THE OREGON PLAN *for Salmon and Watersheds*





Recovery of Wild Coho Salmon
In Salmon River Basin, 2008-2010

Report Number: OPSW-ODFW-2011-10

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INTRODUCTION

Hatcheries have been a centerpiece of salmon management in the Pacific Northwest for more than a century but recent evidence of adverse interactions between hatchery and naturally-produced salmon have resulted in substantial changes in many hatchery programs. In 2007 the Oregon Department of Fish and Wildlife terminated a 30-year artificial propagation program for coho salmon in the Salmon River basin after a status assessment concluded that wild population viability was threatened by hatchery effects on salmon productivity (Chilcote et al. 2005). Hatchery-reared coho comprised 50-100% of the naturally spawning population in recent years. Low productivity was reflected in a low spawner to recruit ratio, and life-stage specific survival was lower than that of nearby populations. The temporal distribution of adult spawning in the basin was truncated and peaked 1.5 months earlier relative to the pre-hatchery period and adjacent coastal populations. The cessation of hatchery releases into Salmon River not only removed the primary factor believed to limit productivity of the local population, it also constituted a rare management experiment to test whether a naturally-spawning population can recover from a prolonged period of low abundance after interactions with hatchery-produced coho salmon are eliminated. This report summarizes the results of coho population studies at Salmon River for the first three years after the hatchery program was discontinued.

The study in Salmon River is timely because ecological interactions between hatchery and wild fish have been implicated in the reduced survival and decreased productivity of wild coho and other salmonid populations (Nickelson 2003, Buhle et al. 2009, Chilcote et al. 2011). Recent studies involving a diversity of salmonid species and watersheds have shown a negative relationship between hatchery spawner abundance and wild population productivity regardless of the duration of hatchery influence (Chilcote et al. 2011). Yet neither the mechanisms of these productivity declines nor their potential reversibility have been investigated. Recent management changes at Salmon River provide an opportunity to experimentally evaluate coho salmon survival and productivity following the elimination of a decades-long hatchery program. The results will provide new insights into the reversibility of hatchery effects and the rate, mechanisms, and trajectory of response by a naturally spawning coho salmon population.

Hatchery programs have been shown to change the timing and distribution of naturally spawning adults, but ecological and genetic influences on the spatial structure and life history diversity of juvenile populations are poorly understood. Conventional understanding of the life history of juvenile coho has presumed a relatively fixed pattern of rearing and migration. However, recent studies have found much greater variation in juvenile life history and habitat-use patterns than previously expected (Miller and Sadro 2003, Koski 2009), including evidence that estuaries may play a prominent role in the life histories of some coho salmon populations.

A recent study in the Salmon River basin found considerable diversity in the life histories of juvenile Chinook salmon, including extended rearing by fry and other subyearling migrants within the complex network of natural and restored estuarine wetlands (Bottom et al. 2005). Unfortunately, interpretation of juvenile life history variations at Salmon River was confounded by the Chinook hatchery program, which has concentrated spawning activity in the lower river near the hatchery and may directly influence juvenile migration and rearing patterns. Discontinuation of the coho hatchery program at Salmon River provides an opportunity to quantify changes in juvenile life history following the elimination of all hatchery-fish interactions with the naturally spawning population. Such responses may provide important insights into the mechanisms of hatchery influence on wild salmon productivity and population resilience.

Our research integrates adult and juvenile life stages, examines linkages to physical habitat conditions in fresh water and the estuary, and describes variability between juvenile performance and adult returns. It also monitors the coho salmon population across habitat types and life history stages to identify population responses at a landscape scale. We will determine productivity and survival at each salmon life stage and monitor the response of the adult population following the cessation of the coho salmon hatchery program. From these indicators, we will determine the potential resiliency of the coho salmon population, and evaluate the biological benefits or tradeoffs of returning the ecosystem to natural salmon production.

Our study design encompasses four population phases: (1) pre-hatchery conditions (Mullen 1979), (2) dominance by hatchery-reared spawners (2008), (3) first generation naturally produced juveniles (2009-2011), and (4) second generation naturally produced juveniles (starting in 2012). This research will validate assumptions about factors limiting coho recovery and determine whether recovery actions have been effective.

Here, we report on findings from 2008-2010 to address four principal objectives:

1. Quantify life stage specific survival and recruits per spawner ratio of the coho salmon population before and after hatchery coho salmon are removed from Salmon River.

2. Assess whether the Salmon River coho population is limited by capacity and complexity of stream habitat.

3. Describe the diversity of juvenile and adult life histories of coho salmon in the Salmon River basin, and estimate the relative contributions of various juvenile life histories to adult returns.

4. Determine seasonal use of the Salmon River estuary and its tidally-inundated wetlands by juvenile coho salmon.

The field sampling that supported the study on coho salmon also captured Chinook salmon and steelhead and cutthroat trout during routine sampling in the watershed and estuary. This report emphasizes coho salmon results, but also summarizes catch, distribution, and migration data for other salmonids to compare densities and abundances in freshwater and the estuary. Additional results for Chinook, steelhead, and cutthroat are presented in Appendix A. See Stein et al. (2011) for more detailed information on life history diversity, migration patterns, habitat use, and abundance of cutthroat trout.

METHODS

Salmon River watershed is located on the north-central Oregon coast immediately north of Lincoln City (Figure 1). The basin is 195 km^2 in size, with an 800 hectare estuary that extends to river kilometer (rkm) 6.5. The estuary has extensive wetlands, some of which were restored in 1978, 1987, and 1996 (Figure 2). Additional area where Rowdy Creek enters the southern edge of the 87 Marsh was opened to tidal influence in 2010 with the removal of a tide gate and associated dikes. The basin has a diverse ownership and management: US Forest Service (USFS) Cascade Head Scenic Research Area in the estuary, USFS and private industrial forest in the uplands, Oregon State Parks in 3.2 km of stream corridor, and rural residential along the lower reaches of the mainstem. ODFW operates a hatchery at Rkm 8 (Figure 1) that was established in 1978 to supplement coho and Chinook salmon populations. The final release of juvenile coho occurred in May 2007, and the last run of hatchery-origin adult coho returned in fall 2008. The hatchery continues annual releases of ~200,000 subyearling fall Chinook salmon into Salmon River during August.

Fish Sampling Overview

We estimated the abundance of adult coho during the fall spawning period, age-0 juvenile (parr) in freshwater streams during the summer, and outmigrant age-0 and age-1 life stages in the spring. We also sampled age-0 and age-1 juvenile coho in the estuary throughout the year. In addition to coho salmon, steelhead and cutthroat abundances were estimated in the summer; Chinook, steelhead, and cutthroat were enumerated at the outmigrant trap in the spring; and Chinook, chum, and cutthroat were measured and recorded in the estuary. Fish were PIT-tagged and antennas were set up to determine migration timing, growth, and behavior of individual fish. Otoliths were collected from juvenile and adult coho to independently assess migration and residence patterns and age at return. Each of these activities is described below.

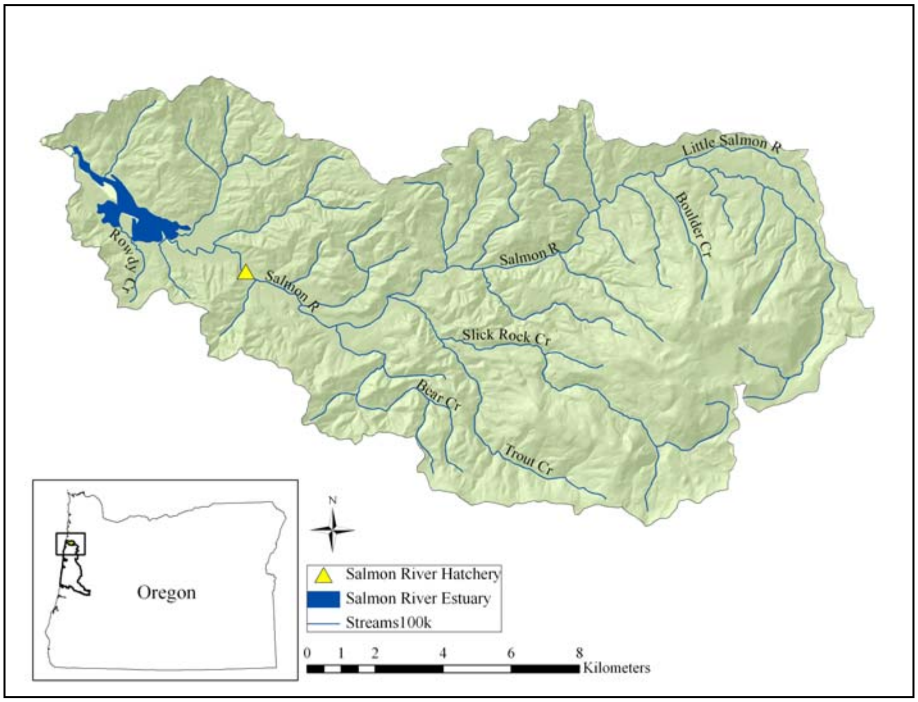


Figure 1. Salmon River basin on the north-central Oregon Coast.

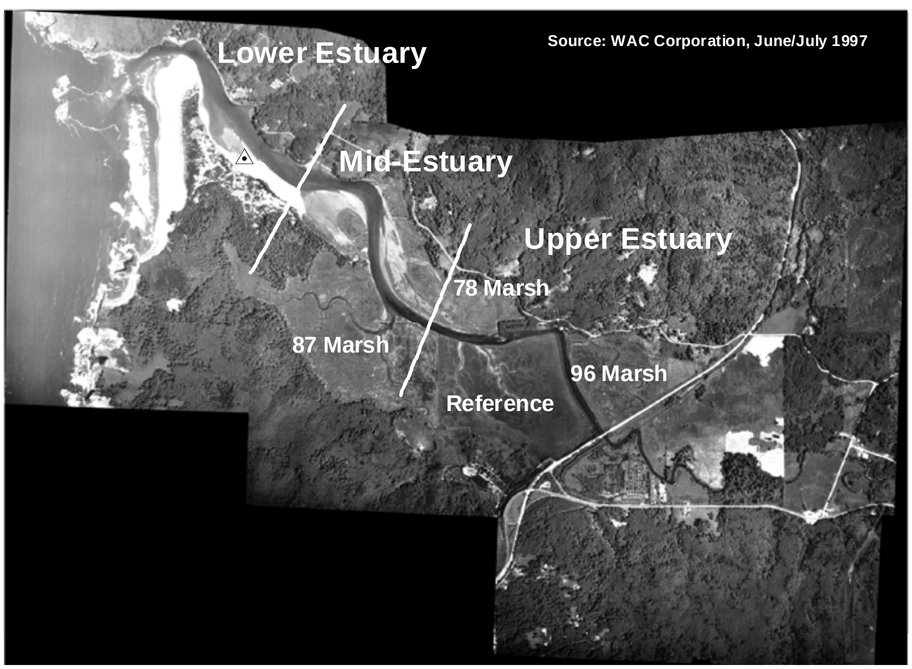


Figure 2. Wetlands in the Salmon River estuary. The number refers to the year the wetland was restored. The reference marsh was never diked. Rowdy Creek enters into the 87 Marsh at the southeast edge of the marsh.

Abundance, distribution, and timing of Adult Coho

ODFW's Oregon Adult Salmonid Inventory and Sampling project (OASIS 2010) conducts annual surveys of adult coho salmon in Salmon River. Since the 2006-2007 spawning season, spawning surveys have encompassed approximately 15-20 percent of the 81 kilometers of potential coho spawning habitat annually using a spatially-balanced random sample. Sites were selected using the generalized random-tessellation stratified (GRTS) sampling methodology (Stevens and Olsen 2004), and surveys were designed to estimate abundance with precision of ±30 percent using a local neighborhood (NBH) variance estimator (Stevens and Olsen 2003). Twelve sites were surveyed in 2007, 2008, and 2010, and 13 sites in 2009. In addition to the standard OASIS protocol (Jacobs et al. 2002), we collected scales and otoliths from all wild coho salmon carcasses handled on spawning ground surveys. Migration time into freshwater was estimated at the PIT antenna (2010 only) in Salmon River at the hatchery (Rkm 7.9) and spawn time was determined during the spawning surveys. Distribution was assessed as a function of site occupancy and density.

A PIT antenna array, consisting of three antennas, has operated continuously in lower Salmon River since deployment on August 26, 2010. The antennas are located at Rkm 7.9 adjacent to the Salmon River hatchery. The antenna array is placed on the north side of the river between the weir and shoreline. Fish generally are forced to the north side of the river to pass upstream until the river rises sufficiently to submerge the weir. The antenna operates even when the weir is overtopped at high flows, although efficiency is likely reduced. The antennas are powered by a multiplexing transceiver (Destron Fearing, Inc. model FS1001M) connected to four 12V deep cycle batteries that are recharged through a 110 AC power line from the hatchery. PIT-tag interrogation and transceiver diagnostic data are downloaded directly from the transceiver memory via a wireless modem. The antenna also records information on tagged adult cutthroat and steelhead, and all tagged juvenile fish passing downstream or upstream.

Figure 3. PIT antenna at Salmon River Hatchery weir. Left – low flow; center – moderate flow; right – high flow and still operating.

Watershed Population Estimates

Juvenile (age-0) coho salmon abundance was estimated in tributary and mainstem habitats in 107 kilometers of wadeable stream in the basin. Within this sampling frame, 25 GRTS-selected survey sites were identified annually. Sites overlapped with the 2007-2009 adult survey sites but also included sites within the rearing-only distribution. Abundance was estimated by depletion removal (Zippin 1958) using backpack electroshockers. Each site was approximately 20 active channel widths in length, with a minimum of 50 meters and a maximum length of 150 meters. Blocknets were placed at the upstream and downstream end of each site, and we made multiple passes through the site until a sufficient reduction in catch was achieved between subsequent passes. In some sites, we estimated population abundance using mark-recapture technique (Rodgers et al. 1992). Depletion estimates of the number of fish at each site were derived from the program CAPTURE (White et al. 1982) and mark-recapture estimates were derived from NOREMARK (White 1996). The total number of summer coho parr rearing in the basin was estimated using the LNB estimator and expanded to all stream kilometers in the basin.

All coho salmon were enumerated, measured and weighed. Coho >65mm in length were PIT tagged with full duplex 12.5 mm tags. Cutthroat and steelhead were enumerated and a subsample of each species was measured, weighed, and PIT tagged. Trout spp. <60mm were classified as trout fry to minimize errors in identification between steelhead and cutthroat. Depending on their size, some cutthroat and steelhead were also tagged with either 12mm or 23 mm tags. Population estimates were generated for steelhead and cutthroat for the sites and watershed. The distribution of steelhead was similar to that for coho, and the distribution of anadromous cutthroat was assumed to be similar. The annual contribution of resident cutthroat to the populations downstream of migration barriers is unknown.

Habitat surveys were conducted at 21 randomly selected sites in Salmon River in 2010 to model the potential rearing capacity of stream habitat during the summer and winter. We used the Habitat Limiting Factors Model (HLFM: Nickelson et al 1992, 1993) to estimate the capacity and quality of stream habitat habitat for juvenile coho. Sites were compared based on the potential capacity, expressed as number of parr per km and the parr per m^2, that the habitat could support. Because winter is the limiting season (lowest capacity) we display the results of winter rearing capacity. Sites considered low quality supported fewer than 900 parr/km or 0.12 parr/ m^2 in the winter. High quality habitat had capacity greater than 1850 parr/km or 0.30 parr/m^2 in the winter

Outmigration

The abundance, size, and migration timing of downstream-migrating juvenile salmonids were quantified at a 1.5 meter diameter rotary screw trap located above the head of tide just below Salmon River Hatchery. From 2008 to 2010, the trap was operated continuously from mid-March through the end of June. Trap efficiency was calculated on a weekly basis, and abundance and confidence intervals were estimated following the techniques of Solazzi et al. (2000). Most juvenile salmonids that were >65mm and collected in the screw trap were marked individually with PIT-tags to allow estimates of estuarine residence time and migration and upon return at the hatchery weir (PIT antenna or handled in the hatchery) or on the spawning grounds. Additional outmigration information is gathered when fish tagged in the watershed (described above) passed through the PIT antenna array on the north side of the river at Rkm 7.9 or at the array in the 96 Marsh.

Estuary residence

We quantified habitat use, residence time, and growth in the estuary. Beach seining is an effective means of capturing juvenile salmonids in the Salmon River estuary (Mullen 1979, Cornwell et al. 2001, Bottom et al. 2005), and catch-per-unit-effort has proven to be a reliable index of salmonid abundance in other small Oregon estuaries (Reimers 1973, Pearcy et al. 1989). The main channel and wetland habitats of the estuary were sampled at least twice monthly during the year using a 38m beach seine. Site selection was representative of available channel and wetland habitat throughout the estuary from the 96 Marsh to ocean entrance (Figure 4). The wetland habitats (natural and restored) are located along a salinity gradient from tidal-fresh to marine zones (Bottom et al. 2005).

