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Monitoring of Grays River Fall Chinook Salmon using an Instream Weir, 2008-2010

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Washington Department of FISH and WILDLIFE

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Executive Summary

The Lower Columbia River (LCR) Chinook Evolutionarily Significant Unit (ESU) was listed as threatened under the Endangered Species Act (ESA) on March 24, 1999. Since the initial listing, the threatened status has twice been reaffirmed, once in 2005 and again in 2014. The Grays River population of Chinook salmon (*Oncorhynchus tshawytscha*) was designated as a "primary" population within the ESU by the Lower Columbia River Fish Recovery Board (LCFRB) in 2004. This designation was changed to a "contributing" population in 2010, and as a result, the viability goal was reduced from 1,400 to 1,000 adult natural-origin spawners.

The Hatchery Scientific Review Group (HSRG) has stated that one of the factors limiting naturally spawning populations is interaction with hatchery-origin fish on the spawning grounds. The HSRG recommended less than 5% hatchery-origin spawners for primary populations and less than 10% for contributing populations (HSRG 2009). Historically, the use of peak count expansion (PCE) and coded wire tag (CWT) expansion have provided a means to estimate spawner abundance and stock composition, respectively. Between 1995 and 2006, PCE abundance estimates ranged from 14-745 Chinook salmon with out-of-basin stray rates ranging from 0 to 41.6% (Jenkins 2006).

In an effort to improve escapement monitoring and to promote recovery of the Grays River fall Chinook salmon population through removal of non-local Chinook salmon (hatchery strays), a resistance board weir was installed at river kilometer 17.2 in the Grays River in September 2008. This was the first resistance board weir used for fall Chinook salmon management in the LCR. The weir was operated through October 2008 before it was removed. It was reinstalled and operated from mid-August through the last week of October in 2009 and from mid-August through mid-October in 2010.

In these three years of operation, a total of 328 Chinook salmon, 1,621 coho salmon, 8 chum salmon, 1 pink salmon, and 3 steelhead were captured. Biological data was collected from all salmonids trapped. The proportion of marked Chinook salmon (defined as having an adipose and/or left ventral fin removed) captured at the weir was 78.7% in 2008, 79.8% in 2009, and 94.9% in 2010. Select Area Bright (SAB) stock fall Chinook represented 93.7% of the marked Chinook salmon trapped. These fish were identified as SAB stock based on the presence of a left ventral (LV) fin clip. Ten CWTs were recovered from Chinook salmon at the weir (three in 2008, five in 2009, and two in 2010) and all were decoded as SAB stock fall Chinook salmon released from the Oregon's South Fork Klaskanine River.

Adult Chinook salmon (defined as a fork length 60 cm and larger) spawner estimates were derived using a Bayesian framework using three independent methods: binomial Lincoln-Petersen, area-under-the-curve (AUC) based on live counts of fish identified as spawners, and redd expansion. Low sample sizes resulted in high CVs when Lincoln-Petersen estimates were generated (56.1% and 55.5% for 2008 and 2009, respectively) and did not allow for a Lincoln-Petersen estimate to be generated in 2010. AUC abundance estimates relied on estimates of apparent residence time (ART) derived from other populations as we did not have adequate mark recapture estimates and/or complete spatial and temporal coverage to develop basin-specific estimates of ART (Parken et al. 2003). We believe there could be bias in applying ART estimates from populations without weirs to populations with weirs as ART may be different due to weir effects. Therefore, we chose to report spawner abundance using redd expansion methods for 2008-2010. Apparent females per redd was derived from other LCR fall Chinook salmon population monitoring programs and was applied to 2008-2010 Grays River Chinook salmon redd and sex ratio data to develop a spawner abundance estimate. The mean value and 95% credible interval (CI) of the posterior distribution for adult Chinook salmon spawner abundance using redd expansion was 95 (95% CI 76 - 123) in 2008, 555 (95% CI 417 - 756) in 2009, and 159 (95% CI 114 - 233) in 2010.

The proportion of marked Chinook salmon spawners, or pMark, (based on a visual cue of having the adipose and/or left ventral fin removed) based on carcass recoveries was much higher than recommended by the HSRG each year. The mean value and 95% credible intervals of the posterior distribution for pMark for adult Chinook salmon was 63.9% (95% CI 47.7 – 78.5%) in 2008, 61.5% (95% CI 49.6 – 73.1%) in 2009, and 54.2% (95% CI 34.6 – 73.4%) in 2010.

Applying the estimated proportion of unmarked carcasses to estimates of spawner abundance yields an estimate of unmarked Chinook salmon spawners. Unmarked Chinook salmon are likely a mix of Tules, naturalized SABs, and their hybrids (Roegner et al. 2010). The mean value and 95% credible intervals of the posterior distribution for unmarked adult Chinook salmon was 33 (95% CI 19 - 52) in 2008, 210 (95% CI 132 - 315) in 2009, and 70 (95% CI 36 - 118) in 2010.

To evaluate weir effectiveness, we used our redd-based Chinook salmon spawner estimates and added sport harvest above the weir based on catch record card data and pre-spawn mortalities based on carcass recovery data to estimate the total number of Chinook salmon that passed the weir site. Weir efficiency was estimated as the proportion of upstream Chinook salmon population captured at the weir. The mean value and 95% credible intervals of the posterior distribution for weir efficiency for adult Chinook salmon was 44.1% (95% CI 36.4 – 52.5%) in 2008, 23.7% (95% CI 17.9 – 29.4%) in 2009, and 15.7% (95% CI 10.1 – 21.6%) in 2010.

Our analysis suggests that weir efficiencies would need to be in excess of 90% to achieve the proportion of hatchery-origin spawners goal of 10%. There are three areas of emphasis that could improve weir efficiencies in the future: 1) improving the substrate rail design; 2) adding additional floatation to the resistance panels; and 3) adding bulkheads where the resistance board weir transitions to the river bank. While these three improvements should improve weir efficiency, it should be noted that the Grays River is a very dynamic system. If weir operations are to continue into the foreseeable future, land acquisition for a suitable weir site, preferably at the upper end of tidal influence, and construction of a concrete sill should be considered to improve weir operations and efficiencies in order to meet HSRG standards.

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Forward

Chinook salmon (*Oncorhynchus tshawytscha*) are the largest of the Pacific salmon. The species' distribution historically ranged from the Ventura River in California to Point Hope, Alaska, in North America, and in northeastern Asia from Hokkaido, Japan, to the Anadyr River in Russia (Healey 1991). Additionally, Chinook salmon have been reported in the Mackenzie River area of northern Canada (McPhail and Lindsey 1970). Of the Pacific salmon, Chinook salmon exhibit arguably the most diverse and complex life history strategies. Healey (1986) described 16 age categories for Chinook salmon, seven total ages with three possible freshwater ages. This level of complexity is roughly comparable to that seen in sockeye salmon (*Oncorhynchus nerka*), although the latter species has a more extended freshwater residence period and uses different freshwater habitats (Miller and Brannon 1982; Burgner et al. 1992). Two generalized freshwater life-history types were initially described by Gilbert (1912): "stream-type" Chinook salmon, which reside in fresh water for a year or more following emergence, and "ocean-type" Chinook salmon, which migrate to the ocean within their first year. Healey (1983, 1991) has promoted the use of broader definitions for "ocean-type" and "stream-type" to describe two distinct races of Chinook salmon. Healey's approach incorporates life history traits, geographic distribution, and genetic differentiation and provides a valuable frame of reference for comparisons of Chinook salmon populations.

Lower Columbia River Chinook Salmon ESU

Lower Columbia River (LCR) Chinook salmon display three life history types including early fall runs ("Tules"), late fall run ("Brights") and spring runs. Both spring and fall runs have been designated as part of a LCR Chinook salmon Evolutionarily Significant Unit (ESU) that includes Oregon and Washington populations in Columbia River tributaries from the ocean to and including the White Salmon River in Washington, and the Hood River in Oregon (NOAA 2013). Fall Chinook salmon historically were found throughout the entire range, while spring Chinook salmon historically were only found in the upper portions of basins with snowmelt driven flow regimes (western Cascade Crest and Columbia Gorge tributaries). Late fall Chinook salmon were identified in only two basins (NF Lewis and Sandy rivers) in western Cascade Crest tributaries. In general, late fall Chinook salmon also mature at an older average age compared to either LCR spring or fall Chinook salmon, and have a more northerly oceanic distribution (Myers et al. 2006).

Run timing was the predominant life history criteria used in identifying populations within the ESU (reviewed by Myers et al. 1998). The LCR Chinook salmon ESU is subdivided into 32 populations (23 fall and late fall runs and nine spring runs), some of which existed historically but are now extinct (Myers et al. 2006). The populations are distributed through three ecological zones (Coast, Cascade and Gorge) that are used to identify population strata within the ESU (Figure 1).

In the Coast Range tributaries, seven historical fall Chinook salmon populations were identified. In the western Cascade Crest tributaries, 10 fall, two late fall, and seven spring Chinook salmon historical demographically independent populations were identified (Myers et al. 2006). The four extant spring stocks within the ESU include those on the Cowlitz, Kalama, and Lewis rivers on the Washington side, and the Sandy River on the Oregon side. The historic habitat for the spring Chinook salmon stocks on the Washington side is now largely inaccessible due to impassable dams. Although some spring Chinook salmon spawn naturally in each of these rivers, they are presumed to be largely hatchery-origin fish with little resulting natural production. The remaining spring stocks are therefore dependent, for the time being, on the associated hatchery production programs.

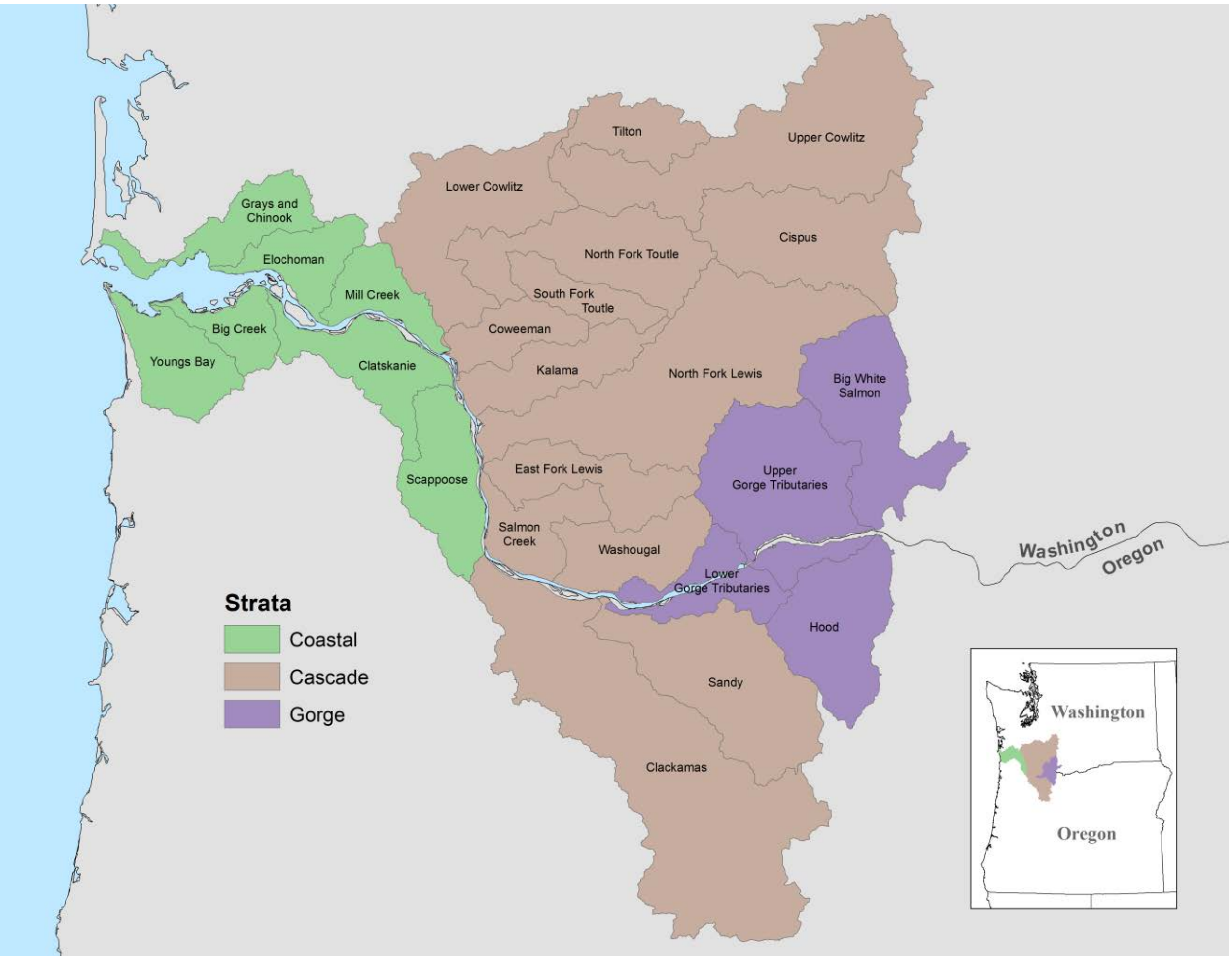

Figure 1. Lower Columbia River Chinook salmon populations and the regional groupings (i.e., strata) in which they occur within the LCR subunit recovery domain.

The Lower Columbia Fish Recovery Board's (LCFRB) Recovery Plan (2004) described a recovery scenario for LCR Chinook salmon. They identified each population's role in recovery as a primary, contributing, or stabilizing population that generally refer to a desired viability level. The Recovery Plan also suggested viable abundance goals for each population. In the 2004 recovery plan, the Grays River population of fall Chinook salmon was identified as a "primary" population. In 2010, the LCFRB downgraded the Grays River Chinook population from to a "contributing" population. With this reclassification, the recovery abundance goal for this population was reduced from 1,400 natural-origin adults to 1,000 natural-origin adults.

Introduction

Fall Chinook salmon native to the Grays River have an early fall run timing and thus are considered a Tule stock. Adults typically enter from early September through mid-November with peak spawning occurring in early-October. Spawning occurs primarily in the lower Grays River between river kilometer (rkm) 16.6 (upper tidewater influence) upstream to rkm 22.9 where distribution can be truncated in some years due to an impassable canyon section depending on river flow levels and in the West Fork Grays River from the hatchery intake (rkm 4.2) to the mouth. Juveniles begin emerging in January/February of the following year and emigrate as fry or sub-yearlings from February through July. WDFW's 2002 Salmonid Stock Inventory Report (WDFW 2002) lists the Grays River Fall Chinook salmon population as depressed.

For nearly 40 years, the Grays River Salmon Hatchery (located at rkm 2.9 on the West Fork Grays River) raised fall Chinook salmon for release into the Grays River. During this timeframe, broodstock was imported from multiple sources (often within a single year) to supplement Grays River returns; these included mostly Tule stocks, but "Bright" stocks (i.e. Priest Rapids) were also used on occasion. The last release of fall Chinook salmon from the Grays River Hatchery occurred in the spring of 1996 (1995 brood). Fall Chinook salmon from the 1996 release would have returned as age 2 - 6 fish in 1997-2001. From 2002 forward, the natural spawning population has been composed of natural-origin fish and out-of-basin strays.

Tule fall Chinook salmon released from LCR hatcheries were not mass-marked with an adipose fin clip until brood year 2006. Before that, only a subset of hatchery released fall Chinook were adipose-clipped as a visual cue to indicate that the fish had been implanted with a coded wire tag (CWT). CWTs are coded to identify the brood year and production facility of returning adults.

A phased approach was implemented to achieve nearly 100% mass-marking (adipose-clip) of all hatchery-origin Tule fall Chinook salmon juveniles released from LCR facilities by the spring of 2007. (Table 1). By 2012, all age classes (age 2-6) of LCR hatchery Tule fall Chinook salmon returning to the Columbia were mass-marked, with the majority of returns (age 2-4) marked by 2010.

Table 1. Tule fall Chinook salmon mass marking implementation schedule.

Hatchery Facility	Operating Agency	Year Mass Marking Began		Return Year - Mass Marked Age Classes Returning					
		Brood Year	Release Year	2007	2008	2009	2010	2011	2012
NF Klaskanine	ODFW	2009	2010	NP	NP	NP	NP	Age 2	Age 2-3
Elochoman	WDFW	2005	2006	Age 2	Age 2-3	Age 2-4	Age 2-5	All	All
Big Creek	ODFW	2006	2007		Age 2	Age 2-3	Age 2-4	Age 2-5	All
Kalama	WDFW	2005	2006	Age 2	Age 2-3	Age 2-4	Age 2-5	All	All
North Toutle	WDFW	2006	2007		Age 2	Age 2-3	Age 2-4	Age 2-5	All
Cowlitz	WDFW	2006	2007		Age 2	Age 2-3	Age 2-4	Age 2-5	All
Washougal	WDFW	2006	2007		Age 2	Age 2-3	Age 2-4	Age 2-5	All
Bonneville	ODFW	2008	2009	NP	NP	NP	Age 2	Age 2-3	Age 2-4
Little White Salmon	USFWS	2008	2009	NP	NP	NP	Age 2	Age 2-3	Age 2-4
Spring Creek	USFWS	2004	2005	Age 2-3	Age 2-4	Age 2-5	All	All	All

In addition to LCR hatchery Tule fall Chinook salmon production, an out-of-basin Bright fall Chinook salmon stock are also propagated artificially for the Select Area Fishery Enhancement (SAFE) program; these fish are referred to as Select Area Brights (SABs). The SAFE program produces fish for release into Washington and Oregon terminal fishery areas near the mouth of the Columbia River. In addition to the subset of adipose-clipped + CWT marked fish, all SAB releases from this program are marked with a left ventral fin clip (North et al. 2006). CWTs and left ventral-clipped adults recovered during spawning ground surveys have been used to determine stock composition of the natural spawning population through CWT expansion (Jenkins 2006). Recoveries from 1995-2006 indicated SABs constitute the majority of out-of-basin fall Chinook salmon returning to, and spawning in, the Grays River. Other sources include fall Chinook salmon released from the Oregon Department of Fish and Wildlife’s (ODFW) Big Creek Hatchery and spring Chinook salmon released from the Deep River Net Pens; the latter are SAFE program fish reared at the Grays River Hatchery prior to transport to the net pens. While the actual number of CWTs recovered annually on the Grays River has been small (range: 0 to 7 for 1995-2006), expanding recoveries by the corresponding tag rate has provided a means of estimating stock composition of the natural spawning population. The proportion of out-of-basin strays in the natural spawning population has been highly variable, ranging from 0 to 41.6% (Jenkins 2006).

The Hatchery Scientific Review Group (HSRG) stated that one of the factors limiting native populations is interaction with hatchery-origin fish on the spawning grounds. The HSRG recommended rates of less than 5% hatchery-origin spawners for primary populations and less than 10% for contributing populations (HSRG 2009).

This project has dual objectives: 1) to complement existing adult salmonid monitoring efforts in the Grays River in developing unbiased and precise estimates of spawner abundance, and 2) to promote recovery of the native Grays River Tule fall Chinook salmon population through removal of non-local Chinook salmon (hatchery-origin strays) to increase productivity and inter-population diversity.

Data collected from adult salmonids at the weir and on spawning ground surveys will be used to derive Viable Salmonid Population (VSP) parameters recommended by NOAA fisheries (McElhany et al. 2000). This project will report on three VSP parameters including abundance, spatial structure, and diversity.

