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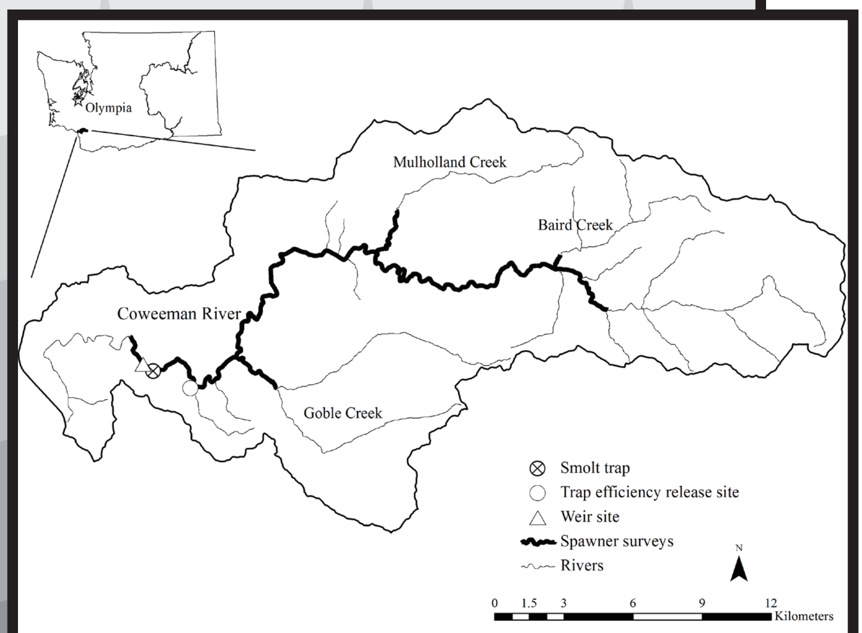
Coweeman River Salmonid Production Evaluation: 2011 Completion Report



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FISH AND WILDLIFE
Fish Program
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Coweeman River Salmonid Production Evaluation:

2011 Completion Report

Washington Department of Fish and Wildlife

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Executive Summary

In 2007, the Washington Department of Fish and Wildlife initiated research designed to better understand the abundance, productivity, diversity, and fisheries contributions of tule Fall Chinook salmon originating from the Coweeman River. The objectives of this work were to estimate adult escapement and juvenile production by two outmigrant life histories (i.e., fry and subyearling smolt), to describe the juvenile freshwater residency period of returning adults, and to determine the relative contributions of the two outmigrant life histories to escapement and fisheries. Additional objectives were to estimate the juvenile production and outmigrant life history characteristics of other anadromous salmonids that occur in the Coweeman River which include coho salmon, natural and hatchery-origin steelhead, and coastal cutthroat trout. This report provides the results of work conducted in 2011 to meet these objectives and summarizes past results.

A 1.5 m (5-foot) diameter rotary screw trap was operated near river kilometer (rkm) 12.0 from February 3 through August 24, 2011 to capture and mark outmigrating juvenile Chinook and other anadromous salmonids. During this period, the trap was not fully operational for 10 days due to high discharge and heavy debris loads.

In 2011, a total of 309,000 (95% CI = 227,900 – 441,200; CV = 18.1%) subyearling Chinook salmon were estimated to have emigrated from the Coweeman River. Of these, 260,476 ± 86,713 (abundance, ± 95% CI; CV = 17.0%) were fry migrants and 48,469 ± 10,501 (abundance, ± 95% CI; CV = 11.1%) were Chinook subyearling smolt migrants.

In 2011, 14,879 ± 3,666 (abundance ± 95% CI; CV = 12.6%) coho, 29,127 ± 16,285 (CV = 28.5%) natural-origin steelhead, 6,976 ± 4,492 (CV = 32.9%) hatchery-origin steelhead, and 2,033 ± 1,341 (CV = 33.7%) coastal cutthroat trout smolts were estimated to have emigrated from the Coweeman River basin.

Since 2007, we have strontium-marked the otoliths of both juvenile outmigrant life histories to estimate the duration of freshwater residency between the Coweeman River and the Columbia River estuary/Pacific Ocean. Preliminary results from adults returning to the Coweeman River in 2009 and 2010 (*n* = 147) suggest that freshwater residency duration varies from days to months between the Coweeman trap and the saltwater environment.

Juvenile Chinook have been coded-wire tagged and released from the Coweeman River for four years. We used this marking approach to determine the contribution of Coweeman Chinook to fisheries. A total of 28 coded-wire tags have been recovered from the 2006 and 2007 brood years. Based on fishery sampling rates, these recoveries were expanded to a total of 114 tags or 0.25% of the 45,647 tags released in 2007 and 2008. Of the estimated tag recoveries, 46% were recovered in coast-wide fisheries and the remaining 54% were recovered on the spawning grounds. The majority of estimated 53 fishery interceptions occurred in Washington sport (43%) and Canadian troll (47%) fisheries.

Fall Chinook salmon escapement was estimated using two mark-recapture approaches. The pooled-Petersen escapement estimate was 668 ranging from 594 to 742 (95% CI; CV = 5.7%); however, we found evidence to suggest that size and age selectivity occurred which violated one assumption of the estimator. The Jolly-Seber escapement estimate was 459 ranging from 310 to 723 (95% CI; CV = 24.4%). These estimates did not differ statistically (Z-test; p=0.072).

Introduction

The Coweeman River is a tributary of the Cowlitz River which supports wild populations of Chinook (*Oncorhynchus tshawytscha)* and coho salmon (*O. kisutch)* as well as steelhead (*O. mykiss*) and coastal cutthroat trout (*O. clarki clarki*). With the exception of cutthroat trout, these species are federally protected as *threatened* under the Endangered Species Act. Coweeman River populations are part of the Lower Columbia Evolutionary Significant Unit (ESU, Myers et al. 2006) and Chinook, coho, and steelhead populations in this watershed have been listed as primary populations for the purpose of recovery planning (LCFRB 2010).

The current life cycle monitoring study in the Coweeman River focuses on Chinook salmon, although information is collected for all salmonid species encountered. Chinook salmon in the Coweeman River are a genetically distinct stock (Myers et al. 2006), moderately abundant, and relatively free of hatchery influence. For fisheries management, Coweeman River Chinook salmon are used as an escapement index stock. Coweeman River Chinook salmon exhibit a "tule fall" Chinook life history, meaning that adults enter freshwater in August and September and spawn within a few weeks of freshwater entry (LCFRB 2010). Tule fall Chinook are one of three adult life histories recognized for the Lower Columbia Chinook ESU (Myers et al. 2006).

Despite the status of Coweeman River Chinook salmon as a primary population and an index stock, direct estimates of juvenile production and fisheries contributions did not exist until recently. In 2007, the Washington Department of Fish and Wildlife initiated a study of juvenile production in the Coweeman River with funding support from the Southern Fund Committee of the Pacific Salmon Commission. Freshwater production of all salmonids, including Chinook salmon, was evaluated between 2007 and 2011, although no field operations were conducted in 2009 due to lack of funding. During this time, improvements to escapement estimation methods have been made through support from multiple sources and include the development of a parentage based genetic mark-recapture tool which combines juvenile and adult data to estimate spawner escapement (Blankenship and Rawding 2012). Together, these juvenile and adult data are beginning to provide a more complete understanding of Chinook salmon abundance, productivity, distribution, and diversity in the Coweeman River.

Initial results on Chinook salmon juvenile production indicate that at least two juvenile life history strategies exist within the same population (Sharpe et al. 2009). Coweeman River

Chinook salmon emigrate primarily as subyearlings and the outmigration is bimodal. Fry migrants emigrate early and at smaller sizes (< 45 mm FL). Subyearling smolt migrants emigrate later and at larger sizes (60-115 mm FL), presumably having used the natal stream habitat for early growth. These life history strategies are consistent with those observed for summer and fall Chinook salmon populations in Puget Sound (Topping and Zimmerman 2011; Kiyohara and Zimmerman 2012) and have even been observed in regions where Chinook salmon populations were introduced (Carl 1984; Davis and Unwin 1989). However, information is lacking about the degree to which these life history strategies contribute to adult returns, and therefore, population viability. Information is also lacking on the extent to which migrating Chinook juveniles use freshwater habitat outside of their natal watershed. Therefore, an additional goal of the study has been to understand the importance of freshwater rearing habitats (natal stream versus Columbia River estuary) on overall Chinook productivity (i.e., return rates).

The overall goals of this study are to identify factors that limit productivity of Coweeman River Chinook salmon and understand the freshwater production of other salmonids in the watershed. This report provides results from the 2011 field season and compares these results to previous years of study. In 2011, the objectives of this study were to:

- Estimate juvenile production, outmigration timing, and body size of Chinook salmon fry and subyearling smolts, and coho salmon, steelhead, and coastal cutthroat smolts,
- Evaluate fishery interceptions of Chinook salmon using coded-wire tags,
- Determine the relative contribution of early life history strategies to adult returns, and estimate the juvenile freshwater residency period of Chinook salmon using otolith microchemistry, and
- Estimate spawning escapement, age structure, and spawn timing of Chinook salmon.

Methods

Study Site

The Coweeman River is a third-order tributary to the Cowlitz River located in Cowlitz County, WA (Figure 1). The mouth of the Coweeman River is approximately 120 km from the Pacific Ocean. The Coweeman River basin drains approximately 329 square kilometers and is a relatively low elevation watershed with elevations ranging from 1 - 1358 m. The overall main-stem stream gradient along the known extent of spawning and rearing is 0.6%. The watershed is managed for timber production with limited residential and commercial development near the river mouth. Native anadromous salmonids in the Coweeman River include tule fall Chinook salmon, coho salmon, coastal cutthroat trout, and winter-run steelhead. Chum salmon were once present in the watershed but are currently at very low abundance or extirpated. Hatchery smolt releases of winter-run steelhead occur annually through a cooperative effort with a local fishing club, the Cowlitz Game and Anglers, a private landowner, and the Washington Department of Fish and Wildlife.

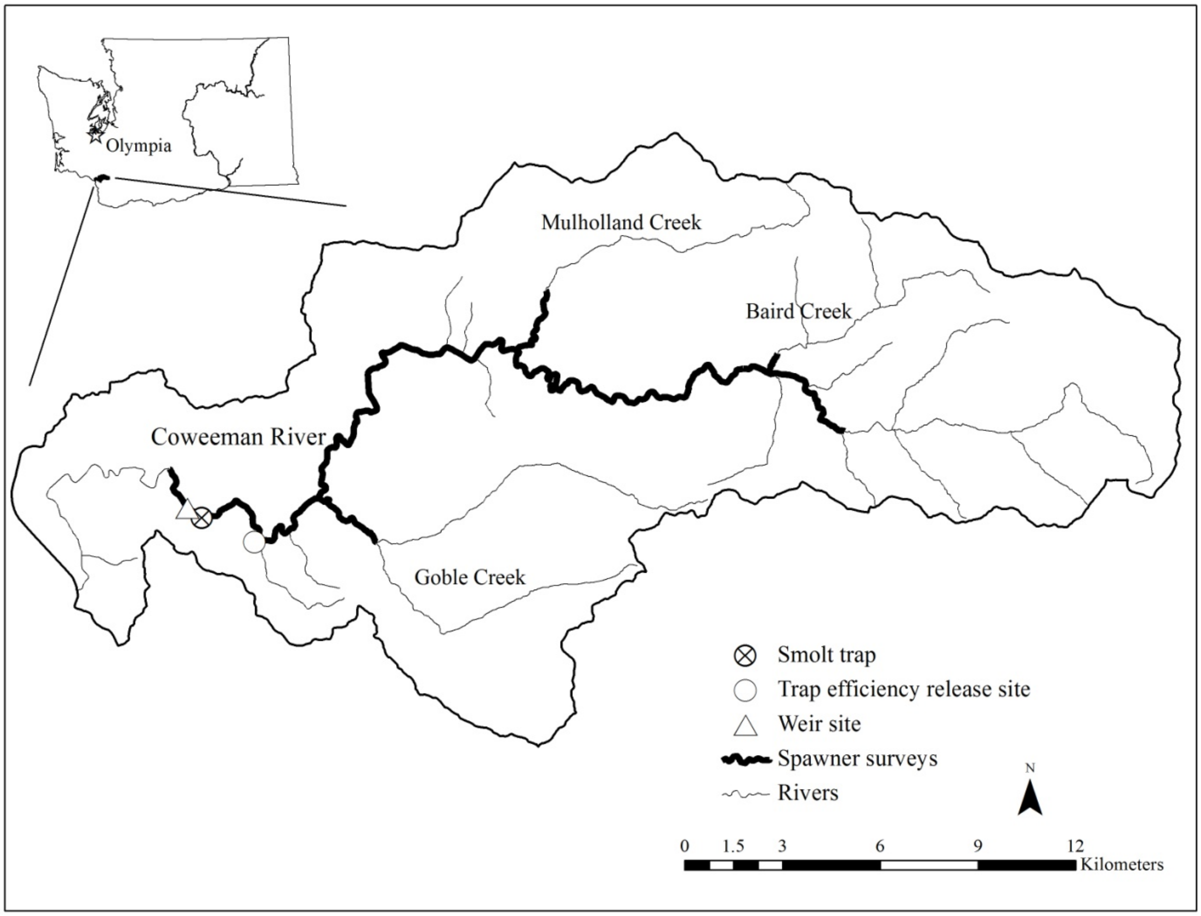

Figure 1. A map of the Coweeman River watershed, Washington showing salmonid trapping locations and spatial extent of spawner surveys.

Juvenile Trap Operation

A 1.5 m (5-foot) diameter rotary screw trap was operated near river kilometer (rkm) 12.0 from February 3 through August 24, 2011 (Figure 1). The trap fished continuously with the exception of 10 days when the trap was not fully operational due to high discharge and heavy debris loads. We operated the trap at two different sites (within 100 m of each other) depending on river discharge conditions. Both sites were located near the head of a pool, just below a high-velocity riffle, and the trap was positioned so stream flow entered directly into the cone. Water velocities at this site produced cone revolutions between 6 and 14 revolutions per minute. We installed panel weirs on June 21, 2011 to force more surface water into the trap and to increase the number and proportion of fish captured.

While the site is relatively high in the watershed, most of the lower 12 km is a tidally influenced slough with minimal to no spawning activity. Prior to 2011, spawner surveys in the lower river reach documented zero steelhead, coho, and chum spawners or redds and only a small proportion (~2.4%) of the total number of Chinook redds observed in the basin (WDFW, unpublished data).