In addition to the biweekly sampling, juvenile coho were sampled more regularly (weekly) in the 96 Marsh through the summer and fall, and at the estuary mouth. The reference, 78, and 87 marshes were used very sparingly by coho except in the winter. Therefore we concentrated the marsh sampling in the 96 Marsh the rest of the year. In 2008 and 2009 we estimated absolute abundance of juvenile coho in the 96 Marsh through short-term mark-recapture sampling (e.g. Reimers 1973). We also seined regularly at the mouth of the estuary to estimate size, time, and abundance of juvenile coho at ocean entrance. Coho, cutthroat, and steelhead were also seined, enumerated, measured and scanned for PIT tags to estimate estuary residence and growth.

From April 22, 2010 to August 25, 2010, we operated a PIT tag antenna array in the main channel of the 96 Marsh. The antenna was placed 200 meters up the marsh channel from the confluence with the main estuary channel. The array consisted of five rectangular inductor coil antennas (three~3.0 m x 1.2 m, two~2 were 2.4m x 1.2 m) arranged in a line stretching across the channel. Antennas were powered by a multiplexing transceiver (Destron Fearing, Inc. model FS1001M). The system was powered by four 12V deep cycle batteries that were recharged with two 85-watt solar panels and a 10-amp, 24-volt charge controller. PIT-tag interrogation and transceiver diagnostic data were downloaded directly from the transceiver memory via a wireless modem.

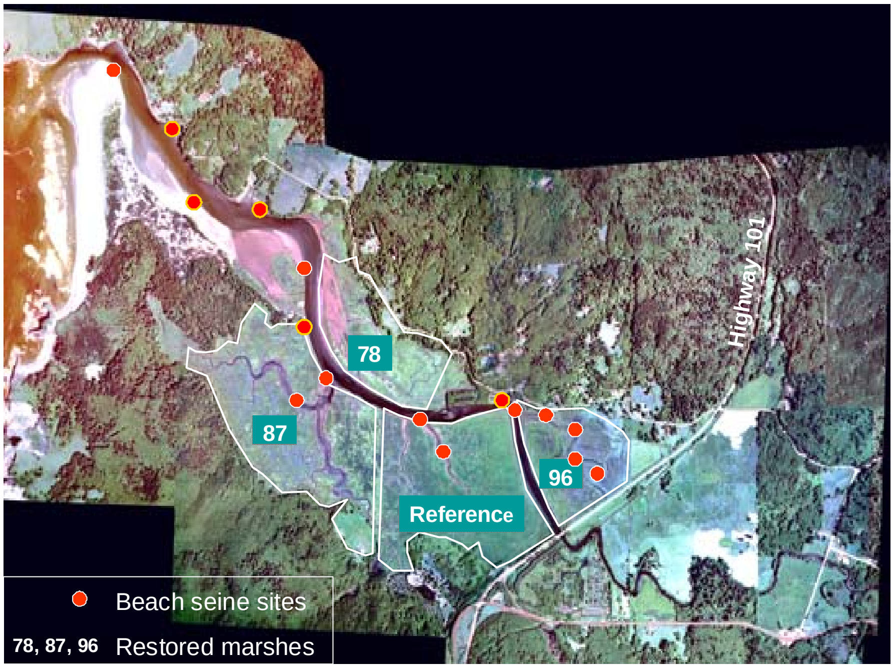


Figure 4. Salmon River estuary. Restored marshes are identified by year of restoration.

Marking activities

We marked fish with unique tags to assess habitat use, migration timing, growth, and survival. Passive Integrated Transponder (PIT) tags were placed in coho, steelhead, and cutthroat during all phases of the field sampling (Tables 1 and 2). Juvenile coho larger than 65 mm were implanted with 12mm full duplex tags during electrofishing surveys in August and September, at the rotary screw trap in the spring, and during beach seining in the estuary throughout the year. Some juvenile cutthroat and steelhead were also implanted with PIT tags during summer electrofishing, spring sampling at the rotary screw trap, and while seining in the estuary. Fish larger than 65mm were implanted with the 12mm tag, while those >120mm were marked with 23.75mm x 3.9 mm full duplex Passive Integrated Transponders (PIT-tags) (Destron-Fearing model TX1415BE, 0.57g dry weight).

Table 1. Number of fish PIT tagged from 2008 – 2010 in Salmon River.

Area/method	Coho yearling	Coho subyearling	Cutthroat Trout	Steelhead Trout	Sum
Upper watershed/electrofishing (August – September)					
2008	0	373	333	69	775
2009	0	1286	465	57	1808
2010	0	658	456	100	1214
Mainstem river/rotary screw trap (March – June)					
2008	1053	40	125	271	1489
2009	531	199	258	428	1416
2010	568	61	153	193	975
Estuary/beach seine (January – December)					
2008	291	433	172	20	916
2009	393	517	287	48	1245
2010	1106	378	388	23	1895

Table 2. Number of PIT tags placed in juvenile coho by brood year, location, and age.

Brood year	Watershed (0)	Smolt trap (0)	Smolt trap (1)	Estuary (0)	Estuary (1)
2006			1053		291
2007	373	40	531	433	393
2008	1286	199	568	517	1106
2009	658	61		378	

Otolith Analysis

We analyzed otolith chemistry and reconstructed the juvenile life histories of 73 adult Salmon River coho (28 in 2008 and 45 in 2009) sampled on the spawning grounds. Otoliths were prepared by the Washington Department of Fish and Wildlife, Fish Ageing and Otolith Laboratories in Olympia, WA. Sagitta otoliths were dissected in the field and prepared in the sagital plane similar to methods used in Volk et al (2010) and Campbell (2010). Chemical analysis was completed at the Keck Collaboratory for Plasma Mass Spectrometry at Oregon State University using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS). Life history transects were made from the otolith core to the otolith edge in the dorsal/posterior quadrant. Instrument conditions were similar to those reported in Campbell (2010).

The elements Strontium (Sr), Barium (Ba) and Zinc (Zn) were used to estimate life history parameters. All elemental values are ratios of Calcium (Ca) and reported as atomic ratios. Points of interest (POI) along the chemical transect were related to the physical location on the otolith by the equation (Brenkman et al. 2007, Volk et al. 2010, Campbell 2010):

$$otolith_{POI}\ (\mu m) = \left(\frac{laser_{POI}\ (ms) - laser_{start}\ (ms)}{1000}\right) * 5\ \mu m/sec$$

To back-calculate fish size at any point of interest we used the fish size/otolith size relationship of Chinook salmon in the Salmon River. We will update these results in the future by developing a distinct fish size/otolith size relationship for coho salmon from measurements of juvenile coho otoliths.

Strontium was used to estimate the location on the otolith of estuary/ocean entrance by recording the point of rapid Sr increase (inflection) that is correlated with salinity (Volk et al. 2000, Zimmerman 2005). The element Zinc was used to locate the point of annuli formation and to subsequently estimate the season of ocean/estuary entrance in conjunction with the Sr inflection point (Halden et al. 2000, Campbell unpublished data). If the point of Sr increase appeared prior to annulus formation in the winter months), we assumed the individual had migrated to the ocean in the summer or fall. If the point of Sr increase occurred during or after annulus formation we assumed the individual had left sometime in the winter/spring.

Juvenile life histories of returning adult coho were classified into four types based on otolith chemistry: 1) yearling spring migrant; 2) subyearling fry migrant (estuary/ocean entry soon after or near yolk absorption), 3) nomadic life history (early estuary entrance, subsequent migration back into freshwater, and yearling outmigration in winter/spring), and, 4) subyearling parr fall migrant

RESULTS

Adult Population

The spawning escapement of adult coho salmon was estimated at 993 $\pm$ 54% (95% confidence interval) in 2007 and 3,853 $\pm$ 38% (95% CI) in 2008. Of the adult coho observed, approximately 5% and 20% were from naturally spawned parents in 2007 and 2008, respectively. Adult coho were present in all sites, but distribution of spawning was concentrated in upper mainstem Salmon River and in Bear Creek (Figure 5). Adult populations in 2009 and 2010 were the progeny of naturally spawned fish because the hatchery discontinued releases of juvenile coho after 2007.

The adult population abundance was 753$\pm$58% CI and 1382$\pm$42% CI in 2009 and 2010 respectively. The fish distribution was similar to that of 2007-08 when spawners were concentrated in upper Salmon River and in lower Bear Creek (Figure 5). Additional concentrations of adult coho were observed by the Chinook survey crew in lower mainstem Salmon River. Migrating adults passed the PIT antenna at the hatchery weir (Rkm 7.9) during mid-September to early October in 2010 (Figure 6). Three adults were detected in late December and early January. The spawning time peaked in early

November in 2010. Spawning typically occurs from late October through early December with a peak early November. Other coast coho populations spawn from early October through early February, with a peak in the later half of December.

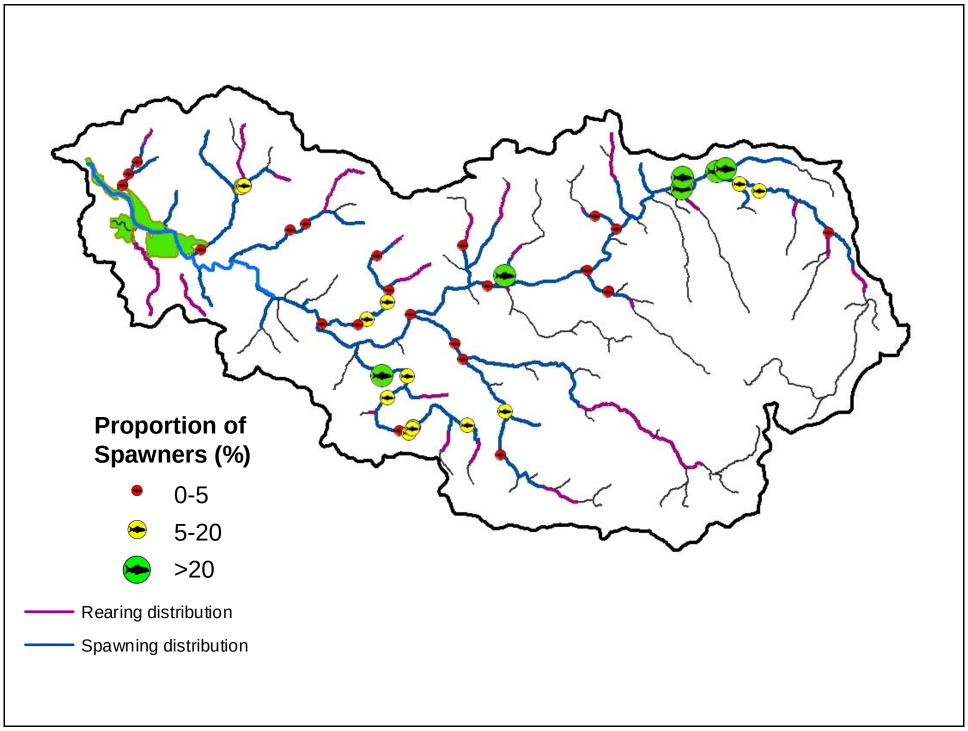


Figure 5. Spawning distribution of adult coho during 2007-2010 in Salmon River. The abundance at each site is proportional to the total annual abundance, or averaged across years for sites surveyed in more than one year.

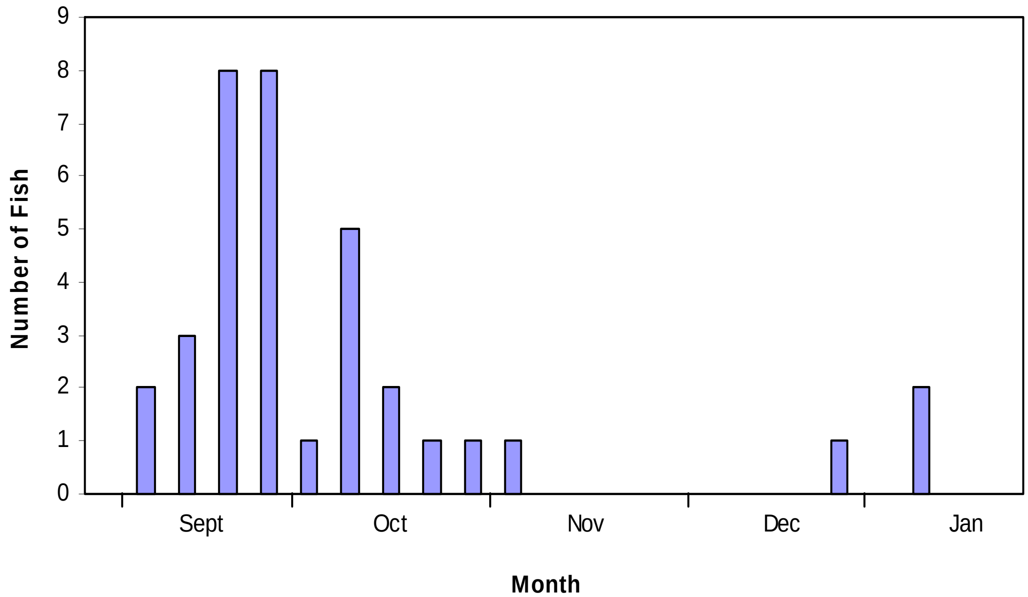


Figure 6. Time of adult migration past the PIT antenna at rkm 7.9 (n=34) during 2010-11. Spawning activity peaked on November 5 in 2010.

Juvenile Salmonid Populations in the Watershed

The randomly selected sites were drawn from a sample frame that encompassed the distribution of anadromous fish in Salmon River. Juvenile coho (parr) were sampled at 56 – 67% of the sites each year (Table 3). Density and overall abundance was highest in 2009, when the parr were progeny of a spawning population of almost 4,000 adult coho. Juvenile abundance and density was quite low in 2008, half of the abundance in 2010 although the spawner populations in 2007 and 2009 were similar. The parr sampled in summer 2010 represented the first cohort in thirty years to be derived entirely from naturally-produced parents (i.e., no hatchery-origin adults in the spawning population). . Distribution of coho parr in the watershed was uneven, not unlike that depicted by the adult surveys. High abundances occurred every year in upper Salmon River and Bear Creek (Figure 7). The relative abundance displayed in Figure 7 was set as the 25th and 75th quartiles of abundance in mid-coast and north coast basins (WORP 2010) in each year. Sites that were surveyed in multiple years also showed similar differences in densities. We handled approximately 2.5 % of the population each year during the August and September sampling effort. The confidence interval around the estimate of the juvenile population is larger than desired because a significant portion of the sites did not have coho present even though the sites were within the potential rearing distribution.

In contrast to juvenile coho, the juvenile steelhead and cutthroat were more evenly distributed during the late summer in 2008-10 (Table 4), with abundances ranging from 34,000 to 44,000 fish of each species in the watershed. Steelhead were present at 75% of the sites, and cutthroat were present at all sites.

Table 3. Population estimates (±95% confidence intervals), mean density per m^2, mean density per km, and percent of sites occupied, by coho in streams of Salmon River watershed.

Year	Abundance	Density (m^2)	Density (km)	Occupancy
2008	19,412 (43%)	0.04 (57%)	180 (43%)	56%
2009	67,794 (29%)	0.19 (36%)	630 (29%)	66%
2010	37,617 (34%)	0.11 (54%)	350 (34%)	67%

Table 4. Estimate of coho, steelhead, and cutthroat in freshwater streams in Salmon River watershed (95% confidence limits are expressed as a percent of the estimate).

Species	2008	2009	2010
Coho	19,412 (43%)	67,794 (29%)	37,617 (34%)
Steelhead	44,623 (38%)	33,626 (38%)	33,674 (50%)
Cutthroat	34,610 (25%)	41,048 (13%)	35,849 (28%)

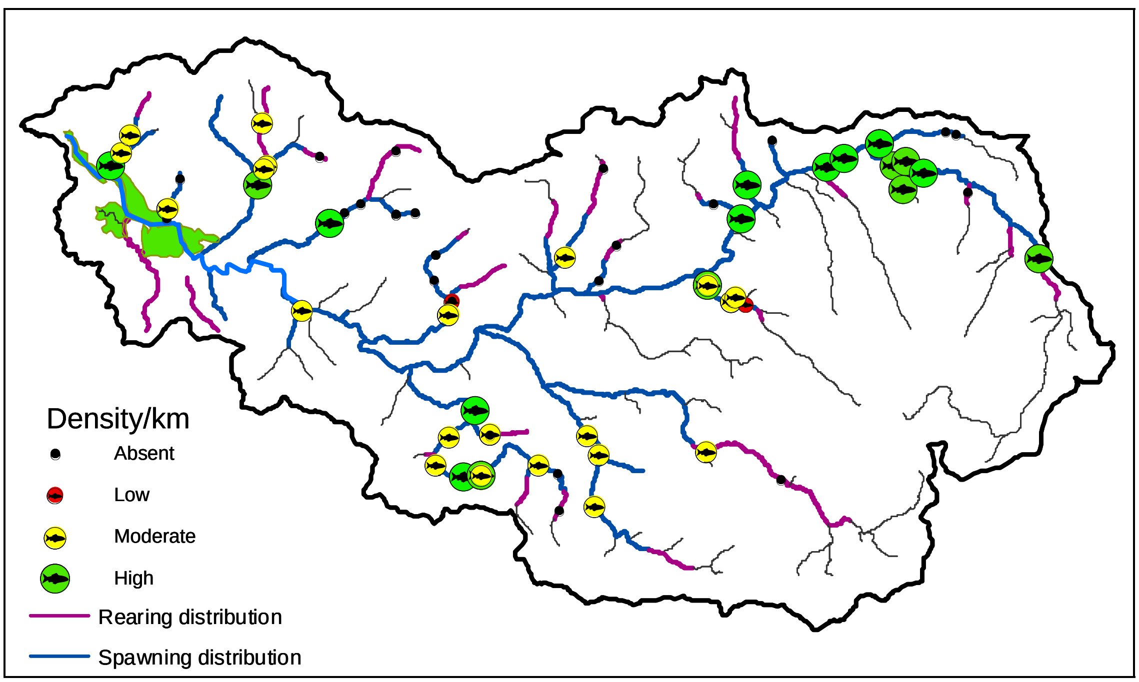


Figure 7. Relative abundance of juvenile coho per km in August and September, 2008-10 in Salmon River.