Study Site

The Grays River is located near Grays River, Washington in Wahkiakum County. This second order tributary enters the Columbia River at river kilometer 33.5. The Grays River watershed drains ~321 square kilometers and is a rainfall dominated system (USGS 2016). The watershed provides habitat for several fish species, including but not limited to: winter steelhead and rainbow trout (*Oncorhynchus mykiss*), Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), chum salmon (*Oncorhynchus keta*) and pink salmon (*Oncorhynchus gorbuscha*), cutthroat trout (*Oncorhynchus clarki*), lamprey (*Lampetra spp.*), mountain whitefish (*Prosopium williamsoni*), suckers (*Catastomas spp.*), sculpins (*Cottus spp.*), stickleback (*Gasterosteus aculeatus*), northern pikeminnow (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), and redside shiner (*Richardsonius balteatus*). The lower portion of the watershed cuts through land dominated by agricultural use while the upper portion lies within privately-owned timberland. Anthropogenic actions such as splash-damming, channel straightening, stream bank hardening, and more recent flood control activities have significantly altered the river channel (LCFRB 2006).

The weir was located approximately 55 meters downstream of the Grays River Covered Bridge at river kilometer 17.2 (Figure 2), which is approximately 1.4 rkm above tidal influence (near the mouth of King Creek at rkm 15.8). The weir location was chosen based on a variety factors including: accessibility from the road, suitable stream bottom for the weir structure, willing landowners, and spawning distribution of fall Chinook salmon.

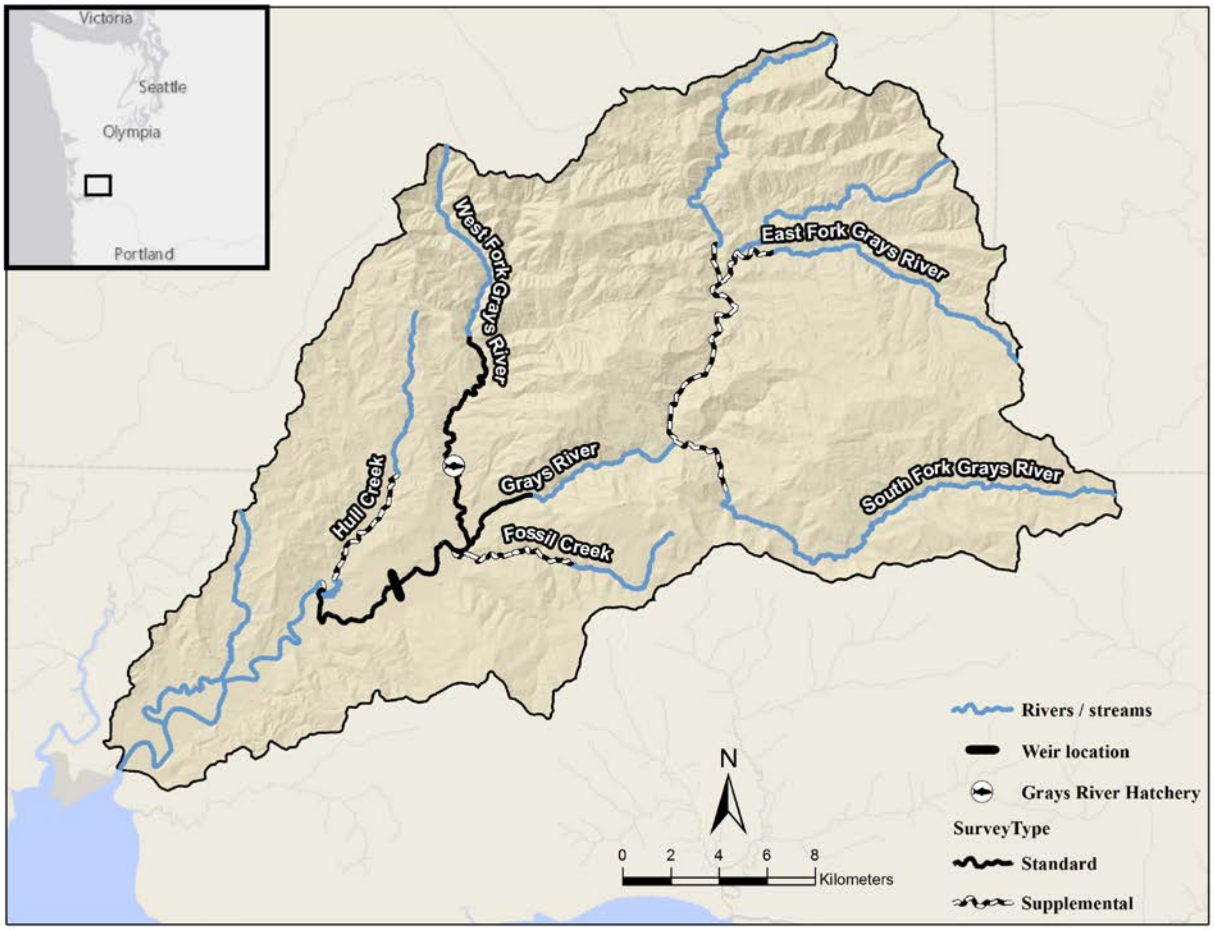

Figure 2. Location of the Grays River Resistance Board Weir and Survey Area, 2008-2010.

Methods

Fish Capture

The Grays River is a rainfall-dominated system and high water events are commonplace in the fall and winter months. This required a weir design that was able to withstand high water events with minimal damage and downtime allowing for nearly continuous trapping operations. The original weir design chosen was a hybrid resistance board/fixed panel design utilizing fixed wooden panels on the perimeter and a river-spanning floating resistance board section constructed primarily of PVC pipe in the center with 3.8 cm spacing (Figure 3). A single 2.4 m x 3.0 m aluminum live trap box was installed between the fixed panel and resistance board section on the river-right bank. Sawhorse and picket sections were held down with ecology blocks. The resistance board sections were anchored with duckbill anchors and cables. In 2009, an additional 2.4 m x 3.0 m trap box was installed upstream of the fixed panel portion of the weir to add flexibility when fishing dynamic water conditions. In 2010, the two live box design was used again while the hybrid resistance board/fixed panel design was discontinued in favor of an all resistance board weir design with the intent of allowing the river to disperse more at higher flows.

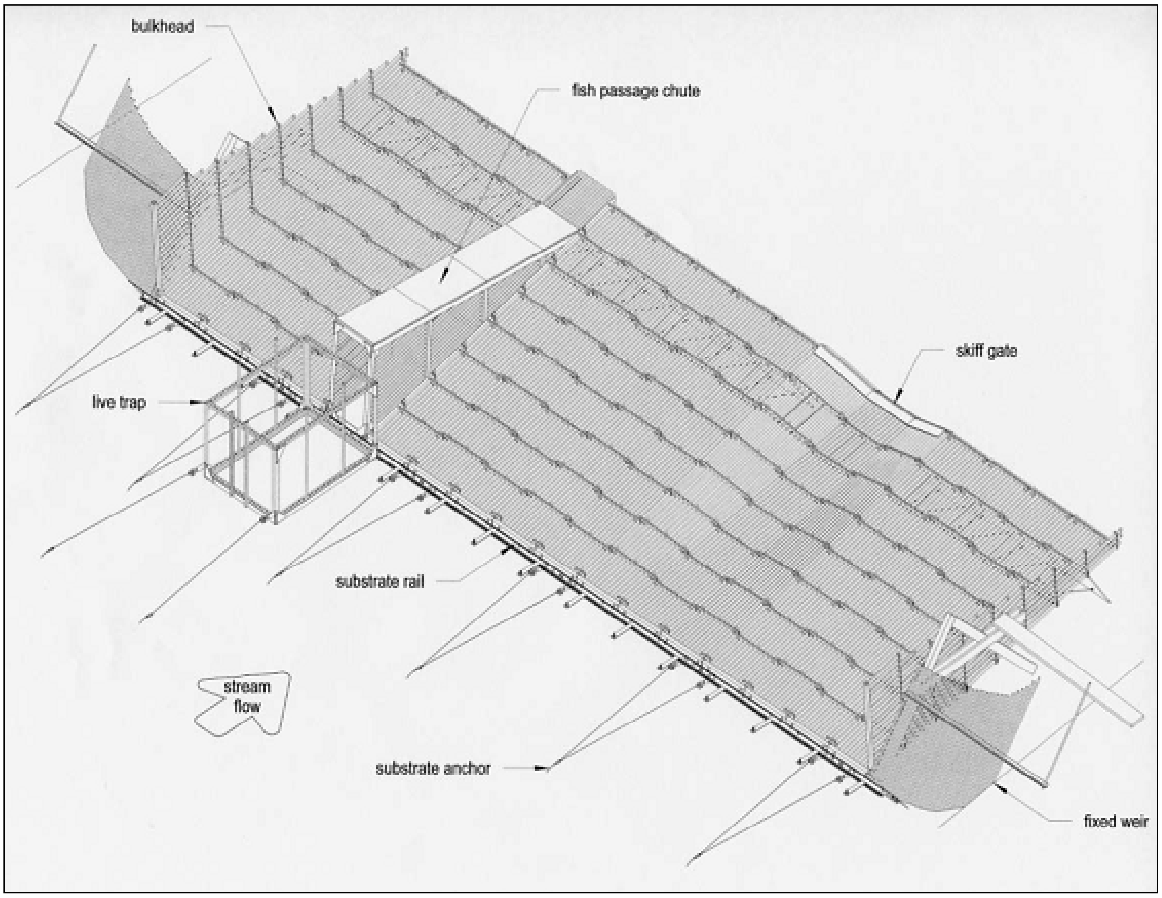

Figure 3. Schematic of a Resistance Board Weir (Stewart 2003).

Weir Operation and Sampling Protocols

The trap was staffed continuously while installed and the trap box was checked daily (multiple times per day when necessary). Close attention was paid to the recruitment of fish into the adult trap and the accumulation of fish below the trap. If the abundance of salmonids exceeded the ability of staff to efficiently work through fish, protocols were in place to allow passage without sampling/handling. This was accomplished by opening the upstream gate on the trap box and allowing fish to pass through without handling or submerging a panel section of the resistance weir to allow fish passage around the trap box.

Stream flow and weather forecasts were monitored closely to ensure the well-being of captured fish in the live box. The Washington Department of Ecology (WDOE) operates a telemetry stream flow gauge that provides near real-time information on stream flows. Stream flow and weather forecast information, and ultimately direct observation, determined when flows began to limit accessibility to the trap box. When these conditions were encountered, the trap box was opened on both the upstream and downstream end to allow direct passage through the trap. Marking/tagging of fish combined with stream surveys provided a means for estimating abundance and weir efficiency when fish were allowed through the trap unsampled and/or high flows compromised the ability to trap fish at the weir.

All salmonids captured were sampled for biological data, genetic tissue, and a portion were externally tagged before release upstream. After sampling and marking, all fish (salmonids and other resident fish) were released unharmed upstream of the weir with the exception of Chinook salmon marked with a fin-clip (adipose and/or ventral). These Chinook salmon are out-of-basin hatchery strays, they are not ESA-listed, and were removed. A complete description of the operational protocols is provided below.

All salmonids captured at the weir were sampled for biological data. All chum salmon, unmarked Chinook salmon, and sub-sample of coho salmon captured at the weir were marked (operculum punch) and tagged (Peterson disc or T-bar anchor) to evaluate weir efficiency and generate spawner escapement estimates above the weir. Marking and tagging was coordinated with spawning ground surveys to re-sight/recover these marks/tags. All salmonids that were bio-sampled were anaesthetized (Tricaine Methanesulfonate, MS-222) prior to handling at the weir with the exception of adipose-clipped coho and steelhead which were not anaesthetized because they could be retained in the sport fishery. All anaesthetized fish were allowed to fully recover before being released upstream of the weir.
Table 2 outlines sampling protocols by species and origin.

Table 2. Sampling protocols by species and origin at the Grays River Weir, 2008-2010.

Species	Mark Type	Enumerated	Bio-sampled	Marked and/or Tagged	Wanded for CWT	Disposition
Fall Chinook	Marked	Yes	Yes	No	Yes	Removed
	Unmarked	Yes	Yes	Yes	Yes	Upstream
Coho	Marked	Yes	Yes	Yes	No	Upstream
	Unmarked	Yes	Yes	Yes	No	Upstream
Chum	Unmarked	Yes	Yes	Yes	No	Upstream
Pink	Unmarked	Yes	Yes	No	No	Upstream
Steelhead	Marked	Yes	Yes	No	No	Upstream
	Unmarked	Yes	Yes	No	No	Upstream
Non-salmonids		Yes	No	No	No	Upstream

Marked are either adipose-clipped and/or left ventral-clipped, unmarked have all fins intact.

Spawning Ground Surveys

The sampling frame, or survey area, for Chinook salmon spawning ground surveys was developed using a logistic regression model to predict uppermost extent of Chinook salmon spawning habitat (Fransen et al. 2006; Rawding et al. 2010). We truncated this model at known barriers for better representation of the true distribution. This was used as a starting point to setup our annual sampling frame, which was adjusted based on a year-specific environmental conditions to ensure complete spatial coverage of Chinook salmon spawning activity. This was accomplished through either weekly, or standard surveys, or a combination of standard and supplemental surveys which was conducted once or twice annually around perceived peak spawning activity.

Weekly spawning ground surveys were conducted throughout the Chinook, coho, and chum salmon spawning period on the Grays River between river kilometer 23.2 and 12.9, West Fork Grays River between river kilometer 5.8 and Crazy Johnson Creek between river kilometer 0.6 and 0 (Figure 1). In 2010, supplemental surveys were conducted during the peak Chinook salmon spawning period outside of the standard survey areas described above including the areas above the canyon section (e.g. Grays River, South Fork Grays River, and East Fork Grays River) and the lower sections of Fossil and Hull creeks.

Monitoring Design

The primary objectives of spawning ground surveys were to: 1) generate unbiased and precise estimates of spawner abundance estimates of salmonids in the Grays River; 2) determine spatial structure; 3) evaluate diversity via the proportion marked, age structure, spawn timing, and genetics; and 4) estimate weir efficiency.

While the intent of the weir was focused on Chinook salmon management and abundance estimates, we setup a study design that would allow us to generate abundance estimates for other salmon species handled at the weir (coho and chum salmon). However, due to the inability to operate the weir throughout the migration period of these other species, an inadequate and unrepresentative number were tagged. Therefore, we did not attempt to generate any estimates for these other species using data generated or collected at the weir for this report. Spawner estimates for chum salmon in the Grays River by return year can be found in Hillson (2012) while 2010 coho salmon spawner abundance estimates can be found in Rawding et al. (2014b). Prior to 2010, no abundance estimates of natural spawning coho salmon in the LCR ESU are available. We only generated Chinook salmon spawner abundance estimates for this report.

Due to uncertainty in which method would generate the most accurate and precise estimate of adult Chinook salmon abundance in the Grays River, four independent methods were evaluated : 1) Lincoln-Petersen via live tagging at the weir and live mark-re-sight/carcass recapture, 2) Jolly-Seber via carcass tagging, 3) area-under-the-curve (AUC), and 4) redd expansion.

Adipose intact Chinook salmon captured at the weir were tagged with a uniquely numbered Petersen disc tag and an operculum punch was applied to serve as a permanent secondary mark. Tag loss was assessed from recovered carcasses that had an operculum punch but no tag. Uniquely colored Petersen disc tags and operculum punch shapes were used each week to allow for a temporal stratification study design as outlined in Darroch (1961). Tagged and untagged live fish and carcasses were then re-sighted and/or recovered as carcasses during weekly spawning ground surveys. To increase the precision of the abundance estimate, pooling of recovery types (carcasses and lives) and temporal periods was done when appropriate. Chi-square tests were used to determine if pooling recovery types and adjacent strata was valid (Darroch 1961; Arnason et al. 1996; Schwarz and Taylor 1998). If the test yielded a P-value greater than 0.05, periods were pooled. The key assumptions of Lincoln-Petersen method are (Schwarz and Taylor 1998): 1) the population is closed; 2) all fish have the same probability of capture in the first sample; 3) the second sample is either a simple random sample, or if the second sample is systematic, marked and unmarked fish mix randomly; 4) marking does not affect catchability; 5) fish do not lose their marks; and 6) all recaptured marks are recognized.

All intact Chinook salmon were carcass tagged (Jolly 1965, Seber 1965; Sykes and Botsford 1986; Boydstun 1994; Rawding and Hillson 2003; Rawding et al. 2014a) to estimate weekly abundance of Chinook salmon carcasses. Carcasses were tagged by stapling a uniquely numbered plastic tag inside of each operculum (McIssac 1977). Tagged carcasses were then placed into moving water to facilitate mixing with untagged carcasses (Sykes and Botsford 1986). On subsequent surveys, technicians would examine carcasses for the presence of tags. If tags were present, the tag numbers were recorded, removed, and the fish were marked by removing the tail which identified the carcass as having been already enumerated and sampled. Sykes and Botsford (1986) list the key assumptions of the JS model as: 1) equal catchability within the population; 2) equal survival within the population; 3) every animal caught has the same probability of being tagged and returned to the population (handling mortality); 4) tagged animals do not lose their marks and all marks are recognized on recovery; and 5) sampling is instantaneous.

Live salmonids were identified to species and enumerated as either a “spawner” or “holder”. A fish was classified as a holder if it was observed in an area not considered spawning habitat, such as pools or large cobble and boulder riffles (Parken et al. 2003). Salmon were classified as a spawner if they were on redds or not classified as holders. Counts of live Chinook salmon spawners were used to develop the “curve” using the trapezoidal method (Hilborn et al. 1999; Parken et al. 2003). The key assumptions for the AUC method are (Rawding et al. 2014a): 1) complete spatial and temporal coverage throughout the spawning period; 2) count of live fish are accurate; and 3) the estimate of ART used is accurate for this basin and year.

Each unique, new Chinook salmon redd location was recorded using a handheld Oregon550 Global Positioning System (GPS) unit. Each redd was given a unique identifying name and flagged for future reference. On subsequent surveys, previously flagged redds were inspected to determine if they should be classified as “still visible” or “not visible”. A redd was classified as “still visible” if it would have been observed and identified without the flagging present, and was classified as “not visible” if it did not meet this criteria. The key assumptions of redd expansion method are (Rawding et al. 2014a): 1) Chinook salmon redds are accurately identified; 2) surveys are a census of all redds constructed; and 3) expansion factors reflect the true spawning activity and sex ratio.

Data Collection

All carcasses that were not totally decomposed were sampled for length, sex, fin marks, marks and/or tags, condition, gill color, and spawn success (females only). Fork length was measured from the tip of the snout to the fork in the tail using a tape measure. The presence of fin marks was identified by a missing adipose and/or ventral fin and a healed scar at the location of the clipped fin. Carcasses were examined for the presence of any external tags (Peterson disc or carcass) or marks (operculum punch). Staff were specifically instructed to clean both opercula and check for the presence of a punch which would indicate a recapture for a marking event at the weir. Carcass condition and gill color were classified using the criteria outlined in Sykes and Botford (1986). Sex was determined based on morphometric differences between males and females. The abdominal cavity was cut open 1 to 2 inches to confirm sex and determine spawning success. Spawn success was approximated based on visual inspection and an estimate of retained eggs, ranging from 100% to 0% success. Any female carcasses with an estimated percent retained eggs value of greater than 75% was considered a pre-spawning mortality.