Juvenile Fish Collection

The trap was checked for fish each morning. Non-salmonids were identified, enumerated, and released at the trap. Salmonids were stored in 19 L buckets when small numbers of fish were being processed. When large numbers of salmonids were processed, they were held in a 100 L tote that was plumbed with a continuous supply of river water to reduce stress. Prior to biological sampling, salmonids were anaesthetized in a buffered ($NaHCO_3$) tricaine methanesulfonate (MS-222) solution (~60 mg/L). Each individual was identified to species and life stage, examined for fin clips and other marks (including recaptures), and enumerated. Fork length (FL) was measured to the nearest millimeter from a subsample of each species. All fish were sampled as quickly as possible and were allowed to fully recover before they were returned to the river.

We classified life stage of each species using length and degree of parr marking and/or silver appearance. Fall Chinook juveniles were classified as fry (< 45 mm FL, parr marks not visible), parr (> 45 mm FL, parr marks visible, no silvery appearance) or subyearling smolts (silvery appearance, typically > 70 mm FL). Coho juveniles were classified as subyearlings (fry and parr, combined, orange-brown coloration, < 80 mm FL) and yearling smolts (silvery, > 80 mm FL). Steelhead and cutthroat juveniles were classified as parr, pre-smolts, or smolts. The criteria for steelhead and cutthroat parr included well-developed parr marks and heavy spotting across the dorsal surface; pre-smolts had faint parr marks, less prominent dorsal spotting, silvery appearance, and no dark caudal fin margin; and smolts had deciduous scales, silver appearance, and dark pigmentation on the outer margin of the caudal fin.

Trap efficiency trials were conducted for Chinook salmon subyearlings (fry and subyearling smolt life stage separately), coho salmon, steelhead (natural and hatchery origin), and coastal cutthroat smolts throughout the emigration period of each group to account for temporal heterogeneity in capture probabilities. Efficiency trials were conducted by marking maiden caught individuals (i.e., fish captured for the first time) and releasing them 3.0 km upstream of the trap for subsequent recapture (Figure 1). The release location was the first available river access point upstream of the trap. The instream habitat between the release location and the trap was variable, consisting of alternating riffles, pools, and boulder gardens, and should have ensured adequate mixing of marked and unmarked fish prior to recapture events.

Three different methods were used to mark fish for efficiency trials depending on species and life stage. All Chinook fry and the majority of Chinook subyearling smolts were marked with Bismarck brown Y (Product # B2759, Sigma-Aldrich, St. Louis, MO). Bismarck brown stain solution was prepared at a concentration of 0.3 g Bismarck brown to10 L of river water (30 mg/L) and soaked the fish for 45 minutes in an aerated bath. In August, Chinook subyearling smolts were marked with a partial caudal clip because stream temperatures elevated to a point that made it unsafe to use Bismarck brown. Coho salmon, steelhead, and coastal cutthroat smolts were injected with colored elastomer (Northwest Marine Technology, Tumwater, WA) into the adipose eyelid.

Marks were administered throughout the emigration period of each group (i.e., species or fall Chinook life stage). Bismarck brown trials were conducted between one and five days per week with several days of no marking in between each period to allow adequate time for marked fish to pass the trap before the next marking period. This increased the probability that all recaptures were captured during the week they were marked. Fin clips and elastomer dye were changed on a weekly basis in order to detect delayed recaptures among the temporally stratified release groups. Elastomer efficiency trials generally occurred five days per week and the elastomer colors varied each week so that recaptures could be assigned to the week they were marked.

Juvenile Production Estimates

Juvenile production estimates were derived for two different subyearling life stages of fall Chinook (fry and subyearling smolts) as well as wild coho salmon smolts, winter-run steelhead smolts (wild and hatchery origin), and wild coastal cutthroat trout smolts. We used a stratified mark-recapture study design to estimate the number of juvenile migrants for each species. In order to conduct each analysis, the data were organized by weekly counts of catch, marks, and recaptures.

Smolt production for coho salmon, natural-origin steelhead, and coastal cutthroat was estimated with the Darroch (1961) stratified-Petersen estimator. The capture probabilities and estimates for each strata were calculated using DARR (Darroch Analysis with Rank Reduction) 2.0.2 (Bjorkstedt 2005; Bjorkstedt 2010). DARR 2.0.2 is a software application update executed in the programming environment R (R Development Core Team 2009). We intended to use this method to estimate the number of migrating hatchery-origin steelhead smolts but low recapture numbers forced us to use a pooled-Petersen method.

Production of juvenile Chinook salmon was estimated using a Bayesian spline analysis of the time-stratified mark recapture data. The spline approach developed by Bonner (2008) addresses problems encountered in our smolt trapping which included no marked releases and missed catch periods in some weeks. These issues are particularly relevant for Chinook salmon which emigrate earlier in the season when high flows interfere with continuous trap operation. The total abundance estimate incorporates the uncertainty from the mark-recapture estimator as well as the absence of marked groups and missed catch periods in some weeks.

The spline approach uses the hierarchical trap efficiency, the shape of the spline curve, and the observed number of captured fish to estimate the weekly abundance when no marked releases are available (detailed equations in Bonner 2008). When only a fraction of the week is sampled, the observed catch is expanded by the weekly sampled fraction. If no data are collected for a particular stratum, the spline interpolates a value for the run size in that week given the shape of the spline and the variability in individual run sizes about the spline.

Weekly estimates of trap efficiency were assumed to come from a normal distribution based on the logit of trap efficiencies. Thus, the logit of trap efficiencies were hierarchically modeled. To allow information across weekly run sizes to be shared, the weekly abundance was modeled as a smooth curve using the Bayesian penalized spline (P-spline) method of Lang and Brezger (2004) and an R package, Bayesian Time Stratified Population Analysis (BTSPAS), developed by Carl Schwarz and Simon Bonner (http://cran.r-project.org/).

The hierarchical trap efficiency model in BTSPAS was modified to more accurately represent the trap efficiencies we observed in 2011. During the first part of the trapping season

(February – June), trap efficiencies were typically < 5% due to high river discharge. When discharge receded to near base flow (mid-June), plywood panel weirs were installed to force more surface water into the trap. This modification resulted in trap efficiencies up to 80% during the later part of the trapping season (June – August). The BTSPAS approach of using a single hierarchical trap efficiency model seemed inappropriate given the observed variation in trapping efficiency. Therefore, we extended Bonner's approach by developing two hierarchical trap efficiency models, one for the early trapping period and one for the late trapping period.

The extended model was run in WinBUGS (Spiegelhalter et al. 2003). Non-informative priors were used for the hierarchical logit of trap efficiency for both periods (Normal(0,100)). The hyperpriors for the spline were as described in the BTSPAS package. Three chains were run, and after the burn-in period, simulations were run until Markov Chain error was < 5% of the posterior standard deviation. Simulations were thinned to reduce autocorrelation. Convergence was monitored using Brooks-Gelman-Ruben diagnostics. Since the Brooks-Gelman-Ruben values were < 1.1, we assumed the Gibbs sampling results were representative of the underlying stationary distribution, and the Markov Chains had converged (Kery 2010).

Coded-Wire Tagging and Strontium Marking of Juvenile Chinook

We marked a subsample of juvenile Chinook caught in the trap with coded-wire tags (CWT) and/or strontium (Sr) for long-term evaluations. Subyearling smolts were injected with CWTs using a Northwest Marine Technology (NMT, Shaw Island, WA, USA) Mark IV automatic tagging system. Specific length classes of fish were marked with specific tag codes. The length classes were 65-75 mm, 76-85mm, 86-95 mm, and > 95 mm FL. Juvenile Chinook less than 65 mm FL were too small to tag.

We marked the sagittal otoliths (hereafter termed otoliths) of emigrating fall Chinook fry and a proportion of subyearling smolt migrants with Sr. This was done by placing the fish in a 400 L vessel containing an aerated solution of strontium chloride hexahydrate at 2000 ppm for 6 h. The Sr bath was sterilized by pumping the solution through an ultra-violet light filter. The vessel was located on the river bank near the fish sampling station.

The Sr-marking procedure (Schroder et al. 1995) has been successfully used for marking emigrating chum salmon fry (Hillson 2006) and fall Chinook (Schroder et al. 1996). Hillson

(2006) reported low mortality (0.044%) during marking and no delayed mortality 48 h after marking.

Contributions of Coweeman River Chinook to Fisheries

Juvenile Chinook have been coded-wire tagged and released from the Coweeman River smolt trap for four years (2007, 2008, 2010, and 2011). Tag recoveries from two of these release years (2007 and 2008) provide a snapshot of Chinook salmon interception rates in coast-wide fisheries. The first tag recoveries from the remaining release years (2010 and 2011) are expected in 2012 and 2013.

Tag recoveries were queried from the Regional Mark Process Center (RMPC) database and summarized by recovery age and by fishery type (sport, net and seine, troll, and spawning grounds) and agency. Summaries were based on the estimated tag recoveries in each fishery as reported in the RMPC database.

Otolith Microchemistry Analysis

Adult Chinook otoliths collected from carcasses on the spawning grounds were chemically analyzed in an attempt to better understand the contribution of fry and subyearling smolt outmigrants to adult returns, and the extent of juvenile freshwater residency. The otoliths were prepared as thin sections for laser ablation inductively coupled mass spectrometry (LA-ICPMS) and analyzed for Sr, Calcium (Ca) and other trace elements at Oregon State University's Keck Laboratory (Corvallis, OR, USA). LA-ICPMS transects were run from the ventral surface of the otolith through the primordia to the dorsal edge. Sr:Ca atomic ratios were calculated along the laser transect and average values at both the ventral and dorsal peaks along with a value just prior to the inflection of the last peak (assumed otolith freshwater value) were collected. Samples were also examined for evidence of Sr marking (i.e., fish marked as juveniles at the Coweeman River screw trap). Sr-marked individuals have an Sr:Ca peak ~ 15 times greater than freshwater values and ~ 7 times greater than expected marine signals (Sharpe et al. 2009).

Data from all samples (i.e, Sr-marked and unmarked samples) were used to estimate body size of juveniles at estuary/ocean entrance. Body size was back calculated using the following fish size-otolith size relationship ($n = 92$; $r^2 = 0.911$):

$$\text{Fork length (mm)} = 0.1449 * \text{Otolith radius (microns)} + 3.3195$$

Data from Sr-marked individuals were used to estimate temporal extent of freshwater residency from natal stream to the saline portion of the Columbia River estuary using a growth rate of 0.5 mm/day (Campbell 2010).

Adult Fish Collection and Spawner Surveys

In 2011, we planned to compare two mark-recapture approaches that are typically used to estimate adult escapement; however, a change in spawner distribution compromised the use of one of the approaches. The first approach, hereafter referred to as Live Tagging Approach, involves uniquely marking live fish captured at a floating weir and resampling marked and unmarked carcasses after spawning. The weir was successfully installed, and fish were marked and recaptured as planned, but this approach was compromised when a significant proportion of salmon spawned below the weir. The second approach, hereafter referred to as Carcass Tagging Approach, involves uniquely marking carcasses and then resampling marked and unmarked carcasses on the spawning ground. This approach proceeded as planned.

In order to capture and mark live Chinook salmon for the Live Tagging Approach, a resistance-board weir (bar spacing = 2.9 cm) was operated at rkm 11.0 between September 9 and October 31, 2011 (Figure 1). The weir blocked the entire river and fish were routed into a live box. The weir operated the entire season except when it was topped during freshets and when it was sunk by heavy debris loads. These events were few and only occurred for short periods of time. All fish in good condition were double tagged with uniquely numbered Floy tags and were operculum punched. The punch location and shape were rotated weekly to assign each fish to a mark stratum. The trap operators identified the origin (i.e., wild or hatchery), measured the length, and collected scales and DNA tissue from all captured fish. Fish were also classified as males, females, or jacks (males < 60 cm).

Weekly surveys were conducted over the known spatial and temporal Chinook spawning distribution in the Coweeman River basin (Figure 1). The surveys were conducted from

September 13 to November 15, 2011 between rkm 9.4 and rkm 53.1 in the main-stem Coweeman River and in the lower portions of two tributaries, Goble and Mulholland creeks. During weekly surveys, live and dead (carcass) fish, and Chinook redds were identified and enumerated. Surveyors georeferenced redd locations using a Garmin Oregon 550 global position system, and classified live fish as either spawners or holders based on characteristics of the occupied habitat (Parken et al. 2003). Spawners occupied relatively shallow habitats with abundant spawning gravel and holders occupied relatively deeper habitats lacking spawning gravel.

Carcasses sampled during weekly surveys provided the second sample for the Live Tagging Approach and the first and second samples for the Carcass Tagging Approach. From each carcass, surveyors recorded the length and sex, collected genetic tissue and scales, examined the carcass for tags and marks, and ranked the carcass condition. Carcasses were placed into one of six carcass condition categories based on flesh firmness, eye clarity, and gill color. If the carcass was not tagged and met the decomposition criteria (i.e., a relatively fresh carcass), the carcass was tagged for the Carcass Tagging Approach. The carcass was double tagged (to minimize tag loss) with uniquely numbered plastic tags stapled to the inside of each operculum. After tagging, carcasses were returned to moving water to allow for uniform mixing with other carcasses. When a tagged carcass was recaptured, surveyors removed the tags, cut off the tail, and returned it to the river.

Adult Escapement Estimates

Using the Carcass Tagging Approach, a whole-basin escapement estimate was derived using the methods outlined in Sykes and Botsford (1986). We developed a Bayesian Jolly-Seber (JS) model using vague prior probabilities in WinBUGS (Lunn et al. 2000). Bayesian methods may be affected by lack of convergence of the Markov chain Monte Carlo sampling and by the modeled priors. We checked the convergence of the models and the sensitivity of the results to the priors with the CODA software (Plummer et al. 2006). We tested the sensitivity of the priors recommended as vague or uninformative for mark-recapture estimates (Rivot and Prévost 2002) in order to ensure there was no effect of truncating the prior on the abundance estimate.

Using the Live Tagging Approach, we first structured the data to use the Darroch estimator (Seber 1982), which is a time-stratified Petersen estimator. We then tested whether we could use a pooled-Petersen estimator with a Chapman modification (PP, a one stratum estimator; Seber 1982) instead of the more complex Darroch estimator. The PP estimator is appropriate to use if there is complete mixing of marked and unmarked fish or if proportions of marked and unmarked fish are similar among strata (Schwarz and Taylor 1998). To test this assumption, we compared the ratio of marked and unmarked fish among strata using a chi-square test. Prior to this test, strata were pooled to meet assumptions of the chi-square test (i.e., no zero cells and no more than 20% of the strata with expected values < 5; Quinn and Keough 2002).

