Technical Report 2015-2-DRAFT

MIGRATION BEHAVIOR AND SPAWNING SUCCESS OF SPRING CHINOOK SALMON IN FALL CREEK, THE NORTH FORK MIDDLE FORK WILLAMETTE AND SANTIAM RIVERS: RELATIONSHIPS AMONG FATE, FISH CONDITION, AND ENVIRONMENTAL FACTORS, 2014

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G.A. Brink, T.J. Blubaugh and M.A. Jepson

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University of Idaho, Moscow, ID 83844-1136

For
U.S. Army Corps of Engineers
Portland District, Portland OR

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Executive Summary

Many adult Chinook salmon in the Willamette River basin die after reaching spawning tributaries but prior to spawning (prespawning mortality, PSM). While PSM rates appear to vary among years and among subbasins, the exact cause and relationships are not well defined. In 2014 we continued to survey the energetic status and prespawn survival rates of three populations of Willamette River spring Chinook salmon, monitored river environmental conditions, and investigated the relationships among prespawn mortality and a suite of potential causative factors.

In 2014, a total of 160 Chinook salmon were sampled at Fall Creek Dam. Fish were collected, assessed for energetic content and overall condition, PIT-tagged and then transported above the dam and allowed to spawn naturally. Nine PIT-tagged salmon were recovered during spawning ground surveys on Fall Creek, a recapture rate of 5.6% that was lower than all previous years (10-12%) except 2013 where record rainfalls precluded surveys during peaks in spawning activity. Of the five PIT-tagged females recovered on the Fall Creek spawning grounds all were prespawn mortalities. Overall, 69 unmarked fish were recovered on the spawning grounds for a recovery rate of 23.3%. Of the 17 unmarked females recovered, 11 (64.7%) were prespawn mortalities. The average water temperature during the study period was 15.7 °C with a peak of 20.8 °C occurring in late July.

A total of 200 Chinook salmon collected at the Dexter Dam trap were outplanted into the North Fork Middle Fork Willamette River (NFMF) in 2014. Overall, 37 (19%) of the PIT and radio-tagged fish were recovered in carcass surveys, a recovery rate within the range in previous years (7-20%). Female prespawn mortality of NFMF outplants was 20% (four out of 20 females recovered) for PIT and radio-tagged fish combined. Mean water temperature in the NFMF during the study period was 11.5 °C with a peak of 14.5 °C in mid-July.

In 2014, we continued the early outplanting into the NFMF initiated in 2013. Of the 200 PIT and radio-tagged fish released in the NFMF, 60 (30%) were released between 21 May and 4 June (early release group, hereafter). The remaining 140 fish (70%) were released between 11 June and 30 July (standard release group, hereafter). Overall, 9% (*n* = 8) from the early release group were recovered on the spawning ground versus 20% (*n* = 28) from the standard release group. Although sample sizes are small, prespawn mortality rates were the same (33%) for the early release group in both years. Prespawn mortality rates were higher in the late release group in 2013 (50%) but lower in 2014 (18%).

We also estimated prespawn mortality in the South Fork Santiam River upstream of Foster Dam and evaluated behavior of adult salmon released in Foster Reservoir. Recovery rates for PIT-tagged salmon were 32% (n = 99) for fish released at Gordon Road. No PIT-tagged fish were released at River Bend or Calkins in 2014. Recovery rates of radio-tagged salmon ranged from 11% for fish released at Calkins to 3% for fish released at Gordon Road. Prespawn mortality estimates for fish released at Gordon Road were 11% for PIT-tagged fish and 40% for radio-tagged fish. The prespawn mortality rate for radio-tagged fish released at Calkins was 50% but the number of fish recovered was low (n = 4).

Of the 75 radio-tagged fish, 44 (59%) were released at Calkins Park in Foster Reservoir; 21 (48%) of the 44 fish were last recorded in the South Santiam, 6 (14%) were last recorded in the Middle Fork Santiam, and 10 (24%) passed downstream past Foster Dam. Median reservoir residence times were 11.4 d for fish last recorded on the South Fork Santiam receiver (*n* = 21) and 12.8 d for fish last recorded on the Middle Fork Santiam receiver (*n* = 6). Mean water temperature in the South Santiam upstream from Foster Reservoir during the study period was 15.2 °C with a peak of 19.5 °C on 1 Aug. Comparison of the thermal history of fish released in the reservoir (n = 75) versus those released in river (n = 99) suggested that reservoir-released fish were exposed to an average of 2.8 fewer degrees per day than fish released in the river and 55 fewer total degree days than those released in the river, representing a 16% reduction in thermal exposure after outplanting. However, thermoregulatory benefits of reservoir releases may have been offset by the high fallback rates (24%) of fish released in the reservoir.

Although recoveries of PIT- and radio-tagged fish were lower than in most previous years and small sample sizes make interannual comparisons challenging, prespawning mortality rates at Fall Creek were among the highest among study years, whereas rates in the NFMF were on the low end of the range. In 2014, PSM rates were 100% for PIT-tagged fish at Fall Creek and 20% (PIT and radio-tagged combined) in the NFMF. Across the six study years (2009-2014) pre-spawn mortality estimates of PIT and radio-tagged females combined were 46.7% (range 6-100%) for Fall Creek and 29.9% (range 13-50%) for immediate outplants to the NFMF.

We tested for associations between fate and a suite of factors potentially related to PSM across study years using univariate and multiple logistic regression models and multi-model selection techniques. The models for Fall Creek included 87 females recovered over six years. Among the univariate logistic regression models, year, fork length and standardized mideye-to-hypural (StdMeH) were significantly associated with prespawn mortality. The most parsimonious multiple logistic regression model included year and tag date. Several additional models had statistical support, including all models that included either year or tag date. The models for the NFMF included 77 females recovered over six years. In the NFMF univariate models, PSM was only significantly associated with tag date, with higher PSM rates associated with release to the NFMF later in the season. No multi-variable logistic regression models were significant for the NFMF. We found no evidence of consistent radio-tagging or PIT-tagging effects on prespawn mortality in Fall Creek or the NFMF.

Introduction

The numbers of adult spring-run Chinook salmon (*Oncorhynchus tshawytscha*) returning to the Willamette River, including tributaries managed as part of the USACE Willamette Valley Project (WVP), have fluctuated widely and have been near historic low levels in recent years. Development of the WVP began in 1941 and currently includes 13 dams and reservoirs on the Long Tom, Santiam, McKenzie, Middle Fork Willamette, and Coast Fork Willamette subbasins. The WVP is managed for flood control, recreation, irrigation, fish and wildlife management, and power generation. Upper Willamette Chinook salmon populations in the WVP have declined for a variety of reasons, including habitat degradation, habitat loss associated with dams, land use practices, overharvest, pollution, changes in hydrologic and thermal regimes, and direct and indirect effects of artificial propagation (NMFS 2008). Due in part to these concerns, the upper Willamette River spring Chinook salmon run was listed as threatened under the U.S. Endangered Species Act in 1999 (NMFS 1999).