Additionally, otoliths, DNA tissue samples, and scale samples were collected from all intact Chinook salmon carcasses. Otolith and DNA tissue samples were placed in uniquely numbered vials with an alcohol preservative. The unique vial ID was recorded on the scale cards to link the sample back each Chinook's biological data. Otolith and DNA tissue samples were then archived for later analysis. Scale samples were collected by selecting scales from the preferred area as described in Crawford et al. (2007). Scales were placed on the gummed portion of WDFW scale cards with their exterior surfaces facing up. The scale samples were later pressed onto acetate and sent to the WDFW aging lab for analysis.

A series of environmental variables were estimated for each survey including visibility, weather conditions, and stream flow. Visibility was estimated by the surveyors at the start of each survey using a 1.8 meter walking gaff. If water visibility exceeded 1.8 meters, visibility was recorded as 1.8m+ ft. Discharge data were obtained from the Washington Department of Ecology (WDOE) Grays River stream gauge located at river kilometer 17.2. Preliminary stream gauge data are available at https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?wria=25.

Data Analysis

For the purpose of this report, adults are defined as individuals with fork lengths (FL) 60 cm and larger. Small fish (fork length less than 60 cm) typically have significantly different recovery rates when compared to larger fish and observations of live fish may be size biased as well (Zhou 2002; Rawding et al. 2006). Therefore, live and carcass counts of small fish (recorded as jacks on WDFW stream survey cards) were excluded from all population and weir efficiency estimates.

All abundance, pMark (proportion of carcasses marked), sex ratio, age structure estimates were parameterized using a Bayesian framework using WinBUGS (Spiegelhalter et al. 2003) from R using the R2WinBUGS package (Sturtz et al. 2005). The formula of the posterior distribution may be complex and difficult to directly calculate. Samples from the posterior distribution can often be obtained using Markov chain Monte Carlo (MCMC) simulations (Gilks et al. 1995). WinBUGS is software package that implements MCMC simulations using a Metropolis within Gibbs sampling algorithm (Spiegelhalter et al. 2003) and has been used to estimate fish abundance (Rivot and Prevost 2002; Su et al. 2001; Link and Barker 2010). We report the mean of the posterior distribution as the point estimate for each parameter.

Summary statistics, parameters, likelihoods, and code (R and WinBUGS) used in this report originated from Rawding et al. (2014a) and were modified to meet the needs of analyses specific to the 2008, 2009, and 2010 Grays River study designs. We used vague or uninformative priors to let the data form the posterior distributions as much as possible. For binomial or multinomial distributions, we used Beta and Dirichlet priors parameterized with $\alpha = \beta = 1$, which is the Bayes-LaPlace uniform prior. For our binomial Lincoln-Petersen, we chose a uniform prior, so that the minimum and maximum bounds did not truncate the posterior distribution.

Spawner Abundance Estimation

Lincoln-Petersen estimates were calculated using a binomial model (Table 3 and Table 4). Unaccounted for tag loss results in an overestimate of tags available for recapture and will positively bias mark-recapture estimates (Rajawani and Schwarz 1997). We assessed tag loss via the application of a permanent secondary mark (operculum punch) during the tagging event and adjusted marks available in the analysis to account for this (Table 5 and Table 6). To develop an estimate of spawners above the weir, we took the Lincoln-Petersen estimate adjusted for tag loss and accounted for sport harvest above the weir and any pre-spawn mortalities (Table 7 and Table 8).

Table 3. Summary statistics used in the mark-recapture binomial Lincoln-Petersen model. Chinook salmon tagged at the weir were the marks, live Chinook resighted on spawning ground surveys above the weir were the captures, and tagged live Chinook resighted on spawning ground surveys above the weir were the recaptures.

Statistic	Definition/Equation
m_b	Number of fish marked in the first sample (*n1*) for the Binomial model
r_b	Number of marked fish recaptured in the second sample (*m2*) for the Binomial model
c_b	Number of fish captured in the second sample (*n2*) for the Binomial model

Table 4. The fundamental parameters and likelihoods for the binomial Lincoln-Petersen model.

Description	Likelihood
Pr(Proportion Marked)	$r_b \sim$ Binomial(p,c_b)
Pr(Recapture)	m_b~Binomial(p,N_b)

Table 5. Summary statistics used in a double tagging experiment to estimate tag loss.

Statistic	Definition/Equation
t_1	Number of fish recovered with 1 tags
t_2	Number of fish recovered with two tags
t_all	Number of fish with one or two tags, *t_all* = *t_1* + *t_2*
Tags	Number of tags released

Table 6. Fundamental and derived parameters in a double tagging experiment to estimate tag loss assuming the probability of losing a tag was the same for each tag, and loss of each tag was independent.

Parameter	Definition/Equation
p_tl	Probability of losing a tag
p_1	Probability of recovering a fish with 1 tag, *p_1* = ((2**p_tl*)*(1-*p_tl*))/(1-*p_tl***p_tl*)
p_2	Probability of recovering a fish with 2 tag2, *p_2* = ((1-*p_tl*)*(1-*p_tl*))/(1-*p_tl***p_tl*)
p_0	Probability of losing two tags, *p_0* = *p_tl* * *p_tl*
q_0	Probability of retaining at least 1 tag, *q_0* = 1 – *p_tl***p_tl*
Mb_adj	Number of tags released adjusted for tag loss, *Mb_adj* = *Tags* * *q_0*

Table 7. Summary statistics used to estimate spawners above weirs.

Statistic	Definition/Equation
count	Number of fish released and passed above the weir
Fcarc	Number of females examined above the weir for spawning success
Fsuc	Number of females examined above the weir that had spawned (i.e., egg retention less than 75%)

Table 8. Likelihoods and derived parameters to estimate spawner abundance above weirs.

Description	Likelihood/Derived Estimates
Mu	*mu* is the mean catch from CRC harvest estimates
Prec	*prec* = 1/variance from the CRC harvest estimates
Pr(catch)	*catch*~ Normal(*mu,prec*) estimated from CRC returns
Pr(spawn success)	*Fsuc*~ Binomial(*pSuc,Fcarc*)
WeirSpawners	*WeirSpawners* is the number of fish above the weir that attempted to spawn, *WeirSpawners = Nb*pSuc-catch*

While we executed a study design each year to estimate abundance using carcass tagging via the Jolly-Seber model, insufficient numbers of marks released and/or recoveries in all three years prevented us from generating spawner abundance estimates using this method.

Area-Under-the-Curve (AUC) and redd-based estimates each rely on parameters known as apparent residence time (ART) and apparent female per redd (AFpR), respectively (Rawding et al. 2014a, Parken et al. 2003). We used mark recapture estimates paired with live spawner counts and census redd counts from other LCR Chinook salmon populations to develop ART and AFpR values to apply to the Grays River. For these datasets, mark recapture estimates were derived using either a Hypergeometric Lincoln-Petersen for closed populations or the Jolly-Seber model for open populations (depending on the study design). These estimates were then adjusted for any prespawn morality then paired with live or redd counts and sex ratio data to derive apparent residence time (ART) and/or apparent females per redd (AFpR) specific to the study year and population.

For ART values, we used the mean of four independent estimates from 2003 and 2004 on the Coweeman River and 2005 and 2006 on the East Fork Lewis River to use for the 2008 and 2009 Grays River AUC estimates. For 2010 Grays River AUC estimates, we used the mean of five values all from 2010 including Mill and Germany creeks and Coweeman, Washougal, and Elochoman rivers.

For AFpR values, we used the mean of four independent estimates from 2003 and 2004 on the Coweeman River and 2005 and 2006 on the East Fork Lewis River to use for the 2008 and 2009 redd-based estimates. For 2010, we used the mean of the same four values as we used in 2008 and 2009 but added an additional value from the Elochoman River in 2010.

These parameters were then applied to live spawner or redd counts from the Grays River surveys to develop estimates of spawners (Table 9 and Table 10) (Gallagher et al. 2007; Parken et al. 2003). We expanded our spawner and redd counts by 30% to account for areas that were not surveyed weekly in 2008 and 2009. This includes the Grays River above the canyon and any tributaries including Fossil and Hull creeks.

Table 9. Summary statistics used from spawning ground surveys.

Statistic	Definition
Redd_tot	Total number of new redds observed during the spawning period
$Spawners_i$	Number of fish classified as spawners on day *i*
PC	The greatest number of live fish and/or carcasses observed on a single day during the spawning period

Table 10. Derived parameters for spawning ground abundance methods.

Parameter	Definition/Equation
F	Number of females in the population, $F = pF * N$
AFpR	Number of apparent females per redd, $AFpR = F / Redd\_tot$
AUCsp	The total number of fish days for spawners or area-under-the-curve. $AUCsp = 0.5\ t_0 Spawner_1 + \sum 0.5\ t_i(Spawner_i + Spawner_{i+1}) + 0.5\ t_s Spawner_{s+1}$. For days $i = 1,\ldots, s+1$.
ART	The apparent residence time, which is the average number of days a fish remains in the survey area; apparent residence time equals residence time when the survey area is the entire spawning distribution, $ART = AUCsp / N$
Nredds	Redd-based spawner abundance, $Nredds = (Redd\_tot * AFpR) / pF$
Nauc	AUC-based spawner abundance estimate, $Nauc = AUCsp / SL$

Peak Count Expansion Factor Estimator

To allow for comparison of 2008-2010 abundance estimates to historical estimates generated using peak counts, a peak count expansion factor was generated for the historical index survey area for each study year (Table 11).

Table 11. Derived parameters for peak count expansion factor.

Parameter	Definition/Equation
PCEF	Peak count expansion factor , PCEF = N/PC
Npc	Peak count-based spawner abundance estimate, $Npc = PC * PCEF$

N is the abundance estimate of adult Chinook salmon in the study year, PC is the peak count of adult Chinook salmon lives and carcasses in the historical index survey area in the study year (Grays River Hatchery bridge (rkm 2.7) to the mouth on the West Fork Grays River (rkm 0) and the mouth of the West Fork Grays (rkm 20.3) to “Torpas” on the Grays River (rkm 16.4)) Npc is an estimate of abundance if the study year’s PCEF is applied to a previous or subsequent year’s peak count of Chinook salmon on the Grays River.

Proportion Marked, Timing, Spatial Structure, and other VSP parameters

Important indicators for salmon populations include the number of females and marked fish (Rawding and Rodgers 2013). In addition, ages are a measure of diversity and are needed to reconstruct salmon runs for forecasting and spawner-recruit analysis (Rawding and Rodgers 2013, Hilborn and Walters 1992). The summary statistics and likelihoods for the proportions are found in Table 12 and Table 13. The annual estimates of marked and unmarked adults, adult males and females, and estimates of marked and unmarked adults by age were estimated by multiplying these proportions by the total escapement estimates.

Table 12. Summary statistics and derived parameters from spawning ground surveys to estimate proportions.

Statistic	Definition/Equation
Females	Number of adults that were females
Males	Number of adults that were females
Adults	Number of adults examined for sex and origin
pF	Proportion of adults that are females
pM	Proportion of adults that are males
Marked	Number of adults that were mass marked (adipose or left ventral fin-clipped)
Unmarked	Number of adults that were not mass marked (adipose and left ventral fin intact)
AD_Age_i	Number of adipose-clipped adults that are age *i*, *i*=3,4,5,6
LV_Age_i	Number of left ventral-clipped adults that are age *i*, *i*=3,4,5,6
U_Age_i	Number of unmarked adults that are age *i*, *i*=3,4,5,6
pMS	Proportion of adults that are mass marked
pAD	Proportion of adults that are adipose-clipped
pLV	Proportion of adults that are left ventral-clipped
pUS	Proportion of adults that are not mass marked
pAD_Age_i	Proportion of adults that are adipose-clipped adults that are age *i*, *i*=3,4,5,6
pLV_Age_i	Proportion of adults that are left ventral-clipped adults that are age *i*, *i*=3,4,5,6
pU_Age_i	Proportion of adults that are un marked adults that are age *i*, *i*=3,4,5, 6

Table 13. The likelihoods for sex, origin, and age proportions.

Description	Likelihood
Pr(Females)	*Females* ~Binomial(*pF*, *Adults*)
Pr(Males)	*Males* ~Binomial(*pM*, *Adults*)
Pr(Adipose-Clipped)	*Adipose-Clipped* ~Binomial(*pADS*, *Adults*)
Pr(Left Ventral-Clipped)	*Left Ventral-Clipped* ~Binomial(*pLVS*, *Adults*)
Pr(Unmarked)	*Unmarked* ~Binomial(*pUS*, *Adults*)
$Pr(AD\_age_i)$	AD_age_i ~Multinomial(pAD_Age_i, *Adults*)
$Pr(LV\_age_i)$	LV_age_i ~Multinomial(pLV_Age_i, *Adults*)
$Pr(U\_age_i)$	U_age_i ~Multinomial(pU_Age_i, *Adults*)

To estimate spawn timing, weekly survey counts of spawners were divided by the total count of spawners for each year to estimate the cumulative timing.

The spatial distribution of Chinook salmon spawning in the Grays River was visually evaluated by plotting the GPS locations of new redds on a stream layer of the basin

Weir Effectiveness

We examined three key metrics regarding weir effectiveness: weir capture efficiency, estimated proportion marked (pMark) without any marked weir removals, and change in pMark on spawning grounds due to marked weir removals. (Table 14 and Table 15).

Table 14. Summary statistics and derived parameters used for weir effectiveness.

Statistic	Definition
N_{aw}	Estimated adult Chinook salmon spawner abundance above the weir site
N_{bw}	Estimated adult Chinook salmon spawner abundance below the weir site
W_{up}	Number of Chinook salmon adults passed upstream at weir
W_{hrem}	Number of hatchery-origin Chinook salmon adults removed at the weir
W_{wrem}	Number of unmarked Chinook salmon adults taken for brood or trap mort.
H_{swim}	Number of adult Chinook salmon swim-ins removed at a hatchery facility above weir
pMS	Proportion of adult marked Chinook salmon spawners
MS_{aw}	Number of marked adult Chinook salmon spawners above weir

Table 15. Derived parameters for weir effectiveness.

Parameter	Definition/Equation
W_{eff}	Adult Weir Capture Efficiency $((W_{up}+W_{hrem}+W_{wrem})/(N_{aw}+W_{hrem}+W_{wrem}+H_{swim}))$
nwpMS	Estimated pMS without hatchery-origin adult removals at weir. $((MS_{aw}+W_{hrem})/(N_{aw}+W_{hrem}+W_{wrem}))$
cpMS	Estimated change in proportion of marked spawners from removal of hatchery-origin fish at the weir site.
% spbw	*nwpMS-pMS* Proportion of the spawning population that spawned downstream of the weir site. $N_{bw} / (N_{bw}+ N_{aw})$

Results

Weir Installation/Removal

In 2008, installation of the hybrid resistance/fixed panel weir began on September 16 and was completed on September 18. The weir was fished continuously while installed except for a five-day period due to a high water event. The resistance portion of the weir submerged and the upstream doors of the live box were opened on October 4 at 1 p.m. The trap was once again fully functioning on October 9 at 2 p.m. The weir was completely removed from the river on October 29.

In 2009, installation of the hybrid resistance/fixed panel weir began on August 12 and was completed on August 14. The weir was fished continuously while installed except during three high water events that occurred in mid-to-late October that caused the resistance panels to submerge. The majority of the weir structure was removed from the river on October 29, but due to high flows not all of it could be removed at that time. The remaining weir structure was removed the following week once flow levels sufficiently dropped.

In 2010, installation of the resistance board weir was completed on August 24 (Figure 4). The weir was fished continuously (Figure 5) while installed except for a couple of overnight periods in mid-September when the resistance panels submerged slightly due to debris loading up on the weir. The most substantial high water event of the season occurred overnight on October 9 into the morning of October 10. This high water event dislodged both trap boxes and sank the resistance panels for five days. On October 15, flows had subsided sufficiently to allow for weir removal to be accomplished.

Figure 4. Photos of the installation of the Grays River Weir, 2010.
(top left) A duckbill anchor driven into the streambed with rebar to secure the substrate rail. (top right) Modified sawhorses placed on each end of the resistance board panels. (bottom left) Attaching the passage chute to the substrate rail. (bottom right) Excavator with biodegradable food grade oil placing trap boxes into the water.

Figure 5. Photo of the Grays River Resistance Board Weir, 2010.

Weir Operation and Sampling

The weir and live box were checked daily while installed. All fish were sampled and removed from the live box daily. A total of 86, 183, and 59 Chinook salmon were handled at the Grays River Weir in 2008, 2009, and 2010, respectively (Table 16). In 2008, the first Chinook salmon was handled on September 22 and the last Chinook salmon was handled on October 4. In 2009, the first Chinook salmon was handled on September 3 and the last Chinook salmon was handled on October 17. In 2010, the first Chinook salmon was handled on August 28 and the last Chinook salmon was handled on September 26. (Figure 6, Appendix A).

Table 16. Numbers of salmonids handled at the Grays River Weir by mark type and disposition, 2008-2010.

		Number Trapped (Male/Female/Jack)			
Species	Mark	2008	2009	2010	Disposition
Chinook	LV or ADLV*	67 (23/38/6)	142 (54/83/5)	45 (19/16/10)	Removed
	AD only	1 (1/0/0) *	4 (2/1/1)	11 (2/6/3)	Removed
	None	18 (8/9/1)	37 (17/20/0)	3 (0/3/0)	Released upstream
	None	0	0	0	Released downstream
Coho	AD	605 (342/261)**	514 (294/217/3)	341 (194/139/8)	Released upstream
	None	24 (12/12)	51 (31/20/0)	86 (54/30/2)	Released upstream
Chum	None	6 (5/1/0)	0	2 (0/2/0)	Released upstream
Pink	None	1 (0/1/0)	0	0	Released upstream
Sockeye	None	0	0	0	Released upstream
	None	0	0	0	Released downstream
Steelhead	AD	0	0	1 (1/0/0)	Released upstream
	AD	0	0	0	Removed
	None	0	0	2 (0/2/0)	Released upstream

LV= Left Ventral Fin Clip; AD = Adipose Fin Clip

* Spring Chinook – visually identified by olive coloration, “snake-like” body and confirmed by scale analysis.