Because a noticeable portion of Chinook spawned below the weir, the Live Tagging Approach, which only provided an estimate of escapement above the weir, did not represent the entire spawning population. We used the following logic to incorporate spawners below the weir. We reasoned that if the ratio of marked to unmarked carcasses was similar across reaches above the weir (i.e., spatially independent carcass recovery rates), then we could reasonably assume that carcass recovery rates were similar across the entire study area (i.e., above and below the weir). If this were true, carcasses encountered below the weir could be expanded by the estimated recovery rate above the weir. Analytically, this was accomplished by adding the carcasses recovered below the weir to the Chapman-Petersen estimator as unmarked fish in the second sample. To test the hypothesis that there was no difference in recovery rates among stream reaches, we partitioned the watershed above the weir into four sections: the weir, main-stem reach 1 (rkm 11.0–19.4), main-stem reach 2 (rkm 19.4–42.1), and Goble Creek. We used a chi-square test to compare the ratio of marked to unmarked carcasses among these sections.

To validate the whole-basin estimate described above, we compared it to two other whole-basin estimates. These latter two estimates were derived by adding an independent estimate of spawners below the weir to the estimate above the weir (i.e., Live Tagging estimate). For the first validation estimate, we expanded weekly redd counts below the weir by the percent females in the population assuming 1 redd per female (Murdoch et al. 2010). This expansion factor, based on recent and empirically derived information, differs from the standard WDFW redd expansion factor of 2.5 adults/redd which assumes1 redd/female and 1.5 males/female (e.g. 2009 Coweeman Chinook escapement, Sharpe et al. 2011). The second validation estimate was derived using counts of live fish and area-under-the-curve (AUC) methodology (see Hilborn et al. 1999 for review). We assumed the temporal distribution of live counts was normal and used

5.8 ± 0.7 days (mean ± 1 SD; Rawding and Glaser 2006) as an estimate of spawner residence time. These escapement estimates were compared using a z test advocated by Seber (1982).

We used several approaches to test whether fish in the population had the same probability of being tagged and recaptured (assumption of the Petersen estimator) and whether survival and catchability (assumptions of the JS estimator) were homogeneous. We determined the validity of these assumptions by testing for age, sex, and length selectivity using chi-square or Kolmogorov-Smirnov tests. These metrics were compared between marked recoveries and fish that were marked but not recovered.

Results

Juvenile Production Estimates

Chinook

We captured a total of 19,519 juvenile Chinook salmon in the rotary screw trap between February 3 and August 24, 2011, the first and last days this species was encountered in the trap. All Chinook captured had an intact adipose fin, consistent with the lack of hatchery releases in this basin.

The temporal distribution of Chinook body size shows the fry emergence period and continual juvenile growth throughout the trapping season (Figure 2). Fry (<45 mm FL) began emerging from the gravel at least at the beginning of February (i.e., the beginning of trapping) and continued through mid-July. However, this was the most abundant life stage only through mid-May when mean FL was between 36.6 and 38.7 mm (Appendix D). After mid-May, mean FL began to increase when small numbers of parr were moving past the trap. Juveniles began to smolt (i.e., exhibit silvery appearance) during the first week of June and continually grew until the end of the trapping season. Body size during peak subyearling smolt outmigration was ~ 90.0 mm FL. May 15, 2011 was used as the fry/subyearling smolt demarcation date to calculate life stage-specific production estimates based on fork length.

We captured, marked, and subsequently recaptured 7,210, 1,312, and 51 fry, respectively. Weekly trap efficiencies for fry were consistently low and ranged from 2.6% to 4.9%. A total of 12,309, 704, and 273 subyearling smolts were captured, marked, and subsequently recaptured, respectively. Weekly smolt efficiencies for subyearling smolts were much higher and ranged from 4.2% to 61.0%.

We estimated 309,000 (95% CI = 227,900 – 441,200; CV = 18.1%) subyearling Chinook salmon emigrated from the Coweeman River in 2011. The abundance and 95% CI of fry and subyearling smolts was 260,476 ± 86,713 (CV = 17.0%) and 48,469 ± 10,501 (CV = 11.1%), respectively (Table 1). The relatively high proportion of fry migrants (84%) was similar to that observed in the 2010 outmigration but much higher than 41– 46% fry migrants observed in the 2007 and 2008 outmigration.

As observed in previous years, the outmigration pattern was bimodal with an early fry peak and a later, less prominent smolt peak (Figure 2). Peak fry migration coincided with high discharge events and peak smolt migration coincided with maximum stream temperatures approaching 20^{o}C (Figure 3). The middle 50% of the fry outmigration occurred between March 12 and 28, 2011 and the middle 50% of the subyearling smolt outmigration occurred between July 3 and July 16, 2011. The outmigration timing of each life stage has been consistent among years except 2007 when the subyearling smolt outmigration occurred 2 – 3 weeks earlier.

Table 1. Juvenile production estimates for Chinook salmon in the Coweeman River, WA, 2007-2011. Juvenile production is reported separately for two outmigrant life histories (fry, subyearling smolt SYS) observed each year. There are no estimates for 2009 because the screw trap did not operate.

			95% CI			Proportion of	25%-75% Emigration
Year	Life Stage	Estimate	Lower	Upper	CV (%)	Annual Emigrants	Date Range
2007	Fry	89,821	22,405	157,237	38.3	0.46	03/17-04/08
2007	SYS	104,545	89,641	119,449	7.3	0.54	06/10-06/28
2008	Fry	42,440	24,606	60,274	21.4	0.41	03/14-03/29
2008	SYS	60,467	52,956	67,978	6.3	0.59	06/30-07/15
2010	Fry	371,234	303,430	438,956	9.3	0.82	03/10-03/26
2010	SYS	79,170	67,759	90,581	7.4	0.18	06/23-07/16
2011	Fry	260,476	173,764	347,189	17.0	0.84	03/12-03/28
2011	SYS	48,469	37,968	58,970	11.1	0.16	07/03-07/16

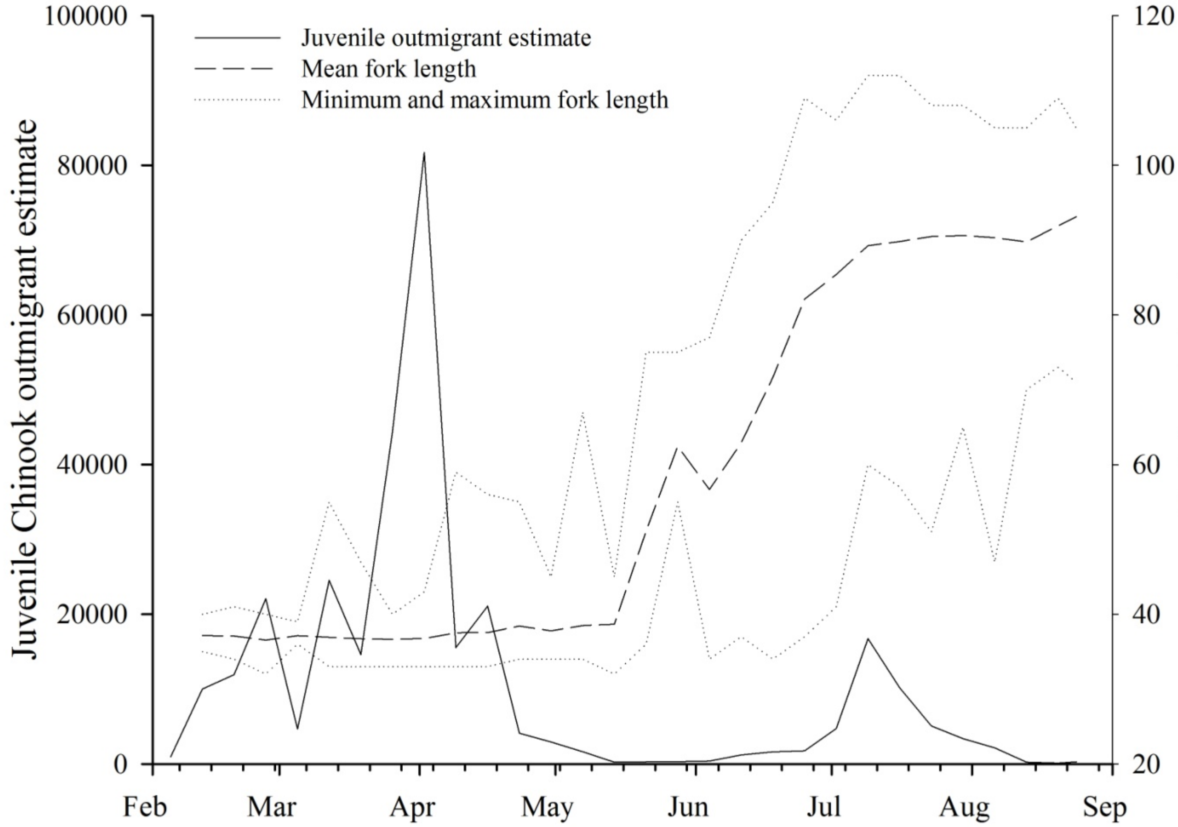

Figure 2. Juvenile Chinook outmigration timing and temporal size distribution in the Coweeman River, 2011.

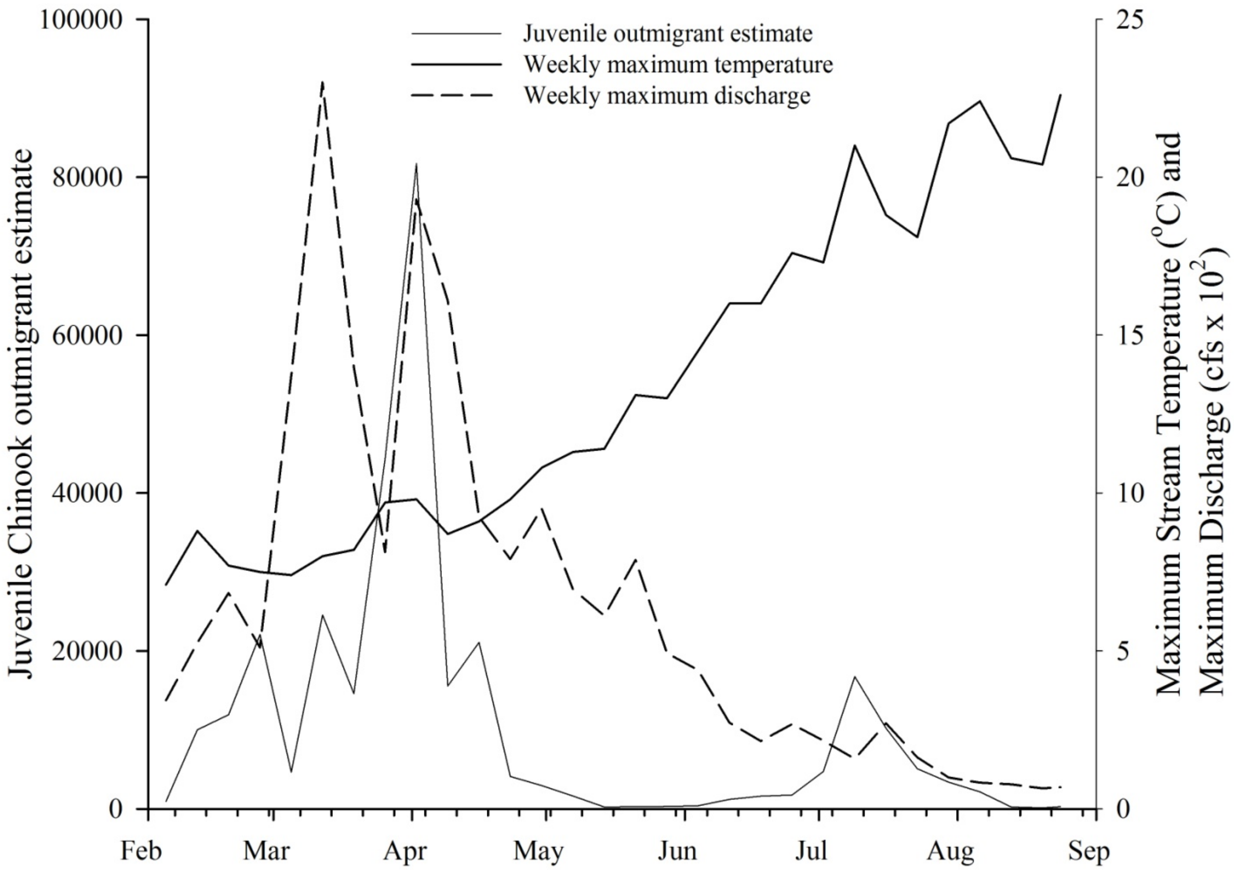

Figure 3. Juvenile Chinook outmigration timing, river discharge and temperature in the Coweeman River, 2011.

Coho

We captured 1,331 coho yearling smolts between April 25 and August 5, 2011, the first and last days this species was encountered in the trap. No adipose clipped coho were captured, consistent with the absence of a hatchery program in this watershed. During this period, we marked and subsequently recaptured 878 and 79 coho, respectively, which resulted in weekly trap efficiencies between 5.8% and 13.1%. The 2011 production estimate ± 95% CI was 14,879 ± 3,666 (CV = 12.6%) with the middle 50% of emigrants passing the trap between May 28 and June 11, 2011 (Table 2). Mean FL ± 1 SD of coho smolts in 2011 was 119.1 ± 8.4 mm.

Since 2007, coho production has been similar among years with slight annual variation in emigration timing. A 2-fold range exists for point estimates of juvenile production (~10,000 – ~23,000); however, the confidence intervals in most years overlap. Based on the three years where migration timing data exist (2008, 2010, and 2011), the middle 50% of emigrants generally leave the basin between the third week of May and the second week of June. The earliest migration occurred in 2010. The length of coho emigrants has shown substantial inter- and intra-annual variation. Among the study years, coho mean FL ± 1 SD has ranged from 111.7 ± 19.7 mm to 123.8 ± 10.4 mm.

Natural-origin Steelhead

We captured 1,031 natural-origin steelhead smolts between April 7 and June 24, 2011 the first and last days they were encountered in the trap. During this period, we marked and subsequently recaptured 651 and 31 fish, respectively. Weekly trap efficiencies ranged between 2.9% and 7.0%. The 2011 production estimate ± 95% CI was 29,127 ± 16,285 (CV = 28.5%) with the middle 50% of emigrants passing the trap between May 10 and May 23, 2011 (Table 2). Mean fork length ± 1 SD of natural-origin steelhead smolts in 2011 was 170.2 ± 14.4 mm.

