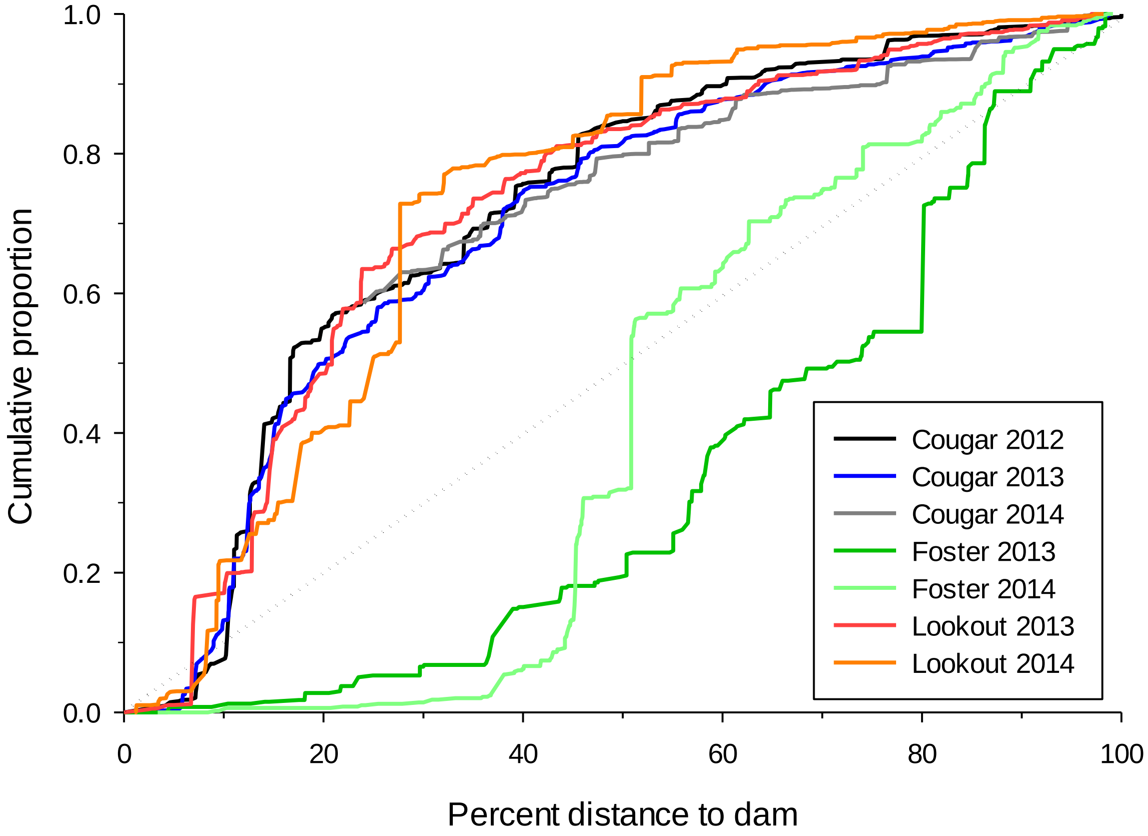

Figure A-1. Cumulative proportion of subyearling Chinook salmon caught during spring in relation to percent of shoreline distance to dam, by reservoir and year. Dotted line represents the cumulative proportion of a theoretical population that is evenly distributed throughout the reservoir.