Juvenile coho in freshwater streams ranged in length from 45 to 100 mm fork length (FL) during all three years (Figure 8). Median length was 78 mm FL in 2008, and was 72 mm FL in 2009 and 2010. The high median length in 2008 coincided with the lowest estimated abundance of the three years. However, no significant size difference was observed between years of very high (2009) and moderate (2010) abundance.

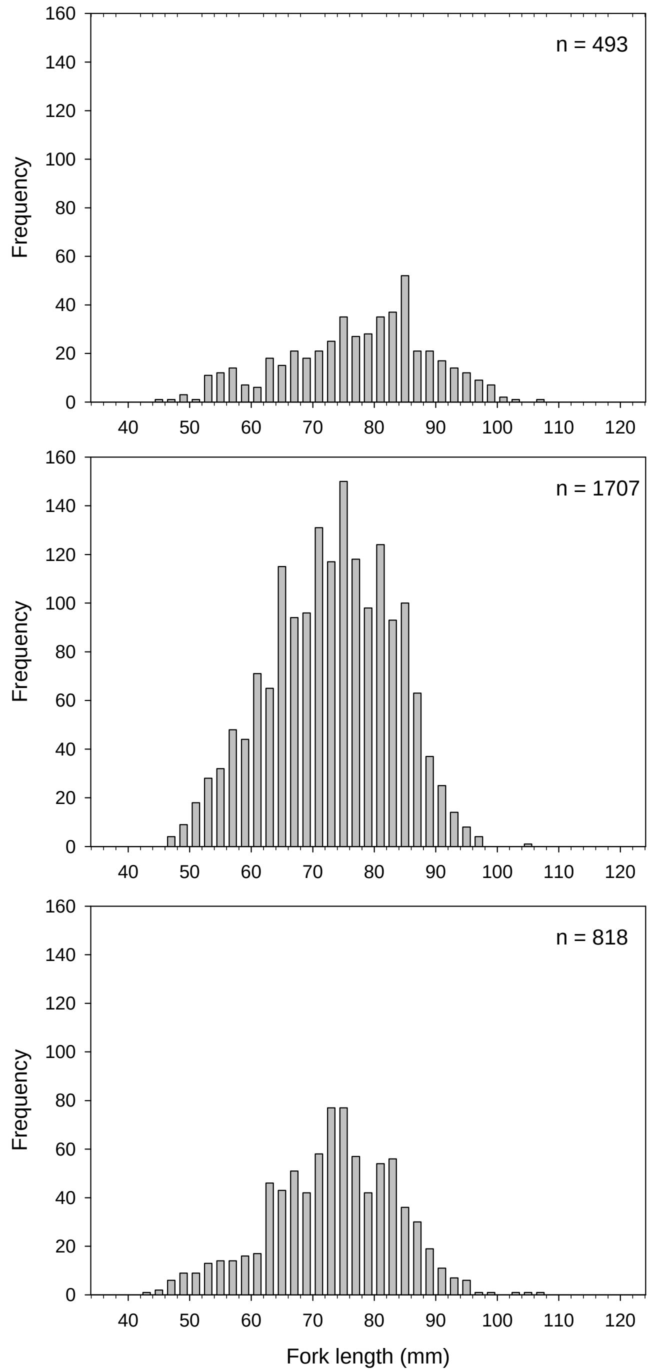


Figure 8. Length frequencies of juvenile coho in streams in 2008 (top), 2009 (center), and 2010 (bottom).

Stream habitat quality for juvenile coho

Habitat quality and capacity for juvenile coho is generally low in the tributaries to the mainstem Salmon River. Habitat capacity and quality habitat for overwintering juvenile coho were high for two of the sites on the main-stem Salmon River and Little Salmon River. The site in lower Bear Creek had moderate quality based on parr per km, and a site in lower Little Salmon had moderate quality based on parr per m^2. The low habitat capacity reflects the lack of pools in all but 4 of the sites, and lack of large wood structure or beaver dams in all but one site. The section of the upper main-stem Salmon River and Little Salmon within the Van Duzer corridor have the highest habitat quality, accounting for over half the potential capacity. Census surveys of the upper 15 km of Salmon River and all of Little Salmon River were conducted in 1999 (Aquatic Inventories Project, ODFW). The habitat capacity and quality values from these surveys were similar to that in the current surveys of these reaches. Sites were not randomly selected (2010) and census surveys (1999) have not been conducted in the lower 15 km of Salmon River. Using the Habitat Limiting Factors Model, the overall summer capacity of freshwater streams for the basin is 150,000 parr and the total winter capacity is 92,277 parr ± 25% (95% CI).

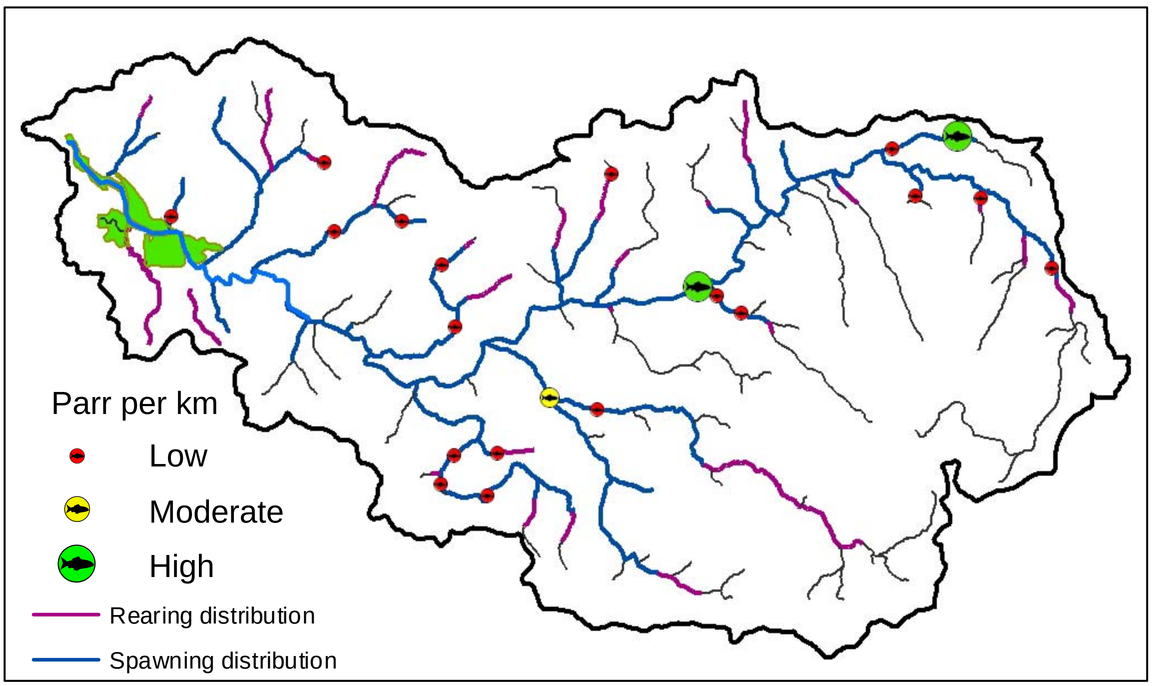


Figure 9. Quality of winter rearing habitat for juvenile coho in Salmon River watershed.

Spring Migration

Migration of age-1 juvenile coho to the estuary occurs from March through June. Peak migration time for the age-1 (yearling) coho was in late April in 2009 and in mid-May in 2008 and 2010 (Figure 10). Large numbers of newly hatched coho fry were caught in March/April in 2008 and 2009. Although smolt trap operations had to be suspended after flows dropped during the summer, sampling in the estuary (discussed below) indicated that subyearling coho entered the estuary continuously through the rest of the year, particularly after large rain events in the fall and winter.

We estimated that approximately 20,000 coho yearlings migrated annually from the Salmon River in 2008 – 2010 (Table 5). Slightly fewer than 40,000 coho fry were estimated to have migrated in 2008 and 2009, and approximately 11,000 fry migrated in 2010. Few coho were observed by Chinook surveyors in the lower main-stem above the hatchery weir and in lower Bear Creek in 2009 whereas large number were observed in 2008, the final year of hatchery adult returns (B. Riggers, ODFW, personal communication).

Yearling smolts ranged from 63mm to 151mm at migration with an average size of 104 mm. A histogram from 2009 shows the lengths of subyearling and yearling coho monthly from March through June (Figure 11). Length frequency by month during 2008 and 2010 were very similar to those shown in Figure 11. Length of age 0 and age 1 may be overlap slightly in June. We will take scale samples in 2011 to separate the age classes more clearly.

We PIT-tagged 2,152 age-1 and 300 age-0 juveniles at the screw trap from 2008 to 2010 (Tables 1 and 2). The 0-age fish were usually too small (<65mm) to tag until late May.

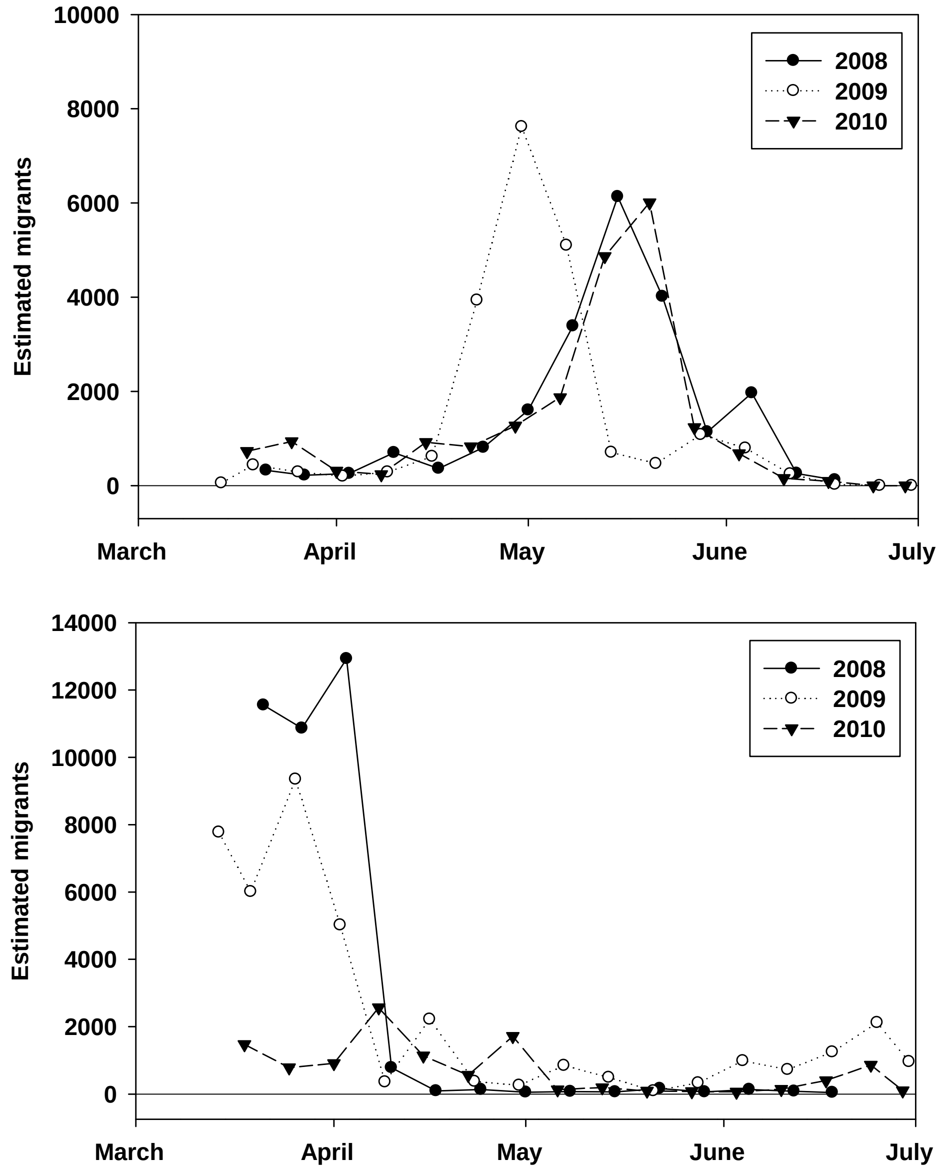


Figure 10. Estimated migration of coho salmon (yearlings in top graph, subyearlings below) from March through June in the Salmon River screw trap.

Table 5. Annual abundance (±95% CI) of salmonids collected in a rotary screw trap in March – June, 2008, 2009, and 2010.

Species	Age or Size Class	2008	2009	2010
Coho	0	37017±72	39141±42	11177±44
	1	21304±29	21864 ± 85	20140±58
Chinook	0	57758±49	53187±19	147457±23
Steelhead	<120	3250±169	5675±115	3299±160
	≥120	3700±151	5500±109	3300±161
Cutthroat	<120	1150±137	1950±162	766±64
	≥120	8700±145	2098±62	4365±169

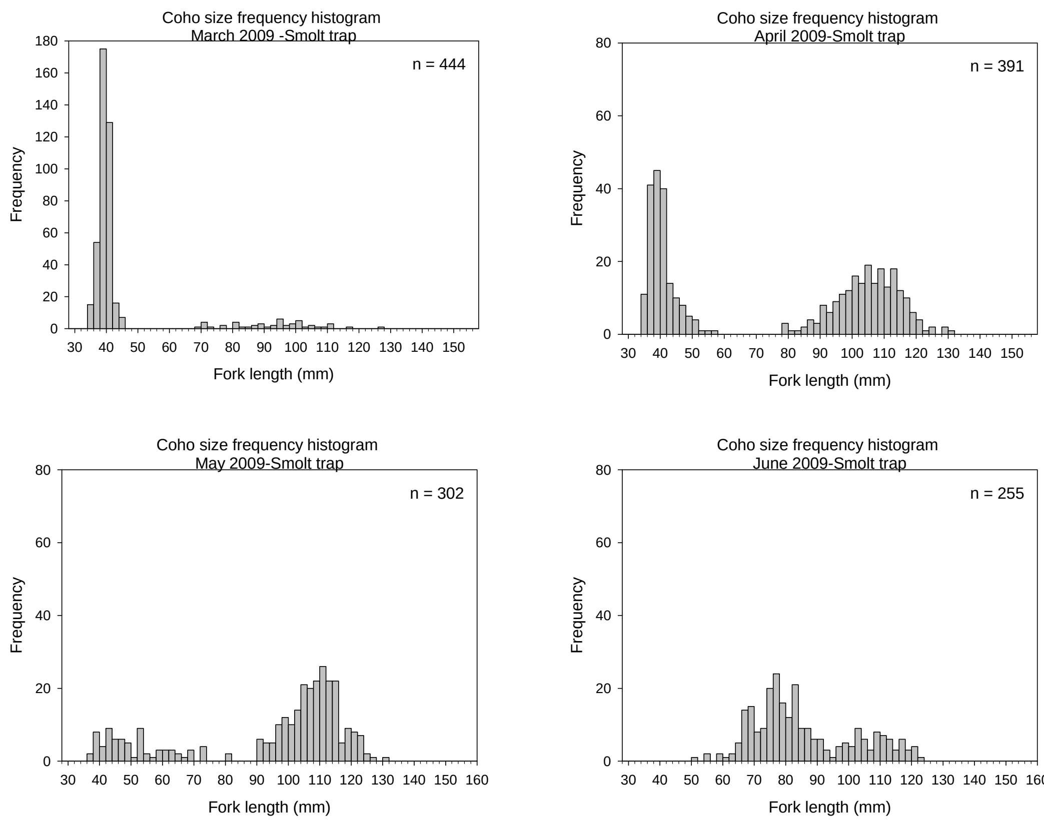


Figure 11. Length frequency of coho salmon captured at the rotary screw trap, March – June 2009.

Abundance, Timing, and Habitat Use in the Estuary

Juvenile coho salmon were observed in the Salmon River estuary in all months of the year. The highest CPUE in the winter and spring corresponded with the high juvenile population in summer 2009 (Figure 12). We caught yearling coho from January to June in the estuary and subyearlings from February to December. We assumed coho in the estuary in winter were yearlings at the turn of the calendar year in January. Yearling coho that migrated from freshwater streams in spring usually traveled quickly through the main estuary channel to the ocean and were rarely sampled after June (Figure 12). Yearling coho marked with a PIT tag at the rotary screw trap (head of tide) and recaptured in the estuary had an average residence time of 13 days, and a range from 2 to 34 days (Table 8). These yearlings grew quickly at an average rate of 0.7 mm per day, (Table 8) and 2% of body weight per day.