Natural-origin steelhead production point estimates have ranged between ~13,000 and ~38,000 since 2007. There may be a general increasing trend over time but due to wide confidence intervals in some years this may only be apparent. Emigration timing has varied slightly with the middle 50% of emigrants leaving the basin between the end of April and the third week of May. The earliest migration occurred in 2010. Steelhead emigrant lengths have shown a sinusoid-like pattern across the study years with longer fish in 2007 and 2010, and smaller fish in 2008 and 2011. The lengths have ranged from 170.2 ± 14.4 mm (mean ± 1 SD) to 177.6 ± 16.9 mm FL.

Hatchery-origin Steelhead

On February 28, 2011, approximately 10,000 hatchery steelhead smolts raised at the Grays River Hatchery (winter run stock of Chambers Creek origin) were planted in an acclimation pond near rkm 21.0. The acclimation pond is on private property and is approximately 1.0 km from the main-stem Coweeman River. The smolts were force-released on May 4, 2011.

We captured 351 hatchery steelhead smolts between May 5 and June 9, the first and last days they were encountered in the trap. During this period, we marked and subsequently recaptured 158 and 7 fish, respectively. The season trap efficiency for hatchery-origin steelhead smolts was 4.4%. The 2011 abundance estimate ± 95% CI of hatchery-origin steelhead emigrants was 7,235 ± 4,656 (CV = 32.8%) with the middle 50% of emigrants passing the trap between May 5 and May 12, 2011 (Table 2). Mean FL ± 1 SD of hatchery-origin steelhead smolts in 2011 was 193.8 ± 19.4 mm.

Unlike the other smolt estimates that were derived using DARR 2.0.2, the hatchery steelhead estimate was derived using a pooled-Petersen estimator with modifications advocated by Carlson et al. (1998). We used this method because the small recapture numbers did not provide enough information to stratify the data by time period and because the release and recaptures occurred over a relatively narrow window of time for the hatchery steelhead smolts.

Coastal Cutthroat

We captured 192 cutthroat smolts between April 4 and July 4, 2011, the first and last days they were encountered in the trap. During this period, we marked and subsequently recaptured 137 and 17 fish, respectively. Weekly trap efficiencies ranged between 6.2% and 32.3%. The 2011 production estimate ± 95% CI was 2,033 ± 1,341 (CV = 33.7%) with the middle 50% of emigrants passing the trap between May 23 and June 11, 2011 (Table 2). Mean FL ± 1 SD of coastal cutthroat smolts in 2011 was 179.0 ± 16.8 mm.

Coastal cutthroat trout have the lowest annual production among anadromous salmonids in the Coweeman basin. Annual production estimates have ranged between ~1,600 and 5,500 fish; however, the estimates have not been sufficiently precise (coefficient of variation > 17.0% across all years). Based on the three years we have data (2008, 2010, and 2011), the middle 50% of cutthroat emigrants leave the basin between the last week of April and the second week of June. The earliest emigration occurred in 2010. Among the study years, cutthroat mean FL ± 1 SD has ranged from 179.0 ± 16.8 mm to 190.1 ± 30.8 mm.

Table 2. Smolt production estimates, migration timing, and body size for coho salmon, natural and hatchery-origin steelhead, and coastal cutthroat trout in the Coweeman River, WA, 2007-2011. There are no estimates for 2009 because the screw trap did not operate. Migration timing is described as the range of dates that the middle 50% of smolts passed the juvenile trap. Body size is described as the mean and standard deviation (SD) for the number of smolts measures (*n*).

Coho								
		95% CI			25%-75% Emigration	Length (mm)		
Year	Estimate	Lower	Upper	CV (%)	Date Range	Mean	SD	*n*
2007	10,121	7,448	12,794	13.5	NA	123.8	10.4	563
2008	13,393	10,772	16,014	10.0	05/22-06/04	122.6	8.8	397
2010	22,924	14,098	31,750	19.6	05/19-05/27	111.7	19.7	818
2011	14,879	11,213	18,545	12.6	05/28-06/11	119.1	8.4	1388

Natural-origin Steelhead								
		95% CI			25%-75% Emigration	Length (mm)		
Year	Estimate	Lower	Upper	CV (%)	Date Range	Mean	SD	*n*
2007	13,757	11,313	16,201	9.1	NA	177.0	19.8	1102
2008	13,260	7,323	19,197	22.8	05/07-05/25	171.7	27.8	721
2010	37,909	28,899	46,919	12.1	04/29-05/19	177.6	16.9	516
2011	29,127	12,843	45,412	28.5	05/10-05/23	170.2	14.4	999

Hatchery-origin Steelhead								
		95% CI			25%-75% Emigration	Length (mm)		
Year	Estimate	Lower	Upper	CV (%)	Date Range	Mean	SD	*n*
2007	19,578	10,172	28,984	24.5	NA	178.1	13.9	663
2008	2,846	2,005	3,687	15.1	04/16-05/19	183.6	15.0	275
2010	4,407	3,327	5,487	12.5	04/29-05/14	200.5	15.2	268
2011	7,235	2,578	11,891	32.8	05/05-05/12	193.8	19.4	228

Coastal Cutthroat								
		95% CI			25%-75% Emigration	Length (mm)		
Year	Estimate	Lower	Upper	CV (%)	Date Range	Mean	SD	*n*
2007	2,841	1,389	4,293	26.1	NA	186.4	24.7	172
2008	1,628	875	2,381	23.6	05/22-06/10	190.1	30.8	168
2010	5,552	3,649	7,455	17.5	04/29-05/25	179.4	24.5	265
2011	2,033	692	3,374	33.7	05/23-06/11	179.0	16.8	209

Coded-Wire Tagging and Strontium Marking of Juvenile Chinook

In 2011, we injected coded-wire tags into 10,007 fall Chinook subyearling smolts or approximately 21% of the estimated outmigration for this life stage (Table 3). The number of 2011 tags was about one half of the total fish tagged in 2007 and 2008 but representative of the proportion tagged each year.

A Sr-mark was applied to the otoliths of 3,954 fry and 4,305 subyearling smolts in 2011 (Table 4). In terms of life stage-specific production estimates, this represents the smallest percentage of fry (1.7%) and the second smallest percentage of subyearling smolts (8.9%) that we have marked since 2007.

Overall, we marked approximately 5.0% of juvenile fall Chinook emigrants with a CWT and/or Sr in 2011 (Table 5). Since 2007, we have marked between 5% and 23% of the estimated emigrants with one or both of these marks.

Table 3. The number of tule fall Chinook subyearlings smolts coded wire tagged by year in the Coweeman River, WA, 2007-2011. Subyearling smolts were not tagged in 2009 because the smolt trap did not operate.

2007						
			Proportion of	Length (mm)		
Tag Code	Size Range (mm)	Number	Production Estimate	Mean	SD	*n*
634075	55 - 65	1,198	0.011	62.5	2.0	13
634076	66 - 75	5,006	0.048	72.0	2.6	107
634077	76 - 105	5,029	0.048	84.8	5.8	535
634079	76 - 105	5,405	0.052	84.8	5.8	535
634089	76 - 105	1,544	0.015	84.8	5.8	535
634078	55 - 105	4,710	0.045	82.2	7.7	655
		22,892	***0.219***	***82.2***	***7.7***	***655***

2008						
			Proportion of	Length (mm)		
Tag Code	Size Range (mm)	Number	Production Estimate	Mean	SD	*n*
634676	55 - 65	318	0.005	59.8	3.5	70
634677	66 - 75	2,614	0.043	71.1	2.9	79
633493	76 - 117	18,534	0.307	91.1	8.4	659
634678	70 - 113	1,289	0.021	87.5	5.4	40
		22,755	***0.376***	***86.4***	***12.5***	***848***

2010						
			Proportion of	Length (mm)		
Tag Code	Size Range (mm)	Number	Production Estimate	Mean	SD	*n*
635071	NA	31	0.000			
635072	NA	1,398	0.018			
635073	NA	7,139	0.090	85.4	7.7	41
635074	NA	1,788	0.023	98.1	2.4	13
635079	NA	3,122	0.039	86.7	4.2	35
		13,478	***0.170***	***87.9***	***6.9***	***1273***

2011						
			Proportion of	Length (mm)		
Tag Code	Size Range (mm)	Number	Production Estimate	Mean	SD	*n*
636087	65 - 75	428	0.009	71.3	3.4	42
636088	76 - 85	1,461	0.030	82.2	2.8	192
636089	86 - 95	3,946	0.082	91.0	2.7	256
635075	86 - 95	1,588	0.033	90.9	2.5	230
636090	96 - 112	2,584	0.053	99.9	3.5	215
		10,007	***0.207***	***90.3***	***7.7***	***935***

Table 4. The number of juvenile Chinook salmon marked with strontium, the proportion of the annual life stage-specific estimate marked with strontium, and length summary statistics by life stage in the Coweeman River, WA, 2007-2011. Salmon were not marked with Strontium Chloride in 2009 because the screw trap did not operate.

Fry					
			Length		
Year	Number	Proportion of Production Estimate	Mean	SD	*n*
2007	2,193	0.024	38.7	4.5	567
2008	1,109	0.026	38.1	3.1	356
2010	21,749	0.059	37.5	3.4	1572
2011	3,954	0.017	37.1	2.1	1216

Parr-Subyearling Smolt					
			Length		
Year	Number	Proportion of Production Estimate	Mean	SD	*n*
2007	18,182	0.174	82.3	8.3	663
2008	20,386	0.337	84.4	14.7	900
2010	174	0.002	62.6	8.1	128
2011	4,305	0.089	90.6	7.4	520

Table 5. The number and proportion (in parentheses) of marked and unmarked subyearling tule fall Chinook outmigrants during migration years (MY) 2007 – 2011. Mark type includes coded-wire tags (CWT) and/or strontium (Sr). Unmarked fish and all proportions are based on the annual production estimates.

MY	CWT Only	Sr Only	CWT and Sr	Unmarked	Production Estimate
2007	4,710 (0.02)	2,193 (0.01)	18,182 (0.09)	169,281 (0.87)	194,366
2008	2,369 (0.02)	1,109 (0.01)	20,386 (0.20)	79,043 (0.77)	102,907
2010	13,478 (0.03)	21,923 (0.05)	0 (0.00)	414,962 (0.92)	450,363
2011	5,702 (0.02)	3,954 (0.01)	4,305 (0.02)	271,951 (0.95)	285,912

Contributions of Coweeman River Chinook to Fisheries

A total of 28 coded-wire tags have been recovered from the 2006 and 2007 brood years of Coweeman River Chinook salmon (RMPC database report, August 1, 2012). Based on fishery sampling rates, these recoveries were expanded to a total of 114 tags or 0.25% of the 45,647 tags released from these brood years (Table 6). This percentage includes any tag loss and tag-related mortality, which are currently not known for wild Chinook salmon smolts tagged during the outmigration period.

The majority (96%) of coded-wire tags were from age-3 and age-4 Chinook salmon (Table 6). These data are preliminary and do not include age-5 interceptions of the 2007 brood year, which will occur in 2012. Age-6 interceptions from either brood year are likely to be few based on the observed age structure of tule fall Chinook salmon.

Of the estimated tag recoveries, 46% were recovered in coast-wide fisheries and the remaining 54% were recovered on the spawning grounds (Table 7). The majority of estimated 53 fishery interceptions occurred in Washington sport (43%) and Canadian troll (47%) fisheries.

Table 6. Estimated number of coded-wire tags by recovery year for wild tule fall Chinook salmon from the Coweeman River. Estimated tag recoveries from RMPC database (August 1, 2012). Dash (---) indicates data are not yet available.

Brood Year	Release Year	Number Tagged	Recovery Year BY+2	BY+3	BY+4	BY+5	BY+6	Percent
2006	2007	22,892	1	12	29	3	---	0.20%
2007	2008	22,755	0	37	32	---	---	0.30%
2009	2010	13,478	0	---	---	---	---	---
2010	2011	10,007	---	---	---	---	---	---
		45,647	***1***	***49***	***61***	***3***	***---***	***0.25%***

Table 7. Estimated tag recoveries from Coweeman River tule fall Chinook salmon (2006 and 2007 brood year) by fishery type and reporting agency.

Fishery	CDFO	WDFW	ODFW	Total
Sport	0	23	3	26
Net & Seine	0	1	0	1
Troll	25	1	0	26
Spawning Ground	0	61	0	61
	25	***86***	***3***	***114***

Otolith Microchemistry Analysis

Otoliths were collected from 147 adult Chinook during spawner surveys in 2009 and 2010. These are the only samples that have been analyzed to date. Of these samples, 11 had been marked with Sr as juveniles at the Coweeman River screw trap.

Preliminary results suggest the migration time of juvenile Chinook from the Coweeman screw trap to the saline portion of the Columbia River estuary ranges from days to months, and they enter saltwater as parr and smolt-sized fish (>60 mm FL). Mean migration time between the juvenile trap and saltwater was 49 days and ranged from ~6 days to ~131 days (Figures 4 and 5). Mean body size at estuary/ocean entrance was 94 and 100 mm FL (range, 61 – 149 mm FL) for 2009 and 2010, respectively (Table 8).

None of the adults that returned to spawn had made their final push into saltwater as fry; minimum size at final saltwater entry was 61 mm FL. However, we found evidence that some individuals migrated back and forth between saline and freshwater habitats (Figure 6). Three individuals recovered from the 2009 spawner surveys entered a high Sr environment at <60 mm FL, but migrated back to and remained in a low Sr environment until they grew to >80 mm FL before making their final seaward migration.