Due to impassable WVP dams on major tributaries of the Willamette River, returning adults in many populations cannot reach much of their historic spawning habitat. Therefore an adult trap-and-haul program was initiated in the 1990's to make use of surplus hatchery broodstock with the objectives of restoring a source of marine-derived nutrients and supplementing the prey base of native resident fish and wildlife, including other threatened species (i.e., bull trout, *Salvelinus confluentus*) (Beidler and Knapp 2005; Schroeder et al. 2007). Secondary benefits of outplanting include facilitating natural spawning of these populations above the dams and reconnecting habitats, and these secondary objectives have been elevated in recent years. There has been high prespawn mortality (PSM) observed in some years since the start of the trap-and-haul program. Rates have been widely variable among years and among sub-basin populations (Schroeder et al. 2007; Kenaston et al. 2009; Keefer et al. 2010; Keefer and Caudill 2010; Roumasset 2012) and underlying mechanisms are not fully understood, but average rates in Chinook salmon appear to be higher in tributaries of the Willamette Valley than other monitored basins (Bowerman et al. 2014). Factors most likely to contribute to adult prespawn mortality include environmental stressors (especially water temperature), infectious disease, and poor energetic condition. Importantly, demographic modeling suggests that observed levels of PSM (e.g. > 50-70%) may strongly negatively affect population growth rates and hinder salmon recovery (Keefer et al. 2010; Spromberg and Scholz 2011). The importance of PSM to the dynamics and viability of Willamette tributary populations may increase if future regional climate warming (e.g., Eaton and Scheller 1996; Mote et al. 2003; Mote et al. 2010; Abatzoglou et al. 2014) increases the rate of temperature-related mortality.

The migration corridors of many rivers in the Willamette River basin have been altered by habitat degradation, hydroelectric installations, and climate change. In addition to the direct effects of passage barriers and lost access to spawning habitat, the operation of dam and reservoir systems for power production, recreation, and flood control can affect salmon and their migrations. Some important indirect effects are the alteration of river flow and temperature regimes. In many river systems, operating dams for flood control has resulted in less variable flow regimes during migration. Depending on dam operation, water stored in reservoirs can either warm or cool downstream reaches when it is released (Rounds 2010). In the Willamette system, tributary dams tend to cool downstream reaches in the spring and early summer and tend to increase water temperatures in the late summer and fall compared to the undammed system (e.g., Rounds 2007). The physiological effects of altered water temperatures during Chinook salmon migration, both below dams and in tributaries during holding and spawning, may have negative effects on energy use and gonad development, potentially resulting in lower reproductive fitness for these populations.

Migrating adult Chinook salmon do not feed during their upstream freshwater migration but rely on finite energy reserves accumulated while feeding in the ocean. Adult salmon die within days to weeks of spawning, indicating that energy stores are likely fine-tuned by past selection to maximize reproductive output (spawning and gametes) while also providing adequate energy to fuel upstream migration, summer holding, and spawning. The energetic costs of migration and spawning activities in the Willamette basin may have changed as a result of altered flow and temperature regimes, degradation of main stem and tributary habitats, and the effects of climate change. Thus, it is possible that energy stores in returning Chinook salmon may currently be mismatched to present conditions and possibly insufficient to allow successful spawning for some fish.

Energy is primarily stored as lipids and energy content tends to be higher in populations traveling greater distances or that return to higher elevations (e.g., Crossin et al. 2004b). Within populations, there is evidence that energetic condition depends on growth conditions experienced in the ocean prior to return migration. For example, adult sockeye salmon (*O. nerka*) return with lower reserves in years following relatively poor ocean feeding conditions (Crossin et al. 2004a). More generally, poor energetic condition at river entry (Crossin et al. 2004a; Rand et al. 2006) and temperature regime during migration and on spawning grounds (Mann 2007; Crossin et al. 2008; Keefer et al. 2008a, 2010; Mann et al. 2010) has been associated with higher probability of PSM.

Stress from trapping and transport efforts, in combination with disease, may also contribute to PSM (Schreck et al. 2001; Bradford et al. 2010; Kent et al. 2013; Mosser et al. 2013). The role of pathogens and parasites in PSM has frequently been overlooked and underestimated because all salmon and most steelhead (*O. mykiss*) die shortly after they spawn and there have been few attempts to document the proportion that die prematurely. Spawning salmon are severely immunocompromised, and thus even those that survive past spawning often are infected with a variety of pathogens. Therefore, infections and lesions in adult salmon in freshwater are considered normal, and commonly post-spawned fish exhibited a variety of infections and lesions. However, if infections become too severe, fish may succumb days or weeks before spawning, reducing recruitment to the subsequent generation. The role of pathogens in PSM of WVP Chinook salmon has been the subject of a parallel set of studies in collaboration with OSU researchers (e.g., Schreck et al. 2013, Benda et al. *in review*).

Release of outplanted adults to Willamette basin reservoirs downstream of traditional outplant streams is being considered as a management alternative that may reduce exposure to stressful river temperatures and depletion of energetic stores. WVP reservoirs offer a potential thermal refuge for adult Chinook salmon during warm summer months if adults select and hold in cooler waters below the thermocline prior to movement into spawning tributaries (e.g., Newell and Quinn 2005; Roscoe et al. 2010). Release to reservoirs could also reduce transport distances and handling time. Additionally, release to reservoirs could provide increased opportunity for homing to natal tributaries in locations with multiple spawning tributaries feeding into a reservoir (e.g., Foster and Detroit reservoirs).

The origin of adults collected for outplanting is uncertain in some cases, particularly for unclipped individuals, and affects trap-and-haul protocols. For instance, unclipped adults passing Minto Dam on the North Santiam River may include offspring from adults translocated above Detroit Dam for spawning, offspring of adults spawning between Minto and Big Cliff dams, or offspring of hatchery and/or wild adults that spawned downstream of Minto Dam that overshoot their natal reach. Successfully homing adults from these respective groups would be expected to migrate to the base of Big Cliff Dam, hold and spawn above Minto Dam or fallback over Minto Dam and attempt to spawn downstream. Currently, no unclipped adults are passed above Detroit because of uncertainty about origin and concerns over depleting the downstream spawning population. During 2014 we radio-tagged and monitored a sample of adults at Minto Dam to evaluate behavior and final distribution in relation to the three natal classes above.

The primary goal of this study has been to evaluate factors potentially associated with PSM in adult Chinook salmon from the time they were collected at the traps through spawning, including environmental stressors, maturation status, disease, parasites, and initial energetic condition. During 2014 adults were collected at Dexter and Fall Creek dams in the Middle Fork Willamette River basin, assessed and tagged, and released above the dams into spawning habitats. In 2013, we began evaluating PSM in salmon outplanted to the South Fork Santiam River and continued a feasibility study of releasing fish into Foster Reservoir. Additionally, subsamples of adults from collected at Dexter and Foster dams were transported to Oregon State University to assess holding benefits and disease prevalence (reported separately). Also new in 2013 was a small-scale comparison of toxins concentrations in carcasses of successful and unsuccessful adult Chinook salmon. A similar sample was collected in 2014 and samples are currently under analysis. Complete toxins results across both years will be reported separately.