**Does not include two adipose-clipped coho with recorded sex as undetermined

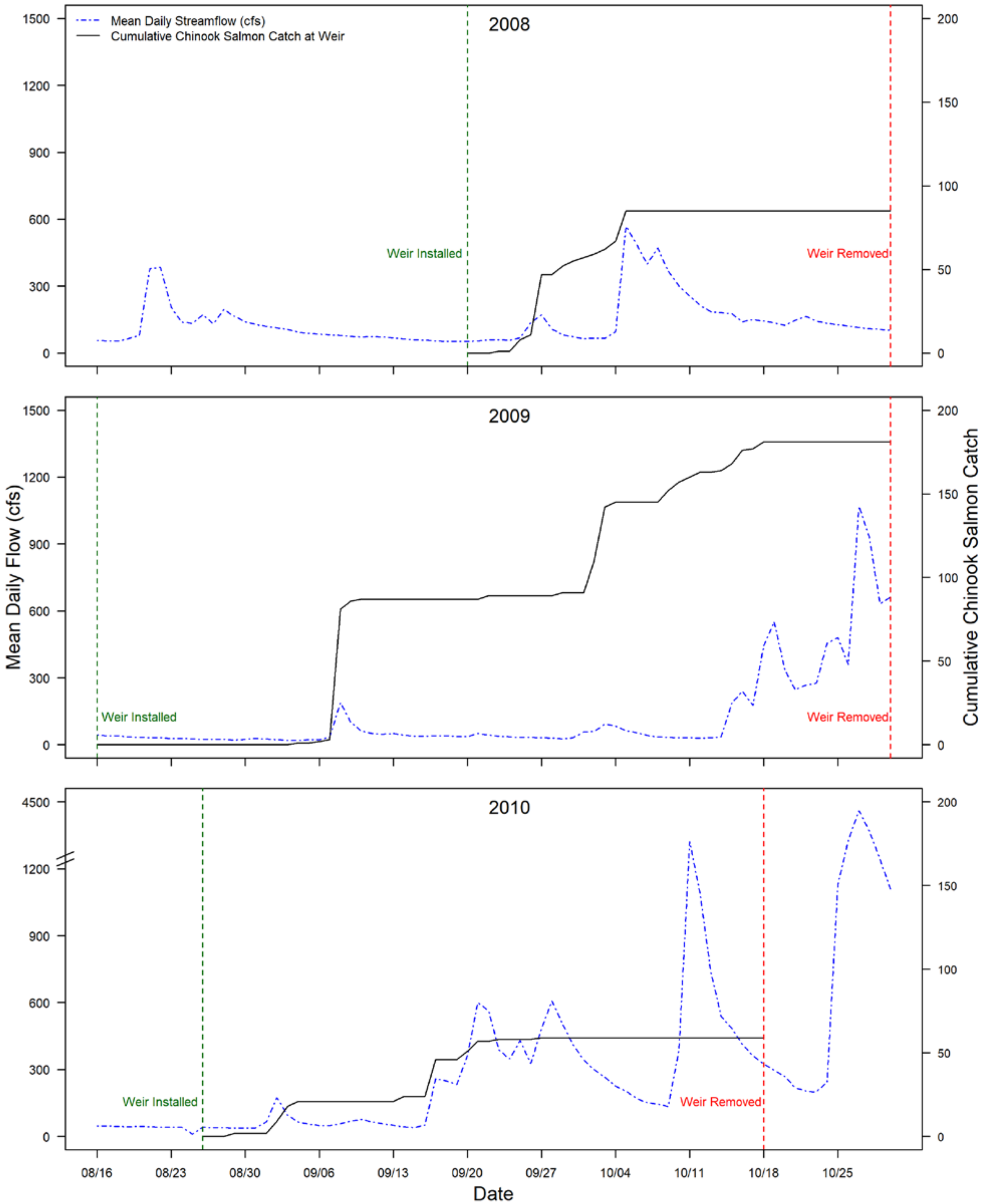

Figure 6. Cumulative Chinook salmon catch at the Grays River Weir by date in relation to mean daily stream flow (cubic feet per second, cfs), 2008-2010.

In 2008, 67 (77.6%) of the Chinook salmon captured at the weir were SAB fall Chinook salmon which were removed from the system. One (1.2%) adipose-clip only Chinook salmon was captured at the weir and it was also removed. This adult was identified visually as a spring Chinook salmon based on its olive coloration and "snake-like" body, and confirmed post-season based on scale analysis. A total of 18 (20.9%) unmarked Chinook salmon were captured, tagged and passed upstream.

In 2009, 142 (77.6%) of the Chinook salmon trapped at the weir were SAB fall Chinook salmon which were removed from the system. Four (2.2%) adipose-clip only fall Chinook salmon were captured and removed. A total of 37 (20.2%) unmarked Chinook salmon were captured, tagged and passed upstream.

In 2010, 44 (74.6%) of the Chinook salmon trapped at the weir were SAB fall Chinook salmon which were removed from the system. Twelve (20.3%) adipose-clip only fall Chinook salmon were captured and removed. A total of three (5.1%) unmarked Chinook salmon were captured, tagged and passed upstream.

Scale samples were collected from all Chinook salmon handled at the weir to determine age structure. A total of 75, 172, and 57 scale samples were successfully aged in 2008, 2009, and 2010, respectively. The overall age structure of Chinook salmon varied from year to year but age-3 Chinook was the dominate age class all three years (Figure 7).

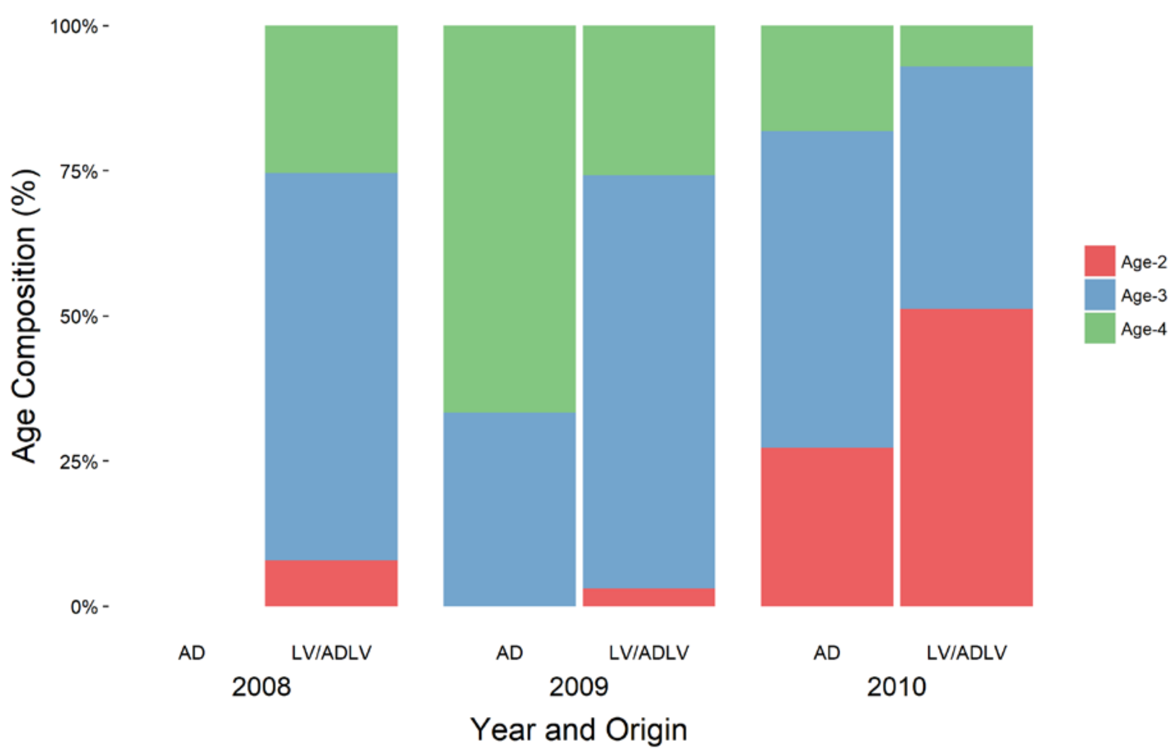

Figure 7. Relative age composition by mark type of Chinook salmon removed at the Grays River Weir, 2008-2010. Note no adipose-clipped fall Chinook salmon fish were removed in 2008.

A total of ten CWTs were recovered from Chinook salmon at the weir in these three years of operation. All were recovered from ADLV-marked SAB fall Chinook salmon and all ten tags decoded as SAB stock fall Chinook salmon released into the South Fork Klaskanine River (Table 17).

Table 17. Coded wire tag (CWT) recoveries from Chinook salmon removed at the Grays River Weir, 2008-2010.

Recovery Date	Recovery Location	Fork Length	Sex	Mark Type	Tag Code	Brood Year	Release Site
09/29/2008	Grays River Weir	84	Male	ADLV	094429	2005	SF Klaskanine River
10/03/2008	Grays River Weir	82	Male	ADLV	094429	2005	SF Klaskanine River
10/03/2008	Grays River Weir	78	Male	ADLV	094429	2005	SF Klaskanine River
09/07/2009	Grays River Weir	77	Male	ADLV	094604	2006	SF Klaskanine River
09/07/2009	Grays River Weir	86	Female	ADLV	094429	2005	SF Klaskanine River
09/07/2009	Grays River Weir	83	Female	ADLV	094604	2006	SF Klaskanine River
10/08/2009	Grays River Weir	81	Female	ADLV	094604	2006	SF Klaskanine River
10/15/2009	Grays River Weir	64	Male	ADLV	094604	2006	SF Klaskanine River
09/01/2010	Grays River Weir	75	Male	ADLV	090142	2007	SF Klaskanine River
09/02/2010	Grays River Weir	95	Male	ADLV	094604	2006	SF Klaskanine River

Genetic samples were collected from the all unmarked Chinook salmon handled at weir in 2008-2010. The samples had not been analyzed at the time this report was written.

Spawning Ground Surveys

Model Convergence and Diagnostics

We ran two chains of 70,000 iterations, with a burn-in period of 20,000 iterations and a thin rate of 5, for a total of 20,000 retained joint posterior parameter draws for subsequent inference. Of the 696 parameters monitored, over 90% had greater than 4,000 effective iterations. The remaining parameters had effective iterations ranging from 1,100 to 4,000. The fitted model was monitored for chain convergence by visually examining Markov Chain Monte Carlo trace plots and monitoring Rhat values which were less than 1.002 for all parameters monitored ensuring tracked parameters likely converged.

Assumption Testing of Spawner Abundance Estimates

We chose to report Chinook spawner abundance estimates using redd expansion. There are three critical assumptions of the redd expansion method (Rawding et al. 2014a): 1) Chinook salmon redds are accurately identified; 2) surveys are a census of all redds constructed; and 3) expansion factors reflect the true spawning activity and sex ratio.

We believe the first assumption, Chinook salmon redds are accurately identified, was met through conducting surveys using experienced field staff that had been trained by senior staff and by supervisors conducting periodic QA/QC walk behinds.

The second assumption, surveys are a census of all redds constructed, we believe was met in 2010 as we expanded our survey frame from 2008 and 2009. However, based on our expanded survey frame and the known spatial distribution in 2010, we believe our 2008 and 2009 sampling frame did not encompass the entire spawning distribution as the area above canyon on the Grays

River was not surveyed. We expanded our counts to account for the missed survey areas in 2008 and 2009. After these expansions, we feel confident in our spatial coverage. Surveys began prior to the start of fall Chinook salmon spawning and continued through December, well past the expected end of the spawning season, so we are confident that we covered the temporal distribution.

The third assumption, expansion factors reflect the true spawning activity and sex ratio, is a bit tougher to quantify. We used AFpR values from other LCR Chinook salmon populations as a surrogate for the Grays River population. We have no reason to believe these values would be substantially different population to population within the ESU provided all of the assumptions are met between the surrogate and study population.

With a weir in place, sex ratios can be determine based on fish passed upstream at the weir or compared to carcass recoveries. We conducted a set of chi-square tests to test for differences in sex ratio of Chinook salmon captured at the weir compared to carcasses recovered on spawning ground surveys. The results of these tests showed no significant difference (2008 χ^2 =2.137, df = 1, P = 0.144, 2009 χ^2 =0.001, df = 1, P = 0.984, 2010 χ^2 =0.810, df = 1, P = 0.368). Due to extremely small sample size of Chinook salmon passed upstream in 2010, and for consistency year to year and basin to basin, we choose to use the sex ratio of carcass recoveries on the spawning grounds rather than the sex ratio at the weir when developing redd-based estimates.

Spawner Abundance Estimates

Chinook salmon spawner abundance based on redd expansion requires an AFpR value, which was not available. Therefore, we used estimates from other Tule Chinook salmon populations as a surrogate (Table 18). Our redd-based Chinook salmon spawner estimates ranged from a low of 95 (95% CI 76-123) in 2008 to a high of 555 (95% CI 417-756) in 2009 (Table 19, Table 20, and Table 21).

Table 18. Estimates of year-specific apparent females per redd values used to derive redd-based fall Chinook salmon spawner abundance estimates (mean, standard deviation, and 95% credible intervals of the posterior distribution).

Year	Parameter	Mean	SD	L 95% CI	U 95% CI
2008	AFpR	1.08	0.08	0.94	1.27
2009	AFpR	1.10	0.07	0.98	1.25
2010	AFpR	1.10	0.07	0.98	1.25

Table 19. Estimates of Grays River fall Chinook salmon abundance in 2008 including sex- and origin-specific estimates for adult salmon (mean, standard deviation, and 95% credible intervals of the posterior distribution) for 2008.

Parameter	Mean	SD	L 95% CI	U 95% CI
Escapement	95	12	76	123
Male Esc.	24	10	9	48
Female Esc.	71	5	62	83
Marked SAB Esc.	36	8	21	55
Marked Tule Esc.	26	7	13	43
Unmarked Esc.	33	8	19	52

Table 20. Estimates of Grays River fall Chinook salmon abundance in 2009 including sex- and origin-specific estimates for adult salmon (mean, standard deviation, and 95% credible intervals of the posterior distribution)for 2009.

Parameter	Mean	SD	L 95% CI	U 95% CI
Escapement	555	87	417	756
Male Esc.	288	81	160	479
Female Esc.	267	16	238	304
Marked SAB Esc.	286	56	193	412
Marked Tule Esc.	59	22	23	113
Unmarked Esc.	210	47	132	315

Table 21. Estimates of Grays River fall Chinook salmon abundance in 2010 including sex- and origin-specific estimates for adult salmon (mean, standard deviation, and 95% credible intervals of the posterior distribution)for 2010.

Parameter	Mean	SD	L 95% CI	U 95% CI
Escapement	159	31	114	233
Male Esc.	62	20	30	108
Female Esc.	97	24	56	154
Marked SAB Esc.	70	20	36	118
Marked Tule Esc.	19	10	4	46
Unmarked Esc.	70	20	36	118

Peak Count Expansion Factor Estimator

We generated peak count expansion factors for the historical index area based on our 2008-2010 estimates of total Chinook spawner abundance for comparison to the historical estimator (Table 22). The PCE factor we estimated is for spawner abundance meaning sport harvest and any pre-spawn mortalities are not included.

Table 22. Grays River fall Chinook salmon peak count expansion factors for historical index area derived from 2008-2010 abundance estimates.

Year	Date of Peak Count	Mean	SD	L 95% CI	U 95% CI
2008	9/3	1.08	0.14	0.86	1.40
2009	10/12	3.15	0.50	2.37	4.30
2010	9/22	3.52	0.69	2.55	5.19
Mean 2008-2010		2.58	0.32	2.07	3.30

Proportion Marked, Timing, Spatial Structure, and other VSP parameters

The proportion of Chinook with external fin clips ranged from a mean of 54.2% in 2010 to a mean of 63.9% in 2008 (Table 23). Carcass recoveries by location and mark type give an indication of where different mark types are spawning. SAB Chinook carcasses tended to be recovered in the West Fork Grays River while unmarked Chinook carcasses were recovered more often in the Grays River (Figure 8).

Table 23. Proportion of marked Grays River fall Chinook salmon based on spawning ground survey carcass recoveries, 2008-2010 (mean, standard deviation, and 95% credible intervals of the posterior distribution).

Year	Parameter	Mean	SD	L 95% CI	U 95% CI
2008	pMark	63.9%	7.9%	47.7%	78.5%
2009	pMark	61.5%	6.0%	49.6%	73.1%
2010	pMark	54.2%	10.0%	34.6%	73.4%

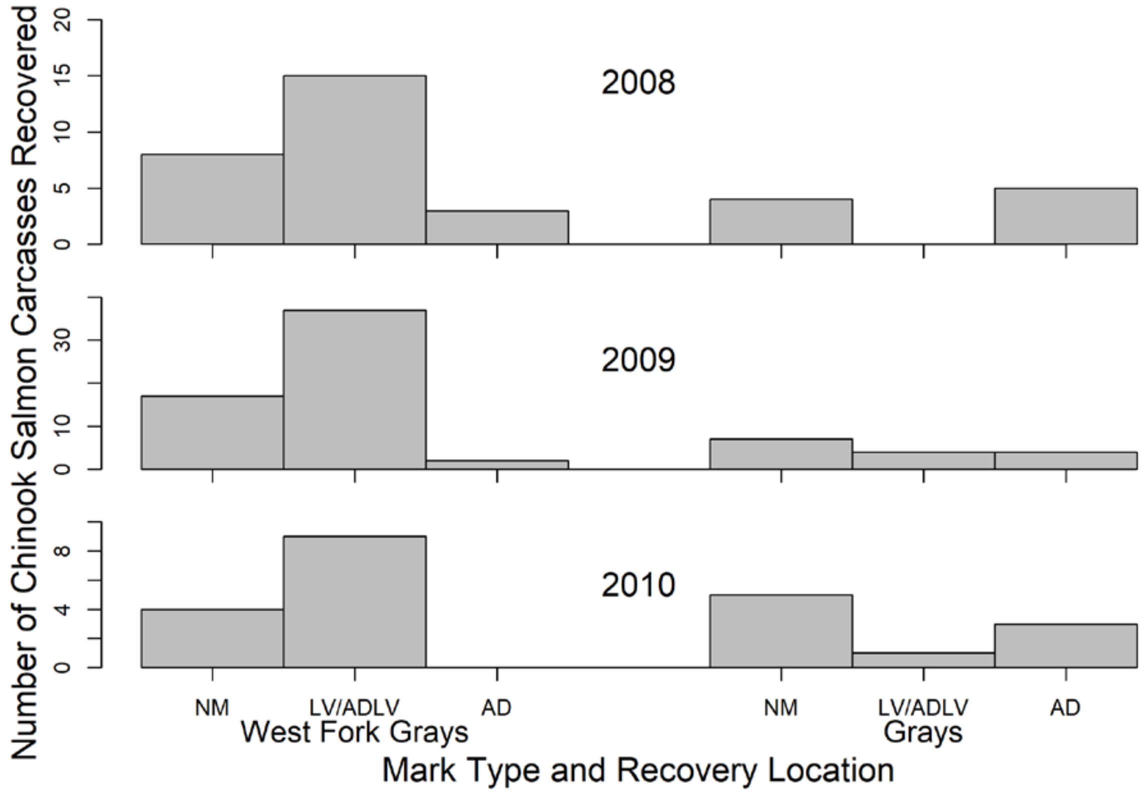

Figure 8. Number of Chinook salmon carcass recoveries by mark type and location in the Grays River basin, 2008-2010. Note no Chinook salmon carcasses were recovered in Crazy Johnson Creek.

A total of two CWTs were recovered from fall Chinook salmon carcasses recovered on spawning ground surveys in the Grays River basin between 2008 and 2010. Table 24 lists the CWT recovery information. Note that no CWTs were recovered in 2010.

Table 24. Coded wire tag (CWT) recoveries from fall Chinook salmon carcasses recovered on spawning ground surveys in the Grays River basin, 2008-2010.

Recovery Date	Recovery Location	Fork Length	Sex	Tag Code	Brood Year	Release Site
10/01/2008	Grays River	77	Female	632882	2005	Elochoman River
10/20/2009	Grays River	45	Male	090142	2007	SF Klaskanine River

The cumulative timing of Chinook salmon identified as “spawners” in the Grays River basin are shown in Figure 9. In 2008 and 2009, the 50% spawning date was October 16th. In 2010, the 50% spawning date was October 5th. Spawn timing is likely being heavily influenced by SAB stock Chinook salmon entering the system after weir is removed or during periods of time when the weir is submerged due to high flows.