Table 6. Coho yearlings marked with PIT tag at screw trap and recaptured in estuary beach seining, March – June, 2008 – 2010 Salmon River.

Recapture location	N	Average length (mm) at tagging (range)	Average length (mm) at recapture (range)	Average # days between mark and recapture (range)	Average growth (mm) per day (range)
Upper estuary	9	95 (77-109)	107 (90-142)	12 (2-34)	.70 (.27-1.2)
Mid estuary	4	104 (100-113)	111 (106-115)	11 (5-16)	.61 (.21 – 1)
Estuary mouth	4	108 (96-117)	121 (109-139)	17 (5-22)	.78 (.5-1)
Total	17	100 (77-117)	111 (90-142)	13 (2-34)	.70 (.27 – 1.2)

Subyearling coho were observed all year in the estuary, with highest numbers sampled in the upper marshes, particularly the 96 Marsh channel (Figure 13). However, we did not observe subyearling coho in the lower estuary in spring or summer except in April of 2008. None were captured at the mouth of the estuary. In October of 2008, we estimated 243 (95% confidence interval = 201-311) subyearling coho were present in the 96 Marsh channel based on a one day mark-recapture experiment. We repeated the mark-recapture estimate in August and October of 2009, resulting in estimates of 326 (95%CI 170-482) and 35 (95%CI 18 – 171), respectively. The subyearling coho in the 96 Marsh grew more slowly than recaptured yearlings, with an average of 0.24 – 0.34 mm/day (Table 7), or 1.1% body weight per day. Subyearling coho tagged and recaptured in the 96 Marsh (n=180) were at large between captures for a mean minimum residence time of 31 days and a maximum of 147 days. The 87 Marsh was used by coho primarily in the winter when salinities were less than 5 PSU.

Few subyearling coho were caught in the estuary main channel from late August through October. However, in November through February, large numbers of coho (up to 336 CPUE) were occasionally caught at a beach seine site at rkm 1.6 (average fork length 111mm and 104mm, respectively) that may suggest a later outmigration coinciding with higher river flows. Seining near the mouth of the estuary on January of 2009 also recorded 23 coho with an average length of 94mm.

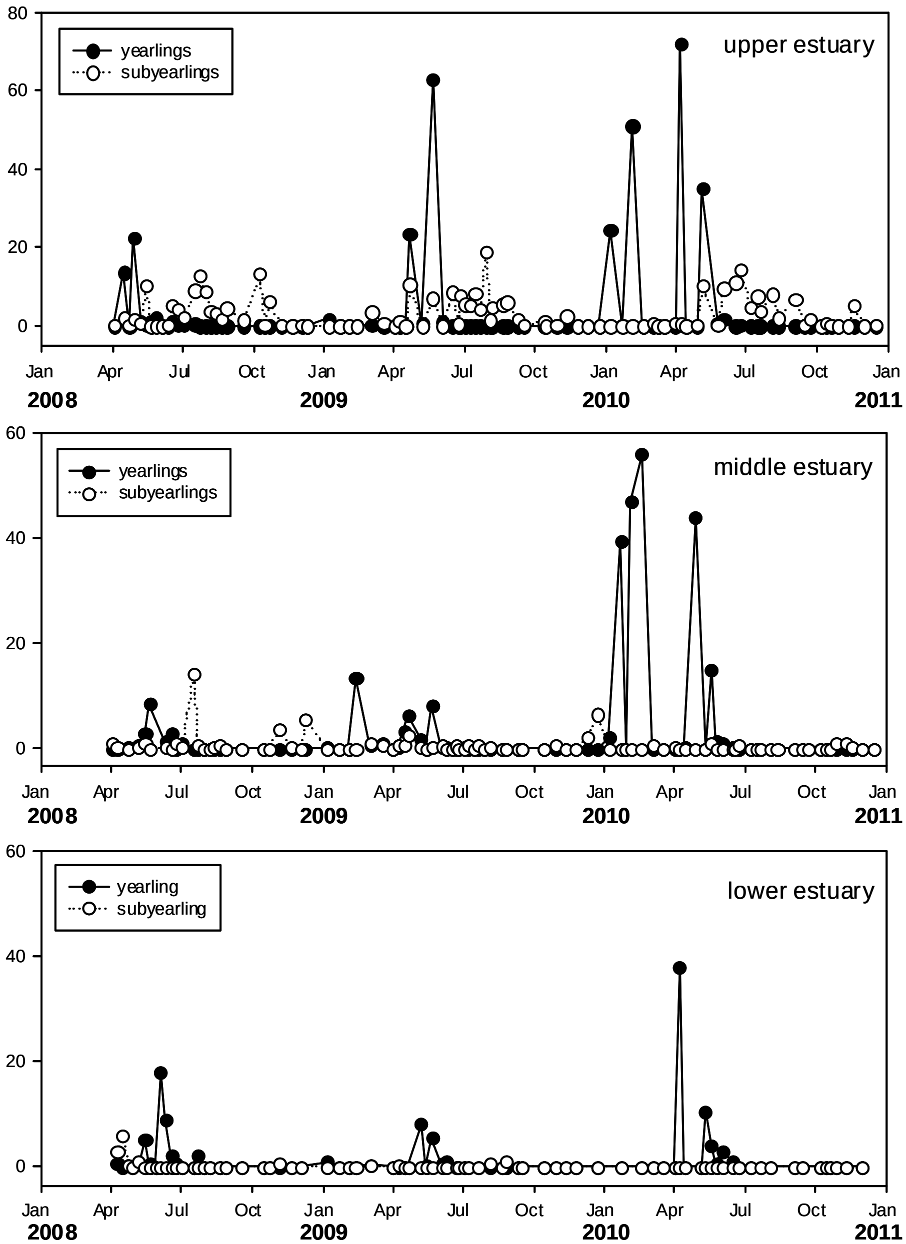
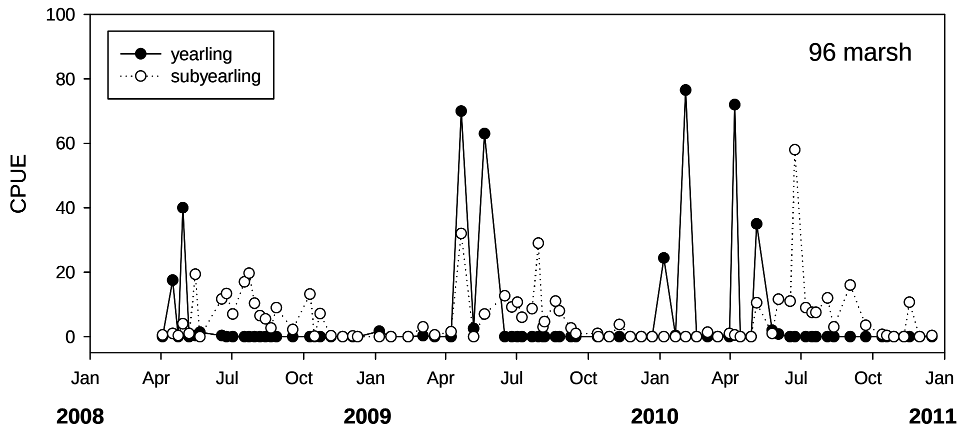


Figure 12. Catch per unit effort for coho salmon in Salmon River estuary beach seine for 3 years.



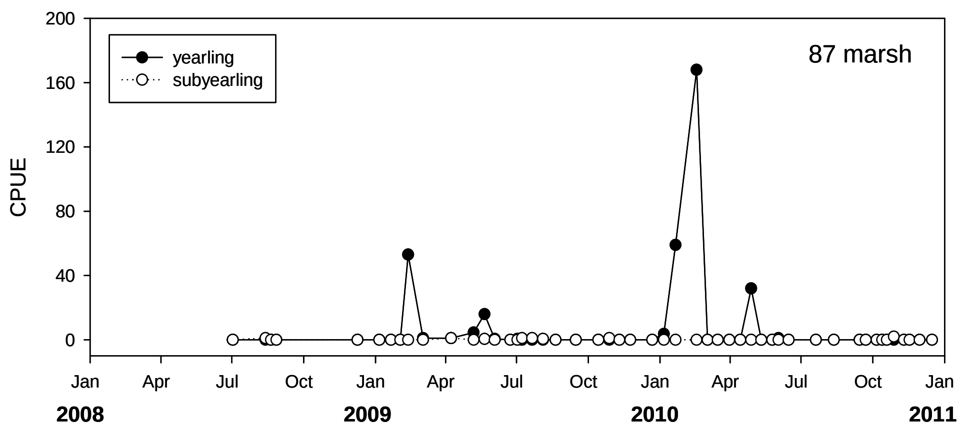


Figure 13. Catch per unit effort for coho salmon in two marshes in the Salmon River estuary, 2008 – 2010.

Table 7. Residence time and growth of subyearling coho tagged and recaptured in the 96 Marsh, June-October.

Sampling Year	N	Average number of days between mark/recapture (range)	Average growth (mm) per day (range)
2008	71	52 (7 – 120)	.34 (.08 - .57)
2009	87	31 (6 – 110)	.24 (0 - .55)
2010	22	40 (6 – 147)	.26 (.13 - .33)

We caught large numbers of yearling coho in the winter months of 2010 in the upper and middle portions of the estuary (Figure 12). These coho included 14 recaptures from the upper watershed (tagged in August and September 2009), fish tagged in freshwater margins of the estuary (stream confluences), and fish tagged in the same area in the estuary, weeks to months earlier (Table 8). The growth rate of fish recaptured in the estuary in January and February 2010 varied by rearing location. Coho that were tagged in streams in August and September 2009 grew slowly in the fall at an average rate of 0.19mm per day. Similarly, coho tagged in streams that flow directly into the estuary grew at 0.24mm per day. In contrast, coho tagged in the estuary in December 2009 and January 2010 and recaptured a month later in the estuary grew at twice the rate, averaging 0.55 – 0.66mm per day. Seven fish tagged in the 87 Marsh and recaptured at the same location four weeks later grew at a rate of 0.83mm per day. Average growth appeared greatest for those fish that were tagged and recaptured in the estuary, and smallest for those fish that had come from the upper watershed, although we do not know the history of the fish between recapture events.

Twenty seven percent (n=167) of the juvenile coho salmon that were PIT tagged at the head of tide (screw trap) in 2010 were detected at the 96 Marsh PIT tag antenna and 7 percent (n=96) of the coho salmon PIT tagged in the 2009 upper watershed population estimate were detected (Table 9). Of the 167, 160 were assumed to be yearlings and 7 subyearlings (only fish >65mm length were tagged), with the latter tagged in June. The yearlings had a median travel time of 4 days to travel the 4.7 km from the head of tide to the 96 Marsh channel (range 1 to 66 days, mean =10) and visited the marsh for a median residence of 2 days (range 1 to 30, mean = 4 days). The 7 subyearlings that were tagged at the screw trap and detected on the antennas had a median travel time of 3 days to travel to the 96 Marsh channel (range 2 to 15 days, mean = 5 days) and visited the marsh a median of 1 day (range 1 to 6, mean = 2.4 days). Eight (4%) of the subyearling coho (>65mm) PIT tagged at the 2009 smolt trap were detected in April and May on the marsh antennas. Their residence time was similar to the yearlings described above.

The PIT antenna array was generally efficient at detecting tagged fish using the marsh channel. In the spring, the greater amount of freshwater flow kept water salinity low. Summer's low river flows acted as less of a buffer against the high salinity of the high tides and the antenna's efficiency at detecting tags presumably suffered (Hering 2010). Coho were detected using the marsh throughout the period that the antennas were present (Figure 14). These fish mainly consist of yearlings tagged in the spring and subyearlings tagged in the estuary in summer. Cutthroat were also frequent users of the 96 Marsh. Even though we rarely collect steelhead in seine sets up in the 96 Marsh, it is apparent that they do spend some time in the marsh at high tide.

Table 8. Growth and residence time of PIT-tagged coho migrants that were recaptured in the estuary in January-February, 2010. Freshwater margins of the estuary included Rowdy Creek, Crowley Creek, and an unnamed tributary to the 78 Marsh.

Tagging site/recapture site	N	Average length (mm) at tagging (range)	Average length (mm) at recapture (range)	Average # days between mark and recapture (range)	Average growth per day (mm) (range)
Freshwater margins of the estuary/main estuary	4	89 (83-94)	110 (102-118)	87 (72-103)	.24 (.14 - .38)
Upper estuary marsh (tag and recap)	7	93 (88-98)	113 (103-138)	37 (28-91)	.55 (.46-.71)
Mid estuary (tag and recap)	19	92 (68-124)	112 (87-134)	31 (13-127)	.66 (.37-1)
Upper watershed (Aug-Sept)/main estuary	9	73 (65-85)	104 (71-130)	153 (114-196)	.19 (.05-.27)

Table 9. Number of PIT tagged fish detected at the 96 Marsh PIT antenna April 22, 2010 to August 25, 2010.

Tagging site	Coho	Cutthroat	Steelhead
Screw trap 2010	167	41	10
Screw trap 2009	8	1	0
Screw trap 2008	0	1	0
Estuary seining 2010	279	72	1
Estuary seining 2009	4	10	0
Upper watershed 2009	96	28	2
Upper watershed 2008	0	1	0
Totals	553	154	13

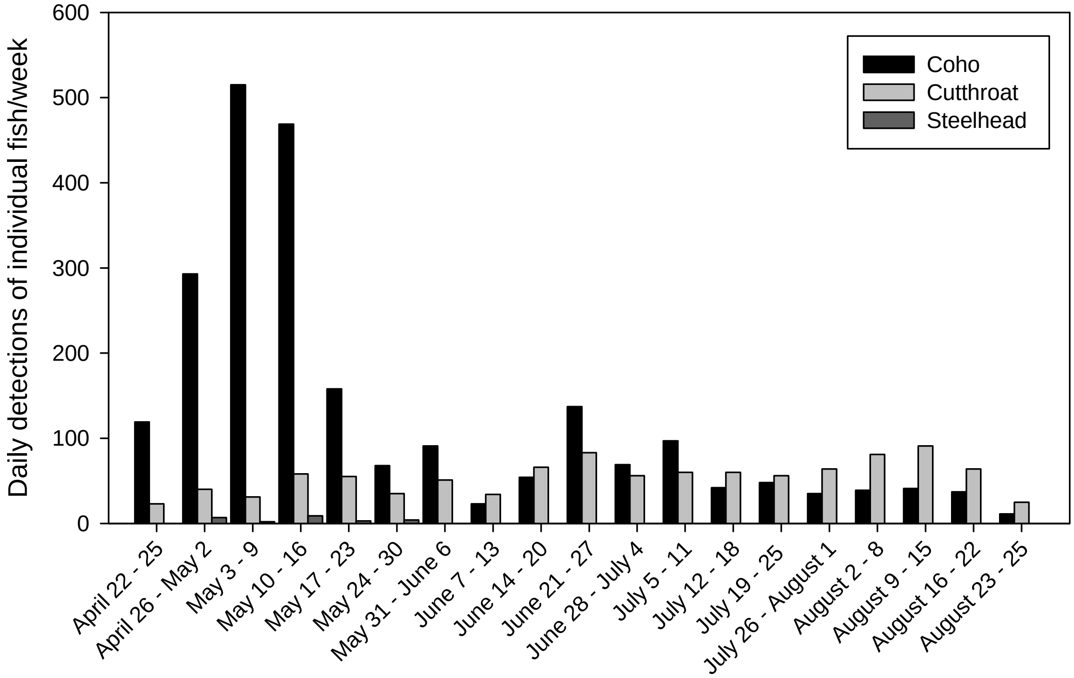


Figure 14. Timing of PIT tagged fish detected in the 96 Marsh.

Freshwater and estuary rearing patterns of returning adult coho

From samples collected at the smolt trap, near the head of tide, and in our estuary beach seines, we discerned a variety of rearing and migration strategies by juvenile coho in the Salmon River basin. Most juveniles stayed in freshwater streams for a year before migrating out of the watershed as yearling smolts, and after a short period in the estuary, migrated to the ocean. However, some subyearling fry migrated quickly to the estuary in the spring of their first year, and an unknown proportion of these fish remained in the uppermost marsh for the summer. Although it is unclear whether any of these fish may have migrated to sea as fry, we did not collect any fry at the estuary mouth. Many subyearlings also migrated from freshwater into the estuary after the fall rains, and were sampled during the late fall and winter. Recaptures or PIT detections of a few tagged fish indicate that some subyearling migrants moved from the estuary back into freshwater streams in the fall.

We identified similar juvenile life history patterns among the spawning adult population as those represented in our juvenile sampling. The contribution of juvenile life histories to the adult populations in 2008-10 were quantified from otolith and scale analyses (2008 and 2009) and detections at the lower river PIT antenna in 2010. We collected otoliths and scales from all adult coho recovered on the spawning grounds in 2008 (n=31) and 2009 (n=45), and therefore, are representative of all returns to the basin. Unfortunately we do not have paired scales and and otoliths from every fish due to logistical issues in the field. All PIT tagged adults detected at return were tagged as juveniles at the screw trap in 2008 or 2009 and were considered representative of the downstream-migrant population. Juveniles tagged in the estuary are indicative of the estuary population only because we cannot quantify the proportion of the total juvenile population that was sampled during the beach seine surveys. We have not yet analyzed the otoliths from any juvenile coho or from the adults that returned in 2010. The following results therefore are preliminary and qualitative.