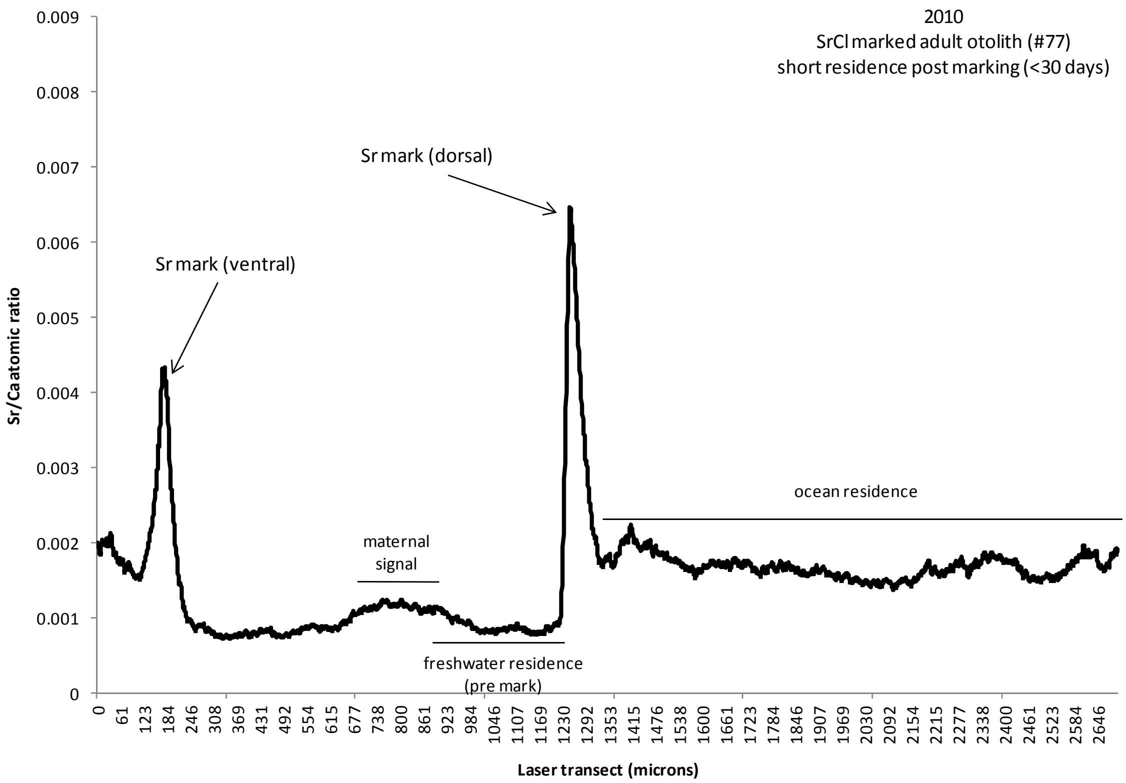

Figure 4. An example of a Sr:Ca profile for a Sr-marked Chinook salmon showing short juvenile freshwater residence time. The profile (from left to right) starts in the ventral plane, passes through the ventral Sr mark, the core (maternal signal), and the dorsal plane to the otolith edge. The estimated freshwater residence time after being Sr-marked at the Coweeman River screw trap was 29 days.

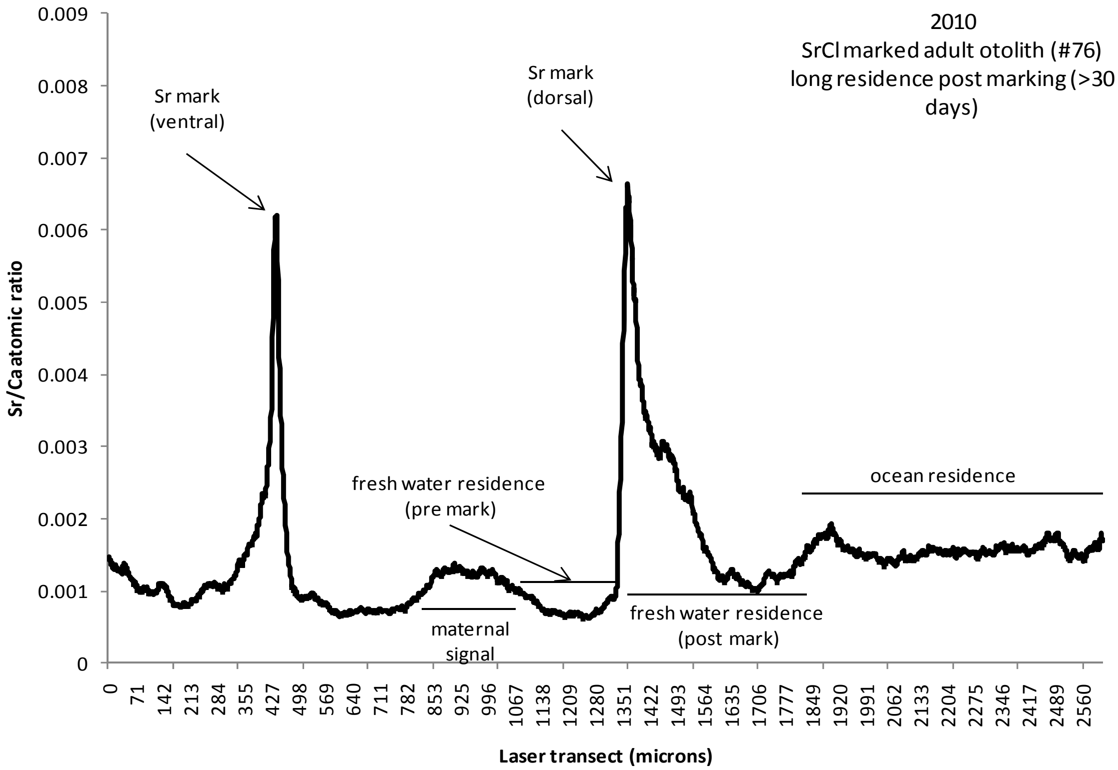

Figure 5. An example of a Sr:Ca profile for a Sr-marked Chinook salmon showing long juvenile freshwater residence time. The profile (from left to right) starts in the ventral plane, passes through the ventral Sr mark, the core (maternal signal), and the dorsal plane to the otolith edge. The estimated freshwater residence time after being Sr-marked at the Coweeman River screw trap was 131 days.

Table 8. Back-calculated body size (mm FL) of Coweeman River juvenile Chinook salmon at estuary/ocean entrance by spawn year using otolith microchemistry. Data are summarized as the proportion of fish per size bin, and the mean length and standard deviation (SD) for the number of otoliths analyzed (*n*).

	Spawn Year	
Body size bin (mm)	2009 (n =106)	2010 (n = 41)
≤60	0.00	0.00
61-90	0.42	0.29
91-120	0.52	0.59
>120	0.06	0.12
Mean length (SD)	94 (15.4)	100 (14.7)

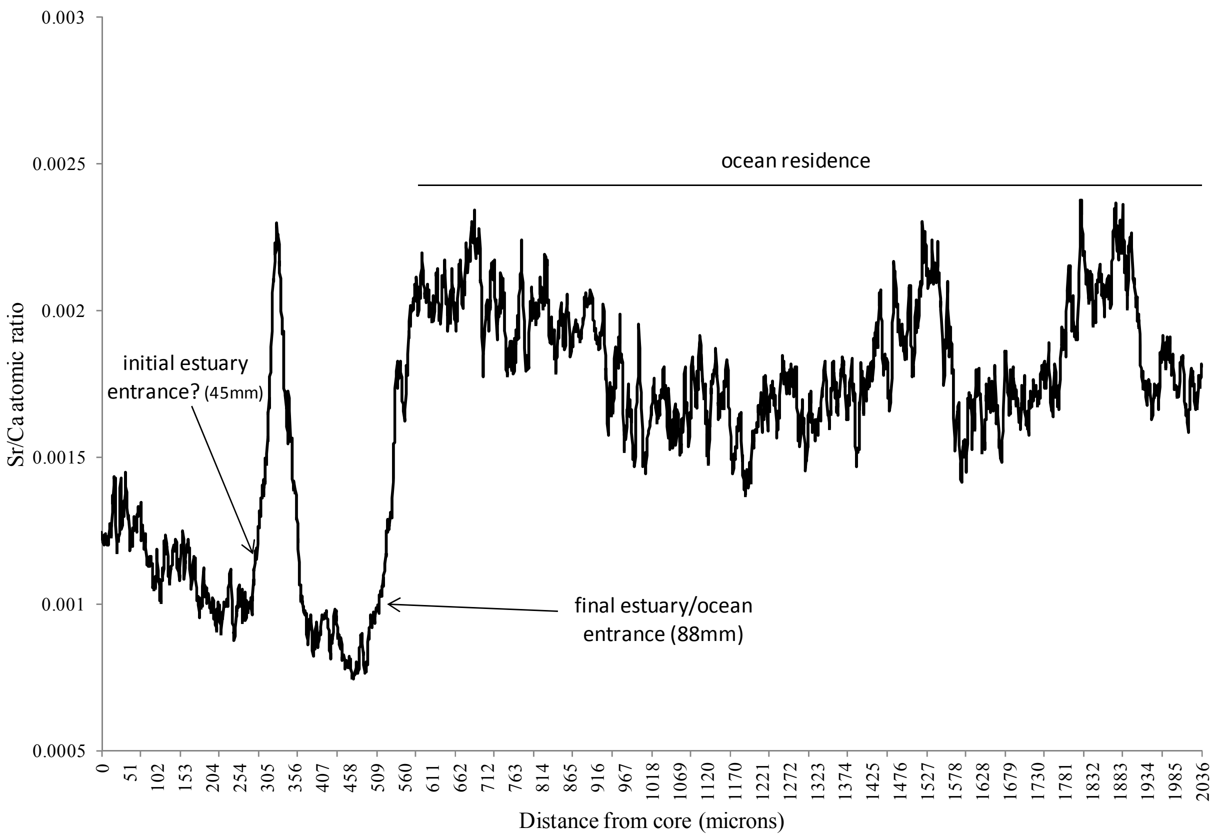

Figure 6. Strontium profile showing a Coweeman River Chinook salmon that reared in saline and freshwater habitats before migrating to sea. This individual entered a strontium-rich environment as a fry and then reared in a strontium-poor environment for an extended period before entering the ocean.

Adult Fish Collection and Spawner Surveys

In 2011, a total of 444 Chinook salmon were captured in the weir trap. Of these, 386 wild Chinook were passed upstream and 57 hatchery-origin fish were removed at the weir. The first and last Chinook salmon were caught on September 9 (the first day of trapping) and October 23, respectively. Wild males and females were similar in size with mean FL ± 1 SD of 79.5 ± 7.9 cm (range, 63 – 108; *n* = 162) and 79.4 ± 4.8 cm (range, 61 – 91; *n* = 206), respectively. The mean FL ± 1 SD of wild jacks captured at the weir was 48.6 ± 4.8 cm (range, 41 – 59; *n* = 18). Hatchery males and females were also similar in size with mean FL ± 1 SD of 77.4 ± 7.3 cm (range, 64 – 92; *n* = 39) and 77.4 ± 7.6 cm (range, 66 – 90; *n* = 18), respectively. No hatchery jacks were captured at the weir. Overall, wild males and females (i.e., jacks excluded) were larger than hatchery fish (t = 2.2, df = 423, p = 0.03) which can be attributed to differences in age structure (see below).

A total of 287 live spawners, 275 new redds, and 196 new carcasses were observed during spawner surveys (Table 9). Peak number of live spawners, new redds, and new carcasses were observed during the weeks of October 10, October 10, and October 17, 2011, respectively. The mean FL ± 1 SD of wild male, female, and jack carcasses collected on the spawning grounds was 83.6 ± 8.8 cm (range, 64 – 101; *n* = 72), 80.4 ± 5.6 cm (range, 63 – 95; *n* = 80), 46.4 ± 5.2 cm (range, 38 – 52; *n* = 7), respectively. The mean FL ± 1 SD of hatchery male and female carcasses (no hatchery jacks were encountered) was 76.8 ± 5.6 cm (range, 69 – 86; *n* = 6) and 77.7 ± 5.1 cm (range, 71 – 84; *n* = 6), respectively.

The proportion of hatchery-origin Chinook salmon was 11% of the weir captures and 12% of the carcasses recovered upstream and downstream of the weir (Table 10). Among Chinook salmon spawners captured at the weir, age structure of hatchery-origin and wild fish differed for both males ($G = 22.9$, df = 3, $p < 0.001$) and females ($G = 25.2$, df = 2, $p < 0.001$). The majority of male and female wild Chinook salmon were age-4 (76%) while the majority of hatchery Chinook salmon were age-3 (60%).

Table 9. The number of live spawners, new redds, and new carcasses observed during the 2011 Coweeman River spawner surveys.

Start Date	End Date	Live Spawners	New Redds	New Carcasses
09/12/2011	09/18/2011	1	0	0
09/19/2011	09/25/2011	1	1	2
09/26/2011	10/02/2011	17	16	5
10/03/2011	10/09/2011	92	36	19
10/10/2011	10/16/2011	98	110	28
10/17/2011	10/23/2011	56	70	75
10/24/2011	10/30/2011	16	21	59
10/31/2011	11/06/2011	4	2	26
11/07/2011	11/13/2011	2	1	14
11/14/2011	11/20/2011	0	0	0
11/21/2011	11/27/2011	0	0	0
11/28/2011	12/04/2011	0	0	0
12/05/2011	12/11/2011	0	0	0
12/12/2011	12/18/2011	0	0	0
		287	***257***	***228***

Table 10. Age structure of Coweeman River tule fall Chinook by origin, sex, and sample type, 2011.

		Natural origin					
Sex	Sample Type	BY+2	BY+3	BY+4	BY+5	BY+6	n
Male	Carcass	5	12	41	3	1	62
Female	Carcass	0	9	55	2	0	66
Male	Live at weir	15	37	118	5	0	175
Female	Live at weir	0	14	161	18	0	193
							496

		Hatchery origin					
Sex	Sample Type	BY+2	BY+3	BY+4	BY+5	BY+6	n
Male	Carcass	0	6	2	0	0	8
Female	Carcass	0	1	6	1	0	8
Male	Removed at weir	1	21	10	1	0	33
Female	Removed at weir	0	9	5	3	0	17
							66

Adult Escapement Estimates

Carcass Tagging Approach – Jolly-Seber Estimator

For the Carcass Tagging Approach, a total of 228 carcasses were encountered, 156 were tagged and 61 were recaptured during the study. The JS model allowed for probability of capture, survival, and entry to vary by week. Our estimate was imprecise due to low recapture rates, especially in the first four periods. Brooks-Gelman-Rubin convergence diagnostic values were less than 1.1, which indicates convergence of the Markov chain Monte Carlo algorithm (Kery 2010). Results indicated that prior probabilities had some effect on the JS estimate and associated variance. This occurred due to the limited amount of data during the first half of the study, where the prior distribution had great influence on the posterior distribution, often referred to as parameter redundancy (King et al. 2010). However, since most of the redundancy occurred during the first part of the study, the effect on the abundance was limited to a few periods when few fish were available.

We found no evidence of sex selectivity whether jacks were included ($\chi^2 = 2.35$, df = 2, p = 0.31) or excluded ($\chi^2 = 0.00$, df = 1, p = 0.99) even though the recovery rate for jacks was less than 50% of the recovery rate for adults. This discrepancy is most likely due to the small sample size of jacks (i.e., *n* = 8). We also found no length difference between marked fish recovered and marked fish not recovered (D = 0.17, p = 0.25).