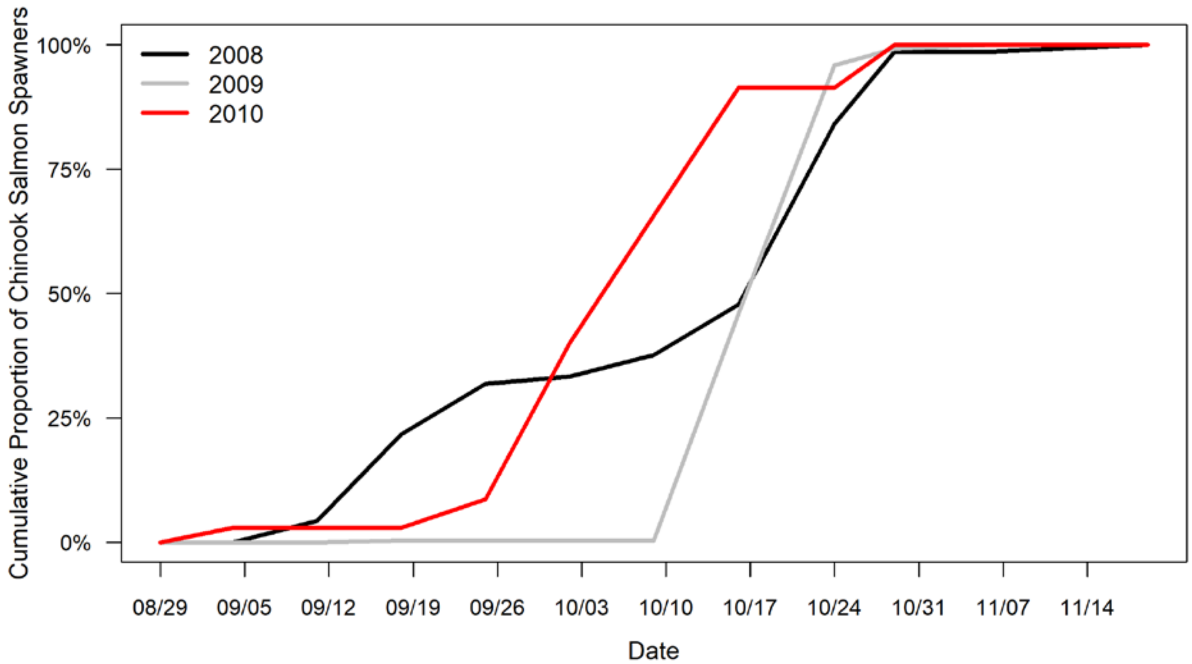

Figure 9. Spawn Timing of Grays River fall Chinook salmon based on cumulative counts of live Chinook identified as spawners, 2008-2010.

Spatial distribution of Chinook salmon was what we anticipated in 2008 based on the WDFW fish distribution model and surveys done in previous years. In 2009, an unseasonably warm and dry September and early October resulted in extremely low stream flows for that time of year. This paired with the weir in place resulted in several redds in the mile below the weir site. However, as flows came up later in the season, we saw Chinook redds distributed throughout the system. In 2010, September was wetter than normal and resulted in relatively high stream flows for that time of year. As a result, we saw no redds below the weir site and spawning distribution was as expected throughout the system (Figure 10).

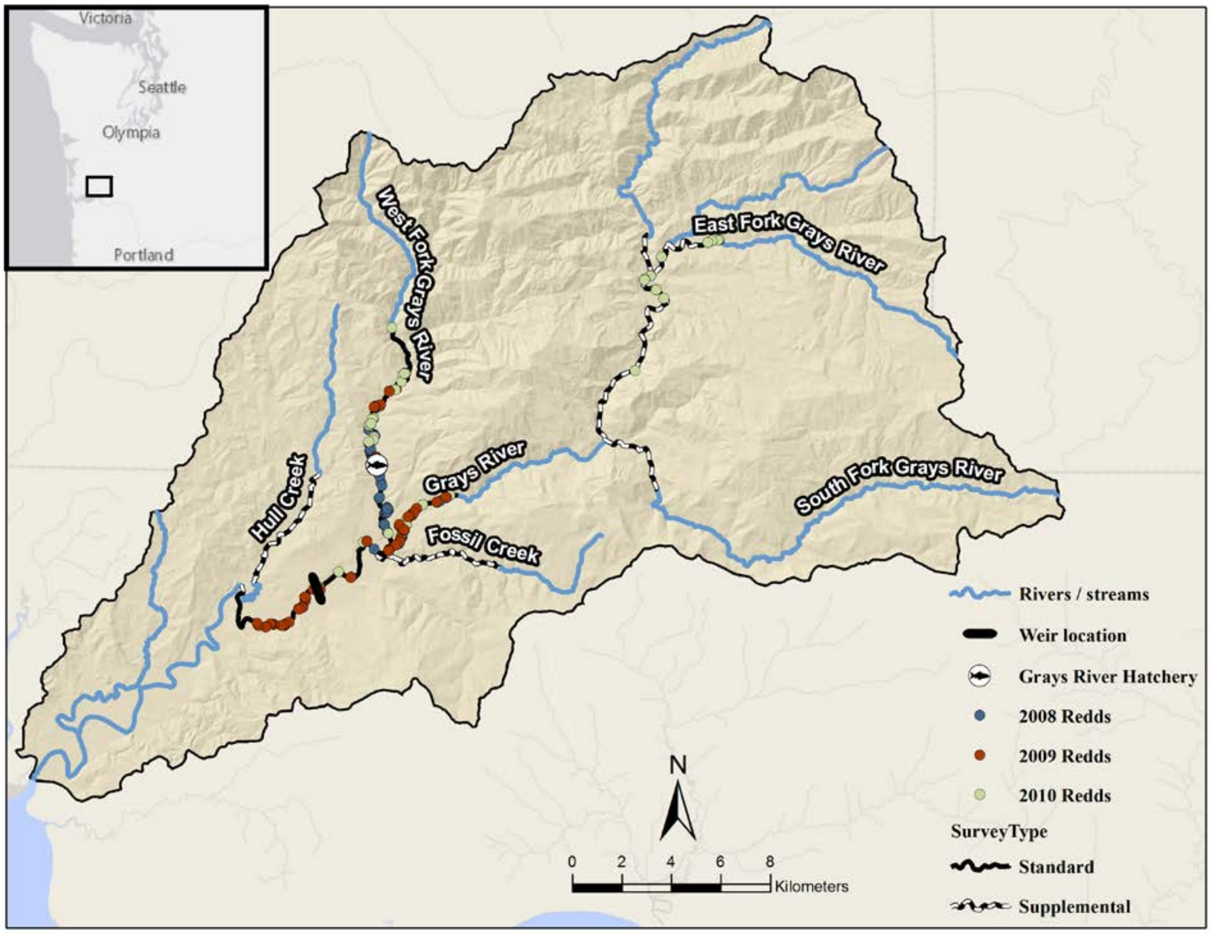

Figure 10. Distribution of fall Chinook salmon redds in the Grays River basin, 2008-2010. Note any redds observed above the canyon on the Grays River were excluded from this figure due to inconsistent survey frequency in those sections.

Scale samples were taken from all intact Chinook salmon carcasses encountered on spawning ground surveys. A total of 30, 57, and 19 readable scales were collected in 2008, 2009, and 2010, respectively. Age-3 Chinook salmon were the dominate age class found on the spawning grounds (Figure 11).

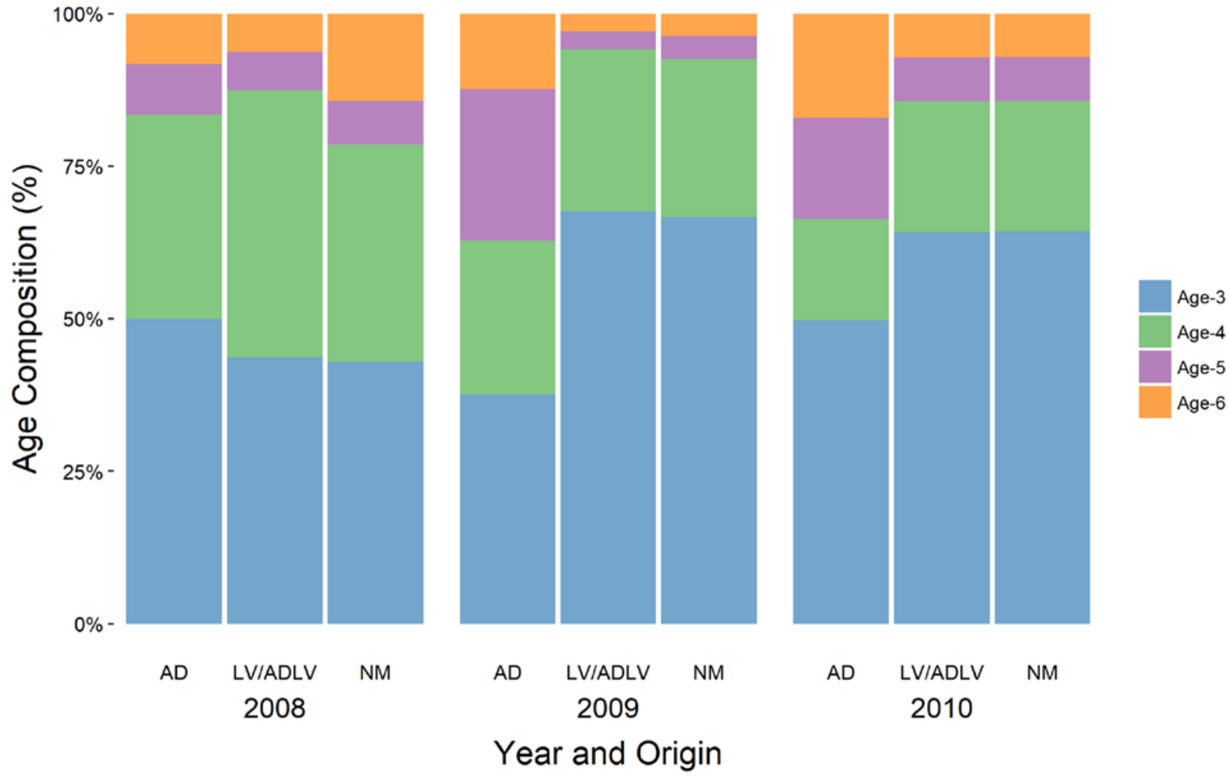

Figure 11. Relative age composition by mark type of adult fall Chinook salmon carcass recoveries during spawning ground surveys, 2008-2010.

Otolith and genetic samples were collected from all Chinook salmon carcasses recovered on stream surveys in 2008, 2009, and 2010. These samples had not been analyzed at the time this report was written.

Weir Effectiveness

To evaluate weir efficiency, the proportion of the upstream population captured at the weir, we used redd-based Chinook salmon spawner estimates for the area upstream of the weir, added in sport harvest above the weir based on catch record card data, and pre-spawn mortalities based on carcass recovery data to estimate the total number of Chinook that passed the weir. The mean and 95% credible interval (CI) values of the posterior distribution for weir efficiency for adult Chinook salmon was 44.1% (95% CI 36.4 – 52.5%) in 2008, 23.7% (95% CI 17.9 – 29.4%) in 2009, and 15.7% (95% CI 10.1 – 21.6%) in 2010 (Table 25).

Table 25. Weir efficiency for adult fall Chinook salmon at the Grays River Weir, 2008-2010.

Parameter	Mean	SD	L 95% CI	U 95% CI
2008 Weir Efficiency	44.1%	4.1%	36.4%	52.5%
2009 Weir Efficiency	23.7%	3.0%	17.9%	29.4%
2010 Weir Efficiency	15.7%	3.0%	10.1%	21.6%

While pMark for Chinook salmon in the Grays River is much higher than recommended by the HSRG (less than 10% for a contributing populations), counts of Chinook salmon handled at the weir show that pMark could be in the 79-95% range without using the weir for hatchery-origin stray removal. A total of 270 stray hatchery-origin Chinook salmon were removed through operation of the weir in these three years. Of the 270 adults removed, 253 Chinook salmon (93.7%) were SAB stock fall Chinook produced from SAFE program releases (Table 26) (Figure 12).

Table 26. Number of Chinook salmon captured by mark type at the Grays River Weir, 2008-2010.

	2008	2009	2010
Examined for marks	86	183	59
Marked SAB Chinook	67	142	44
Marked Tule Chinook	1	4	12
Unmarked Chinook	18	37	3
Proportion marked	79.1%	79.8%	94.9%

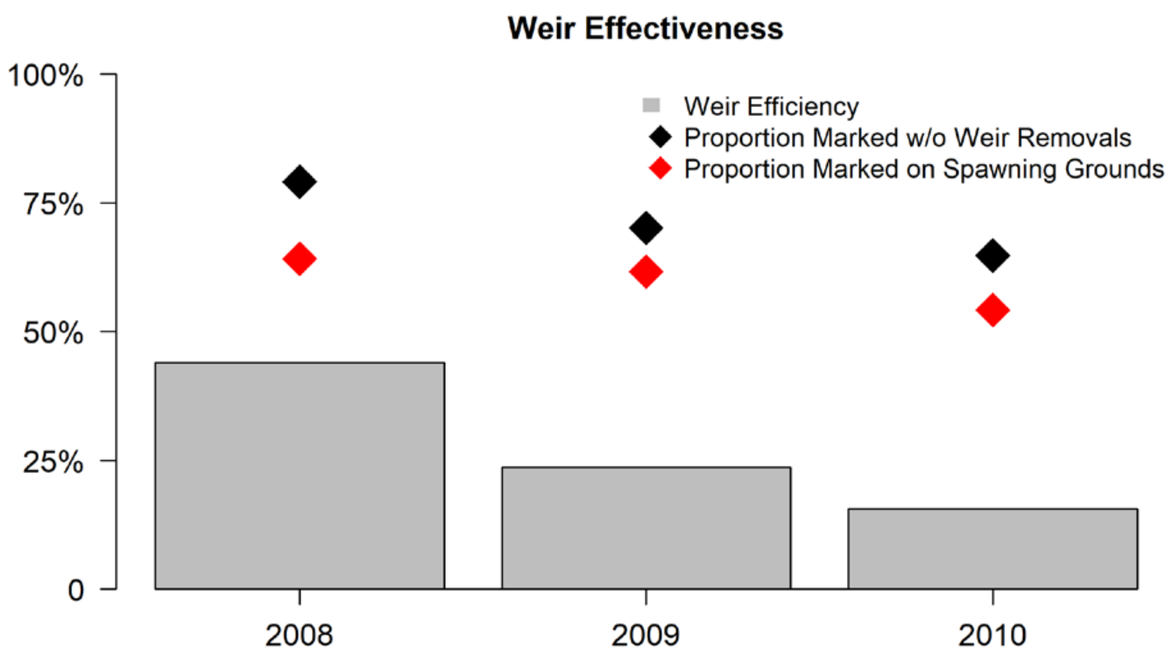

Figure 12. Estimates of weir capture efficiency, pMark, and pMark without hatchery-origin weir removals for fall Chinook salmon in the Grays River, 2008-2010. Weir efficiency is the proportion of the upstream population that was captured at the weir. The red diamond represents the proportion of the spawning population that was marked (indicated by an external fin clip). The black diamond represents what proportion of the spawning population would have been marked without removal of marked fish at weir.

To evaluate size selectivity of the weir, we conducted Kolmogrov-Smirnov (KS) tests for each year (Zar 1999). The results of the KS tests indicated there was no significant difference in size between Chinook salmon captured at the weir and carcasses recovered on spawning ground surveys for any of the three years ($D=0.0817$, $p=0.995$ in 2008; $D=0.1384$, $p=0.266$ in 2009; $D=0.3035$, $p=0.093$ in 2010) (Figure 13).

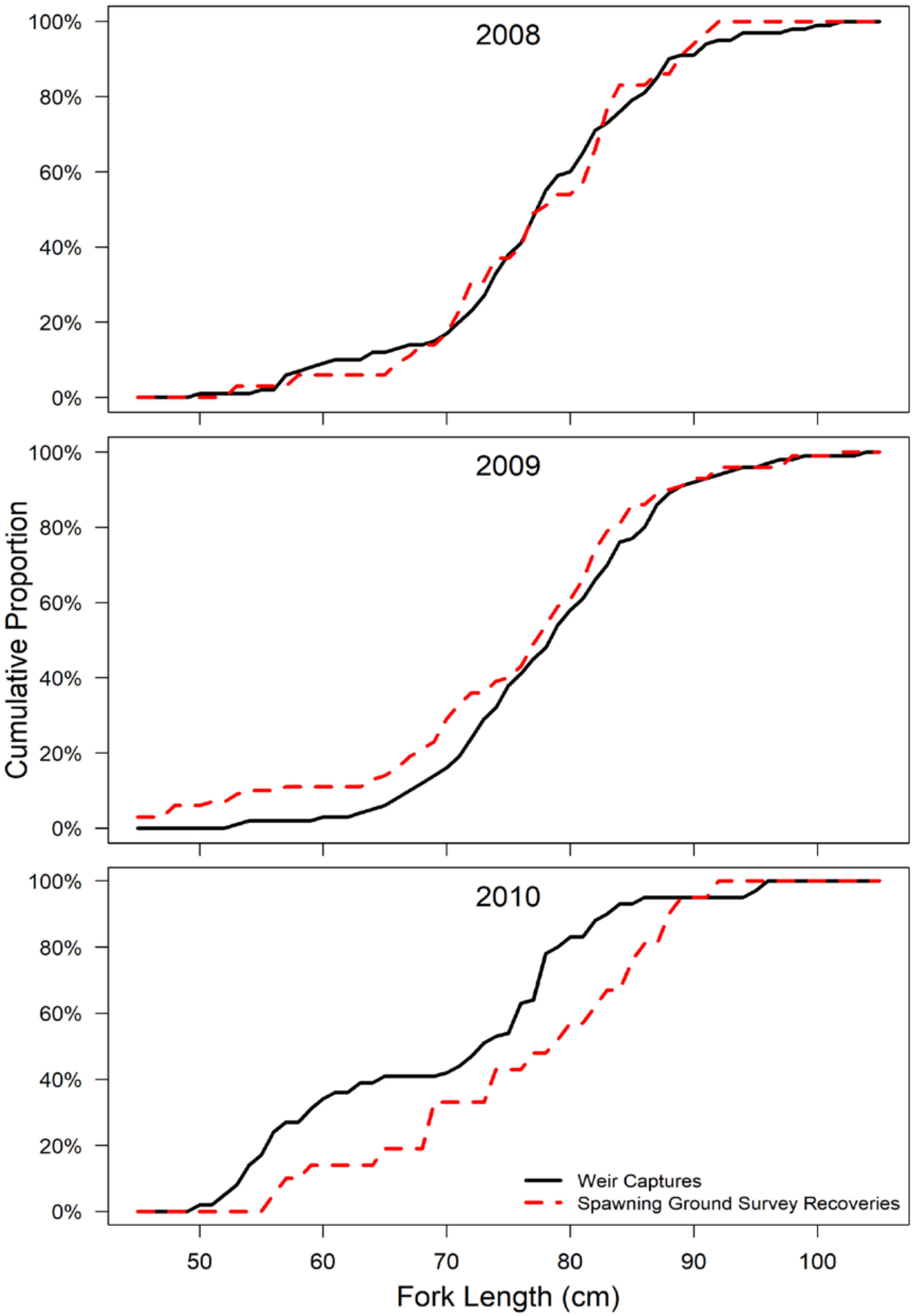

Figure 13. Cumulative fork lengths of fall Chinook salmon captured at the Grays River Weir compared to carcasses recovered on the spawning grounds.