The strontium/calcium signals on adult otoliths indicated four principal patterns of juvenile migration to the estuary (Table 10): (1) yearling migrant (spring), (2) fry migrant (spring/summer), (3) nomad (i.e., subyearling migrant and return to fresh water; defined by Koski 2009), and, (4) subyearling parr migrant (fall). Scale analyses indicated that all juveniles returned as age-3 adults, regardless of their time or age of ocean migration.

Each of the four juvenile life history patterns was represented in the 2008 and 2009 adult returns. The yearling migrant strategy contributed 78 and 55% of the returns in 2008 and 2009, respectively. The remaining spawners were composed of a variety of juvenile migrant types that had entered the estuary within their first year of life and either had returned to fresh water or entered the ocean. Cumulatively, subyearling strategies accounted for a significant proportion of the total population each year (22 and 45% in 2008 and 2009, respectively) (Figure 15). All spawners from the otolith analysis returned as 3-year-old adults. Therefore, we assume that none of the returnees had entered the ocean during the fry stage, since this life history pattern likelywould have produced two-year old adult. Examples of strontium profiles of each type are displayed in Appendix B.

Table 10. Classification of juvenile rearing patterns in thecoho salmon spawning population at Salmon River, 2008 and 2009. Juvenile life histories are inferred from otolith chemical transects (see Methods).

Age at estuary/ocean migration	Season of estuary/ocean migration	Average size (mm) At salt-water entry	Definition
Yearling	Winter/Spring	107	Typical yearling spring migrant
Subyearling	Spring/Summer	35-45	Subyearling fry migrant estuary/ocean entry soon after or near yolk absorption
Subyearling	Spring/Summer	35-45	Early estuary entrance followed by a migration back to freshwater (low Sr) and then outmigration as a yearling in winter/spring (nomad)
Subyearling	Fall	91	Subyearling parr fall migrant

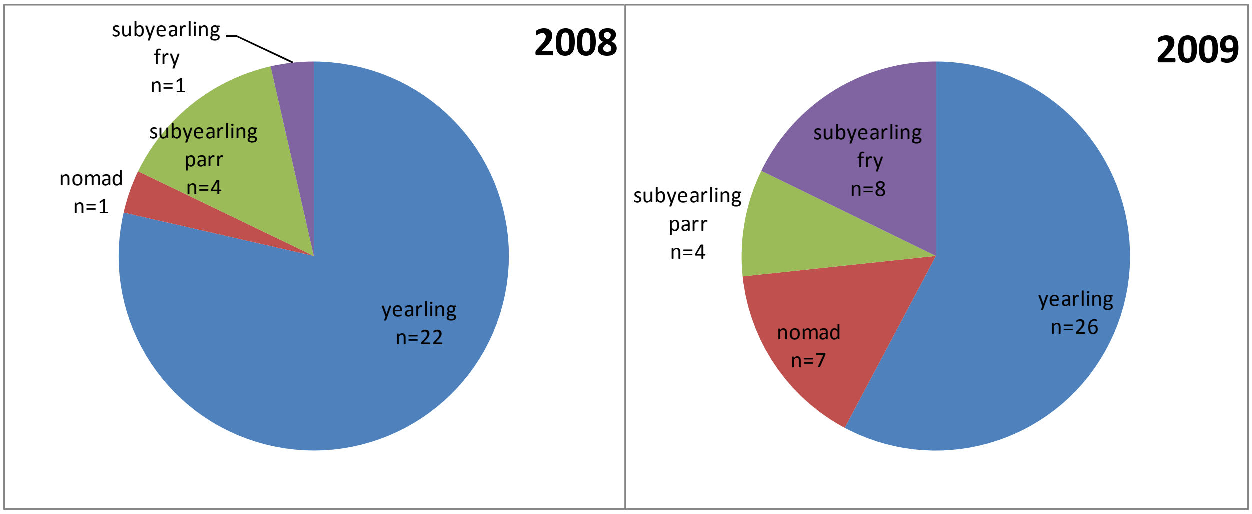
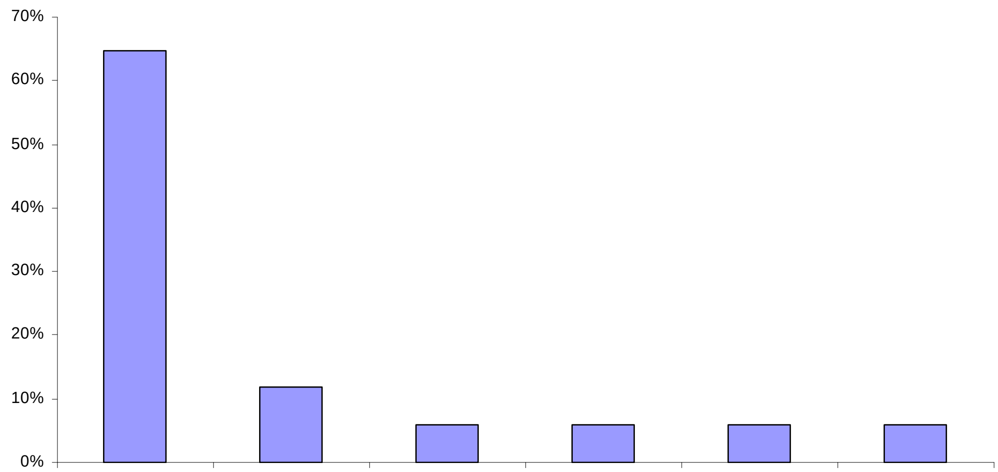


Figure 15. Estimated rearing and migration patterns of returning adult coho salmon based on otolith analysis in 2008 and 2009.

In 2010, the detections at the PIT antenna in the lower Salmon River indicated a similar mix of juvenile rearing and migration patterns as those defined by otolith chemistry (Figure 16). Yearling migrants that were tagged (n=22) at the screw trap or in the estuary in the spring and returned as 3-year olds represented the predominant life history type. Based on original tagging location and detection at the hatchery weir antenna, 35% of the returning adults showed some estuary rearing. These included four yearling fish tagged in the estuary during winter, two subyearling fish tagged at the screw trap in late June, and two subyearlings tagged in the estuary in January and February. All of these individuals returned as 3-year-old adults.

Our PIT tag detections also provided evidence for other migratory pathways that were not represented in the otolith results (Figure 16). Two fish tagged as age-1 juveniles in January and February 2010 returned in late September 2010; we presume these are jacks. Two other individuals that were tagged at 67 and 69 mm (presumed age-0) at the screw trap on 16 and 19 June 2009 also returned two-year-old adults or jacks, depending on their exact time of ocean entry. Although adult coho were not observed on the spawning grounds after mid-December, three adults or jacks arrived at the PIT antenna in late December through mid-January.



Tagging location	Trap/Est	Est	Trap	Est	Est	Trap
Age at tagging	1	1	0	0	1	0
Age at return	3	3	3	3	2-Jack	2-A/J
Sample size	22	4	2	2	2	2

Figure 16. Juvenile life histories of adult coho that were detected at the PIT antenna in 2010. Tagging locations were at the screw trap or in the estuary. Fish returned at age 3 (adults) or age-2 (jack or adult).

Based on field surveys of juvenile migrants, analysis of adult otoliths and scales, and PIT detections, we identified as many as six life history patterns in the Salmon River coho population:

1) Yearling migrant: one year in streams (non-tidal) before migrating to the estuary and ocean in the spring. Return as age-3 adult.
2) Fry migrant: enter the estuary in the spring or early summer, reside in the estuary summer through winter, and enter the ocean the following spring. Return as age-3 adult.
3) Fry migrant: enter the estuary in the spring or summer, return to freshwater (streams), and re-enter the estuary and ocean in the spring at age-1. Return as age-3 adult. Defined by Koski (2009) as a nomad.
4) Parr migrant: enter the estuary in the fall, remain in the estuary during the winter, and enter the ocean in the spring at age-1. Return as age-3 adult.
5) Fry migrant: enter the estuary and ocean in spring or early summer and spend two summers in the ocean. Return as age-2 adult.
6) Yearling male migrant: enter the ocean at age-1, and reside in ocean until the following fall. Return as age-2 jack.

Type 1 is the most common, accounting for about two-thirds of the returning adults. The proportions vary by brood year, but among returning adults estuary rearing life histories are common. The resolution of type 5 life history remains problematic without recovery of adult otoliths and scales or verification of when the juveniles enter the ocean.

DISCUSSION

We quantified juvenile and adult coho salmon distribution, abundance, survival, and life histories in the Salmon River during the first three years after the hatchery program discontinued all yearling coho smolt releases in the basin. Our initial surveys encompassed the transition from a hatchery-dominated spawning population (2008) to one composed of the naturally produced progeny of hatchery spawners (2009 and 2010). We found little evidence that spawner distribution or abundance has changed significantly in the short period since hatchery releases ended in 2007. Although recruits per spawner ratios remain below that of adjacent populations, our monitoring data and otolith chemical results revealed an unexpected diversity of juvenile coho life histories that contributed to adult returns and may strengthen population resilience following the recent hatchery changes. The trajectory of response may become more apparent as the first and subsequent generations of 100% naturally produced progeny return to Salmon River beginning in 2012.

Adult Distribution and Abundance

The temporal distribution of coho salmon spawners in the Salmon River basin remains narrowly truncated relative to that of other coastal populations. Adults in Salmon River spawned over a relatively brief period from late October through mid-November, peaking in early November and ending by early December (OASIS 2010). Other coastal coho populations typically spawn from early October through early February, with peak spawning in mid-December. Prior to hatchery development the spawning period for coho salmon in Salmon River also extended into February (Mullen 1979). In 2010 we observed the last fish on the spawning grounds in early December. However, we detected three other coho passing the PIT antenna in late December 2010 and in early January 2011. Considering the substantial shift in temporal spawning distribution that occurred within the first few decades of the coho hatchery program, spawning timing may prove a sensitive indicator of population recovery in the post-hatchery period.

Spatial distribution of coho salmon spawners was concentrated in a relatively small proportion of the Salmon River basin, although the distribution expanded into the lower main-stem Salmon River since the hatchery began operating. During the mid-1970s coho were not observed spawning in the main-stem Salmon River below Boulder Creek at Rkm 25 (Mullen 1979). Now coho spawners are abundant in the lower main stem above the hatchery (ODFW, unpublished data). Other areas show high numbers of spawning coho prior to hatchery operations and at present, including the upper Salmon River and Little Salmon River, Bear Creek, and the lower portions of Prairie and Widow creeks. We expect spawning activity to decrease in the lower main-stem Salmon River as the hatchery influence wanes.

An increased number of surveys coupled with the new GRTS design has improved the precision of recent population abundance estimates compared to that of previous coho spawning surveys in Salmon River. The 95% confidence intervals around the estimates of the spawning populations in 2007-2010 (54 -38%) were lower in previous years because the surveys were randomly selected and were increased to cover more than 20% of the habitat available to spawning coho. The improved precision provides an accurate baseline for detecting trends in the abundance and spawning times of the Salmon River population. Although the PIT antenna independently measures the return times of individually marked adults, few of these PIT tagged fish were detected subsequently on the spawning grounds. Recovery of PIT-tags from adults is unlikely given the small number of tags, the random selection of survey sites (20% of potential spawning areas), and the potential loss of tags during spawning activity. Estimates of naturally produced spawning coho in 2009 and 2010 were slightly lower than those estimated by Mullen (1979) in Salmon River in 1976-77 (prior to hatchery operations), 1,526 (594-3,270; 95% CI). However, the earlier estimates corresponded to a higher total production, since estimated fishing mortality in 1975 was ~70-85% of the returning adults compared to less than 11% in recent years (OASIS 2010).

Juvenile Abundance and Habitat Capacity

The Salmon River coho population failed all five viability criteria in the Oregon coast coho assessment: abundance, distribution, persistence, productivity, and diversity (Chilcote et al. 2005). The first four measures are an effect of a low recruits per spawner ratio: fewer wild adults returned than the spawning population that produced them. The assessment was unable to identify which life stage(s) were most susceptible to mortality because no quantitative estimates of juvenile salmon production or survival were available in Salmon River for the period preceding the first releases of hatchery coho. In 2008-10 we documented a three-fold variation in the abundance of 0-age juveniles (subyearlings), which probably reflected the four-fold variation in adult abundance. The 4,000 (mostly hatchery) adults that spawned in 2008 produced 67,000 parr the following summer. Approximately 750 naturally produced adults accounted for the relatively large number of juvenile coho observed in 2010.

Juvenile population estimates provide an indicator of the survival from egg to summer parr life stages. Assuming ~2,500 eggs per female (Nickelson 1998), we estimated the survival from egg to parr for the 2007, 2008, and 2009 broods was 1.6%, 1.4%, and 4.0 %, respectively. The first two values are much lower than those estimated in other basins (LCM 2010). Survival of the 2009 brood year--the first brood composed of 100% naturally produced adults--was three-fold greater than that of the naturally spawning hatchery fish. The 4% survival rate was comparable to other basins, although we might have expected even higher egg to parr survival given the low spawner population and juvenile densities that were well below the estimated carrying capacity of the habitat. Hatchery influences on the genetic structure of the population (Nickelson 2003) or on the spatial and temporal distribution of spawners could influence survival of coho salmon eggs. In particular, the present spawning period for Salmon River coho may leave eggs vulnerable to flood events that typically occur in late November and December after most adults have spawned. In the absence of direct hatchery influence, we may expect to see a shift in the peak time of spawning, a continued increase in egg to parr survival, or both.

In coastal basins and in the Salmon River, complex overwinter habitat is potentially limiting to coho salmon populations (Nickelson et al. 1992, Solazzi et al. 2000, Rodgers et al. 2005). Survival from summer parr to migrant smolts the following spring requires complex, slow-water habitat. For example, pools with wood jams, beaver ponds, and off-channel alcoves provide refuge and promote survival during winter freshets. In the Salmon River, high quality freshwater habitat occurs primarily in the upper Salmon River and Little Salmon River through the Van Duzer State Park corridor. We estimated that the habitat presently available in the basin could support up to 92,000 parr during the winter, although this capacity may be slightly over estimated because we do not have adequate surveys in the lower 15 km of Salmon River. Winter capacity in the upper river alone is more than 30,000 parr, and based on similar estimates in 1999, has remained relatively consistent in recent years. Present population estimates thus remain well under the estimated capacity of the freshwater habitat. We would expect overwinter survival should be relatively high in the absence of mitigating factors such as high-flow events. This is supported by estimates from the first two brood years (2007 and 2008), when screw trap estimates yielded overwinter survivals of 100% to 30%, respectively.

Despite an apparent underutilization of available rearing habitat upriver, a substantial number of subyearlings moved into the estuary to rear in 2009 and 2010. Fourteen coho parr tagged in streams in 2009 (1% of tagged fish) were recaptured during winter beach seining in 2009-10. Although the CPUE was high, the recapture data were insufficient to quantify the number of coho using the estuary. Four recaptured fish were tagged in upper Salmon River, which suggests that even parr from high-quality winter habitat may migrate downstream before the spring. In addition, 39 of 658 (6%) juveniles tagged in the watershed in August and September 2010 were detected at the PIT antenna in the lower river from Sept through Dec 2010. This indicates that a minimum of 2,230 parr moved into the estuary during late summer or early fall. Our PIT efficiency is unknown, and the detectors only encompass one side of the river. However, individuals from both low quality and high quality habitats moved downstream past our PIT detector to rear in the tidally influenced habitats of the estuary.

The number of yearling smolts estimated at the screw trap remained very consistent at just over 20,000 annually from 2008-2010. The number of migrant fry varied considerably. The statistical expansion of the trap catch provided narrow confidence intervals on the number of fish that migrate out of the river, although the efficiency of the trap is only about 5% because of the large size of the river and the high flows in the spring. We would prefer to capture and tag 10-20% of the run during the peak migration period to increase our sample size. Assuming the smolt numbers are accurate, the freshwater survival from egg to smolt was 1.6% (2007 brood) and 0.4%

(2008 brood). At an ocean survival of ~5%, 1,000 adults would be produced from 20,000 smolts entering the ocean. The 2007 brood year had a positive recruits per spawner ratio of 1.4 based on the preliminary counts of adults in 2010, although this value is considerably lower than that of nearby basins (OASIS 2010).

The yearling coho spent an average of two weeks in the estuary (6.5 km distance to ocean) before leaving for the ocean, and 26% of the yearlings tagged at the screw trap were detected in the 96 Marsh. In contrast, hatchery coho spend very little time in the estuary; 80% spent less than 5 days in Salmon River in 1997-2001 (unpublished data) and an average of 8 days in the Nehalem estuary (S. Clements, ODFW, personal communication). The estuary appears to be a productive transition environment for wild juvenile coho before they go to the ocean. The primary estuarine habitat for these coho was the tidally inundated freshwater marsh in the upper estuary. It was notable that the yearling smolts grew rapidly in the estuary, twice as fast as the subyearlings. One individual smolt doubled in size during its 28 d residence. The estuary may provide a very important rearing and transitional environment for the relatively short time that smolts spend before entering the ocean.