The population estimate for the Carcass Tagging Approach was 459 ± 112 (escapement ± SE). However, the posterior estimate had a skewed distribution and the 95% CI ranged from 310 to 723.

<u>Live Tagging Approach – Petersen Estimator</u>

For the Live Tagging Approach, a total of 161 males, 207 females, and 18 jacks were tagged at the weir during the first sampling event. During the second sampling event, we encountered 74 male, 81 female, and 9 jack carcasses upstream of the weir. These numbers include only carcasses in which tag status could be reliably determined. Of these, 43 male, 58 female, and 2 jack carcasses had been tagged during the first sampling event.

We found no evidence to suggest that carcass encounters were spatially dependent on sampling reach (χ^2 = 5.09, df = 3, p = 0.17). We also found no evidence to suggest that marked and unmarked carcasses encountered on the spawning grounds were temporally stratified (χ^2 = 7.45, df = 4, p = 0.12). Therefore, we used the pooled-Petersen method to estimate the abundance of adult Chinook salmon above the weir.

We found no evidence of sex selectivity among males, females, and jacks (χ^2 = 2.42, df = 2, p = 0.30). In other words, the proportion of marked fish recovered to marked fish not recovered above the weir was similar among the three groups. However, both age and length selectivity tests suggested that three year olds (~ 80 cm) were recovered at a much higher rate than older or smaller fish. Selectivity tests among ages were significant whether jacks were included (χ^2 = 12.03, df = 3, p = 0.007) or excluded (χ^2 = 9.52, df = 2, p = 0.009). Length selectivity tests for adults using the KS test were also significant as higher recovery rates occurred in the middle of the length distribution (D = 0.25, $p < 0.001$; Figure 7).

The PP estimate for Chinook salmon spawners upstream of the weir was 563 ± 28 (escapement ± SE). Adding carcasses encountered below the weir yielded a whole-basin estimate ± SE of 668 ± 38 (Table 11). Based on the redd expansion and AUC methods, there were 101 and 112 spawners below the weir site, respectively. Adding each of these estimates to the PP estimate for adults upstream of the weir gives whole-basin estimates of 664 (redd expansion + PP) and 675 (AUC + PP) adults (i.e., two validation methods). The whole-basin estimate was not different than the two validation methods (Z test; p-values > 0.78) and it did not differ from the JS whole-basin estimate (Z-test; p = 0.07).

Each year since 2007, we have used several approaches to estimate escapement in the Coweeman River (Table 11). The objective of the multiple methods has been to compare and validate each approach to determine which is most appropriate for this watershed. The estimates have ranged from 251 (2007) to 792 (2009). In general, the JS approach has not performed well when carcass numbers are low, and the standard redd expansion method (i.e., 2.5 adults/redd) consistently provides a higher escapement estimate than the other methods. Escapement estimates based on a genetic mark-recapture approach are being finalized for 2010 and 2011 and will be compared to the other methods.

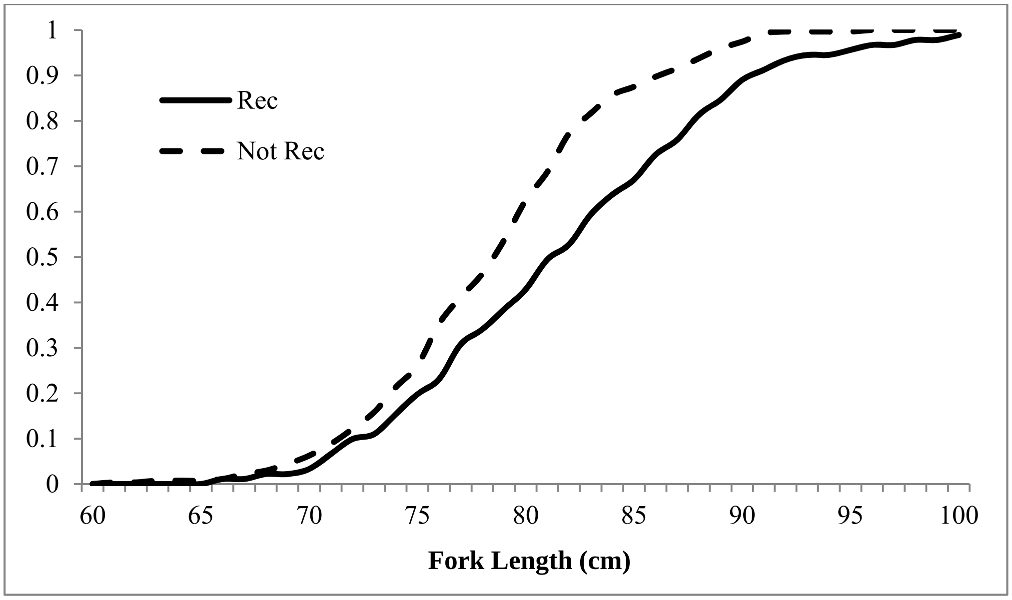

Figure 7. Comparison of cumulative length frequency plots between fish marked and recovered (Rec) and fish marked but not recovered (Not Rec) in 2011 during the Live Tagging Approach (see text for details). Kolmogorov-Smirnov test results were significant suggesting differential recovery rates by size.

Table 11. Adult escapement estimates (95% CI in parentheses) of Chinook salmon in the Coweeman River, WA, 2007-2011. AUC is area under the curve using live fish residence time of 5.8 ± 0.7 (mean ± 1SD), Redd is redd expansion using an expansion factor of 2.5 adults/redd (except 2009, used expansion factor of 1.95 ± 0.08 [mean ± 95% CI] adults/redd; Sharpe et al. 2011), JS is Jolly-Seber, A-D MLE is Arrival-Death maximum likelihood estimator (Hilborn et al. 1999) and PP is pooled-Petersen.

	Estimator				
Year	AUC	Redd	JS	A-D MLE	PP
2007	251 (221-290)	560 (NA)	NA	NA	NA
2008	423 (319-537)	720 (NA)	286 (233-339)	333 (280-405)	NA
2009	770 (678-866)	712 (683-741)	792 (587-1284)	NA	NA
2010	461 (373-603)[a]	745 (NA)	NA	NA	NA
2011	NA	NA	459 (310-723)	NA	668 (594-742)

[a] AUC estimate in 2010 was previously reported to be 251 spawners (Sharpe et al. 2011, p. 30). This estimate has been corrected in the table above. Confidence intervals were calculated based on apparent residence time of 5.8 ± 0.7 (mean ± 1SD).

Discussion

Juvenile Production Estimates

In 2011 we successfully estimated the abundance of juvenile and adult Chinook salmon in the Coweeman River basin. A bimodal outmigration pattern was observed for juvenile Chinook. This pattern was similar to that observed in previous years and had a high proportion of the smaller, earlier fry outmigrants. Since 2007, peak outmigration of fry migrants has occurred during the third or fourth week of March, and peak outmigration of subyearling smolts has typically occurred the first week of July. The outmigration timing of subyearling smolt migrants has been more variable over time than the fry migrants. Some variables contributing to subyearling smolt migration timing may include stream temperature and discharge. Summer stream temperatures are uniquely high in Coweeman River as compared to other Lower Columbia watersheds. Mean temperatures in July and August can exceed 22^{o}C with instantaneous maximum temperatures up to 26^{o}C (WA Dept Ecology gage # 26C075), temperatures which should present challenges for the growth and survival challenges of subyearling smolts. The relationship between environmental variables and outmigration timing warrants additional investigation and will benefit from additional data points provided from years of monitoring.

Production estimates for the other anadromous salmonids in the Coweeman River basin have shown species-specific annual variation. Coho estimates have ranged 2-fold but most confidence intervals around the estimates overlap suggesting similar production among years. Steelhead estimates have ranged nearly 3-fold with 2010 and 2011 production exceeding 2008 and 2009 production. Coastal cutthroat production is the lowest in the basin with annual estimates ranging from approximately 1,500 to 5,500 migrants. Out migration timing for each species was similar in 2008 and 2011 but consistently earlier in 2010 across all species. Interestingly, the highest production for all species (including Chinook) across the study years (2007-2011) occurred in 2010. This most likely is due to suitable incubation and over-winter conditions such as relatively low peak discharge events.

Each year during the study period ~10,000 hatchery-origin juvenile steelhead were planted in an acclimation pond for release into the Coweeman River. Our outmigrant estimates for these fish showed high variability in the number of outmigrating smolts (between 2,800 and 19,500 per year). The approximate numbers planted fell within the confidence intervals of the outmigrant hatchery steelhead estimates on just two of the four years. The difference between our estimates and the number planted could be due to residualism, pre-release predation, or mortality during the outmigration.

Two important limitations to the 2011 juvenile production estimates resulted from operational challenges early in the trapping season (i.e., February – April). This time period is characterized by high water which results in low numbers of recaptures and unknown numbers of captures during trap outage periods. Low recapture rates could also be the result of the distance between release location and trap. Predation-related mortality or additional rearing opportunities between the release site and the trap are two factors which would violate assumptions of the mark-recapture estimator (i.e., no mortalities and marking does not change the behavior of the fish) and bias the final estimate. These issues have the greatest impact on the estimates of Chinook salmon fry, which appear to vary considerably from year to year (41% to 84% of the entire outmigration). In future years of study, we aim to address these issues as they relate to potential estimate bias.

Our mark-recapture methods for hatchery steelhead were compromised which limits the use of our 2011 estimate. On the night these fish were force-released from the acclimation pond, a tree fell in front of the screw trap. This structure may have diverted the initial pulse of fish away from the trap and inhibited us from capturing many of the outmigrants leaving the system. Our measure of trap efficiency for trap-caught hatchery steelhead occurred after the tree was removed. As a result, the outmigrant estimate was most likely biased low. In addition, we were unable to recapture many of these fish during our efficiency trials which decreased the precision of the estimate.

Juvenile Rearing Strategies

The average size of juvenile Chinook leaving the Coweeman smolt trap (both fry and subyearling smolts) is approximately 45-65 mm (appendix A-D), the average size of juveniles at saltwater entry based on otoliths recovered from returning adults was estimated to be 40-50 mm longer than that measured at the juvenile trap. If we assume a 0.5mm/day growth rate for the lower Columbia River (Campbell 2010), this length difference corresponds to an additional 80-100 days of rearing in the freshwater estuary habitats of the Lower Columbia River. However, this conclusion does not account for size selected mortality or variable growth rates. For example, if we assume high mortality of the fry migrants passing the juvenile trap and remove fry migrants from our calculations, we see a much smaller difference (~10-20mm) between subyearling smolts leaving Coweeman and the back-calculated size at estuary/ocean entry. This latter interpretation would require rapid movement of juvenile Chinook through the freshwater estuary which is inconsistent with the measured mean downstream residency of 49 days (n = 11) of Sr-marked fish. Therefore, we currently cannot exclude the contribution of fry migrants to the adult population. Additional evidence presented in this report suggests some portion of fry migrants may make it as far as the saline portion of the estuary before taking up extended residency in the freshwater portion of the estuary (Figure 5). This suggests additional fry migrants may be residing in the Columbia River freshwater estuary and growing to fork lengths that are similar to the subyearling smolt migrants before estuary/ocean migration. A similar migration pattern has been documented in coho salmon (Koski 2009; Jones et al. 2011). Alternatively, this pattern could also mimic short residency in an undetermined high Sr freshwater system.

In order to successfully evaluate juvenile rearing strategies, an adequate number of fry and subyearling smolt migrants must be Sr marked and released each year. In 2011, we again experienced limitations marking the Chinook salmon outmigrants. At the fry stage, strontium marking is limited by the proportion of fry migrants handled in the juvenile trap. High flows during this early trapping period reduce the trapping efficiency and has resulted in 2% to 6% of the fry migrants being strontium marked over four years of study. At the subyearling stage, strontium marking is limited by stream temperatures. The present marking protocol requires a 6 hour strontium bath which would expose juvenile Chinook salmon to potentially lethal water temperatures during the months of July and August. As a result, the percent of subyearling migrants that have been strontium marked has ranged from negligible (<1% in 2010) to high (34% in 2008) over four years of study. Remedies for these limitations, including a marking protocol of shorter duration, will be the focus of future work.

Adult Escapement Estimates

Several assumptions must be met to provide consistent escapement estimates with the two primary estimators we used. We believe the JS estimator assumptions were met but the assumptions of the PP estimator may have been violated.

Schwarz and Arnason (1996) indicate the primary assumptions for the JS model are: 1) there is no mark loss, 2) there are no marking effects, 3) all marked and unmarked fish are correctly identified and enumerated, 4) sampling is instantaneous, 5) survival probabilities are the same for all animals (marked and unmarked) between each pair of sampling occasions (homogeneous survival), and 6) catchability is the same for all animals (marked and unmarked) at each sampling occasion (homogeneous catchability). To test assumption one, we double-tagged each carcass to estimate tag retention. The probability of retaining at least one tag was 99.94% so we believe this assumption was met. Assumption two and three were most likely met because there are no marking effects on carcasses, and a well-trained crew carefully examined each carcass. Sampling was generally done on one day, which is not considered a serious violation of the instantaneous assumption (Schwarz et al. 1993).

For the Petersen estimate, Schwarz and Taylor (1998) list the following assumptions: 1) there is no mark loss; 2) there are no marking effects; 3) all marked and unmarked fish are correctly identified and enumerated; 4) the population is closed; and 5) all fish in the population have the same probability of being tagged, or all fish have the same probability of being captured in the second sample, or marked fish mix uniformly with unmarked fish. The first assumption was met because we marked each fish with three marks, two Floy tags and a permanent weekly batch mark (i.e., operculum punch). Steps were taken to meet assumption two by maximizing survival of tagged fish. This was done by frequently checking the trap, marking only fish in good condition, and monitoring marked fish after release. Assumption three was most likely met because each fish had multiple marks, and we placed special emphasis on mark identification during surveyor training.

Two assumptions of the Petersen estimator were not completely met. The population closure assumption was only partially met because fish spawned below the weir. However, we are confident the closure assumption was met for the proportion of the population that passed the weir because the weir operated effectively, and sampling occurred from the beginning of the run and continued until all salmon spawned and died (Arnason et al. 1996).