Specific 2014 objectives reported here were to:

1) Estimate PSM rates in two populations of adult Chinook salmon outplanted to WVP tributaries (Fall Creek and the NFMF) as part of a multi-year monitoring program (in collaboration with the Oregon Department of Fish and Wildlife [ODFW]).
2) Test for associations between PSM, individual adult traits evaluated at the time of collection, and environmental conditions encountered after release.
3) Estimate PSM rates in populations of adult Chinook salmon outplanted to the South Fork Santiam River (in collaboration with ODFW).
4) Continue evaluating the feasibility of releasing adults in Foster Reservoir on the South Fork Santiam River.
5) Evaluate interannual patterns in PSM.
6) Estimate fallback rates of unclipped Chinook salmon at Minto Dam on the North Santiam River and duration of holding upstream from the dam.

Methods

Chinook salmon collection and tagging for this study took place at two sites in Middle Fork Willamette River, west of Eugene, OR (Figure 1) and two sites in the Santiam River drainage upstream of Albany, OR. The first site was at Fall Creek Dam on Fall Creek, a tributary of the Middle Fork of the Willamette River. The second was at Dexter Dam on the Middle Fork of the Willamette River. Dexter Dam regulates the outflow from Lookout Point Dam just upstream. The third location was Foster Dam, Foster Dam Reservoir and upstream tributaries on the South Santiam River and the fourth location was the Minto Fish Facility on the North Santiam River.

Middle Fork Willamette River: Study Sites and Facilities

The Fall Creek trap included a small ladder that led to a finger weir in front of a large collection area. USACE personnel operated a mechanical sweep to crowd trapped fish and raise them into a chute that dropped the fish into an anesthetic tank containing eugenol. The tank was lifted using a fixed crane and placed on the ground where USACE personnel provided anesthetized fish to UI for tagging and assessment. Fish were then transported by USACE approximately 3 km upstream from the head of Fall Creek Reservoir and released at rkm 505.4.

The Dexter trap was operated by ODFW and sampled fish were provided to UI by ODFW. ODFW primarily uses the Dexter facility to collect broodstock for the Willamette Hatchery (WH) in Oakridge, OR. In 2009-2014, a fish ladder led to a slot weir at the entrance to a holding raceway. At the time of sorting, fish were mechanically crowded into an elevator which lifted them to an anesthetic tank. After fish were sedated with CO_2, they were transferred to a secondary tank with fresh river water then transferred to an anesthetic tank with AQUI-S 20E in 2014 (AquaTactics Fish Health, Kirkland, WA; 5-17 mg/L) where they were assessed and tagged. Fish were transferred to a transportation truck for recovery then transported above Lookout Point Dam into the NFMF or above Hills Creek Dam for release. No fish were held for late outplant at the Willamette Hatchery in 2013 or 2014 because the facility was being used to rear fish for the Coast Fork of the Willamette River. Only salmon above the hatchery's broodstock and other allocation quotas were transported and released for natural spawning. In 2013 and 2014, we evaluated outplanting into the NFMF approximately a month earlier than in previous years. Figure 2 outlines the 2014 study design for Fall Creek and NFMF.

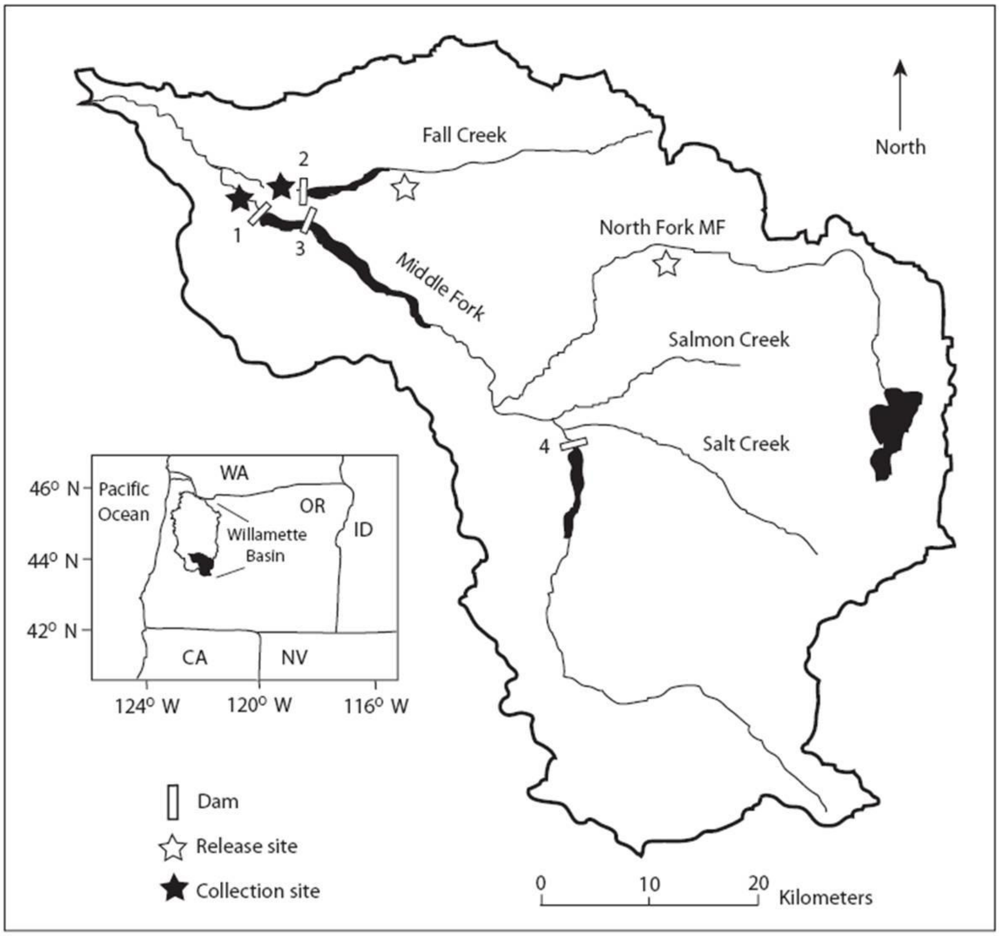

Figure 1. Map of the Middle Fork Willamette River basin showing Chinook salmon collection and outplant sites. Dams are numbered: 1 = Dexter Dam, 2 = Fall Creek Dam, 3 = Lookout Point Dam, and 4 = Hills Creek Dam.