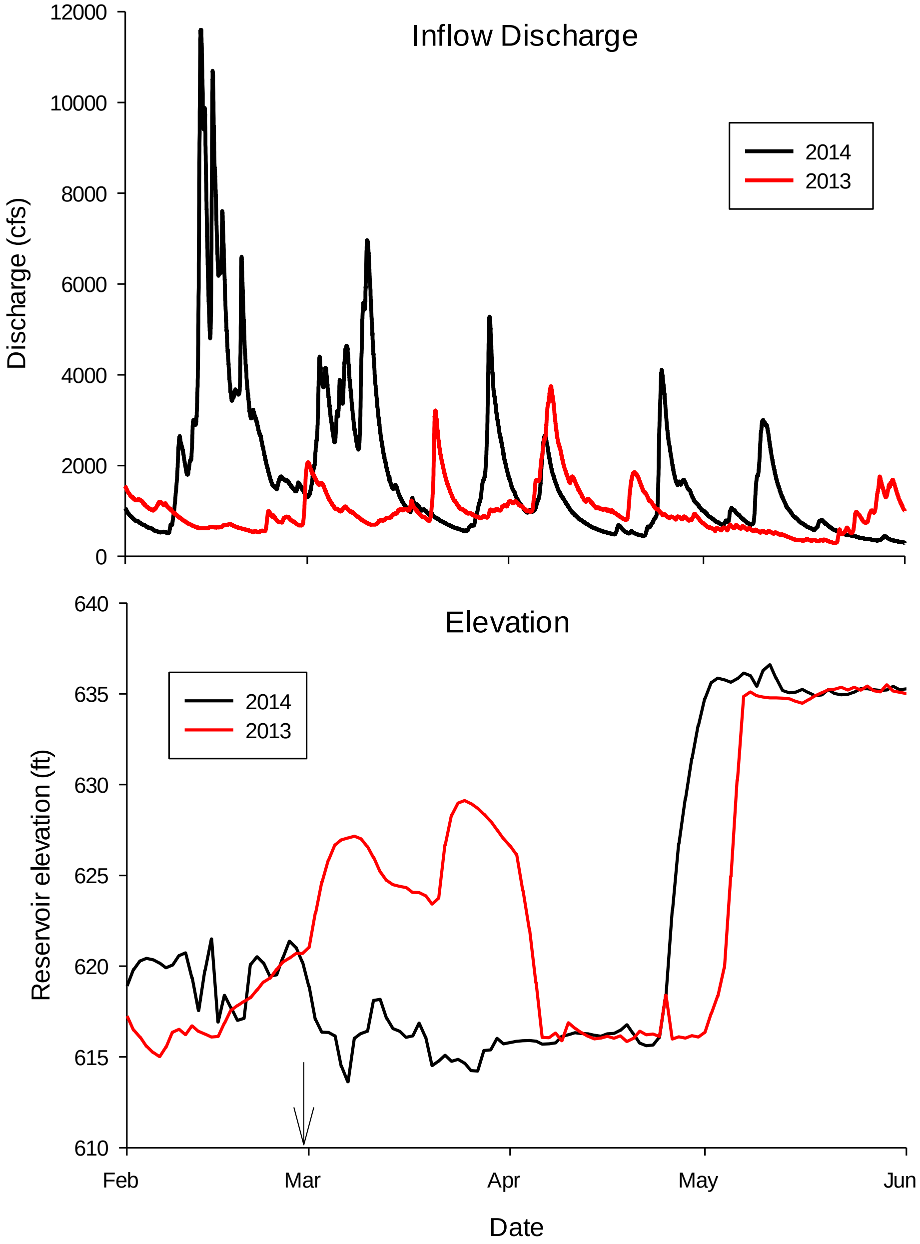

Figure A-2. South Santiam River discharge into Foster Reservoir and reservoir elevation in 2013 and 2014. Discharge data from USGS gauge station 1418500 below Cascadia, OR. Arrow on date axis denotes date of peak migration of subyearling Chinook salmon into reservoir.