Discussion

Weir Operation and Sampling

While sampling of captured salmonids went well overall, higher than expected tag loss rates in 2008 and 2009 were encountered. Peterson disc tags were chosen based on the ability of surveyors to correctly identify uniquely colored tags on live fish for mark/re-sight estimates and their expected low tag loss rates (Smith and McPherson 1981). The application of Peterson disc tags proved difficult due to the thick skin on Tule stock fall Chinook salmon. Field staff had a hard time pushing the metal pin through the skin and tissue at the base of the dorsal fin. The wire often bent and had to be discarded. This often occurred multiple times on a single fish. Tag retention was also much lower than expected. Between 2008 and 2010, five carcasses were recovered on spawning ground surveys with a LOP mark, indicating they were tagged at the weir, but only three had retained their Petersen disc tag. Research done on the Rogue River showed tag retention of Petersen disc tags on fall Chinook salmon can be over 90% (Smith and McPherson 1981).

In an attempt to solve this problem, uniquely numbered T-bar anchor tags were used in 2010 rather than Peterson disc tags. This made tag application easier but the T-bar anchor tags brought a new problem. Field staff noted that T-bar anchor tagged live fish were more difficult to identify, especially in deeper holding water. Correctly identifying tagged and non-tagged individuals is one of the key assumptions for the Lincoln-Petersen method. We will continue to work to resolve this issue in the future.

Weir Effects

In 2008, spawning ground surveys and direct observation at the weir site showed no displaced spawning or delay in upstream migration of any salmonids. In 2009, there was some displaced spawning that occurred below the weir (12.3% of the new, unique redds were below the weir site) as a result of delayed upstream migration. This occurred primarily the second week of October and was caused, in part, by unseasonably warm and dry conditions that resulted in lower than normal flows for that time of the year. The first substantial rain event didn’t occur until October 14 after which displaced spawning was no longer an issue. Weir design modifications were made in 2010 which improved fish recruitment into the trap box. In 2010, the impacts of displaced spawning and delayed upstream migration were not observed. We visually examined the spawning distribution of Chinook salmon in the Grays River basin from three years prior to weir installation (2005-2007) compared to the three years with the weir installed (2008-2010) (Figure 14). Note that surveys were only conducted down to Torpas (rkm 16.4) prior to 2008, which is downstream of the weir a few hundred meters. From 2008 to 2010, surveys were conducted down to river kilometer 12.9.

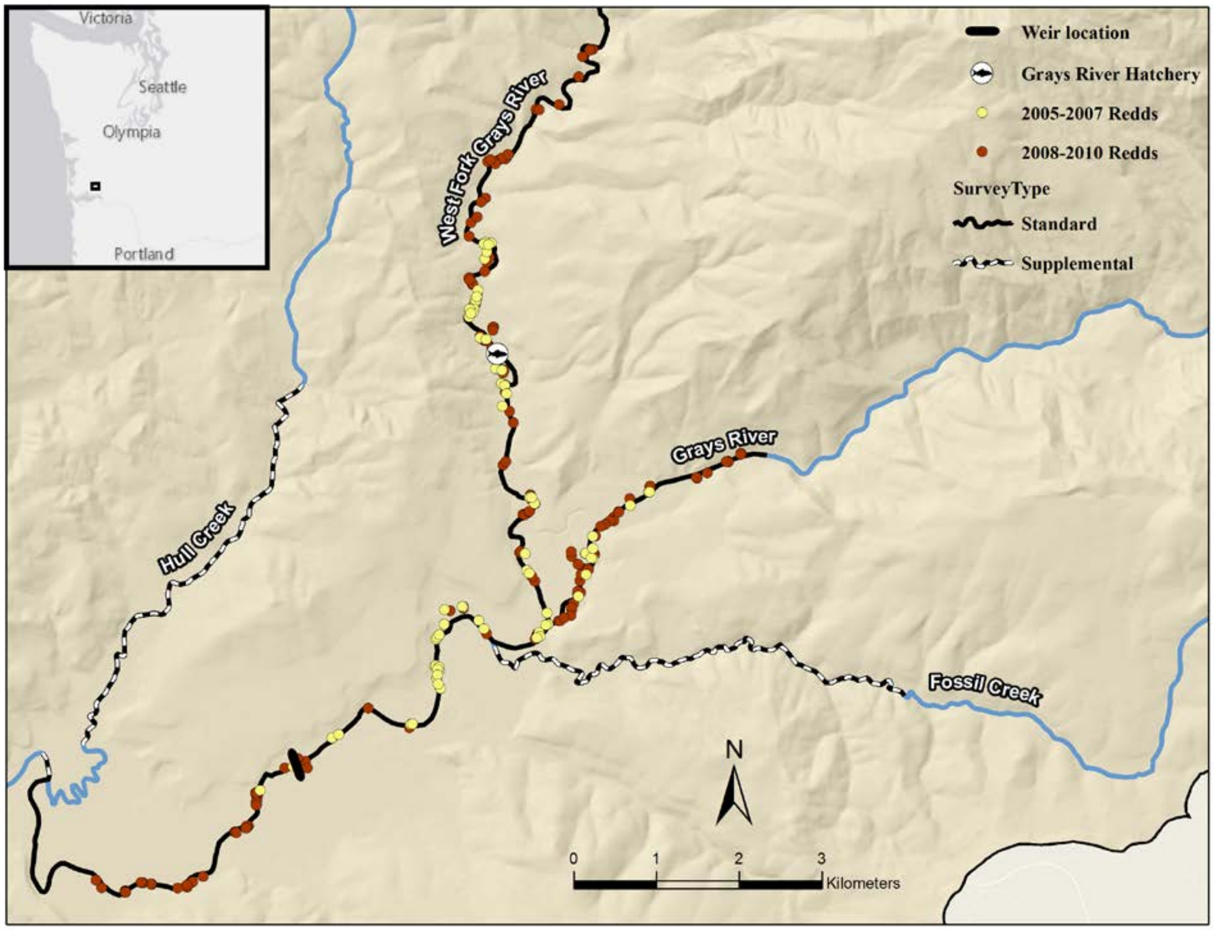

Figure 14. Distribution of fall Chinook salmon redds in the Grays River basin, 2005-2010.

Weir operations resulted in a total of three direct mortalities in these three years of operation. All were adipose-clipped coho salmon found inside of the live box. The overall mortality rate for salmonids handled at the weir was 0.42% in 2008, 0% in 2009, and 0% in 2010 (Table 27).

Table 27. Permitted and actual take levels of ESA-listed salmon by species, origin, and year.

		2008	2009	2010
Unmarked Chinook	Permitted Non-Lethal	750	750	750
	Actual Non-Lethal	18	37	3
	Permitted Unintentional Mortality	23	23	23
	Actual Unintentional Mortality	0	0	0
Marked Chinook	Permitted Non-Lethal	1500	1500	1500
	Actual Non-Lethal	0	0	0
	Permitted Removals	1500	1500	1500
	Actual Removals	68	146	56
Unmarked Coho	Permitted Non-Lethal	800	800	800
	Actual Non-Lethal	24	51	86
	Permitted Unintentional Mortality	24	24	24
	Actual Unintentional Mortality	0	0	0
Marked Coho	Permitted Non-Lethal	6300	6300	6300
	Actual Non-Lethal	605	514	341
	Permitted Unintentional Mortality	189	189	189
	Actual Unintentional Mortality	3	0	0
Unmarked Chum	Permitted Non-Lethal	14500	14500	14500
	Actual Non-Lethal	6	0	2
	Permitted Unintentional Mortality	435	435	435
	Actual Unintentional Mortality	0	0	0

Delayed mortality due to handling was not evaluated. Delayed mortality is hard to assess on adult salmon that are on or near their spawning grounds due to salmon spawning and naturally dying shortly after being handled at the weir. To minimize stress, and potential delayed mortality, all adult salmonids that could not be retained in the sport fishery were anaesthetized (MS-222) prior to sampling and tagging activities. All anaesthetized fish were allowed to fully recover before being released upstream. No tagged salmonids were recovered below the weir during stream surveys. This suggests that fallback of fish passed above the weir and their susceptibility to displacement downstream during the recovery period was negligible. Based on the metrics used to evaluate the weir's impact on natural-origin adults, we believe the weir's impact was minimal in all three years of operation.

Spawning Ground Surveys

2008-2010 Chinook Salmon Estimates

The study was designed to estimate Chinook salmon spawner abundance using four independent methods: Jolly-Seber via tagging of carcasses (Sykes and Botsford, 1986), Lincoln-Petersen via tagging at the weir and spawning ground survey observations of tagged and untagged individuals using a binomial model (Seber 1982), AUC based on live counts of Chinook salmon identified as "spawners" (Parken et al. 2003), and redd expansion based on a census of new, unique Chinook salmon redds.

In mark-recapture experiments, five to ten marked animals should be recovered per release group in order to produce unbiased estimates (Schwarz and Taylor 1998). Additionally, Seber (1982) recommends more than nine recaptures per recovery period for unbiased estimates of open populations. The low abundance of Chinook salmon in the Grays River made achieving these benchmarks difficult and removal, instead of tagging and releasing upstream, of hatchery-origin strays at the weir further exacerbated this problem.

Using the carcass tagging methodology, no more than four tagged carcasses were recovered in any given year (two in 2008, four in 2009, and two in 2010). We did not attempt generate any estimates using the Jolly-Seber model.

Estimates were generated using the binomial Lincoln-Petersen estimator in 2008 and 2009 but the estimates had large CVs (59.8% and 62.5% for 2008 and 2009, respectively). In 2010, only three Chinook salmon were tagged and passed upstream at the weir and none of these fish were re-sighted or recovered on subsequent stream surveys. Therefore, no abundance estimate was generated in 2010 using this method. We choose to not report the Lincoln-Petersen estimates for 2008-2010. While we did not use the Lincoln-Petersen estimator, it can be an accurate method of estimating Chinook salmon abundance in LCR Chinook salmon populations (Rawding et al. 2014a).

While AUC using counts of live "spawners" is a robust estimator of LCR Chinook salmon abundance, we felt there was some uncertainty in applying estimates of ART from other LCR Chinook salmon populations to the Grays River for two reasons. The main reason being that the weir could effect residence time due to upstream migration delays and this would result in the actual ART being shorter than what was used to derive abundance estimates, resulting in a negatively biased estimate. The other reason is that ART estimates available for use in this analysis have been derived from LCR Tule stock Chinook salmon populations and could be inappropriate for SAB stock Chinook salmon, which make up the majority of the Chinook salmon spawning population in the Grays River.

We ended up using redd expansion for our Chinook salmon spawner estimates. The assumptions of this method were met and provided an accurate estimate with a reasonable level of precision. However, based on the worked detailed in this report, it appears that use of the binomial Lincoln-Petersen estimator, AUC based on live counts of adult spawners, and redd expansion all have the potential to work well for estimating Chinook salmon spawner abundance in the Grays River. Mark-recapture would typically be the preferred method as mark-recapture assumptions can be tested relatively easily and it provides a way to develop estimates of ART and AFpR specific to the basin and year. However, it is dependent on tagging and recovering (or re-sighting) enough Chinook salmon throughout the run.

Peak Count Expansion Factor Estimator

Prior to 2005, Grays River Chinook salmon abundance estimates were developed solely through peak count expansion. The PCE factor for Grays River Chinook salmon was developed based on a single carcass tagging study conducted in 1978 (Fiscus and McIsaac 1979). Weekly surveys were conducted in the "index area" (Grays River Hatchery Bridge to "Torpas") where carcasses were sampled and tagged and total lives, deads, and redds were enumerated. Supplemental surveys were conducted during the presumed peak week in non-index areas to develop the PCE factor of 3.58 that has been used from 1978-2004 (Jenkins 2006).

As detailed in Jenkins (2006), each year, three weekly spawning ground surveys were scheduled in the established index area (Grays River Hatchery Bridge to "Torpas") around peak spawning activity to enumerate live and dead fall Chinook salmon. The highest single day peak count of combined live and deads was then multiplied by an expansion factor of 3.58 to estimate total escapement. While peak count expansion method can be a valuable and cost-effective method for estimating abundance trends, it can be biased as the assumptions are hard to meet (Parken et al. 2003; Parsons et al. 2010). One of the key assumptions of peak count expansion is that the run is similarly distributed spatially year to year. This assumption is often not tested and may be invalid as the spawning distribution can change based on environmental conditions, available spawning habitat, stock, and abundance. All four of these have likely changed since the peak count expansion factor was developed for the Grays River in 1978. Without multiple years' worth of mark recapture data to account for the year to year variability, peak count expansion can be a biased way of estimating abundance (Parsons et al. 2010). There is also uncertainty in what the historical PCE factor is estimating (total abundance or spawner abundance).

Another important point is the date of the peak count was highly variable year to year. In 2008, the peak was on September 3, while in 2009, the peak was on October 12. If staff had been only surveying the three weeks around the historical Tule peak, the last week of September, they would have missed both of these peaks resulting in a negatively biased estimate.

Our peak count expansion factor value for 2008 appears low (see Results – Table 22). There are two potential reasons for this: our 2008 spawner estimate is biased low or counts of fish identified as "holders" are in inaccurate (Chinook counted as holders may have been another species such as coho). The biases and uncertainty around PCE abundance estimates reaffirms the need for more accurate and precise methods of estimating abundance and suggest that historical PCE estimates should be used cautiously when evaluating long term abundance trends.

Proportion Marked, Timing, Spatial Structure, and other VSP parameters

Historically, CWT expansion of carcasses recovered on spawning ground surveys has provided a method of estimating out-of-basin strays prior to mass marking. Results of this expansion method showed 0 to 41.6% out-of-basin stray Chinook salmon in the Grays River between 1995 and 2006 (Jenkins 2006). The results of weir operations in 2008-2010 combined with more intensive spawning grounds surveys suggests the percentage of out-of-basin strays is much higher than previously documented for this population. There are two potential reasons for this: improved/increased monitoring effort in recent years and the transition to 100% mass marking in recent years.

Spawning ground surveys have historically been done weekly over a three-week period around the expected peak of Tule stock spawning in late September and early October. This likely biased stock composition towards Tule stock Chinook salmon rather than an unbiased stock composition for the entire spawning population. Since 2005, spawning ground surveys have been conducted from late August through December. This encompasses the spawn timing of the different Chinook salmon stocks present in the Grays River: spring Chinook, Tule stock fall Chinook, and SAB stock fall Chinook salmon. Additionally, the addition of the weir in 2008 has increased the number of Chinook salmon examined for external marks and CWTs rather than relying on spawning ground surveys alone.

While CWT expansion can be a reliable tool for estimating stock composition, it can become severely biased when the number of CWT recoveries are low (Pacific Salmon Commission coded wire tag work group 2008) which is often the case with spawning ground surveys. The implementation of mass marking has made the identification and enumeration of hatchery-origin fish more accurate as a fish can largely be identified as hatchery-origin or natural-origin based on visual cue. However, there are a few key assumptions that need to be met to accurately estimate the proportion of hatchery-origin spawners, or pHOS: 1) all hatchery-produced Chinook salmon must be marked/and or tagged prior to release and 2) all marks/tags are 100% recognizable.

These assumptions were not 100% met at the time of our work on the Grays River in 2008-2010. Mass marked releases of Tule fall Chinook salmon were beginning to return during these years (see Introduction – Table 1) and not all Chinook salmon were checked for the presence of a CWT (only Chinook salmon with an adipose clip). We examined only using age classes that were known to be 100% mass marked. For example, only including age-3 for 2008 rather than all age classes. However, there was not a significant difference between using on known mass marked age classes and all age classes; therefore, we chose to use all age classes. This is likely due to very few hatchery Tule Chinook salmon strays in the Grays River and the large number of SAB strays which were 100% mass marked for all age classes. Additionally, there are double index tag (DIT) groups (releases of hatchery-origin fish that are CWT tagged, but not fin clipped, used to assess mark selective fisheries) released from ODFW's Big Creek hatchery which is relatively close to the Grays River. Without examining all Chinook salmon for CWTs, there is the potential for enumerating these fish as natural-origin rather than hatchery-origin. In addition to DIT releases, some hatchery fish are unintentionally unmarked during release (though usually only 1-3%), but we did not adjust pMark to pHOS to account for these. For small populations, this can result in a sizeable underestimate of pHOS when using pMark, and an overestimate of pNOS when using pUnmark.

Therefore, we use the term pMark for this report which is simply the number of carcasses with a fin clip (either AD, LV, or ADLV) divided by the total number of carcasses examined for fin clip. While the pMark and the unmarked escapement estimates in this report gives a better estimate of the status of Grays River Chinook salmon than past methods, it should be noted that there are still potential sources of biases that we were not able to account for.

Weir Effectiveness

In 2008, five days of weir operations were lost due to high water events that caused the resistance panel portion of the weir to submerge. The first substantial rainstorm of the fall began late in the day on October 3 and lasted into the early afternoon on October 4. The Grays River Hatchery (an official NOAA weather station, located approximately 3.6 river miles upstream of the weir site on the West Fork Grays River) reported daily rainfall amounts of 1.65 and 0.76 inches on October 3 and 4, respectively. Subsequently, the average daily stream flow rose from 65 cfs on October 2 to an average daily stream flow of 539 cfs on October 4, with a peak stream flow of 1,141 cfs occurring at 4 pm on October 4 (WDOE 2010).

At 1 pm on October 4, the resistance portion of the weir submerged due to the high flows (564 cfs) and sediment deposits on the resistance panel portion of weir. At that time, the upstream trap door was opened to facilitate fish passage and prevent any fish from being trapped in the live box for the duration of the high water event. Figure 15 is a photo of the weir taken just after the resistance portion of the weir submerged (~500 cfs). Grays River stream flows gradually subsided and the weir was once again fully operational on October 9 at 2 pm when stream flows were 307 cfs. Some damage to the weir structure occurred during the high water event. A few resistance boards were lost when some of the 45 degree PVC brackets that they were attached to broke. For an in-season fix, anchor buoys were placed underneath panels that lost their resistance boards.

Figure 15. Photo of Grays River Weir taken on October 4, 2008 after resistance board portion of the weir had submerged (564 cfs) (data from WDOE 2008).

Prior to installing the weir in 2009, three significant modifications were made to the weir design in an attempt to improve weir/trapping efficiency at higher flows: 1) a second “high water” live box was added; 2) both live boxes had been modified to allow for the floor and V-weir to be raised and lowered; and 3) an air bladder was added underneath the resistance panel section in place of resistance boards. The two live box design allowed one live box to be placed in deeper water for use during low flows in August and early September, and the second live box to be placed in shallower water, for use during moderate to high flows. The two box system allowed field staff the ability to close the first trap box as flows increased and use the second trap box during higher flow periods. The movable floor and V-weir added to the primary live box, which was in deeper water when flows rose, improved sampling efficiency and added more flexibility in accessing trapped fish. The air bladder system was designed to improve weir efficiency at higher flows and reduce downtime after a substantial high water event. The bladder system consisted of two 50 foot cylindrical bladders with air hose fittings that could be inflated or deflated. This enabled buoyancy of the resistance panel section of the weir to be specifically adapted to the water conditions on any given day.

In 2009, six days of weir operations were lost due to high water events that caused the resistance panel portion of the weir to submerge. The first high water event took place late in the day on October 14. The Grays River Hatchery reported 1.09 inches of rain on October 14 resulting in a peak flow of 419 cfs at 6 pm. This caused a portion of the resistance panel weir to submerge at roughly the same time as flows peaked, 6 pm on October 14. The weir was once again fully operational on October 15 at 10:30 am at which time flows has decreased to 254 cfs.