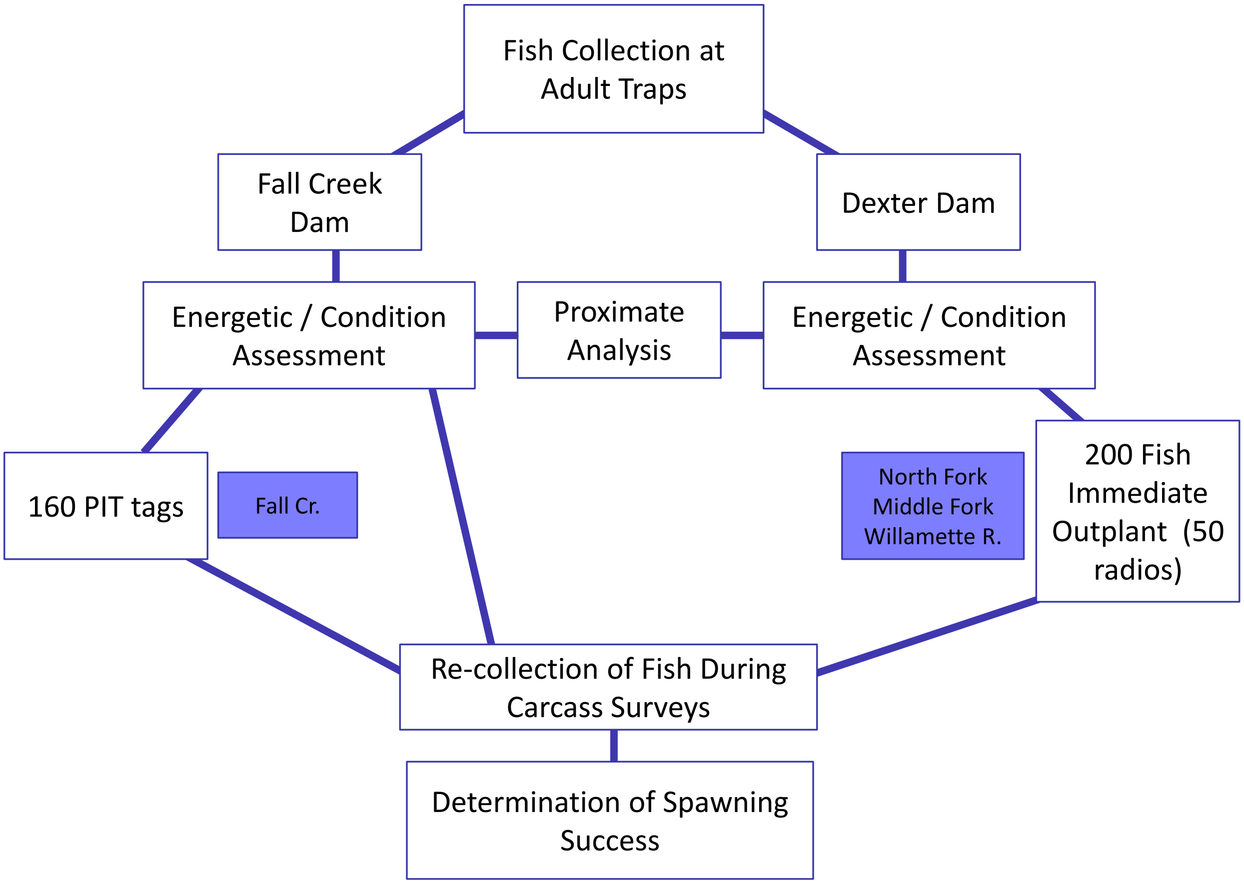

Figure 2. Study design for 2014. All salmon tagged at Fall Creek trap were immediately outplanted into Fall Creek. Salmon collected and tagged at Dexter Dam were immediately outplanted into the NFMF Willamette River. Additionally, a sub-sample of salmon from Dexter Dam was sent to Oregon State University after tagging and assessment.

Tagging and Assessment of Condition

Salmon were fully anesthetized prior to handling at the Dexter and Fall Creek trap sites. Adults were anesthetized in approximately 60 mg/L eugenol at Fall Creek trap. Sampling at Dexter trap used CO_2 during initial trapping (using ODFW protocols) followed by AQUI-S- 20E according to University of Idaho protocols (approximately 10 mg/L). Following tagging, fish were loaded into a truck filled with fresh river water and transported to an upstream release site. Oxygen was monitored during transportation with a target concentration of 10 mg/L. Tagging temperature was recorded and was generally less than 16°C because bottom-draw reservoir water was used for the anesthetic tank and hauling truck at both Dexter and Fall Creek.

While anesthetized, salmon were sexed and inspected for clips or markings. A composite condition score was recorded based on injuries, marine mammal marks, headburn, parasites, and descaling. A score of three indicated no obvious damage or minimal healed scrapes, two indicated minor or healed injuries with potential scarring, and one indicated open/severe wounds or multiple minor injuries. Fish were PIT tagged in the dorsal sinus, near the back of the dorsal fin in an effort to increase tag retention on scavenged carcasses. Fork lengths to the nearest 0.5 cm were taken as well as four morphological measures previously used by Mann et al. (2010) to estimate energetic status (Figure 3). Mid-eye to hypural length was defined as the distance along the lateral line from the middle of the eye to the end of the scales on the hypural plate on the caudal peduncle. Hump height was the distance from the anterior origin of the dorsal fin to the lateral line, perpendicular to the lateral line. Depth at anus was the total depth of the fish perpendicular to the lateral line at the anal opening. Breadth at anus was the width of the fish at the intersection of the lateral line and a theoretical line perpendicular to the lateral line at the anus. Morphometric measurements were taken using calipers and recorded to the nearest mm. Fish weights (to the nearest decagram) were collected using a flat table scale (Ohaus Defender bench scale, Ohaus Corp., Pine Brook, NJ).

The percentage of lipids in the muscle tissue was used as the estimation of energy condition because lipids are the primary energy reserve fish use during migration and spawning (Brett 1995). Lipid levels were estimated using a Distell Fatmeter (Distell Industries Ltd., West Lothian, Scotland). The fatmeter was developed in the commercial fish industry to estimate the percent of lipids in a trimmed fillet. The meter uses a low energy microwave sensor to estimate water content in the muscle tissue. Based on the inverse relationship between water and lipid levels in fish tissue (Craig et al. 1978; Higgs et al. 1979), the meter estimates the percent lipid in Chinook salmon muscle tissue using a proprietary algorithm. We used proximate analysis of tissues in each study year (see below) to test the accuracy of fatmeter estimates and correct for any instrument drift among years. Four readings were taken just above the lateral line, progressing toward the posterior of the fish and the average was recorded for each fish.

A sub-sample of 50 fish was radio-tagged prior to outplanting in the NFMF in 2014. A 3-volt transmitter (Lotek Wireless Inc., New Market, Ontario; MCFT-3A, 43 mm × 14 mm diameter, 11 g in air) was inserted gastrically through the mouth. A silicone band was placed on each transmitter to reduce regurgitation (Keefer et al. 2004). The purpose of radio tagging was to verify that fish were moving upstream after release, estimate distribution during holding (Naughton et al. 2011; Roumasset 2012) and evaluate residence time and fate. Additionally, the use of radio transmitters aided in the collection of carcasses for PSM assessments.

Blood samples from radio-tagged fish at the Dexter trap were taken from the sub-vertebral caudal vessel posterior to the anal fin. The blood sample was centrifuged for a minimum of four minutes until the red blood cells separated from the plasma. The plasma was transferred to a vial using a pipette, and immediately stored on ice. Samples were frozen as soon as possible and transferred to OSU.