Juvenile Life History

The diversity component of the population viability analysis reflects genetic and phenotypic diversity (McElhany et al 2000), including variations in morphological, behavioral, and life-history traits. The failure of the diversity measure for the Salmon River coho population (Chilcote 2005) was based on the likely genetic effects of the hatchery program, as evidenced by the dominant proportion of hatchery spawners (i.e., identifiable by a fin clip) in the population, the narrow and early spawning time, and the low recruit to spawner ratios. Our study quantifies the life history characteristics of juvenile and adult coho salmon immediately after all coho hatchery releases were discontinued and returning hatchery-origin adults were eliminated from the spawning population.

The conventional coho life history in the Pacific Northwest (e.g. Sandercock 1991, Nickelson and Lawson 1998, Koski 2009) has been characterized as a uniform, three-year life cycle: 1½ years of freshwater (stream) rearing, ocean migration in the 2nd spring, 1½ years of ocean rearing, and a return migration to the natal river to spawn in the fall or early winter of the third year. The most commonly recognized deviation from this pattern is the early return of some precocial males (“jacks”) after just one summer in the ocean. In 1976, wild jack salmon were commonly captured in beach seines and entered the hatchery in Salmon River but were not observed in sufficient numbers on the spawning grounds to estimate the abundance (Mullen 1979).

Previous studies have identified other juvenile coho rearing and migratory behaviors that differ from the conventional yearling-riverine smolt strategy. However, these often were dismissed as minor population constituents that do not contribute significantly to adult returns. For example, the term “nomad” originally was given to juvenile coho that leave their natal streams between the time of emergence and October of the same year (Chapman 1962). Rather than an adaptive migration, nomad behavior generally was considered the excess production of natal streams such that subordinate individuals were displaced through competition to less favorable rearing sites further downstream (Sandercock 1991). Coho apparently "displaced" to the estuary and ocean during the first year of life presumably perished and did not contribute to the adult population (Crone and Bond 1976). Underyearling smolts thus were considered "extremely rare in nature" (Sandercock 1991).

A recent synthesis of coho life history studies (Koski 2009) suggests that populations across their range express a more diverse array of rearing and migratory behaviors than has been recognized by the traditional (i.e., yearling-riverine smolt) model. This conclusion is reinforced by our recent Salmon River results, which reveal a wide range of sizes and times of juvenile coho migration to the estuary and ocean, including many nomads that successfully rear and grow in the estuary for extended periods.

Coho fry occupied the 96 marsh in the upper estuary during the spring, and some individuals remained at the site through the summer and into the fall. By late summer, a relatively small number (~300) of subyearling coho remained in the 96 marsh. We surmise that most of the fry that migrated past the screw trap in the spring either moved back upstream into freshwater habitats by late spring or simply perished; we observed no fry at the mouth of the estuary in the spring. The number of migrant fry in the estuary may reflect the increased number of adult coho that now spawn in the lower main stem of Salmon River near the hatchery. The number of fry migrants was substantially lower in 2010, which corresponded with fewer adult coho spawning in the lower river in 2009 (Coastal Chinook Project, ODFW, unpublished data).

The distribution and abundance of fry in the estuary were influenced by distance from the river mouth, salinity, and temperature. The fry in the estuary were observed most often in the least saline of the tidal wetlands (i.e., the 96 Marsh) in the spring and early summer. Some remained at the site all summer and fall, even though salinities exceeded 20 PSU in September and October, and in some years, water temperatures approached 20°C. We did not observe subyearling coho in the reference marsh, located 0.5 kilometers downstream, which had a slightly higher salinity but lower temperature, suggesting that a salinity threshold may limit the suitability of estuarine rearing habitats earlier in the summer. Subyearling coho grew in the 96 Marsh at rates comparable to that in freshwater streams.

The extensive area of off-channel wetland habitat within the Salmon River estuary may play an important role in maintaining juvenile populations over the winter. A variety of studies indicate that juvenile coho redistribute widely both upstream and downstream during fall freshets (Sandercock 1991). We observed movement of juvenile coho into the estuary during late fall and winter, and into the lower estuary during November through January when salinities were below 5 PSU. A substantial number of fish that were PIT tagged in streams during August and September were either detected or handled in the estuary in the winter. During high winter flows, the tidal-fresh zone of the estuary extends further toward the river mouth to include the extensive 87 marsh and also allowed juvenile coho to access the recently restored area at the confluence of Rowdy Creek and the 87 Marsh (Figure 2). Juvenile coho tagged in the lower estuary down to Rkm 1.6 were recaptured back upstream in the 87 Marsh. Growth rates of coho that reared in the estuary in January and February were much higher than those for coho in freshwater streams.

Survival of 2007 brood coho varied by tag group based on detections at the hatchery weir antenna in 2010. Not all returning adults are detected at the antenna so these estimates represent minimum survival rates. Fish that were tagged as age-0 subyearlings in the estuary returned to the hatchery PIT antenna at a 0.9% rate. Age-1 juveniles tagged in the estuary in the winter returned at a 1% rate. Yearling smolts tagged at the screw trap returned at a 2.3 % rate. We did not observe any of the 373 juvenile coho tagged in the watershed returning as adults. Ocean survival of conventional smolts was double that of subyearlings, although subyearlings reared in the estuary for 3-9 months after tagging before entering the ocean.

Based on the field observations, otolith and scale analyses, and the PIT detection results, we identified six potential life history types for the coho population in Salmon River. The yearling smolt (Type 1) and jack (Type 6) life histories have been well established in other populations. However, prior to this study, the contributions of the other four juvenile life histories to adult populations were unknown (Koski 2009). We have strong evidence from otolith analysis and PIT detections that three alternative subyearling life histories (Types 2-4) may contribute up to one third of the adults returning to Salmon River. From the information analyzed to date, we can only speculate whether emergent fry entering ocean as subyearlings may return as two-year-old adults (Type 5). Regardless, the extensive tidal-marsh habitats in Salmon River may allow coho to more fully exploit the estuary and express subyearling-migrant life histories compared with many other Pacific Coast populations.

Survival of juvenile coho in the ocean has been high the past three years resulting in record returns of adult coho to coastal basins (OASIS 2010). Without a doubt, this has caused a short-term boost for naturally produced coho in Salmon River and provided a foundation for recovery of the wild population. However, the narrow temporal distribution and early time of spawning increases the risk that egg to parr survival may remain low. In Salmon River, high flow events after mid-November affect the whole population, scouring redds or flushing emergent fry prematurely. Juvenile life history diversity may partially compensate for low survival at early life stages, although past recruit to spawner ratios suggest this is not the case. Recovery likely will require a broader spawning distribution more closely linked to the local hydrograph and higher survival across all life stages. In the absence of intensive hatchery pressure, we hypothesize that the stream and estuary habitats in Salmon River will have sufficient connectivity, capacity, and quality to recover and sustain a resilient population of wild coho salmon.

ACKNOWLEGEMENTS

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APPENDIX A

The salmonid community in Salmon River includes coho, Chinook, and chum salmon and steelhead and cutthroat trout. The field sampling that supported the study on coho salmon also captured other salmonids during routine sampling in the watershed and estuary. This appendix reports estimates of abundance, distribution, and migration of these other salmonid species. See Stein et al. (2011) for more detailed information on life history diversity, migration patterns, habitat use, and abundance of cutthroat trout.

METHODS

Fish Sampling Overview

In addition to coho salmon, steelhead and cutthroat abundances were estimated in the summer; Chinook, steelhead, and cutthroat were enumerated at the outmigrant trap in the spring; and Chinook, chum, and cutthroat were measured and recorded in the estuary. Fish were PIT-tagged and antennas were set up to determine migration timing, habitat use, and behavior of individual fish.

Watershed Population Estimates

Cutthroat and steelhead were enumerated and a subsample of each species was measured, weighed, and PIT tagged. Trout <60mm were classified as trout fry to minimize errors in identification between steelhead and cutthroat. Depending on their size, some cutthroat and steelhead were tagged with either 12mm or 23 mm tags. Population estimates were generated for steelhead and cutthroat for the sites and watershed. The distribution of steelhead was similar to that for coho, and the distribution of anadromous cutthroat was assumed to be similar. The annual contribution of resident cutthroat to the populations downstream of migration barriers is unknown.

Estuary residence

Chinook and chum salmon and cutthroat trout and steelhead were also seined, enumerated, measured and scanned for PIT tags (cutthroat and steelhead) to estimate estuary residence and growth.

Marking activities

We marked fish with unique tags to assess habitat use, migration timing, growth, and survival. Passive Integrated Transponder (PIT) tags were placed in steelhead, and cutthroat during all phases of the field sampling (Appendix Table A-1). Some juvenile cutthroat and steelhead were also implanted with PIT tags during summer electrofishing, spring sampling at the rotary screw trap, and while seining in the estuary. Fish larger than 65mm were implanted with the 12mm tag, while those >120mm were marked with 23.75mm x 3.9 mm full duplex Passive Integrated Transponders (PIT-tags) (Destron-Fearing model TX1415BE, 0.57g dry weight).

Appendix Table A-1. Number of cutthroat and steelhead PIT tagged from 2008 – 2010 in Salmon River.

Area/method	Cutthroat Trout	Steelhead Trout
Upper watershed/electrofishing (August – September)		
2008	333	69
2009	465	57
2010	456	100
Mainstem river/rotary screw trap (March – June)		
2008	125	271
2009	258	428
2010	153	193
Estuary/beach seine (January – December)		
2008	172	20
2009	287	48
2010	388	23

RESULTS

Juvenile Salmonid Populations in the Watershed

Chinook

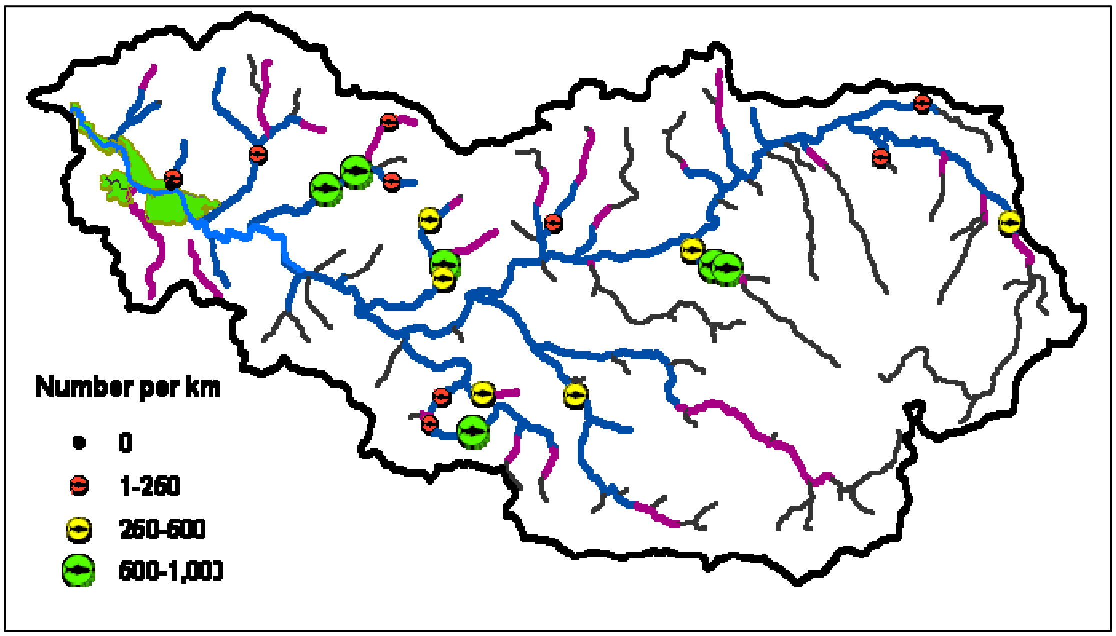
We did not observe any juvenile Chinook salmon during our sampling in August and September in the upper Salmon River watershed and tributaries, 2008-2010. It appears that most Chinook migrate to the lower river or estuary as subyearlings as is typical with most coastal fall Chinook populations.

Cutthroat trout

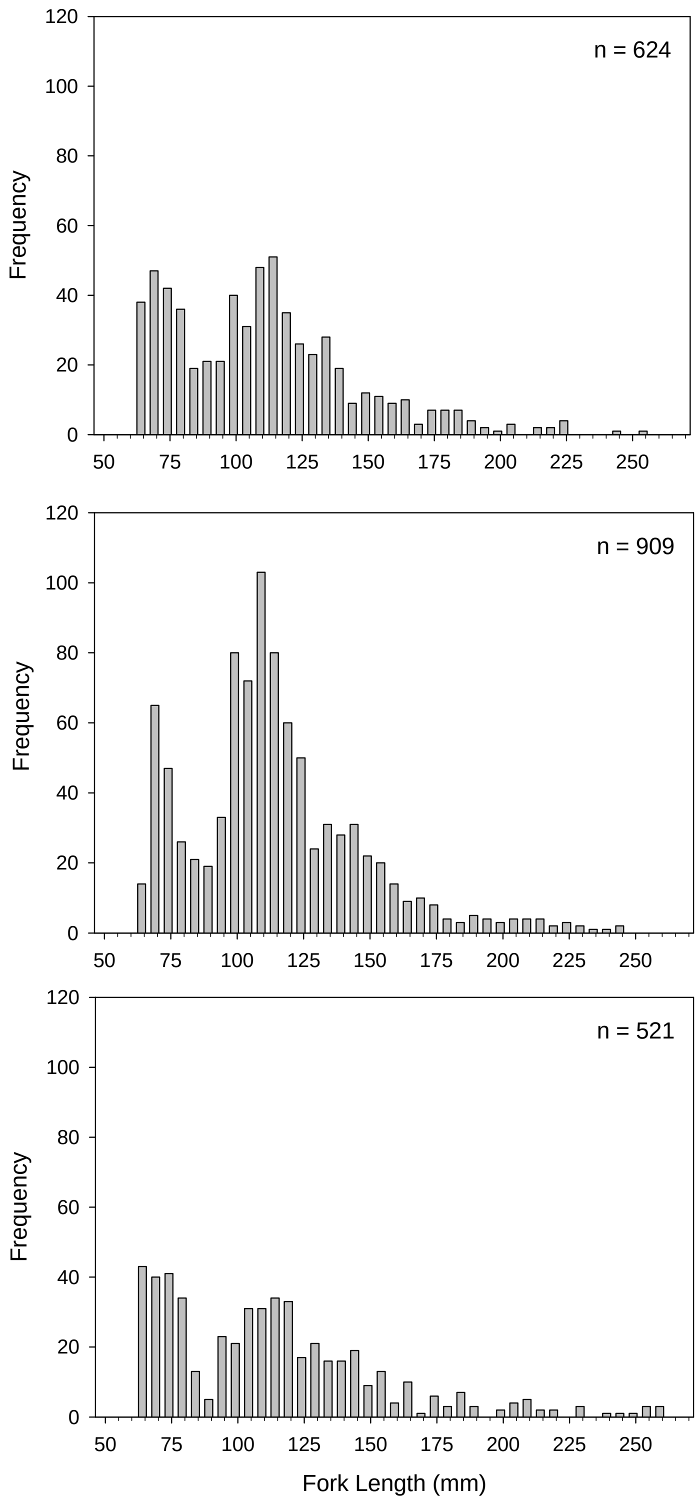
Population estimates of cutthroat in the basin ranged from 34,610 in 2008 to about 41,000 in 2009 (Appendix Table A-2). Cutthroat were observed at all but one site, and were abundant in many of the tributaries (Appendix Figure A-1). Sizes of cutthroat in streams ranged from 60mm to 274mm, with an average length of 111mm and a median of 107mm (Appendix Figure A-2).

Appendix Table A-2. Population estimates (±95% confidence intervals), mean density per m^2, mean density per km, and percent of sites occupied, by cutthroat in streams of Salmon River watershed.

Year	Abundance	Density (m^2)	Density (km)	Occupancy
2008	34,610 (25%)	0.10	321	100%
2009	41,048 (13%)	0.15	382	100%
2010	35,849 (28%)	0.11	333	95%



Appendix Figure A-1. Density of juvenile cutthroat trout in 2010.