Assumption five (i.e., all fish have the same probability of capture during the first and second sampling events) was not met as we found evidence for length and age selectivity even though complete mixing of marked and unmarked fish occurred. This finding was not expected and is not consistent with other studies. For example, we compared weir census with carcass recoveries on the Green and Elochoman Rivers in 2010 and found no evidence for length selectivity (DR, unpublished data). If disproportional recovery rates do occur, they are expected to be higher for older and longer fish (Murdoch et al. 2010 and Zhou 2002). In this study, disproportional recovery rates occurred in the middle of the length and age distributions. The discrepancy between the 2011 Coweeman River results and results from these past studies will require additional comparisons in future years. One remedy for this type of bias would be to generate age-based estimates of Chinook spawner abundance using two groups, age 3 and age 4/5 fish.

In the five years of implementing the Carcass Tagging Approach, we have found that this method results in low precision of the escapement estimate (Sharpe et al. 2009 and 2011). In 2011, our modified Jolly-Seber estimate (459) was approximately 200 fish less, but not statistically different, than the pooled-Petersen estimate. The large uncertainty for the current and past estimates is due to the small numbers of carcasses encountered. Multiple factors contribute to our ability to collect carcasses including the inherent small numbers of fish in a depressed population and low flow conditions during the spawning period which facilitates high predation rates on carcasses. Because of the large uncertainty associated with the Jolly-Seber estimate, we believe the pooled-Petersen estimate is the most accurate estimate for the 2011 Chinook escapement at this time. Selection of final escapement estimates for all years and the basis for this selection is still in process of being determined.

The escapement estimates presented here do not include jacks which is consistent with previous Chinook salmon escapement estimates in the Lower Columbia River region. Accurate jack estimates are difficult to derive because so few jacks are observed or recovered on the spawning grounds. The 2011 jack estimate was 69 ± 62 (95% CI; CV = 45.8%). Similar to previous years, low observations and recoveries of jacks yielded a jack escapement estimate with wide confidence intervals.

Recommendations

1) Calculating precise Chinook fry outmigrant estimates continues to be a challenge as a result of low recapture rates and trap outages. Low recapture rates during the fry outmigration period may occur due to consistently high discharge which diminishes the formation of a thalweg needed to concentrate the outmigrant fry into the trap. Alternately, low recapture rates may result from predation on marked fry which are released over 1 mile above the trap site. In order to identify the contribution of predation to the recapture rates, experiments should be conducted to evaluate recapture rates at different release distances from the trap.

   Trap outages occur during high discharge events and greatly increase uncertainty of the fry outmigrant estimate. In rain-dominant watersheds such as the Coweeman River, high discharge events typically occur between November and March and coincide with the outmigration timing of the Chinook fry migrants. High flow events mostly occur during the fry outmigration and not the subyearling smolt outmigration period, and flow-stratified study designs should be implemented and evaluated.

2) Summer stream temperature in the Coweeman reaches upper thermal limits for Chinook. The correlation between stream temperature and outmigration timing of subyearling smolts should be investigated.

3) Our understanding of Chinook juvenile rearing strategies has been limited by the small proportion of fry migrants that are Sr marked each migration year. Future work should incorporate and evaluate capture methods, in addition to the screw trap, to mark a larger proportion of fry migrants. One approach would be to use beach seines and/or fyke nets to target Chinook fry during peak outmigration (i.e., March – April). The largest push of fry typically occurs during high discharge events which, in itself, present challenges for placing nets in the river. Therefore, effectiveness evaluation should be incorporated when employing these capture methods. If these captures are conducted upstream of the screw

trap, an additional benefit would be the opportunity to increase the number of mark-released fry and the precision of fry trap efficiency estimates.

4) Strontium marking of subyearling smolt migrants has been limited by stream and holding-vessel temperatures. These migrants move during the summer when maximum daily stream temperatures approach or exceed upper thresholds for handling. During this period, marking does not occur because the temperature in the Sr marking vessel is typically warmer than the stream temperature. Temperature would not be a factor for the vast majority of the outmigration if Sr marking did not occur during the warmest period of the day. Current marking protocols call for soaking fish for 6 h. This time interval in conjunction with work schedules presents challenges because soak time extends into the hottest time of the day.

   Experiments should be developed to evaluate shorter soak times. These experiments should incorporate mark effectiveness and evaluate fish health risks. Ideal soak times would be in the 2 – 3 h range. If soak time cannot be reduced, focus should be placed on developing Sr marking infrastructure that does not elevate holding water temperature above stream temperature, and ensuring the number of subyearling smolts marked prior to mid-July is maximized.

5) Chinook migrant length at saltwater entry is back-calculated using estimated otolith growth rates. This method should be validated.

6) Determining the relative contribution of fry and subyearling smolt life history strategies to population persistence will take a long-term monitoring approach because Chinook generation time is between 3 – 5 years. Continued Sr marking of outmigrants combined with otolith microchemistry methods should be used to build on the current results and provide a more complete evaluation.

References

Arnason, A. N., C. W. Kirby, C. J. Schwarz, and J. R. Irvine. 1996. Computer analysis of data from stratified mark-recovery experiments for estimation of salmon escapements and other populations. Canadian Technical Report of Fisheries and Aquatic Science 2106. 37p.

Bjorkstedt, E. P. 2005. DARR 2.0: updated software for estimating abundance from stratified mark-recapture data. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-368. 13 p.

Bjorkstedt, E. P. 2010. DARR 2.0.2: DARR for R. http://swfsc.noaa.gov/textblock.aspx?Division=FED&id=3346

Blankenship, S., and D. Rawding. 2012. Escapement estimates using genetic mark-recapture and sibship distributions: an application to the Coweeman River tule fall Chinook salmon populations - Final report to the Pacific Salmon Commission Chinook Letter of Agreement (Award No. NA10NMF4380185). Washington Department of Fish and Wildlife, Olympia, Washington.

Bonner, S. J. 2008. Heterogeneity in capture-recapture: Bayesian methods to balance realism and model complexity, Ph.D. Thesis, Department of Statistics and Actuarial Science, Simon Fraser University, Burnaby, B.C. Available from http://www.stat.sfu.ca/people/alumni/Theses/Bonner-2008.pdf.

Campbell, L. A. 2010. Life histories of juvenile Chinook salmon (*Oncorhynchus tshawutscha*) in the Columbia River estuary as inferred from scale and otolith microchemistry. Master's thesis. Oregon State University, Corvallis.

Carl, L. M. 1984. Chinook salmon (*Oncorhynchus tshawutscha*) density, growth, mortality, and movement in two Lake Michigan tributaries. Canadian Journal of Zoology 62:65–71.

Carlson, S.R., L. Coggins, and C.O. Swanton. 1998. A simple stratified design for mark-recapture of salmon smolt abundance. Alaska Fisheries Research Bulletin 5(2): 88–102.

Darroch, J. N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. Biometrika 48:241–260.

Davis, S. F., and M. J. Unwin. 1989. Freshwater life history of chinook salmon (*Oncorhynchus tshawytcha*) in the Rangitata River catchment, New Zealand. New Zealand Journal of Marine and Freshwater Research 23:311–319.

Hilborn, R., B.G. Bue, and S. Sharr. 1999. Estimating spawning escapements from periodic counts: a comparison of methods. Canadian Journal of Fisheries and Aquatic Sciences 56:888–896.

Hillson, T. 2006. Re-introduction of Lower Columbia River chum salmon into Duncan Creek, 2004-2005 Annual Report, Project No. 200105300, (BPA Report DOE/BP-00020932-1). 73 p.

Jones, K. K., T. J. Cornwell, D. L. Bottom, S. Stein, H.W. Kelly, and L. A. Campbell. 2011. Recovery of Wild Coho Salmon in Salmon River Basin, 2008-10. Monitoring Program Report Number OPSW-ODFW-2011-10, Oregon Department of Fish and Wildlife, Salem, OR.

Kery, M. 2010. Introduction to WinBUGS for ecologists: A Bayesian approach to regression, ANOVA, mixed models and related analyses. Academic Press.

King, R., B. J. T. Morgan, O. Gimenez, S.P. Brooks. 2010. Bayesian analysis for population ecology. Boca Raton, FL. CRC Press.

Kiyohara, K., and M. S. Zimmerman. 2012. Evaluation of juvenile salmon production in 2011 from the Cedar River and Bear Creek, FPA 12-01. Washington Department of Fish and Wildlife, Olympia, Washington.

Koski, K V. 2009. The fate of coho salmon nomads: the story of an estuarine-rearing strategy promoting resilience. Ecology and Society 14(1): 4. [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art4/57: 2280-2292.

LCFRB. 2010. Lower Columbia Salmon Recovery and Fish and Wildlife Subbasin Plan. Lower Columbia Fish Recovery Board, Kelso, Washington.

Lang, S. and, A. Brezger. 2004. Bayesian P-splines. Journal of Computational and Graphical Statistics13: 183–212.

Lunn, D. J., A. Thomas, N. Best, and D. Spiegelhalter. 2000. WinBUGS: A Bayesian modelling framework: concepts, structure, and extensibility. Statistics and Computing 10: 325–337.

Murdoch, A. R., T. N. Pearsons, and T. W. Maitland. 2010. Estimating the spawning escapement of hatchery- and natural-origin spring Chinook salmon using redd and carcass data. North American Journal of Fisheries Management 30: 361–375.

Myers, J., and coauthors. 2006. Historical population structure of Pacific salmonids in the Willamette River and lower Columbia River basins. U.S. Department of Commerce, NOAA Technical Memorandum NMFW-NWFSC-73.

Parken, C. K., R. E. Bailey, and J. R. Irvine. 2003. Incorporating uncertainty into area under the curve and peak count salmon escapement estimation. North American Journal of Fisheries Management 23:78–90.

Plummer, M., N. Best, K. Cowles, and K. Vines. 2006. CODA: Convergence Diagnosis and Output Analysis for MCMC. R News 6: 7–11.

Quinn, G. P., and M. K. Keough. 2002. Experimental design and data analysis for biologists. Cambridge University Press. New York, NY.

R Development Core Team 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, Available from http://www.R-project.org.

Rawding, D., and B. Glaser. 2006. Draft progress report: Escapement of tule fall Chinook salmon in the Coweeman River. Draft progress report to WDFW. August 2006. 10 p.

Rivot, E., and E. Prévost. 2002. Hierarchical Bayesian analysis of capture-mark-recapture data. Canadian Journal of Fisheries and Aquatic Sciences 59: 1768–1784.

Schroder, S. L., C. M. Knudsen, E. C. Volk. 1995. Marking salmon fry with strontium chloride solutions. Canadian Journal of Fisheries and Aquatic Sciences 52:1141–1149.

Schroder, S. L., E. C. Volk, C. M. Knudsen, and J. J. Grimm. 1996. Marking embryonic and newly emerged salmonids by thermal events and rapid immersion in alkaline-earth salts. Bull. Natl. Res. Inst. Aquacult. Suppl. 2:79–83.

Schwarz, C. J., and A. N. Arnason. 1996. The general method for analysis of capture-recapture experiments in open populations. Biometrics 52:860–873.

Schwarz, C. J., and G. G. Taylor. 1998. The use of the stratified-Petersen estimator in fisheries management: estimating pink salmon (*Oncorhynchus gorbuscha*) in the Frazier River. Canadian Journal of Fisheries and Aquatic Sciences 55:281–297.

Schwarz, C. J., R. E. Bailey, J. R. Irvine, and F. C. Dalziel. 1993. Estimating salmon escapement using capture-recapture methods. Canadian Journal of Fisheries and Aquatic Sciences 50:1181–1197.

Schwarz, C.J., D. Pickard, K. Marine, and S.J. Bonner. 2009. Juvenile Salmonid Outmigrant Monitoring Evaluation, Phase II – December 2009. Final Technical Memorandum for the Trinity River Restoration Program,Weaverville, CA. 155 pp. + appendices. Available from http://www.stat.sfu.ca/~cschwarz/Consulting/Trinity/Phase2.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, 2nd edition. Charles Griffin and Company, London.

Sharpe, C. S., B. G. Glaser, and D. J. Rawding. 2009. Spawning escapement, juvenile production, and contribution to fisheries of Coweeman River fall Chinook salmon: A completion report for work in 2007 and 2008. FPA 09-01. Washington Department of Fish and Wildlife, Olympia, Washington.

Sharpe, C. S., B. G. Glaser, D. J. Rawding, and L. Campbell. 2011. Spawning escapement, juvenile production, and contribution to fisheries of Coweeman River fall Chinook salmon: A completion report for work in 2010. Delivered to the Pacific Salmon Commission, June 2011. 42 p.

Spiegelhalter, D., A. Thomas, N. Best, and D. Lunn. 2003. WinBUGS User Manual, Version 1.4. MCR Biostatistics Unit, Institute of Public Health and Epidemiology and Public Health. Imperial College School of Medicine, UK.

Sykes, S. D., and L. W. Botsford. 1986. Chinook salmon, *Oncorhynchus tshawytscha*, spawning escapement based on multiple mark-recapture of carcasses. Fisheries Bulletin 84:261–270.

Topping, P., and M. S. Zimmerman. 2011. Green River juvenile salmonid production evaluation: 2009 and 2010 annual report, FPA 11-01. Washington Department of Fish and Wildlife, Olympia, Washington.

Zhou, S. 2002. Size-dependent recovery of Chinook salmon in carcass surveys. Transactions of the American Fisheries Society 131:1194–1202.

Appendix A

Weekly juvenile Chinook production and length statistics, 2007

Appendix A. Weekly production estimates and length summary statistics of juvenile tule fall Chinook salmon captured in the Coweeman River juvenile screw trap, 2007. Seasonal length statistics are weighted by weekly migration.