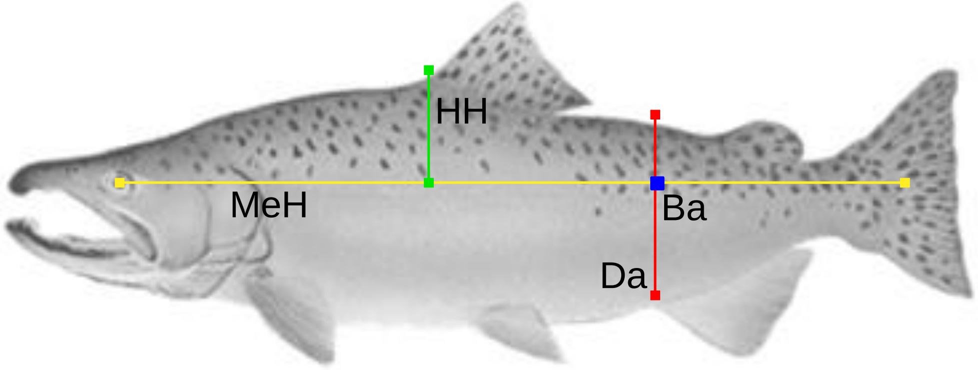

Figure 3. Diagram of morphometrics collected. MeH = Mid-eye to hypural length, HH = Hump height, Da = Depth at anus, Ba = Breadth at anus.

Proximate Analysis

Fifteen additional salmon were lethally sampled at the Dexter trap to estimate mean lipid, protein, water, and ash amounts in tissues and to validate the accuracy of the fatmeter estimates of energy condition. Processing fish entailed partitioning the fish carcass into four tissues types: muscle, skin, viscera, and gonads (e.g., Mann et al. 2010). Each of the tissues was removed as entirely as possible from a carcass, and weighed to the nearest gram to establish the total weight of each tissue type. Then each tissue was homogenized independently in a Cuisinart® food processor and a 50 g subsample of the homogenate was taken. The samples were frozen and later transported to Washington State University where they underwent proximate analysis.

Proximate analyses were performed using established methods. Lipid amounts were calculated by passing volatized ether through the 50 g tissue samples which removed all ether-soluble products including lipids. Lipids were then extracted from the ether, dried and weighed (AOAC 1965). Ash content was calculated by combusting weighed samples at 500–600 ºC for 12 hours and reweighing (AOAC 1965; Craig et al. 1978). The percent moisture in the samples was obtained by placing a weighed sample in a freeze drier at -40º C for 24 to 36 hours and reweighing. Protein content was determined by subtraction (% protein =100 - % water - % fat - % ash), as in other studies on salmon energetics (e.g., Berg et al. 1998; Hendry and Berg 1999; Hendry et al. 2000). Carbohydrate content was assumed to be negligible. After lipid weights were calculated for each 50 g subsample, we calculated total lipid per tissue and total body lipid levels. Energy density or gross somatic energy was calculated as kJ of energy per kg of fish mass, assuming energy equivalents for fat and protein of 36.4 kJ g^{-1} and 20.1 kJ g^{-1}, respectively (Brett 1995). Total energy included gonadal tissues.

Gross somatic energy density (kJ/kg) was used as a second measure of energy condition and was calculated for the lethally sampled fish. Gross somatic energy density represents the energy density contained within somatic tissues of the fish and is a measure of energy contained not only in the muscle tissue, but also the viscera and skin (Crossin and Hinch 2005). Because it is standardized by mass, it can be directly compared among individuals. Gross somatic energy density was regressed on lipid percentage (natural log [$\log_e$] transformed) estimated by the fatmeter (non-standardized values, see below) to examine the relationship between fatmeter estimates and gross somatic energy density (e.g., Colt and Shearer 2001; Crossin and Hinch 2005).

We used linear regression to estimate the relationship between muscle lipid content and fatmeter readings. The relationship was then used to estimate muscle lipid content for each outplanted fish by inverse prediction (Sokal and Rohlf 1995) using fatmeter measurements taken at the time of tagging. Fatmeter readings from 2014 were also collected from fish tagged at Willamette Falls (see Jepson et al. *in review*) and compared with readings from fish tagged at the Fall Creek and Dexter traps.

Temperature Monitoring

Temperature recorders (HOBO V2 Pro and Tidbit, Onset, Inc., Bourne, MA)were installed in 2014 at four sites in Fall Creek and four in the NFMF. In Fall Creek, loggers were located at the release site (rkm 505.4), the bridge near Johnny Creek (rkm 513.0), near the mouth of Portland Creek (rkm 516.5), and at the unnamed falls that act as a fish barrier (rkm 529.6) (Appendix Figure 1). In the NFMF Willamette River, loggers were placed at the release site (rkm 557.9), below the bridge near Kiahanie campground (rkm 565.4), at the forest road 1944 bridge (rkm 572.5), and above Skookum Creek (rkm 585.9) (Appendix Figure 2). Depth of temperature loggers ranged from approximately 0.5-1.5 m. Temperatures were logged at 15 minute intervals from mid-May to mid-October. (Note: river kilometers are measured from the mouth of the Columbia River.)

Spawning Ground Surveys and Spawning Success

After transport to release sites above the dams, salmon were allowed to spawn naturally and spawning areas were monitored to collect carcasses and assess spawning success. Carcass surveys were conducted by both UI and ODFW approximately 1-2 times per week from the beginning of releases through the spawning period (June through early October). Fish encountered during spawning ground surveys were inspected by UI and/or ODFW personnel for radio and PIT tags. When the carcass of an individual from this study was located, it was inspected to determine spawning status and its general condition was noted (how recently it died, obvious wounds, fungus levels, or other apparent visual cues that caused mortality). In addition, otoliths and scales were collected from non-marked fish (presumed natural origin fish with no fin clips). If a fish had recently died (gills were red or pink), the fish was transported on ice to OSU, and tissue samples were collected for histology.

In 2014 spawning success was assessed by inspecting the gonads of females and estimating the proportion of gametes remaining to the nearest 25%. A successfully spawned fish was defined as having less than 25% of gametes remaining in the body cavity (Pinson 2005; Bowerman et al. *in prep*). PSM rates were calculated separately for males and females because the proportion of remaining gametes could not be reliably estimated in males and in some carcasses that had been scavenged. Males that died prior to spawning (based on the date the first redd was observed) were considered prespawn mortalities. However, statistical analyses were performed only for female PSM rate.

Multi-year summary

We performed several statistical analyses to test for associations between PSM and a suite of potential causative factors for both Fall Creek and the NFMF salmon across study years. We used logistic regression and multi-model selection techniques (Burnham and Anderson 2002) and compared fit using Aaike Information Criteria (AIC). Predictor variables included year, tag date, composite condition score (condition), fatmeter percent, Fulton's condition factor K (K = (10^5*weight/FL^3), fork length (FL), weight, mideye-to-hyperal (MeH), depth at anus (Da), breadth at anus (Ba) and hump height (HH). We also calculated standardized morphometric measurements for the four morphometric parameters (StdMeH, StdDA, StdBA, StdHH) to control for differences in body size by dividing each estimate by individual fork length.