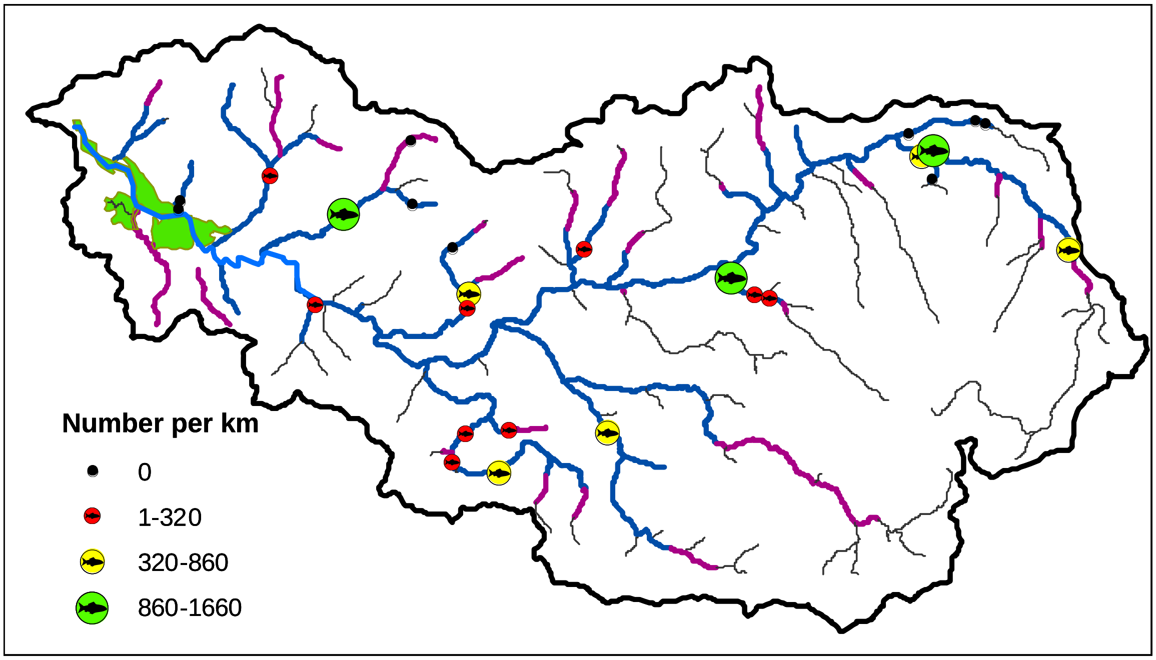
Appendix Figure A-2. Length frequency histograms for a subsample of cutthroat trout captured in the upper watershed and tributaries of Salmon River in 2008 (upper graph), 2009 (middle), and 2010 (lower).

Steelhead trout

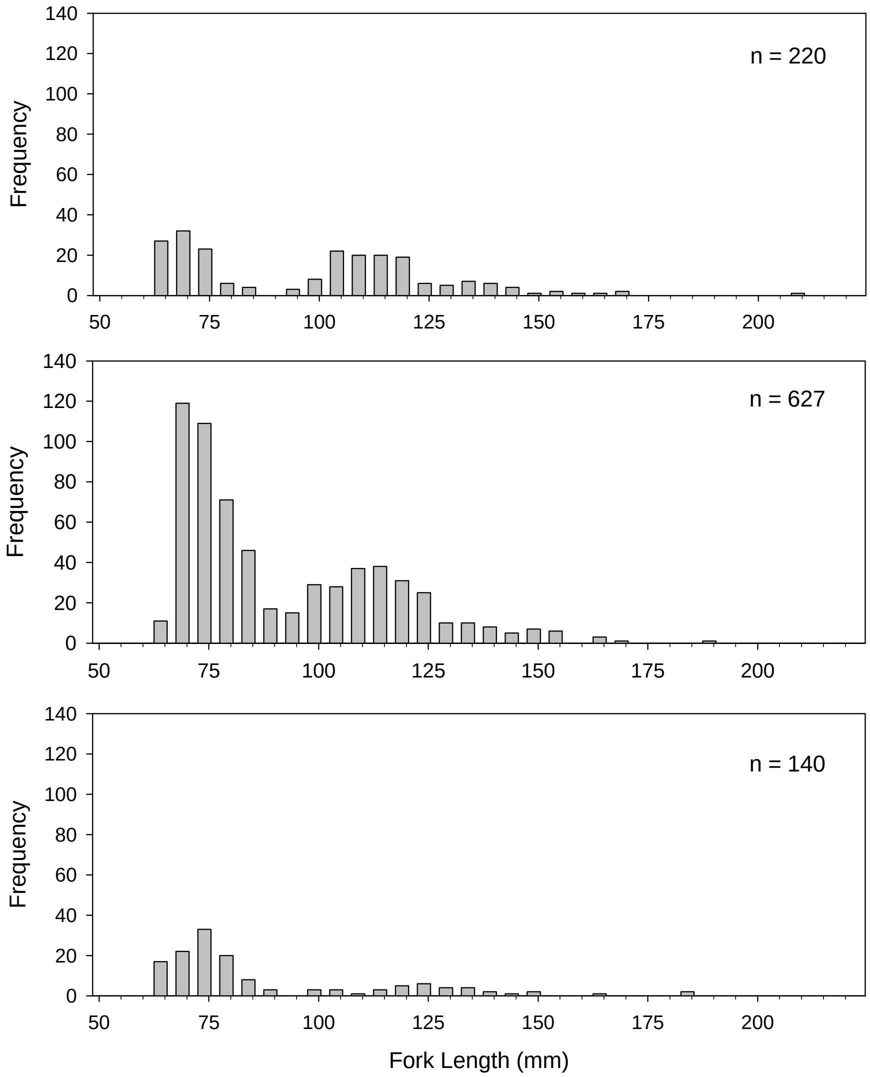
Juvenile steelhead population abundance was greatest in 2008 and ranged between 33,000 and 45,000 during the three years of sampling (Appendix Table A-3,). Steelhead distribution was similar to coho in 2010 (more abundant in the mainstem Salmon River), although occupancy rates were slightly higher (Appendix Figure A-3). We did not observe steelhead or coho at five of the sites in 2010: upper Little Salmon River (2), North Fork Panther Creek, Toketa Creek, and in the lower section of an unnamed tributary to the estuary. We were not able to determine if a barrier prevented passage to these sites. Salt water likely intruded into the unnamed tributary and the shocker may not have been effective at capturing fish since we sampled fish further upstream. We measured a subsample of the juvenile steelhead and it appears that two age classes were present (Appendix Figure A-4). The fish we measured ranged from our lower identification limit of 60mm to 207mm. The average length for the 3 years was 90 mm and the median was 80 mm.

Appendix Table A-3. Population estimates (±95% confidence intervals), mean density per m^2, mean density per km, and percent of sites occupied, by steelhead in streams of Salmon River watershed.

Year	Abundance	Density (m^2)	Density (km)	Occupancy
2008	44,623 (38%)	0.07	415	71%
2009	33,626 (38%)	0.08	313	76%
2010	33,674 (50%)	0.07	341	65%



Appendix Figure A-3. Density of juvenile steelhead in 2010.



Appendix Figure A-4. Length frequency histograms for a subsample of steelhead trout captured in the upper watershed and tributaries of Salmon River in 2008 (upper graph), 2009 (middle), and 2010 (lower).

Spring Migration

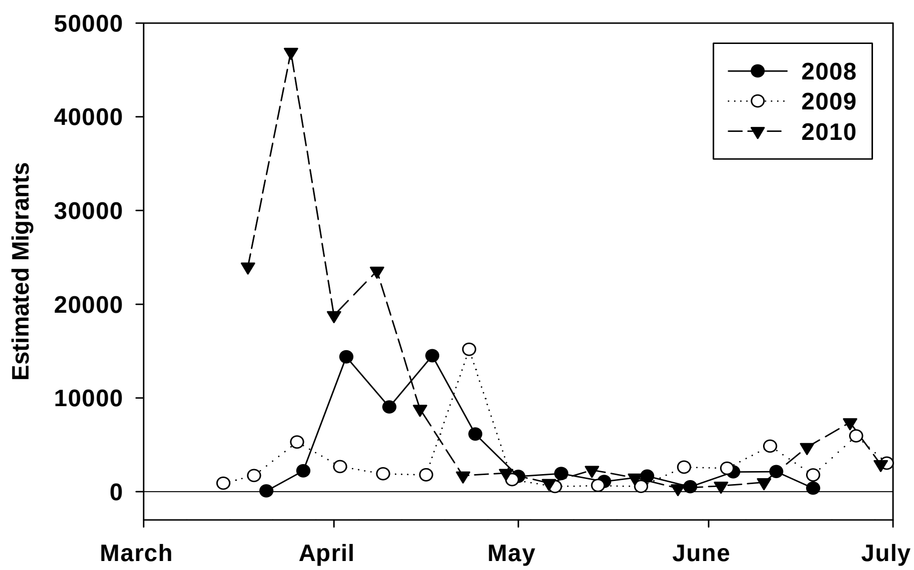
The rotary screw trap captured all downstream migrating salmonids. Efficiencies were estimated for each species and size class and expanded to the abundances in Appendix Table A-4.

Appendix Table A-4. Annual abundance (±95% CI) of salmonids collected in a rotary screw trap in March – June, 2008, 2009, and 2010.

Species	Age or Size Class	2008	2009	2010
Coho	0	37017±72	39141±42	11177±44
	1	21304±29	21864 ± 85	20140±58
Chinook	0	57758±49	53187±19	147457±23
Steelhead	<120	3250±169	5675±115	3299±160
	≥120	3700±151	5500±109	3300±161
Cutthroat	<120	1150±137	1950±162	766±64
	≥120	8700±145	2098±62	4365±169

Chinook salmon

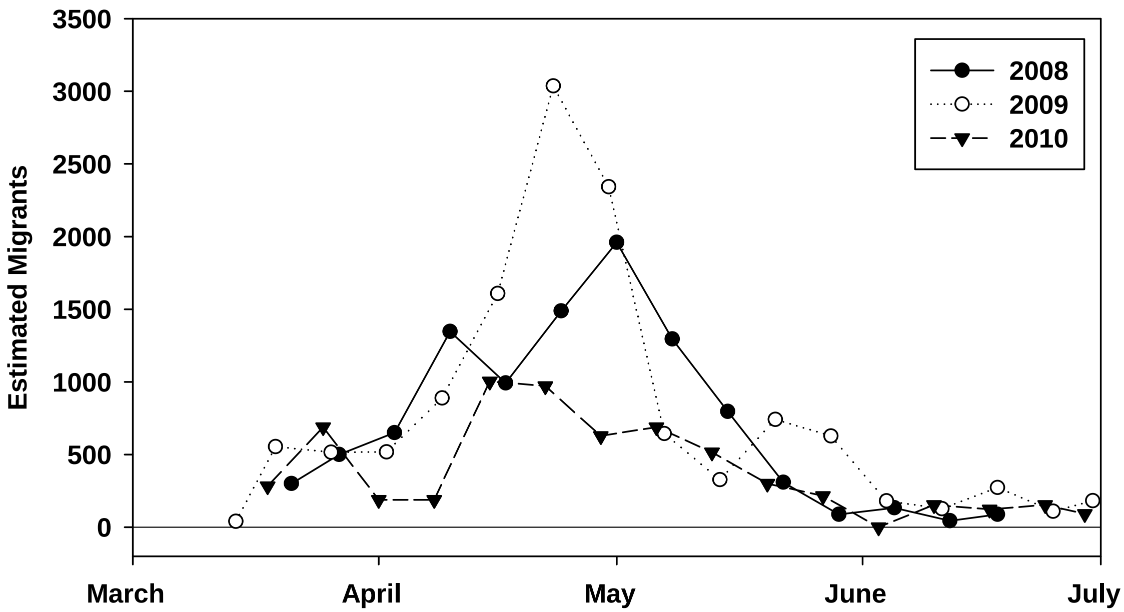
The majority of juvenile Chinook migrated in April. In 2010, we caught a large number of fry in March (Appendix Figure A-5). Fish continue to migrate out through May, with a second pulse in June. Based on sampling in the estuary, we know that juvenile Chinook continue to leave freshwater into the fall. We did not capture any age-1 Chinook. Estimated migrants numbered approximately 55,000 in 2008 and 2009 and ~150,000 in 2010 (Appendix Table A-5). Fork length sizes ranged from 33mm to 105mm.



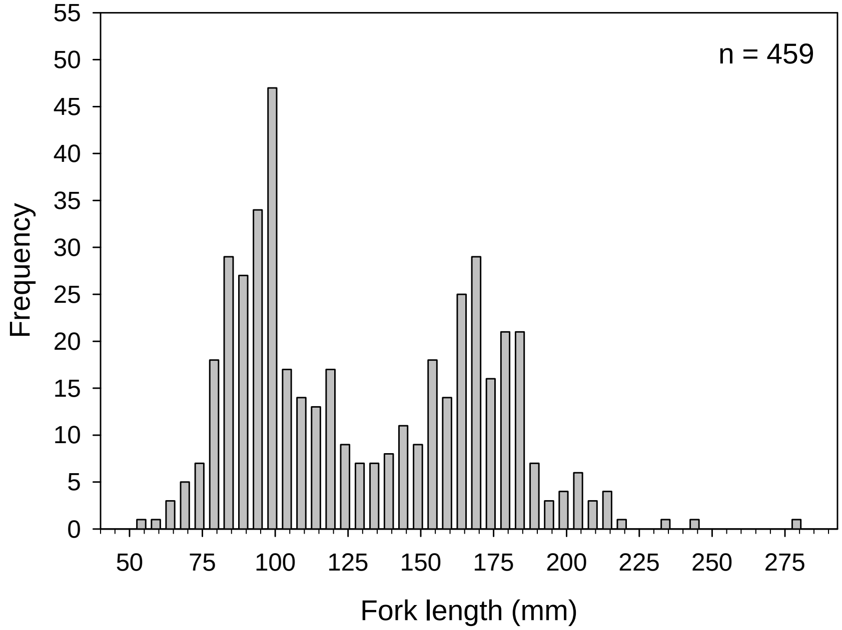
Appendix Figure A-5. Estimated migration of juvenile chinook salmon from March through June, Salmon River.

Steelhead trout

The annual migration of juvenile steelhead peaked sharply in the later half of April, with few fish caught by late June (Appendix Figure A-6). Estimates for steelhead migrants less than 120 mm (assumed age 0) ranged from 3,250 in 2008 to 5,675 in 2009. Those >120 mm in length were presumed to be age-1. They numbered 3,300 in 2010 to 5,500 in 2009 (Appendix Table A-4). The degree of size overlap between age classes in not known. Confidence intervals are large due to very low trap efficiency for trout, and larger juvenile steelhead may avoid the trap in greater numbers than smaller fish. Sizes of steelhead caught in the screw trap range from 54 to 276, with an average size of 127 mm, and a median of 116 mm (Appendix Figure A-7). We also caught two adult steelhead in 2009, a 475mm fish on May 3, and a 635mm fish on June 18. We presume these were post-spawn adults, migrating back to the ocean.



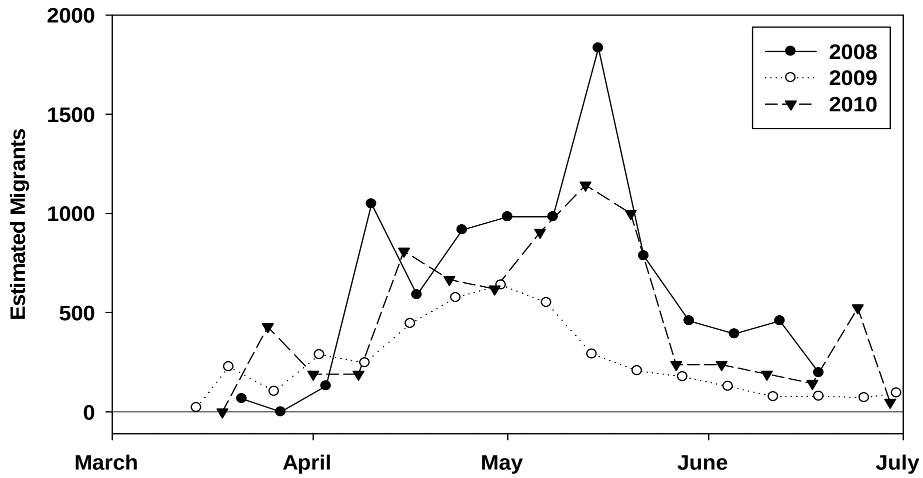
Appendix Figure A-6. Estimated migration timing of steelhead trout in Salmon River, 2008 – 2010.



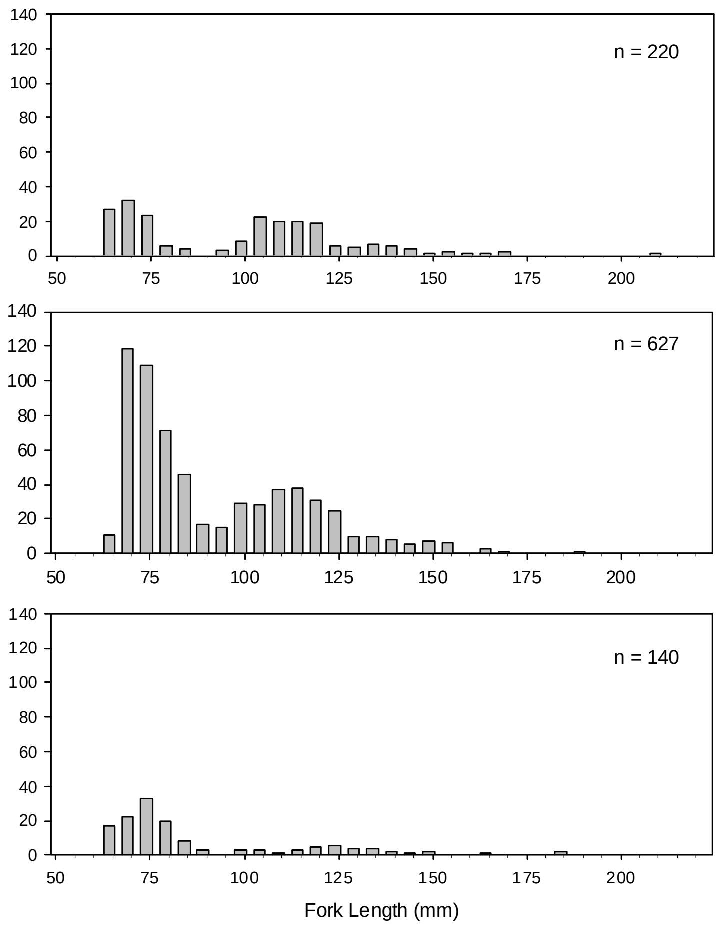
Appendix Figure A-7. Fork lengths of downstream migrating steelhead captured from March through June, 2009.