The second high water event of the 2009 trapping season occurred on October 23 when the resistance panel portion of the weir sank at 2:30 pm, flows were 663 cfs. Flows from that rain event peaked on October 23 at 5:30 pm at 685 cfs. As flows receded, the weir was once again fully functioning on October 24 at 2:30 pm when flows were 455 cfs. The Grays River Hatchery reported 1.08 and 0.29 inches of rain of October 22 and 23, respectively.

The third and most substantial high water event of the 2009 trapping season occurred on October 26. The weir sank at 7:00 am when flows were 756 cfs and rapidly increasing. Flows from this rain event peaked at 1,620 cfs at 12:00 pm on October 26. The Grays River Hatchery reported 1.95 and 0.73 inches of rain on October 25 and 26, respectively. The high flows from the October 26 event caused a scour hole beneath the fixed panel portion of the weir and caused the both trap boxes to tilt forward due to scour that occurred beneath them. Due to the scour damage done, the increasing risk of future high water events based on the weather forecast, and the fact that no Chinook salmon had been handled at the weir since October 17, the decision was made to remove the weir when flows subsided enough to do so. The majority of the weir structure was removed from the river on October 29 when flows dropped to around 700 cfs. Two sawhorses were left in the river that day and removed the following week when flows receded (Figure 16).

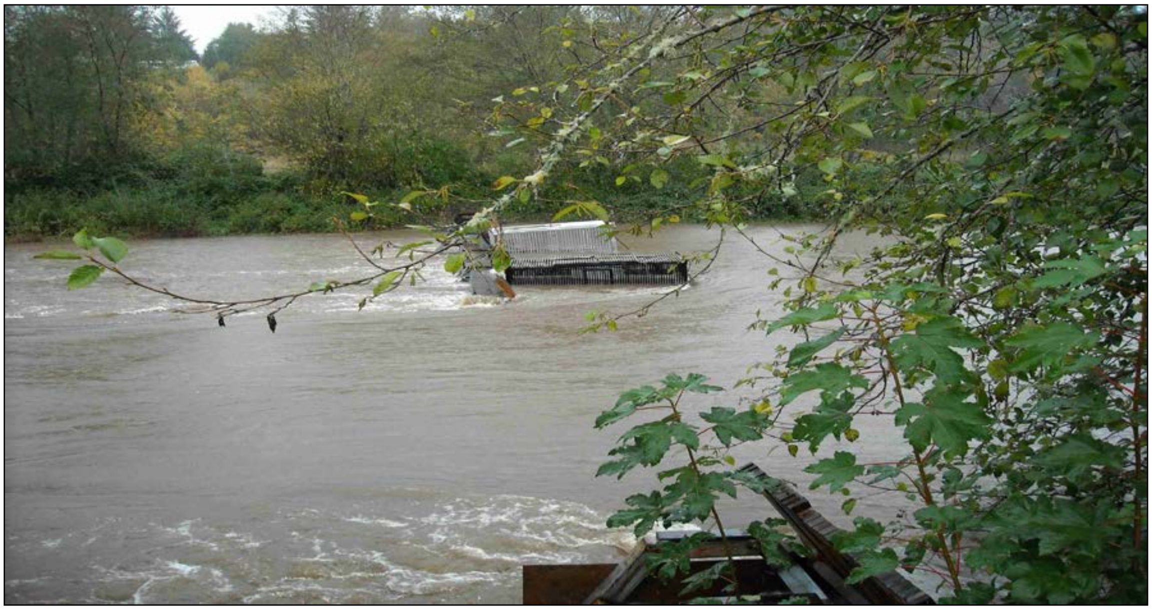

Figure 16. Photo of Grays River Weir taken on October 26, 2009 at noon (1,620 cfs) (data from WDOE 2010).

The live box movable floor modification done in 2009 was a success. The movable floor allowed field staff flexibility in accessing fish in the trap box which improved sampling efficiency. While the second live box was only used on one day in 2009, the two live box design appears to have the potential to work well if the weir can be fished successfully at higher flows. The bladder system that was added in 2009 in place of the resistance boards worked well at lower flows but did not improve the weir's efficiency at higher flows as anticipated. The resistance board portion of the weir submerged at a similar flow in 2009 as in 2008 (between 400-570 cfs).

The design of the Grays River weir was again changed in 2010 in a continued attempt to improve the weir's efficiency at higher flows and fish recruitment. There were three major changes done in 2010 to increase weir efficiency at higher flows: 1) fourteen new resistance board panels were added which replaced the majority of the fixed panel portion of the weir; 2) reinforced resistance boards were added to each of the resistance panels; 3) expanded metal was used to "seal up" each of the sawhorses that anchor the resistance board section of the weir; and 4) box tubing with holes drilled in it was mounted horizontally on each of these sawhorses. Sections of PVC pipe were installed to help seal the transition areas between resistance and fixed panels on each side of the resistance panel section of the weir. These transition areas were problematic in 2008 and 2009 as they were the first to sink during high water events (Figure 17).

Figure 17. Photos of Grays River Weir modifications made between 2009 and 2010 trapping seasons.

In 2008-09, the live box/es had been integrated into the fixed panel portion of the weir. This had been a problem for fish recruitment due to the lack of flow going through the live box to attract fish as the majority of the flow went over the resistance panels rather than through the live box as with a traditional fixed panel weir. As a result, fish tended to hold underneath the resistance panels and had a hard time finding the live box. To improve fish recruitment in 2010, the location of the live boxes was changed to include them in the resistance panel section of the weir instead of being part of the fixed portion and two resistance panels were modified to include passage chutes. The new design improved fish recruitment as fish were still attracted to underneath the resistance panels but they were be able to find the passage chute opening which led them to the live box. Figure 18 shows the Grays River weir design in 2008 compared to 2010.

Figure 18. Photo of the Grays River Resistance Board Weir. The top photo was taken in 2008 and the bottom photo was taken in 2010.

In 2010, no substantial time was lost due to the weir being submerged until October 10. Field staff were stationed at the weir 24 hours a day but only cleaned the weir during daylight hours due to safety concerns. As a result, the weir submerged slightly overnight on a two occasions due to debris loading up on the weir. Once staff cleaned off the weir in the morning, the weir "popped up" and was once again fully functioning. We believe fish passed the weir unsampled during these two events due to the number of Chinook salmon observed below the weir before and after these occasions (Figure 19).

On the evening of September 20, 2010, both Chinook and coho salmon were observed jumping over the weir when flows were ~720 cfs. This is the first time that this was observed.


Figure 19. Photo of Grays River Weir at 700-800 cfs river level, 2010.

In 2010, the most substantial high water event occurred overnight on October 9 into the morning of October 10. The weir submerged overnight as flows were rapidly rising. The Grays River Hatchery reported 0.15 and 2.30 inches of rain on October 10 and 11, respectively. Flows from this rain event peaked at 4,180 cfs at 05:45 am on October 11. The high flows caused both trap boxes to dislodge as the duckbill anchors were pulled out of the riverbed substrate. Both trap boxes were subsequently recovered downstream with little damage. Due to the trap boxes being dislodged (requiring heavy equipment to reinstall) and most of the Chinook salmon being trapped prior to October 10 in 2008 and 2009, the weir was removed on October 15. A positive outcome of the high water event was it demonstrated the weir's ability to withstand the high flows and debris load with minimal scour damage and minimal damage to the PVC resistance panels. If the trap boxes hadn't dislodged, the weir would have been fishable again in a few days as flows subsided.

Weir efficiency for Chinook salmon was lower than desired all three years. There were a few different reasons for this. In 2008 and 2010, permitting delays resulted in the weir not being installed by our target timeframe of early August. In 2008 and 2009, there were consistent problems with the transition areas between the fixed and resistance board panel sections of the weir. Changes were made to the design of the weir in 2010 which eliminated these transition area problems and helped improve the weir's ability to fish high flow events.

In all three years of weir operations, Chinook salmon catch at the weir was very flow dependent. While the weir was able to stay afloat to flows in excess of 500 cfs in 2008 and 2009, and close to a 1,000 cfs in 2010, over 80% of the Chinook catch occurred when average daily stream flows were less than 200 cfs. The highest Chinook catch was typically observed on the first significant rainfall event of the season. This would typically increase flows enough to cause fish to move upstream within the system but not large enough to cause the weir to submerge.

An increase in sport harvest is an important thing to consider when determining the effectiveness of the Grays River Weir as the weir may artificially increase harvest rates below the weir site as fish stage to enter the weir's trap box. We examined WDFW catch record card data from 2003-2010 to help answer this question. For the purpose of this report, we classified any Chinook salmon caught between August and December as a fall Chinook. In the five years prior to the weir being installed (2003-2007), there was no reported adult fall Chinook salmon catch in the Grays River or West Fork Grays River. In 2008, the first year the weir was installed, 44 adult fall Chinook salmon were harvested (25 in the Grays River and 19 in the West Fork Grays River). In 2009, harvest increased to 391 adults (all from the Grays River). In 2010, harvest was 173 adult fall Chinook salmon (167 in the Grays River and 6 in the West Fork Grays River) (*Eric Kraig, WDFW, personal communication*). While we do not know the breakdown of adult Chinook salmon harvest below and above the weir site in 2008-2010, our on the ground professional judgement makes us believe that most of the harvest is occurring below the weir site. Any Chinook harvested below the weir are not accounted for in our weir efficiency estimates. However, these additional fish being harvested in mark selective fisheries below the weir site are ultimately helping achieve one of the project goals (i.e. reducing the number of hatchery-origin spawners) with the trade-off of a potential increase in the number of natural-origin fish caught and released with an unknown hooking mortality rate and/or these fish being illegally harvested.

Recommendations

Data collected after three years of weir operations in conjunction with intensive spawning ground surveys in the Grays River basin shows a high proportion of marked spawners (pMark) in a basin where there are no hatchery-origin fall Chinook salmon releases. Spawning ground surveys conducted in nearby tributaries (Mill, Abernathy, and Germany creeks) between 2008 and 2011 shows a similar high proportion of pMark (93.0% - 94.5%) in basins where there are no Chinook salmon plants (*Jeremy Wilson, WDFW, unpublished data)*. The number of out-of-basin hatchery-origin stray Chinook salmon , particularly SAB stock, in the Grays River basin poses a serious threat to the naturally spawning population of early fall Chinook salmon by compromising genetic integrity through hybridization (Roegner et al. 2011) and potentially limiting the productivity of the native stock (Araki et al. 2008; Chilcote et al. 2011). We recommend the following measures be taken:

1.) The Grays River Weir should be installed no later than August 1 each year. This will ensure the weir is installed prior to the start of the fall Chinook salmon upstream migration which will increase weir efficiency and the number of out of basin strays removed.

2.) SAB stock fall Chinook salmon releases from the SAFE program should be closely monitored through spawning ground surveys in the coast strata encompassing the spawn timing of SABs , and modified if needed, to reduce straying to Washington populations. All of the CWT recoveries at the weir in 2008, 2009, and 2010 were SAB stock fall Chinook salmon released into the SF Klaskanine River. This suggests a straying problem specific to the broodstock releases rather than the Youngs Bay net pen releases.

3.) An integrated, conservation level fall Chinook salmon hatchery supplementation program should be considered on the Grays River to assist and expedite recovery efforts as specifically recommended in the Columbia River Hatchery Reform System-Wide Report (2009). All of these fish should be coded wire tagged and not adipose-clipped to determine smolt to adult return rates, non-selective fishery exploitation rates, and their contribution to the naturally spawning population.

4.) Expand on the work done by Roegner et al. (2010) by analyzing archived adult and juvenile genetic samples. Genetic samples were collected from all carcasses recovered on spawning ground surveys, from all live unmarked Chinook salmon passed upstream at the weir, and a subsample of juveniles captured at an out-migrant trap operated in the basin (Hillson et al. 2017). It would be very informative to know what proportion of the natural production is Tule stock vs. SAB stock vs. hybrids as this could have management and recovery planning implications.

5.) The suite of population estimation methodologies outlined in this report should continue to be used until all of the critical assumptions for each method can be verified and basin-specific estimates of AFpR and ART can be developed. This includes: conducting QA/QC surveys to verify live and redd counts and ensure tags/marks are not missed; conducting a snorkel survey above the weir after installation to verify the weir was installed prior to the start of upstream migration; expanding the supplemental survey areas (e.g. Fossil and Hull creeks) to ensure the entire spawning distribution is covered and to validate the assumption we made that 30% of the Chinook salmon spawning is occurring above the canyon; and further assessment of tag retention.

6.) Explore adding a second weir (or video weir) and/or increasing survey frequency to improve the precision of Lincoln-Petersen mark-recapture estimates. The precision of a mark-recapture experiment is directly related to the number of recaptures (Seber 1982). As with many LCR Chinook salmon populations, the critically low abundance makes mark-recapture work difficult. A second weir and/or more surveys would result in more observations of tagged and untagged fish throughout the season thus increasing the precision of the abundance estimates.

7.) Monitoring juvenile salmonid production in the Grays River should continue. Juvenile production estimates and genetic analysis of out-migrant Chinook salmon juveniles can be used to evaluate the success of and adaptively manage recovery and management strategies.

8.) It will take substantial investments to upgrade the weir designs to achieve a weir effectiveness of 90%, which we believe would begin to achieve pHOS targets. Continue to explore weir design improvements including: improving the substrate rail design by installing heavier duty duckbill anchors, adding additional floatation to the resistance panels, and adding bulkheads where resistance board weir transitions to the river bank.

9.) Station two technicians at the weir on nights when flows are up or expected to rise. This will enable the weir to be cleaned safely overnight and improve weir efficiency.

10.) Develop models to account for unclipped hatchery-origin spawners. While the analyses completed for this report does not account for this, methods to do so are in development (*Jeremy Wilson, WDFW, unpublished data*) and these should be included when estimating pHOS in the future.

11.) Develop a hierarchical mixed effect model with inputs from multiple LCR fall Chinook salmon populations across several years to develop more accurate estimates of ART and AFpR for populations and/or years where it is unknown.

12.) Explore the use of informative or hierarchical age priors. With sparse data (as is the case on the Grays River for Chinook salmon), vague priors can have more influence on the estimates than is intended.

13.) Calibrate historical fall Chinook salmon estimates based on newly developed peak count expansion factors when all of the assumptions have been fully vetted.

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Appendix A: Grays River Weir Chinook Biodata

The tables in this appendix are the raw biological data collected from Chinook salmon captured at the Grays River Weir during its operation in the fall of 2008, 2009, and 2010. The biological data consists of fork length, sex, fin clips, disposition, and scale age of all Chinook as well as tag colors and numbers and opercula punches applied to live fish passed upstream. These tables also link recapture information including carcass recovery data and location back to the maiden capture event at the weir site.

Table A1. 2008 biological data collected from Chinook salmon captured at the Grays River Weir.

Date	Fish #	Fork Length	Sex	Fin Clips	Disposition	Scale Age	Tag Color	Tag #	Tag #	Operculum mark	Carcass Recapture Date	Carcass Recovery Location
9/22/2008	1	98	Male	None	Upstream	41	Orange	3500	3501	LOP		
9/24/2008	2	74	Male	None	Upstream	31	Orange	3502	3503	LOP		
9/24/2008	3	102	Male	None	Upstream	41	Orange	3504	3505	LOP		
9/24/2008	4	75	Male	LV	Removed	31						
9/24/2008	5	88	Male	LV	Removed	41						
9/24/2008	6	77	Male	LV	Removed	31						
9/24/2008	7	82	Female	LV	Removed	41						
9/24/2008	8	73	Male	LV	Removed	31						
9/25/2008	9	81	Female	None	Upstream	41	Orange	3506	3507	LOP		
9/25/2008	10	83	Female	None	Upstream	41	Orange	3508	3509	LOP		
9/25/2008	11	81	Male	LV	Removed	31						
9/26/2008	12	70	Female	None	Upstream	41	Orange	3510	3511	LOP		
9/26/2008	13	74	Male	None	Upstream	41	Orange	3512	3513	LOP		
9/26/2008	14	50	Male	None	Upstream	NA	Orange	3514	3515	LOP		
9/26/2008	15	75	Female	None	Upstream	31	Orange	3516	3517	LOP		
9/26/2008	16	60	Male	None	Upstream	31	Orange	3518	3519	LOP		
9/26/2008	17	74	Female	LV	Removed	31						
9/26/2008	18	91	Female	LV	Removed	41						
9/26/2008	19	91	Female	LV	Removed	41						
9/26/2008	20	79	Female	LV	Removed	31						
9/26/2008	21	89	Female	LV	Removed	41						
9/26/2008	22	55	Male	LV	Removed	31						
9/26/2008	23	71	Male	LV	Removed	31						
9/26/2008	24	100	Male	LV	Removed	41						
9/26/2008	25	58	Male	LV	Removed	NA						
9/26/2008	26	84	Male	LV	Removed	31						
9/26/2008	27	66	Male	LV	Removed	21						
9/26/2008	28	57	Male	LV	Removed	21						
9/26/2008	29	80	Male	LV	Removed	31						
9/26/2008	30	78	Male	LV	Removed	31						
9/26/2008	31	88	Male	LV	Removed	41						
9/26/2008	32	78	Female	LV	Removed	31						
9/26/2008	33	88	Female	LV	Removed	41						
9/26/2008	34	71	Female	LV	Removed	31						
9/26/2008	35	77	Female	LV	Removed	31						
9/26/2008	36	79	Female	LV	Removed	NA						
9/26/2008	37	85	Female	LV	Removed	41						

Table A1. Continued

Date	Fish #	Fork Length	Sex	Fin Clips	Disposition	Scale Age	Tag Color	Tag #	Tag #	Operculum mark	Carcass Recapture Date	Carcass Recovery Location
9/26/2008	38	77	Female	LV	Removed	31						
9/26/2008	39	77	Female	LV	Removed	31						
9/26/2008	40	72	Female	LV	Removed	NA						
9/26/2008	41	76	Female	LV	Removed	NA						
9/26/2008	42	75	Female	LV	Removed	31						
9/26/2008	43	78	Female	LV	Removed	31						
9/26/2008	44	72	Female	LV	Removed	31						
9/26/2008	45	64	Female	LV	Removed	31						
9/26/2008	46	70	Female	LV	Removed	31						
9/26/2008	47	82	Female	LV	Removed	31						
9/28/2008	48		Female	None	Upstream	41	Orange	3520	3521	LOP	10/28/2008	WF Grays
9/28/2008	49	85	Female	None	Upstream	51	Orange	3522	3523	LOP		
9/28/2008	50	87	Female	LV	Removed	41						
9/28/2008	51	77	Female	LV	Removed	31						
9/28/2008	52	85	Female	LV	Removed	31						
9/29/2008	53			None	Upstream	31	Y/Red	1	2	LOP	10/1/2008	Grays
9/29/2008	54	67	Male	LV	Removed	42						
9/29/2008	55	84	Male	ADLV	Removed	31						
9/29/2008	56	72	Female	LV	Removed	31						
9/30/2008	57	75	Male	LV	Removed	31						
9/30/2008	58	79	Male	LV	Removed	31						
10/1/2008	59	88	Male	LV	Removed	31						
10/1/2008	60	77	Male	LV	Removed	31						
10/2/2008	61	87	Female	LV	Removed	41						
10/2/2008	62	82	Female	LV	Removed	41						
10/2/2008	63	78	Male	LV	Removed	31						
10/3/2008	64	86	Male	None	Upstream	41	Yellow	6898	6899	LOP		
10/3/2008	65	78	Male	None	Upstream	41	Yellow	6896	6897	LOP		
10/3/2008	66	82	Male	ADLV	Removed	31						
10/3/2008	67	78	Male	ADLV	Removed	31						
10/3/2008	68	81	Male	LV	Removed	31						
10/4/2008	69	87	Female	None	Upstream	41	Y/Red	6894	6895	LOP		
10/4/2008	70	82	Male	None	Upstream	31	Y/Red	6892	6893	LOP		
10/4/2008	71	83	Female	None	Upstream	41	Y/Red	6889	6891	LOP		
10/4/2008	72	74	Male	LV	Removed	31						
10/4/2008	73	73	Male	LV	Removed	31						
10/4/2008	74	94	Male	LV	Removed	41						
10/4/2008	75	73	Female	LV	Removed	31						
10/4/2008	76	86	Female	LV	Removed	41						

Y/Red=Yellow/Red

Table A1. Continued

Date	Fish #	Fork Length	Sex	Fin Clips	Disposition	Scale Age	Tag Color	Tag #	Tag #	Operculum mark	Carcass Recapture Date	Carcass Recovery Location
10/4/2008	77	59	Male	LV	Removed	21						
10/4/2008	78	74	Female	LV	Removed	31						
10/4/2008	79	79	Male	LV	Removed	NA						
10/4/2008	80	81	Female	LV	Removed	31						
10/4/2008	81	75	Female	LV	Removed	31						
10/4/2008	82	91	Female	LV	Removed	41						
10/4/2008	83	57	Male	LV	Removed	21						
10/4/2008	84	61	Male	LV	Removed	31						
10/4/2008	85	69	Female	LV	Removed	31						
10/4/2008	86	57	Male	LV	Removed	21						

Table A2. 2009 biological data collected from Chinook salmon captured at the Grays River Weir.