The model set included all univariate models plus eighteen multiple logistic regression models with adult fate (spawned, PSM) as the dependent variable. The full logistic regression model was:

PSM (y/n) = year + tagdate + condition + fatmeter + Fulton's K + FL + weight + StdMeH + StdDA + StdBA + StdHH.

In addition, to statistical analyses we summarized PSM rates across study years and streams. We also compared PSM rates among PIT, radio-tagged, and unmarked fish to evaluate potential tagging effects.

Methods: South Santiam River

Adult Chinook salmon were collected and tagged at the Foster Dam trap on the South Santiam River. The trap was operated by ODFW and sampled fish were provided as part of routine trap operations. The Foster trap consists of a ladder and a collection area and an anesthetic tank. ODFW personnel sorted fish and transferred fish into an anesthetic tank where they were anesthetized with AQUI-S 20E (15-20 mg/l) before transfer to a secondary tank containing a lower concentration of AQUI-S 20E (5 mg/l). Tagging, handling, and proximate analysis methods were similar to those reported above for salmon trapped at Dexter Dam. Salmon were released in Foster Reservoir near the Calkins Park boat launch (rkm 421.7; measured from mouth of the Columbia River) and in the South Fork Santiam River at River Bend (rkm 428.3) and Gordon Road (rkm 444.7).

We used IBT submersible temperature loggers (Embedded Data Systems, LLC, Lawrenceburg, KY; 17.35×5.89 mm, 3.3 g in air) to record internal temperatures on a subsample of radio-tagged fish (n = 49). The tags were waterproofed (Plasti Dip multipurpose rubber coating; Plasti Dip International, Blaine, Minnesota, see Donaldson et al. 2009) and attached to the bottom of the radio tags with electrical tape and then inserted gastrically. The temperature recorders were recovered during carcass surveys and were downloaded.

Methods: Toxicology sampling

In 2014, we also collected tissue samples from female spring Chinook salmon carcasses in Fall Creek, the NFMF and the South Fork of the Santiam River to estimate the concentrations of toxins. The primary goal was to screen samples for a broad spectrum of metals (~25 elements) and organic toxins (~100 compounds) to identify potential toxins of concern, while also testing for differences in adults that were either prespawn mortalities or successful spawners. We focused on radio or PIT-tagged fish but unmarked fish were also collected. After determining spawning status, we removed a 2.5×2.5 cm (one inch) square of muscle and skin tissue from the belly about 2.5 cm anterior to the pelvic fin on the left side of the fish. The sample was then placed in a labeled 60 ml amber glass jar. Samples were placed in a freezer at the end of each day then transferred to the University of California, Davis where samples are undergoing toxicological screening using previously described methods (e.g., Greenfield et al. 2008, Hwang et al. 2009a, 2009b, McGourty, et al. 2009).

Methods: Minto Fish Facility tagging

In 2014, we initiated a pilot study to evaluate fallback behavior and upstream movement of Chinook salmon radio-tagged and released at the Minto Fish Facility on the North Santiam River. The Minto fish trap was operated by ODFW and sampled fish were provided as part of routine trap operations. The trap consists of a ladder and a collection area and an anesthetic tank. ODFW personnel sorted fish and transferred fish into an anesthetic tank where they were anesthetized with AQUI-S 20E (approximately 15-20 mg/l) before transfer to a secondary tank containing a lower concentration of AQUI-S 20E (approximately 5 mg/l). Analyses for this objective also included data from Chinook salmon that were radio-tagged at Willamette Falls (Jepson et al. *in review*) and migrated to Minto.

Results: Middle Fork Willamette River

Fall Creek

Tagging occurred from 19 May to 10 July, 2014. A total of 160 fish (90 females, 70 males) were PIT tagged (Figure 4). Tagging was representative of the overall timing of the run, which peaked in early June followed by a smaller peak in mid-July (Figure 4). All fish transported above the dam had intact adipose fins (i.e., were presumed wild origin). The mean condition score in 2014 was 2.4, mean fork length was 77.3 cm, mean weight was 5.3 kg, and mean lipid percentage was 5.0% (Table 1).