			Fork Length (mm)				
Start	End	Production Estimate	Mean	SD	Minimum	Maximum	n
02/09/2007	02/11/2007	336	35.1	3.3	30	39	8
02/12/2007	02/18/2007	1,050	35.9	2.1	33	41	25
02/19/2007	02/25/2007	3,906	36.8	1.8	31	39	62
02/26/2007	03/04/2007	2,982	38.0	5.4	35	81	68
03/05/2007	03/11/2007	6,888	37.8	1.1	35	40	97
03/12/2007	03/18/2007	11,671	38.4	5.1	33	94	134
03/19/2007	03/25/2007	10,633	38.4	1.9	34	46	66
03/26/2007	04/01/2007	9,482	39.4	2.9	35	48	71
04/02/2007	04/08/2007	20,176	38.6	3.1	33	56	137
04/09/2007	04/15/2007	15,617	39.1	3.4	35	52	71
04/16/2007	04/22/2007	4,268	38.1	4.2	31	59	81
04/23/2007	04/29/2007	1,455	42.1	7.9	31	60	30
04/30/2007	05/06/2007	582	53.2	12.1	37	71	12
05/07/2007	05/13/2007	776	58.0	7.0	50	63	3
05/14/2007	05/20/2007	259	62.2	12.5	37	83	28
05/21/2007	05/27/2007	3,284	68.6	11.4	41	92	160
05/28/2007	06/03/2007	1,248	80.6	17.4	41	108	24
06/04/2007	06/10/2007	20,724	82.7	8.2	62	98	51
06/11/2007	06/17/2007	16,249	83.1	7.9	59	100	107
06/18/2007	06/24/2007	25,968	85.1	6.5	64	100	46
06/25/2007	07/01/2007	13,893	81.8	7.0	63	96	87
07/02/2007	07/08/2007	13,544	82.7	8.0	60	100	60
07/09/2007	07/15/2007	2,820	80.1	5.5	69	92	90
07/16/2007	07/22/2007	2,600	80.6	6.1	62	94	85
07/23/2007	07/29/2007	764	79.7	6.1	65	93	55
07/30/2007	08/05/2007	257					0
08/06/2007	08/12/2007	746					0
08/13/2007	08/19/2007	856					0
08/20/2007	08/26/2007	116					0
08/27/2007	09/02/2007	86					0
09/03/2007	09/09/2007	220	92.8	8.9	67	111	30
09/10/2007	09/16/2007	260					0
09/17/2007	09/23/2007	235					0
09/24/2007	09/30/2007	158					0
10/01/2007	10/07/2007	114	82.0	10.9	63	104	20
10/08/2007	10/14/2007	22					0
10/15/2007	10/21/2007	29					0

Continued on next page

Appendix A. Continued.

Start	End	Production Estimate	Fork Length (mm) Mean	SD	Minimum	Maximum	n
10/22/2007	10/28/2007	0					0
10/29/2007	11/04/2007	33	78.0	9.0	68	89	6
11/05/2007	11/11/2007	55					0
11/12/2007	11/13/2007	7	91.0	21.2	76	106	2
		194,369	***62.1***	***5.6***	***30***	***111***	***1,716***

Appendix B

Weekly juvenile Chinook production and length statistics, 2008

Appendix B. Weekly production estimates and length summary statistics of juvenile tule fall Chinook salmon captured in the Coweeman River juvenile screw trap, 2008. Seasonal length statistics are weighted by weekly migration.

			Fork Length (mm)				
Start	End	Production Estimate	Mean	SD	Minimum	Maximum	*n*
02/18/2008	02/24/2008	68	37.9	3.0	32	40	7
02/25/2008	03/02/2008	2,654	37.7	1.8	33	42	80
03/03/2008	03/09/2008	2,470	37.7	1.7	33	42	100
03/10/2008	03/16/2008	7,694	37.5	1.4	34	40	80
03/17/2008	03/23/2008	9,623	37.5	1.7	34	43	81
03/24/2008	03/30/2008	9,939	37.5	1.9	34	47	66
03/31/2008	04/06/2008	7,435	37.5	1.8	34	44	88
04/07/2008	04/13/2008	791	37.5	2.3	34	48	30
04/14/2008	04/20/2008	26	51.0		51	51	1
04/21/2008	04/27/2008	343	45.8	6.7	36	53	13
04/28/2008	05/04/2008	158	60.7	9.6	48	75	6
05/05/2008	05/11/2008	1,239	52.1	10.6	36	75	47
05/12/2008	05/18/2008	172	50.5	9.7	35	70	15
05/19/2008	05/25/2008	630	58.6	8.6	45	77	47
05/26/2008	06/01/2008	2,757	56.8	7.5	43	72	39
06/02/2008	06/08/2008	3,425	65.8	10.8	42	91	60
06/09/2008	06/15/2008	5,063	73.5	10.7	46	92	39
06/16/2008	06/22/2008	1,024	79.5	11.4	37	103	47
06/23/2008	06/29/2008	1,020	83.6	9.5	54	102	60
06/30/2008	07/06/2008	13,131	91.8	8.5	70	110	60
07/07/2008	07/13/2008	15,874	89.0	6.2	73	103	80
07/14/2008	07/20/2008	8,730	88.1	6.0	76	106	40
07/21/2008	07/27/2008	2,859	86.9	6.2	71	99	40
07/28/2008	08/03/2008	2,058	86.2	6.8	71	113	60
08/04/2008	08/10/2008	731	86.8	6.8	71	100	60
08/11/2008	08/17/2008	366	88.0	6.6	77	105	40
08/18/2008	08/24/2008	795	94.3	6.8	77	110	40
08/25/2008	08/31/2008	267	94.4	7.1	79	111	60
09/01/2008	09/07/2008	657	98.9	6.1	90	115	40
09/08/2008	09/14/2008	132	98.9	8.3	84	117	20
09/15/2008	09/21/2008	149	99.7	7.1	86	113	20
09/22/2008	09/28/2008	277	101.6	8.1	71	114	40
09/29/2008	10/05/2008	69	101.8	8.0	84	114	20
10/06/2008	10/12/2008	133	105.4	10.5	84	123	40
10/13/2008	10/19/2008	66	91.0	12.4	73	113	26
10/20/2008	10/26/2008	61	100.7	14.1	75	130	37
10/27/2008	10/30/2008	23	92.6	15.5	74	126	14
		102,909	***65.6***	***5.3***	***32***	***130***	***1,643***

Appendix C

Weekly juvenile Chinook production and length statistics, 2010

Appendix C. Weekly production estimates and length summary statistics of juvenile tule fall Chinook salmon captured in the Coweeman River juvenile screw trap, 2010. Seasonal length statistics are weighted by weekly migration.

			Fork Length (mm)				
Start	End	Production Estimate	Mean	SD	Minimum	Maximum	n
02/02/2010	02/07/2010	823	36.2	2.2	31	39	52
02/08/2010	02/14/2010	7,475	35.8	1.8	32	39	101
02/15/2010	02/21/2010	8,243	36.5	1.6	33	39	100
02/22/2010	02/28/2010	10,825	36.6	1.7	31	43	179
03/01/2010	03/07/2010	51,791	37.2	2.0	33	42	120
03/08/2010	03/14/2010	24,269	37.4	2.3	34	50	140
03/15/2010	03/21/2010	107,095	38.0	2.6	33	52	180
03/22/2010	03/28/2010	61,766	37.9	3.4	32	62	160
03/29/2010	04/04/2010	61,668	39.0	4.7	32	54	200
04/05/2010	04/11/2010	16,397	37.9	4.1	31	59	180
04/12/2010	04/18/2010	16,361	37.5	4.6	32	62	110
04/19/2010	04/25/2010	2,645	38.7	5.5	34	59	50
04/26/2010	05/02/2010	121					0
05/03/2010	05/09/2010	1,716	60.8	6.7	43	75	85
05/10/2010	05/16/2010	40	65.0	1.4	64	66	2
05/17/2010	05/23/2010	912	64.9	9.6	43	81	53
05/24/2010	05/30/2010	2,096	64.7	9.9	46	83	61
05/31/2010	06/06/2010	3,376	66.7	12.1	37	93	40
06/07/2010	06/13/2010	6,416	74.1	10.8	44	99	159
06/14/2010	06/20/2010	2,083	83.2	8.8	53	102	160
06/21/2010	06/27/2010	6,267	87.3	9.0	55	106	139
06/28/2010	07/04/2010	11,816	89.9	6.6	65	104	140
07/05/2010	07/11/2010	11,120	90.5	5.7	67	105	120
07/12/2010	07/18/2010	20,060	87.3	6.0	72	100	198
07/19/2010	07/25/2010	5,419	88.1	6.3	74	104	160
07/26/2010	08/01/2010	4,176	88.4	5.5	74	105	120
08/02/2010	08/08/2010	3,683	87.8	6.1	71	101	120
08/09/2010	08/15/2010	1,038	87.7	6.9	72	111	100
08/16/2010	08/22/2010	447	90.2	7.2	72	112	75
08/23/2010	08/23/2010	261					0
		450,405	***46.3***	***3.8***	***31***	***112***	***3,304***

Appendix D

Weekly juvenile Chinook production and length statistics, 2011

Appendix D. Weekly production estimates and length summary statistics of juvenile tule fall Chinook salmon captured in the Coweeman River juvenile screw trap, 2011.

		Production	Fork Length (mm)				
Start	End	Estimate	Mean	SD	Minimum	Maximum	n
02/03/2012	02/05/2012	951					0
02/06/2011	02/12/2011	10,010	37.2	1.2	35	40	81
02/13/2011	02/19/2011	11,930	37.1	1.2	34	41	140
02/20/2011	02/26/2011	22,080	36.6	1.4	32	40	100
02/27/2011	03/05/2011	4,666	37.1	1.0	36	39	14
03/06/2011	03/12/2011	24,540	36.9	2.3	33	55	88
03/13/2011	03/19/2011	14,600	36.7	1.6	33	47	140
03/20/2011	03/26/2011	44,430	36.6	1.3	33	40	139
03/27/2011	04/02/2011	81,720	36.8	1.8	33	43	81
04/03/2011	04/09/2011	15,560	37.5	3.4	33	59	135
04/10/2011	04/16/2011	21,090	37.6	2.7	33	56	140
04/17/2011	04/23/2011	4,101	38.4	2.9	34	55	94
04/24/2011	04/30/2011	2,940	37.8	1.9	34	45	74
05/01/2011	05/07/2011	1,627	38.5	5.7	34	67	35
05/08/2011	05/14/2011	231	38.7	4.9	32	45	6
05/15/2011	05/21/2011	284	51.1	14.3	36	75	9
05/22/2011	05/28/2011	306	62.4	5.6	55	75	9
05/29/2011	06/04/2011	393	56.7	12.2	34	77	15
06/05/2011	06/11/2011	1,200	62.9	12.6	37	90	35
06/12/2011	06/18/2011	1,612	71.7	14.1	34	95	70
06/19/2011	06/25/2011	1,753	82.1	13.4	37	109	126
06/26/2011	07/02/2011	4,737	85.4	12.9	41	106	176
07/03/2011	07/09/2011	16,750	89.2	10.2	60	112	174
07/10/2011	07/16/2011	10,190	89.8	9.2	57	112	163
07/17/2011	07/23/2011	5,074	90.5	7.8	51	108	172
07/24/2011	07/30/2011	3,375	90.6	6.9	65	108	170
07/31/2011	08/06/2011	2,156	90.3	7.5	47	105	140
08/07/2011	08/13/2011	233	89.8	8.2	70	105	77
08/14/2011	08/20/2011	119	91.9	7.9	73	109	70
08/21/2011	08/24/2011	286	93.1	9.1	71	105	36
		308,945	***44.8***	***3.1***	***32***	***112***	***2,709***

Appendix E

Adult Chinook salmon mark, capture, and recapture data matrix for the Petersen estimator, 2011

Appendix E. Adult Chinook salmon mark, capture, and recapture matrix from the Coweeman River, 2011. Data are organized by week and include the number of live fish marked at the weir (Tags), the number of carcasses encountered during spawner surveys (Captures), and the number of tagged carcasses encountered during spawner surveys (Recaps).

Males (≥ 60 cm)

Stat Week	Start Date	End Date	Tags	Captures	38	39	40	41	42	43	44	45	46	47	Recaps
38	09/12/11	09/18/11	3	0	0	0	0	1	0	0	0	0	0	0	1
39	09/19/11	09/25/11	16	0	0	0	2	0	0	0	0	0	0	0	2
40	09/26/11	10/02/11	22	3	0	0	0	1	1	0	1	0	0	0	3
41	10/03/11	10/09/11	83	8	0	0	0	1	4	18	3	0	0	0	26
42	10/10/11	10/16/11	37	15	0	0	0	0	2	6	2	1	0	0	11
43	10/17/11	10/23/11	0	32	0	0	0	0	0	0	0	0	0	0	0
44	10/24/11	10/30/11	0	14	0	0	0	0	0	0	0	0	0	0	0
45	10/31/11	11/06/11	0	2	0	0	0	0	0	0	0	0	0	0	0
46	11/07/11	11/13/11	0	0	0	0	0	0	0	0	0	0	0	0	0
47	11/14/11	11/20/11	0	0	0	0	0	0	0	0	0	0	0	0	0
			161	***74***											***43***

Females

Stat Week	Start Date	End Date	Tags	Captures	38	39	40	41	42	43	44	45	46	47	Recaps
38	09/12/11	09/18/11	6	0	0	0	3	0	1	0	0	0	0	0	4
39	09/19/11	09/25/11	33	3	0	3	0	1	2	1	0	0	0	0	7
40	09/26/11	10/02/11	15	4	0	0	0	1	2	1	0	0	0	0	4
41	10/03/11	10/09/11	110	4	0	0	0	0	7	14	3	5	1	0	30
42	10/10/11	10/16/11	42	14	0	0	0	0	1	5	5	1	1	0	13
43	10/17/11	10/23/11	1	22	0	0	0	0	0	0	0	0	0	0	0
44	10/24/11	10/30/11	0	19	0	0	0	0	0	0	0	0	0	0	0
45	10/31/11	11/06/11	0	13	0	0	0	0	0	0	0	0	0	0	0
46	11/07/11	11/13/11	0	□□0	0	0	0	0	0	0	0	0	0	0	0
47	11/14/11	11/20/11	0	0	0	0	0	0	0	0	0	0	0	0	0
			207	***81***											***58***

Jacks (< 60 cm)

Stat Week	Start Date	End Date	Tags	Captures	38	39	40	41	42	43	44	45	46	47	Recaps
38	09/12/11	09/18/11	0	0	0	0	0	0	0	0	0	0	0	0	0
39	09/19/11	09/25/11	3	0	0	0	0	0	1	0	0	0	0	0	1
40	09/26/11	10/02/11	2	0	0	0	0	0	0	0	0	0	0	0	0
41	10/03/11	10/09/11	11	1	0	0	0	0	0	0	0	0	0	0	0
42	10/10/11	10/16/11	2	2	0	0	0	0	0	1	0	0	0	0	1
43	10/17/11	10/23/11	0	3	0	0	0	0	0	0	0	0	0	0	0
44	10/24/11	10/30/11	0	3	0	0	0	0	0	0	0	0	0	0	0
45	10/31/11	11/06/11	0	0	0	0	0	0	0	0	0	0	0	0	0
46	11/07/11	11/13/11	0	0	0	0	0	0	0	0	0	0	0	0	0
47	11/14/11	11/20/11	0	0	0	0	0	0	0	0	0	0	0	0	0
			18	***9***											***2***