Date	Fish #	Fork Length	Sex	Fin Clips	Disposition	Scale Age	Tag Color	Tag #	Tag #	Operculum mark	Carcass Recapture Date	Carcass Recovery Location
9/3/2009	1	87	Female	LV	Removed	31						
9/4/2009	2	79	Male	LV	Removed	31						
9/4/2009	3	88	Female	LV	Removed	41						
9/5/2009	4	71	Female	LV	Removed	31						
9/6/2009	5	84	Male	LV	Removed	41						
9/7/2009	6	69	Female	LV	Removed	31						
9/7/2009	7	76	Female	LV	Removed	31						
9/7/2009	8	87	Female	LV	Removed	41						
9/7/2009	9	66	Male	LV	Removed	21						
9/7/2009	10	77	Male	ADLV	Removed	31						
9/7/2009	11	72	Female	LV	Removed	31						
9/7/2009	12	79	Female	LV	Removed	41						
9/7/2009	13	83	Male	LV	Removed	31						
9/7/2009	14	72	Male	LV	Removed	31						
9/7/2009	15	87	Female	LV	Removed	41						
9/7/2009	16	74	Female	LV	Removed	31						
9/7/2009	17	94	Female	LV	Removed	41						
9/7/2009	18	84	Female	LV	Removed	41						
9/7/2009	19	89	Male	LV	Removed	41						
9/7/2009	20	76	Female	LV	Removed	31						
9/7/2009	21	84	Female	LV	Removed	41						
9/7/2009	22	89	Male	None	Upstream	41	Orange	3550	3551	LOP		
9/7/2009	23	73	Female	None	Upstream	31	Orange	3552	3553	LOP		
9/7/2009	24	82	Female	None	Upstream	41	Orange	3554	3555	LOP		
9/7/2009	25	79	Female	None	Upstream	41	Orange	3556	3557	LOP	9/29/2009	Weir Carc
9/7/2009	26	82	Female	None	Upstream	41	Orange	3558	3559	LOP		
9/7/2009	27	71	Male	None	Upstream	31	Orange	3561	3562	LOP		
9/7/2009	28	78	Male	None	Upstream	31	Orange	3524	3525	LOP		
9/7/2009	29	79	Male	None	Upstream	41	Orange	3526	3526	LOP		
9/7/2009	30	73	Female	None	Upstream	NA	Orange	3528	3529	LOP		
9/7/2009	31	100	Male	None	Upstream	31	Orange	3530	3531	LOP		
9/7/2009	32	77	Female	None	Upstream	31	Orange	3532	3533	LOP		
9/7/2009	33	72	Female	None	Upstream	41	Orange	3534	3535	LOP		
9/7/2009	34	68	Male	None	Upstream	31	Orange	3536	3537	LOP		
9/7/2009	35	99	Male	None	Upstream	41	Orange	3538	3539	LOP		
9/7/2009	36	70	Male	None	Upstream	31	Orange	3540	3541	LOP		
9/7/2009	37	83	Female	None	Upstream	41	Orange	3542	3543	LOP		
9/7/2009	38	86	Female	None	Upstream	31	Orange	3544	3545	LOP	10/14/2009	Weir Carc
9/7/2009	39	72	Male	None	Upstream	31	Orange	3546	3547	LOP		

Table A2. Continued

Date	Fish #	Fork Length	Sex	Fin Clips	Disposition	Scale Age	Tag Color	Tag #	Tag #	Operculum mark	Carcass Recapture Date	Carcass Recovery Location
9/7/2009	40	74	Male	None	Upstream	31	Orange	3548	3549	LOP		
9/7/2009	41	84	Female	LV	Removed	41						
9/7/2009	42	92	Female	LV	Removed	41						
9/7/2009	43	85	Female	LV	Removed	41						
9/7/2009	44	86	Female	ADLV	Removed	31						
9/7/2009	45	73	Female	LV	Removed	31						
9/7/2009	46	87	Female	LV	Removed	41						
9/7/2009	47	87	Female	LV	Removed	NA						
9/7/2009	48	75	Female	LV	Removed	31						
9/7/2009	49	78	Female	LV	Removed	31						
9/7/2009	50	79	Female	LV	Removed	31						
9/7/2009	51	82	Female	LV	Removed	31						
9/7/2009	52	71	Female	LV	Removed	31						
9/7/2009	53	82	Female	LV	Removed	31						
9/7/2009	54	89	Female	LV	Removed	41						
9/7/2009	55	68	Female	LV	Removed	31						
9/7/2009	56	75	Female	LV	Removed	31						
9/7/2009	57	75	Female	LV	Removed	31						
9/7/2009	58	98	Male	LV	Removed	NA						
9/7/2009	59	75	Male	LV	Removed	31						
9/7/2009	60	54	Male	LV	Removed	21						
9/7/2009	61	91	Female	LV	Removed	41						
9/7/2009	62	67	Male	LV	Removed	31						
9/7/2009	63	63	Male	LV	Removed	31						
9/7/2009	64	53	Male	LV	Removed	21						
9/7/2009	65	87	Male	LV	Removed	31						
9/7/2009	66	57	Male	AD	Removed	21						
9/7/2009	67	83	Male	LV	Removed	31						
9/7/2009	68	73	Female	LV	Removed	31						
9/7/2009	69	65	Male	LV	Removed	31						
9/7/2009	70	71	Male	LV	Removed	31						
9/7/2009	71	54	Male	LV	Removed	21						
9/7/2009	72	66	Female	LV	Removed	31						
9/7/2009	73	83	Female	ADLV	Removed	NA						
9/7/2009	74	83	Female	LV	Removed	NA						
9/7/2009	75	78	Female	LV	Removed	31						
9/7/2009	76	77	Female	LV	Removed	31						
9/7/2009	77	76	Female	LV	Removed	31						
9/7/2009	78	81	Female	LV	Removed	41						

Table A2. Continued

Date	Fish #	Fork Length	Sex	Fin Clips	Disposition	Scale Age	Tag Color	Tag #	Tag #	Operculum mark	Carcass Recapture Date	Carcass Recovery Location
9/7/2009	79	96	Female	LV	Removed	41						
9/7/2009	80	86	Female	LV	Removed	41						
9/7/2009	81	76	Male	LV	Removed	31						
9/7/2009	82	72	Male	LV	Removed	31						
9/7/2009	83	79	Male	LV	Removed	31						
9/8/2009	84	79	Female	LV	Removed	41						
9/8/2009	85	92	Female	LV	Removed	41						
9/8/2009	86	88	Female	LV	Removed	41						
9/8/2009	87	104	Male	None	Upstream	41	Orange	3563	3564	LOP		
9/8/2009	88	84	Male	None	Upstream	31	Orange	3565	3566	LOP		
9/9/2009	89	86	Male	AD	Removed	31						
9/21/2009	90	96	Male	LV	Removed	41						
9/21/2009	91	69	Female	LV	Removed	31						
9/28/2009	92	88	Male	AD	Removed	41						
9/28/2009	93	84	Female	AD	Removed	41						
10/1/2009	94	83	Female	None	Upstream	41	Y/O	6848	6849	LOP		
10/1/2009	95	94	Male	None	Upstream	41	Y/O	6846	6847	LOP		
10/1/2009	96	66	Male	None	Upstream	31	Y/O	6844	6845	LOP		
10/1/2009	97	97	Male	None	Upstream	41	Y/O	6841	6842	LOP		
10/1/2009	98	81	Male	None	Upstream	41	Y/O	6839	3840	LOP		
10/1/2009	99	77	Male	LV	Removed	31						
10/1/2009	100	88	Female	LV	Removed	41						
10/1/2009	101	72	Male	LV	Removed	31						
10/1/2009	102	68	Female	LV	Removed	31						
10/1/2009	103	72	Male	LV	Removed	31						
10/1/2009	104	81	Female	LV	Removed	31						
10/1/2009	105	80	Female	LV	Removed	31						
10/1/2009	106	75	Female	LV	Removed	31						
10/1/2009	107	85	Male	LV	Removed	31						
10/1/2009	108	74	Female	LV	Removed	31						
10/1/2009	109	82	Female	LV	Removed	NA						
10/1/2009	110	75	Female	LV	Removed	31						
10/1/2009	111	77	Female	LV	Removed	41						
10/1/2009	112	63	Female	LV	Removed	31						
10/2/2009	113	77	Female	None	Upstream	31	Y/O	6887	6888	LOP		
10/2/2009	114	83	Female	None	Upstream	41	Y/O	6885	6886	LOP		
10/2/2009	115	79	Female	None	Upstream	31	Y/O	6883	6884	LOP		
10/2/2009	116	74	Female	LV	Removed	31						
10/2/2009	117	87	Female	LV	Removed	41						

Y/O=Yellow/Orange

Table A2. Continued

Date	Fish #	Fork Length	Sex	Fin Clips	Disposition	Scale Age	Tag Color	Tag #	Tag #	Operculum mark	Carcass Recapture Date	Carcass Recovery Location
10/2/2009	118	71	Female	LV	Removed	31						
10/2/2009	119	90	Female	LV	Removed	41						
10/2/2009	120	70	Female	LV	Removed	31						
10/2/2009	121	68	Male	LV	Removed	NA						
10/2/2009	122	77	Male	LV	Removed	31						
10/2/2009	123	73	Male	LV	Removed	31						
10/2/2009	124	75	Male	LV	Removed	31						
10/2/2009	125	84	Male	LV	Removed	31						
10/2/2009	126	80	Male	LV	Removed	31						
10/2/2009	127	81	Male	LV	Removed	31						
10/2/2009	128	71	Male	LV	Removed	31						
10/2/2009	129	73	Male	LV	Removed	31						
10/2/2009	130	83	Male	LV	Removed	31						
10/2/2009	131	78	Male	LV	Removed	31						
10/2/2009	132	80	Female	LV	Removed	31						
10/2/2009	133	78	Male	LV	Removed	31						
10/2/2009	134	70	Male	LV	Removed	31						
10/2/2009	135	74	Male	LV	Removed	31						
10/2/2009	136	79	Female	LV	Removed	NA						
10/2/2009	137	80	Female	LV	Removed	31						
10/2/2009	138	84	Female	LV	Removed	41						
10/2/2009	139	84	Female	LV	Removed	41						
10/2/2009	140	79	Male	LV	Removed	31						
10/2/2009	141	87	Female	LV	Removed	41						
10/2/2009	142	89	Male	LV	Removed	31						
10/2/2009	143	93	Female	LV	Removed	NA						
10/2/2009	144	72	Male	LV	Removed	31						
10/3/2009	145	80	Female	None	Upstream	41	Y/O	6881	6882	LOP		
10/3/2009	146	72	Female	None	Upstream	31	Y/O	6880	6870	LOP		
10/3/2009	147	79	Male	LV	Removed	31						
10/8/2009	148	81	Female	ADLV	Removed	31						
10/8/2009	149	76	Female	LV	Removed	31						
10/8/2009	150	75	Female	LV	Removed	31						
10/8/2009	151	84	Female	LV	Removed	41						
10/8/2009	152	82	Female	LV	Removed	41						
10/8/2009	153	88	Male	LV	Removed	31						
10/8/2009	154	82	Male	LV	Removed	31						
10/9/2009	155	67	Female	LV	Removed	31						
10/9/2009	156	87	Male	LV	Removed	31						

Y/O=Yellow/Orange

Table A2. Continued

Date	Fish #	Fork Length	Sex	Fin Clips	Disposition	Scale Age	Tag Color	Tag #	Tag #	Operculum mark	Carcass Recapture Date	Carcass Recovery Location
10/9/2009	157	86	Female	LV	Removed	41						
10/9/2009	158	72	Male	None	Upstream	31	Gr/O	6875	6876	LOP		
10/9/2009	159	80	Male	None	Upstream	31	Gr/O	6877	6878	LOP		
10/10/2009	160	67	Female	LV	Removed	31						
10/10/2009	161	89	Female	LV	Removed	41						
10/10/2009	162	86	Male	LV	Removed	31						
10/11/2009	163	77	Male	LV	Removed	31						
10/11/2009	164	82	Female	LV	Removed	NA						
10/11/2009	165	76	Male	LV	Removed	31						
10/13/2009	166	82	Male	None	Upstream	31	Grey/O	6837	6838	LOP		
10/14/2009	167	75	Female	LV	Removed	31						
10/14/2009	168	67	Male	LV	Removed	31						
10/14/2009	169	73	Female	LV	Removed	31						
10/14/2009	170	84	Male	LV	Removed	31						
10/15/2009	171	64	Male	ADLV	Removed	NA						
10/15/2009	172	73	Female	LV	Removed	31						
10/15/2009	173	79	Male	None	Upstream	31	Grey/O	6835	6836	LOP		
10/15/2009	174	70	Female	None	Upstream	31	Grey/O	6833	6834	LOP	10/21/2009	WF Grays
10/15/2009	175	87	Male	LV	Removed	31						
10/15/2009	176	60	Male	LV	Removed	31						
10/15/2009	177	75	Male	LV	Removed	31						
10/15/2009	178	73	Female	LV	Removed	31						
10/16/2009	179	91	Female	LV	Removed	31						
10/17/2009	180	61	Female	LV	Removed	31						
10/17/2009	181	69	Female	LV	Removed	31						
10/17/2009	182	93	Male	LV	Removed	41						
10/17/2009	183	81	Female	None	Upstream	41	Grey/O	6831	6832	LOP		

Grey/O=Grey/Orange, Gr/O=Green/Orange

Table A3. 2010 biological data collected from Chinook salmon captured at the Grays River Weir.

Date	Fish #	Fork Length	Sex	Fin Clips	Disposition	Scale Age	Tag Color	Tag #	Tag #	Operculum mark	Carcass Recapture Date	Carcass Recovery Location
8/28/2010	1	80	Female	LV	Removed	41						
8/28/2010	2	84	Male	LV	Removed	31						
9/1/2010	3	60	Male	LV	Removed	21						
9/1/2010	4	63	Male	AD	Removed	31						
9/1/2010	5	75	Male	ADLV	Removed	31						
9/1/2010	6	60	Male	LV	Removed	21						
9/1/2010	7	73	Female	LV	Removed	31						
9/1/2010	8	72	Male	LV	Removed	31						
9/1/2010	9	76	Female	LV	Removed	31						
9/2/2010	10	72	Female	None	Upstream	NA	Y/Blu	4501	4502	LOP		
9/2/2010	11	83	Female	None	Upstream	31	Y/Blu	4503	4505	LOP		
9/2/2010	12	79	Female	None	Upstream	31	Y/Blu	4506	4508	LOP		
9/2/2010	13	70	Male	LV	Removed	31						
9/2/2010	14	74	Female	LV	Removed	31						
9/2/2010	15	76	Female	LV	Removed	31						
9/2/2010	16	76	Female	LV	Removed	41						
9/2/2010	17	95	Male	ADLV	Removed	41						
9/2/2010	18	82	Female	LV	Removed	31						
9/3/2010	19	78	Female	LV	Removed	31						
9/3/2010	20	56	Male	LV	Removed	21						
9/3/2010	21	55	Male	LV	Removed	21						
9/13/2010	22	52	Male	LV	Removed	21						
9/13/2010	23	96	Female	AD	Removed	41						
9/13/2010	24	78	Female	AD	Removed	31						
9/16/2010	25	86	Male	AD	Removed	31						
9/16/2010	26	53	Male	LV	Removed	21						
9/16/2010	27	56	Male	LV	Removed	21						
9/16/2010	28	63	Male	AD	Removed	21						
9/16/2010	29	96	Male	AD	Removed	41						
9/16/2010	30	65	Male	AD	Removed	21						
9/16/2010	31	78	Female	AD	Removed	31						
9/16/2010	32	76	Female	LV	Removed	31						
9/16/2010	33	80	Female	AD	Removed	31						
9/16/2010	34	78	Female	LV	Removed	31						
9/16/2010	35	55	Male	LV	Removed	21						
9/16/2010	36	57	Male	LV	Removed	21						
9/16/2010	37	57	Male	LV	Removed	21						
9/16/2010	38	54	Male	LV	Removed	21						

Y/Blu=Yellow/Blue

Table A3. Continued

Date	Fish #	Fork Length	Sex	Fin Clips	Disposition	Scale Age	Tag Color	Tag #	Tag #	Operculum mark	Carcass Recapture Date	Carcass Recovery Location
9/16/2010	39	56	Male	LV	Removed	21						
9/16/2010	40	54	Male	LV	Removed	21						
9/16/2010	41	84	Male	LV	Removed	21						
9/16/2010	42	59	Male	LV	Removed	21						
9/16/2010	43	53	Male	LV	Removed	21						
9/16/2010	44	59	Male	AD	Removed	21						
9/16/2010	45	76	Female	LV	Removed	31						
9/16/2010	46	56	Male	LV	Removed	21						
9/19/2010	47	78	Male	LV	Removed	31						
9/19/2010	48	73	Female	AD	Removed	31						
9/19/2010	49	78	Female	LV	Removed	31						
9/19/2010	50	71	Female	AD	Removed	31						
9/19/2010	51	77	Female	LV	Removed	31						
9/20/2010	52	52	Male	LV	Removed	21						
9/20/2010	53	54	Male	LV	Removed	21						
9/20/2010	54	50	Male	LV	Removed	21						
9/20/2010	55	61	Male	LV	Removed	21						
9/20/2010	56	78	Female	LV	Removed	NA						
9/20/2010	57	82	Female	LV	Removed	21						
9/22/2010	58	78	Female	LV	Removed	31						
9/26/2010	59	82	Male	LV	Removed	31						