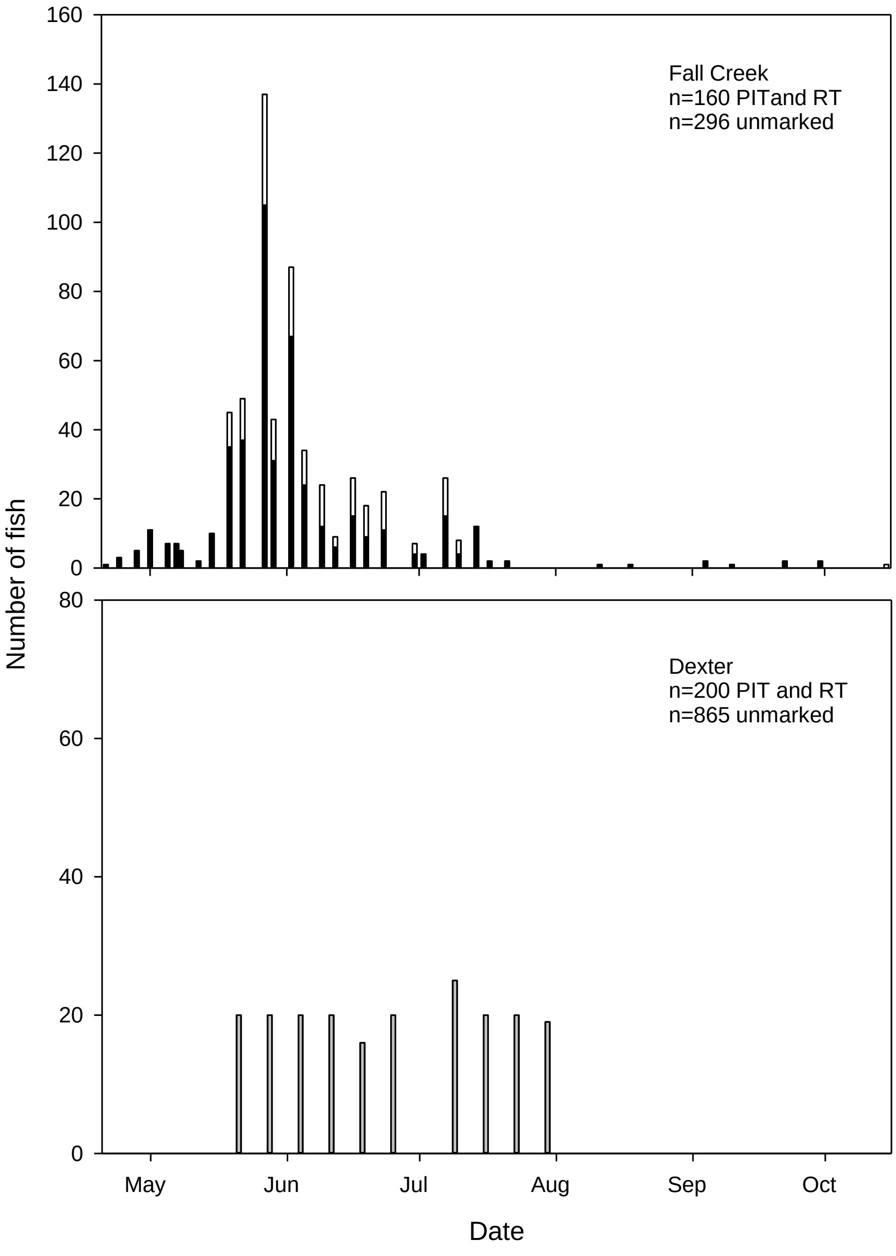

Figure 4. Numbers of adult Chinook salmon tagged in 2014. Top panel: distributions of Chinook salmon that were (open bars) and were not (black bars) tagged at Fall Creek trap. Fall Creek fish were immediately outplanted above Fall Creek Dam and Reservoir. Bottom panel: distributions of Chinook salmon collected and tagged at Dexter Dam and immediately outplanted to the NFMF on the date of tagging (gray bars).

Table 1. Adult Chinook salmon size, lipid content, and condition metrics for fish sampled at Fall Creek trap in 2014. MeH = Mid-eye to hypural length, Da = Depth at anus, Ba = Breadth at anus, HH = Hump height, % Lipid = fatmeter reading of muscle tissue, wet weight.

Fall Creek (*n* = 160)	Fork Length (cm)	Weight (kg)	MeH (cm)	Da (cm)	Ba (cm)	HH (cm)	% Lipid	Condition Score
Mean	77.3	5.3	65.7	12.2	6.5	8.5	5.0	2.4
St. Deviation	5.5	1.2	4.6	1.1	0.7	0.8	1.8	0.7
Max	90	9.0	75	14.9	8.4	10.3	10.2	3
Min	58	2.3	49	8.7	4.4	6.3	1.3	1

On average, fatmeter readings of tagged adults arriving to Fall Creek trap (*mean* ~ 5.0%) were about 30% lower than for adults at Willamette Falls (*mean* ~ 7.1%; Figure 5). Lipid estimates for the Fall Creek sample also decreased through the 2014 season, with an $r^2 = 0.22$ (Figure 5 and 6). This seasonal decline was similar to results in previous years.

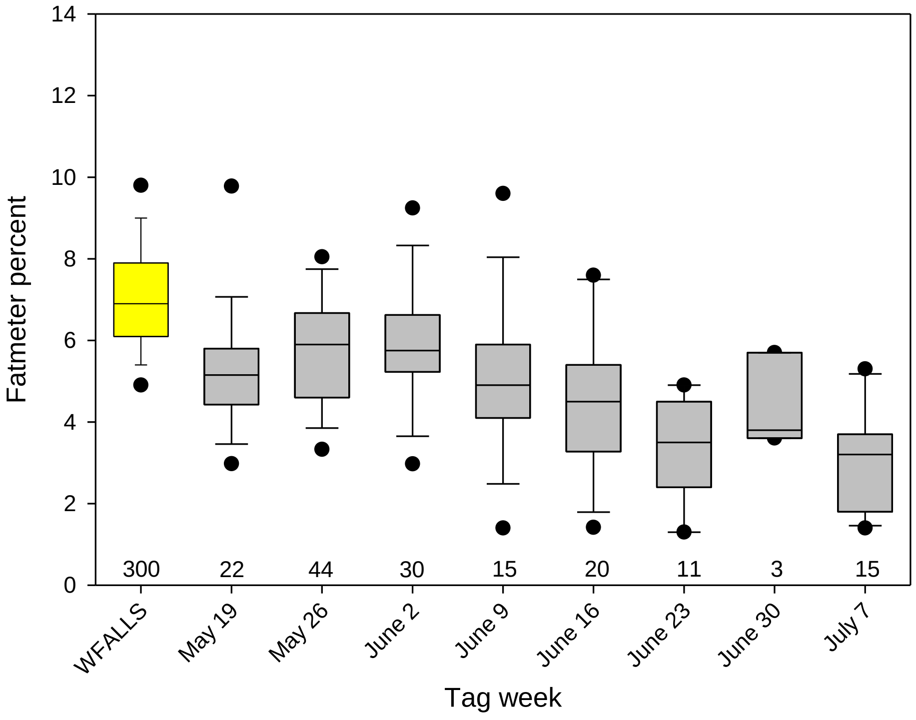

Figure 5. Weekly distributions of fatmeter estimates for Chinook salmon tagged at Fall Creek trap in 2014. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (●). Sample size for each weekly start date given below each box. First box on left shows data for Chinook salmon sampled at Willamette Falls Dam (WFALLS) from Jepson et al. (*in review*).

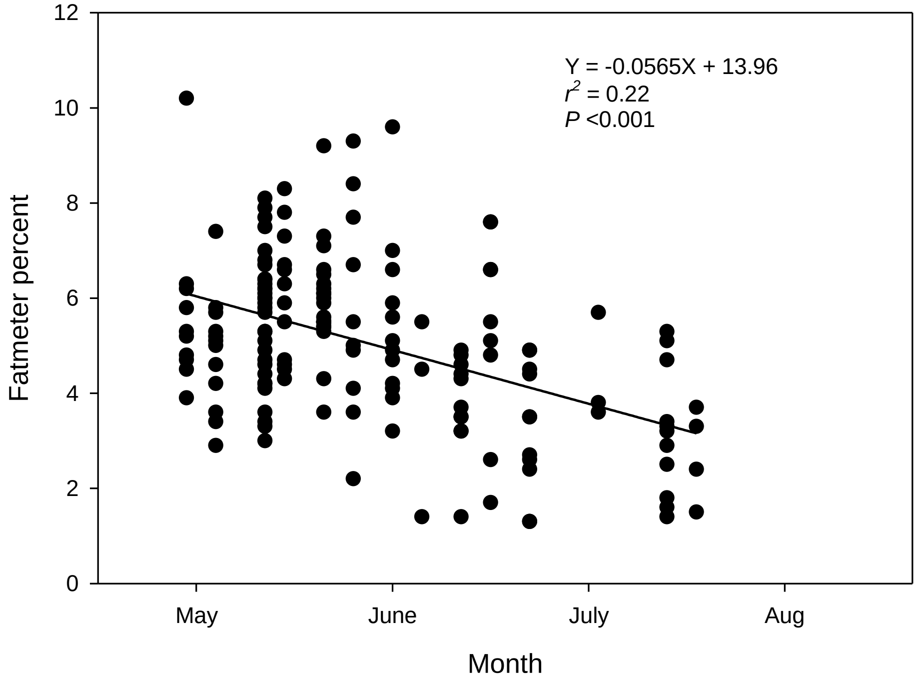

Figure 6. Fatmeter percentages for all Chinook salmon tagged at arrival at Fall Creek Dam in 2014.