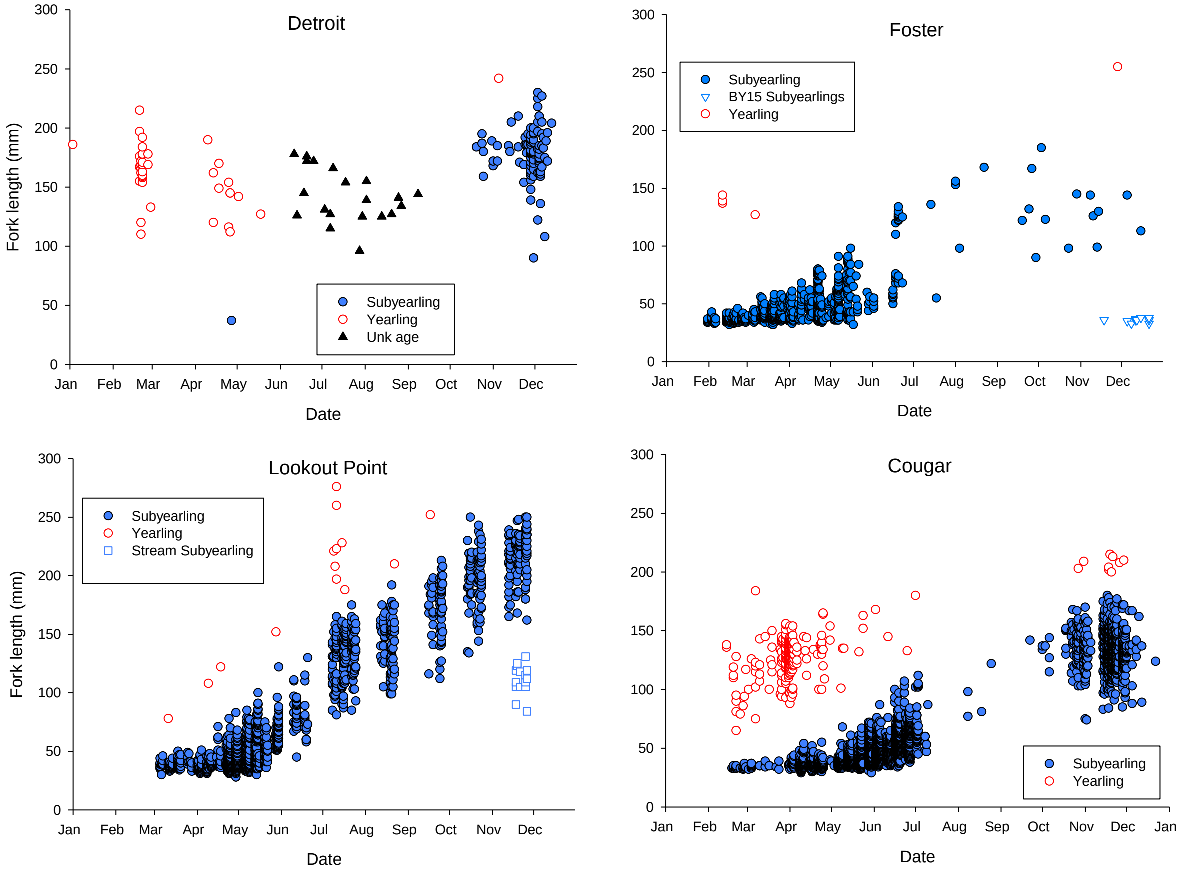

Figure A-3. Fork lengths of juvenile Chinook salmon caught in Willamette Valley Project reservoirs, 2014. Age determination based on length-frequency analysis.

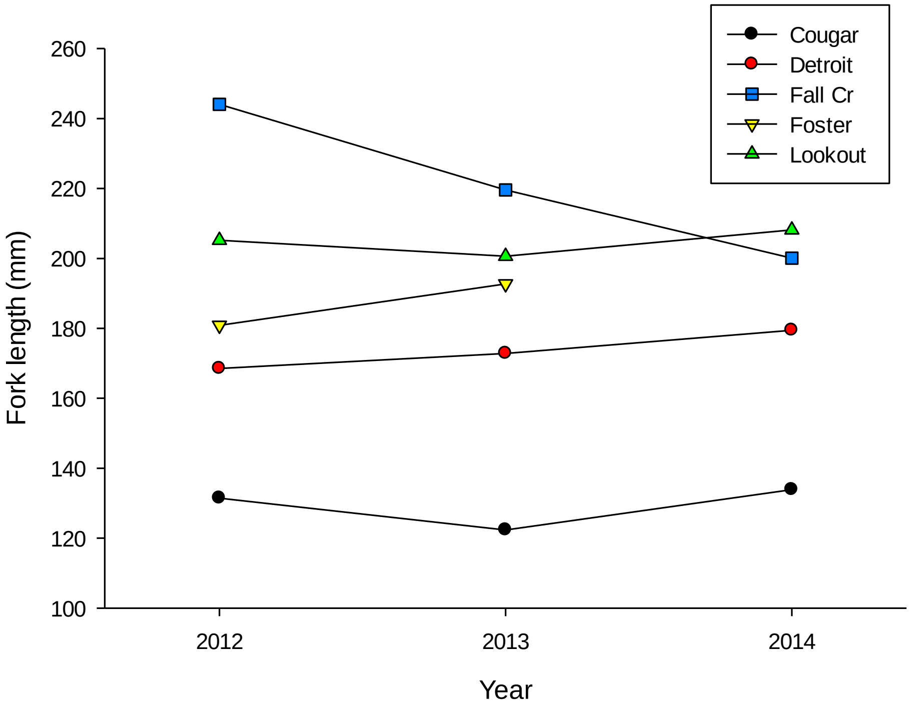

Figure A-4. Mean fork length of reservoir-rearing subyearlings in the fall (October-December), 2012-2014.