Cutthroat trout

The primary migration of cutthroat trout extends from early April through June (Appendix Figure A-8). We estimated the number of migrants <120mm between 766 (2010) and 1,950 (2009), and the number of those >120mm between 2,100 (2009) and 8,700 (2008) (Appendix Table A-4). Confidence intervals are large due to very low trap efficiency for trout. The fork lengths for cutthroat caught in the trap ranged from 57mm to 365mm, with an average length of 138mm, and a median of 136mm (Appendix Figure A-9).



Appendix Figure A-8. Estimated migration timing of cutthroat in Salmon River, 2008 – 2010.



Appendix Figure A-9. Fork lengths of downstream migrating cutthroat captured from March through June, 2008 (top), 2009 (center), and 2010 (bottom).

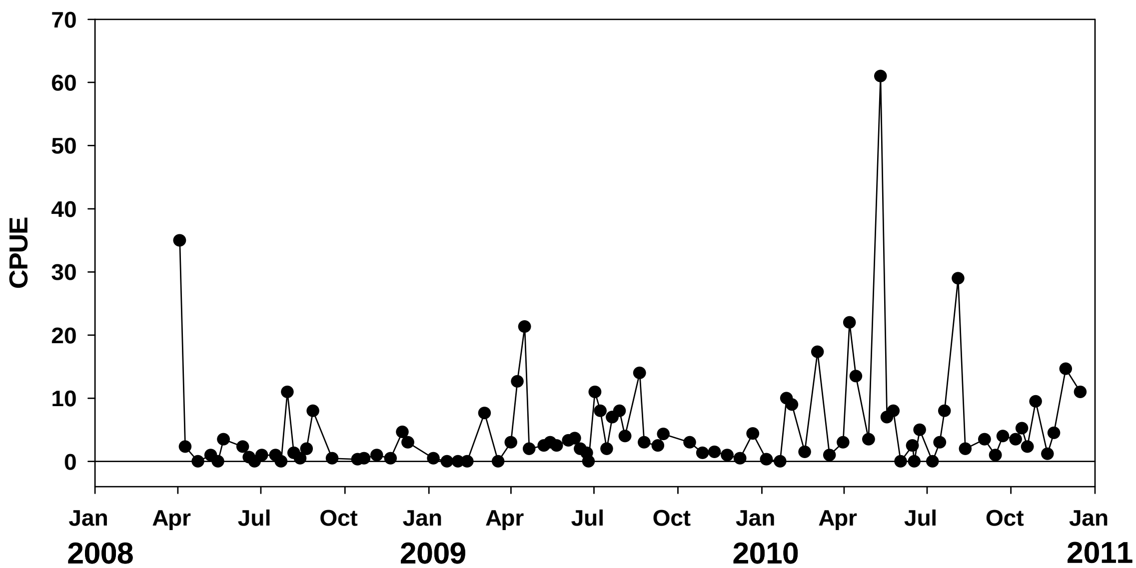
Abundance, Timing, and Habitat Use in the Estuary

Chinook

Juvenile Chinook salmon use of the Salmon R. estuary has been well-documented (Cornwell 2001, Bottom et al. 2005, Hering 2010, Hering et al. 2010). Despite lower abundance compared to previous years, the patterns of habitat use were similar. We caught Chinook from March – December, with peak use of upper estuary marshes in April and May, and peak catches in the lower estuary in August and September.

Cutthroat trout

Cutthroat trout were observed in the estuary in every month of the year and have been the focus of past studies in Salmon River estuary (Appendix Figure A-10) (Krentz 2007, Jones et al. 2008). Cutthroat typically show consistent catches or detections at selected sites in the estuary, including the 96 Marsh. The findings from 2008-10 are summarized in Stein et al. (2011).



Appendix Figure A-10. Catch per unit effort for cutthroat trout in the middle section of the Salmon River estuary, 2008 – 2010.

Steelhead trout

We did not catch large numbers of steelhead in the estuary with a beach seine. In 2008 we caught 20 juvenile steelhead, in 2009, 104 (50 were adipose clipped hatchery that escaped from Salmon River hatchery during a flood event) and in 2010, 27 steelhead were caught. Of these 151 fish, 112 (74%) were caught in April. Steelhead were usually caught in seine hauls that included large numbers of cutthroat and other juvenile salmonids.

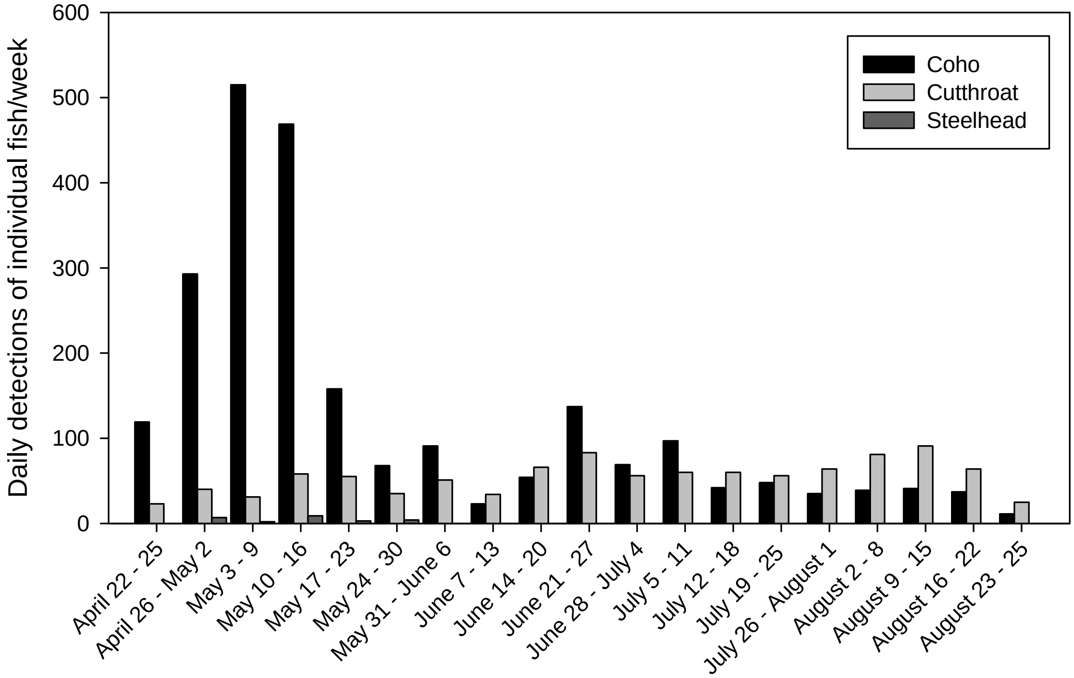
Thirteen tagged steelhead smolts were detected on the 96 Marsh PIT antenna. 10 of those were tagged at the smolt trap, 2 were tagged in the upper watershed in August and September the previous summer, and 1 was tagged 5 days earlier in a beach seine at a the mid-estuary site. The median time it took the 10 smolts tagged at the head of tide screw trap to be detected in the 96 Marsh (1.4 km) was 7.5 days, with a range of 1 – 46 days. Three smolts tagged at the screw trap were detected at the antennas the next day.

96 Marsh PIT tag antenna

Cutthroat were also frequent users of the 96 Marsh throughout the time period the detector was in operation (Appendix Figure A-11). Even though we rarely collect steelhead in seine sets up in the 96 Marsh, 5% of the steelhead tagged at the screw trap in 2010 were detected on the marsh PIT antenna at high tide during the spring.

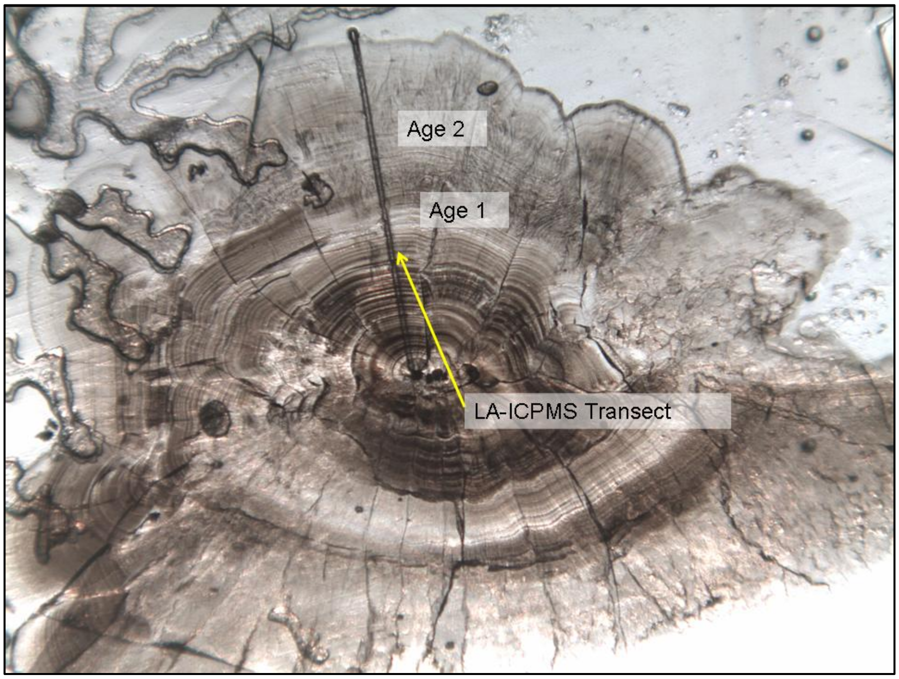
Appendix Table A-5. Number of PIT tagged fish detected at the 96 Marsh PIT antenna April 22, 2010 to August 25, 2010.

Tagging site	Cutthroat	Steelhead
Screw trap 2010	41	10
Screw trap 2009	1	0
Screw trap 2008	1	0
Estuary seining 2010	72	1
Estuary seining 2009	10	0
Upper watershed 2009	28	2
Upper watershed 2008	1	0
Totals	154	13

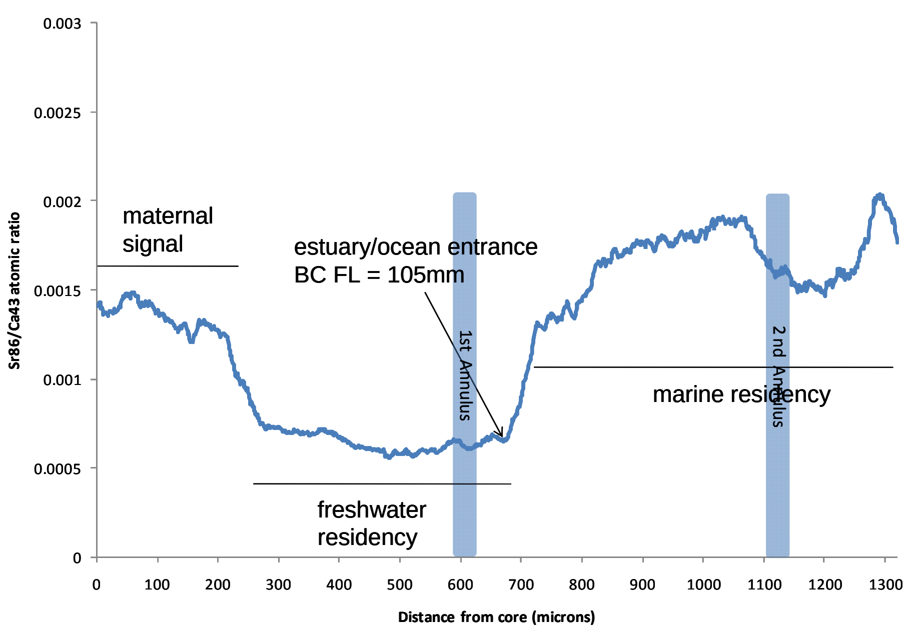


Appendix Figure A-11. Timing of PIT tagged fish detected in the 96 Marsh.

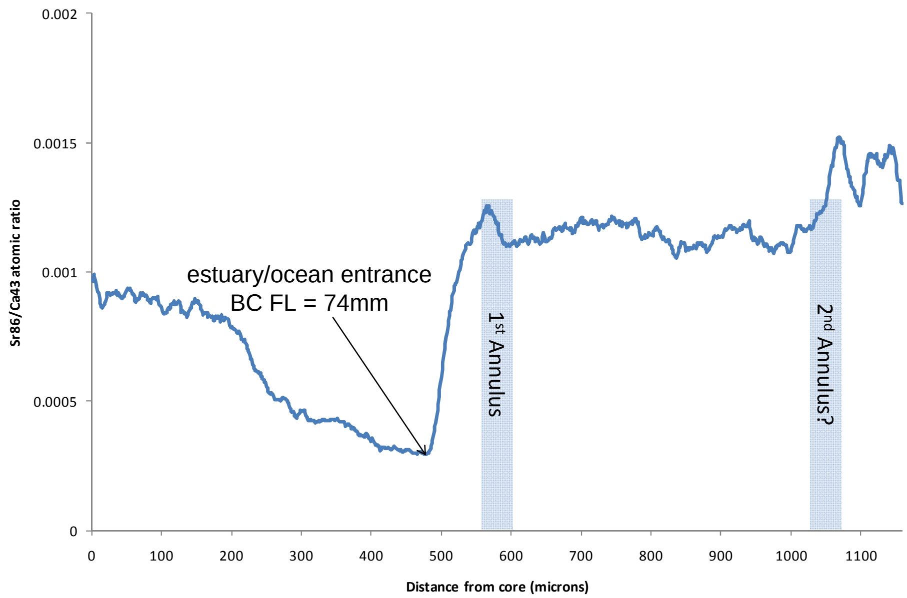
APPENDIX B



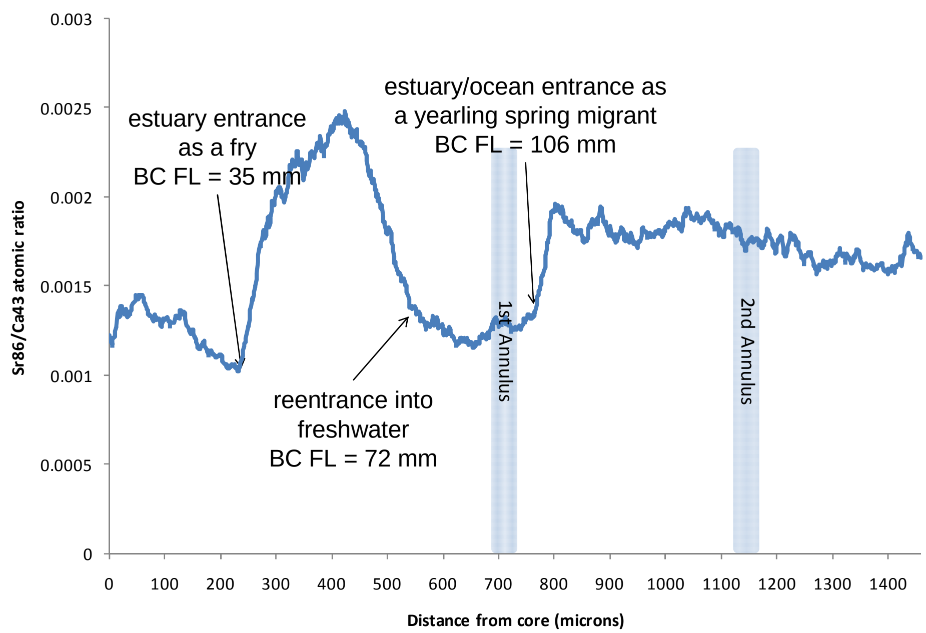
Appendix Figure B-1. Photo of otolith from wild female coho collected in Salmon River at 475 mm length. Otolith analysis presented in detail in Figure B-2.



Appendix Figure B-2. Strontium/calcium profile of otolith from 475 mm female adult coho collected in Slick Rock Creek, Salmon River. The coho entered salt water at 105 mm length at age-1.



Appendix Figure B-3. Strontium/calcium profile of otolith from 605 mm male adult coho collected in Upper Bear Creek, Salmon River. The coho entered salt water at a length of 74 mm at age-0.



Appendix Figure B-4. Strontium/calcium profile of otolith from 605 mm male adult coho collected in Upper Bear Creek, Salmon River. The coho entered salt water at a length of 35 mm, re-entered freshwater to 72 mm, and migrated back to salt water at 106mm at age-1.