North Fork Middle Fork Willamette River

As in 2013, we initiated outplanting into the NFMF in 2014 approximately a month earlier than in previous years in an attempt to reduce the residence time of adults in the Dexter Dam tailrace. Tagging began on 21 May and continued until 30 July (Figure 6). This group included 200 fish (98 females, 102 males), and had mean length of 74.4 cm, mean weight of 4.6 kg, mean condition score of 2.4, and mean lipid percentage of 2.9% (Table 2). Mean fatmeter readings from fish tagged at the Dexter Dam trap (2.9%) were about 59% lower than those for fish tagged at Willamette Falls (7.1%) and decreased across the ten eight tagging events (Figure 7).

Table 2. Adult Chinook salmon size, lipid content, and condition metrics for fish collected and sampled at Dexter trap and then immediately outplanted in 2014. MeH = Mid-eye to hypural length, Da = Depth at anus, Ba = Breadth at anus, HH = Hump height, % Lipid = fatmeter reading of muscle tissue, wet weight.

Dexter (*n* = 200)	Fork Length (cm)	Weight (kg)	MeH (cm)	Da (cm)	Ba (cm)	HH (cm)	% Lipid	Condition Score
Mean	74.4	4.6	62.4	11.2	6.0	7.7	2.9	2.4
St. Deviation	5.7	1.1	5.0	1.0	0.7	0.8	1.6	0.7
Max	92	9.0	76.0	14.8	9.5	10.0	8.7	3
Min	55	1.7	45.0	8.1	4.4	5.0	0.3	1

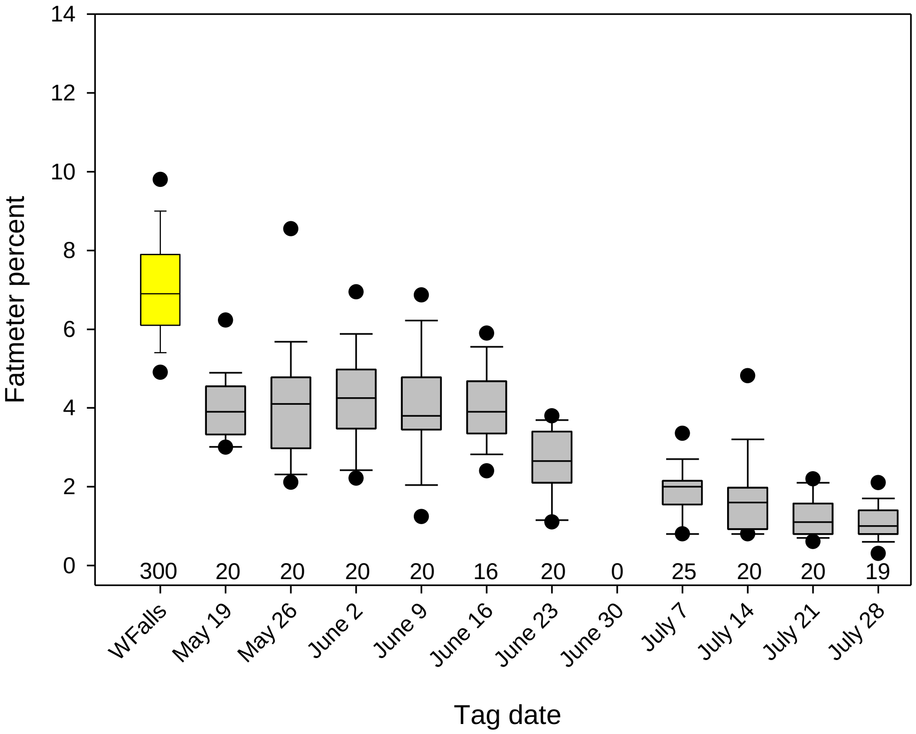

Figure 7. Weekly distributions of fatmeter results for Chinook salmon tagged at Dexter trap in 2014. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (solid circles). First box on left shows data for Chinook salmon sampled at Willamette Falls Dam (WFALLS) from Jepson et al. (*in review*).

Proximate Analysis

In 2014, proximate analysis was performed on 15 (9 males and 6 females) salmon collected at Dexter trap (Table 3). No fish were sampled from Fall Creek because of concerns over lethally sampling unclipped (presumed natural origin) adults from this location. Lethal takes for proximate analysis were conducted on 18 June (*n* = 5), 23 July (*n* = 5), and 20 August (*n* = 5). The average muscle lipid level was 4.1% Table 3) and ranged from 1-7%. Average gonadal lipid composition was 6.7% for females and 1.8% for males (Table 4). Individual lipid concentrations as estimated with the fatmeter during 2014 were positively but weakly correlated with the values estimated from proximate analysis taken from lethally sampled adults (adj. $r^2 = 0.31$, $P = 0.018$, $n = 15$; Table 5).

Table 3. Mean tissue composition of 15 Chinook salmon collected at Dexter trap and used in proximate analysis in 2014.

Tissue	% Moisture	% Crude Lipid	% Total Ash	% Protein
Gonads	69.4	3.8	2.0	24.8
Muscle	74.6	4.1	1.1	20.2
Skin	64.6	4.2	0.8	30.5
Viscera	77.8	1.9	1.4	19.0

Table 4. Tissue composition of 15 Chinook salmon used in proximate analysis by sex.

Tissue	% Moisture	% Crude Fat	% Total Ash	% Protein
Males (*n* = 9)				
Gonads	76.3	1.8	2.5	19.3
Muscle	74.4	4.2	1.2	20.2
Skin	64.9	3.3	0.8	31.0
Viscera	78.2	2.1	1.3	18.5
Females (*n* = 6)				
Gonads	59.1	6.7	1.3	32.9
Muscle	74.9	3.8	1.1	20.1
Skin	64.0	5.5	0.8	29.7
Viscera	77.3	1.6	1.4	19.7

Fatmeter readings were taken on proximate analysis fish at the time of trapping to simultaneously assess the accuracy of the fatmeter readings and provide regression equations to calculate standardized values across years. Preliminary multiple regression models provided no evidence of a difference between sexes in the relationship between uncorrected fatmeter and proximate analysis lipid estimates ($P > 0.1$ in all years), but did suggest differences in the relationship among years ($P < 0.05$). Consequently, we performed regression analyses for each year with combined sexes. In all years the relationship was positive. However, the significance and strength of the relationship varied among years (Table 5).

Table 5. Linear regression results that show the relationships between fatmeter percentages (Y) and percent lipid in wet weight muscle tissue (X) calculated in proximate analysis (PA) for combined males and females. These equations were used to obtain standardized fatmeter estimates for individual adults.

Year	*n*	Intercept	Slope	*P*	*adj* r^2
2014	15	15	0.372	0.018	0.31
2013	15	-1.348	0.726	<0.001	0.68
2012	15	0.523	0.514	0.408	0.61
2011	15	1.854	0.460	0.072	0.17
2010	30	0.703	0.413	<0.001	0.65
2009	29	3.097	0.758	<0.001	0.38
2008	11	3.738	0.387	0.090	0.21

We also tested whether the fatmeter provided accurate estimates of total energy in all body compartments combined (muscle, skin, and viscera). Specifically, we estimated whole-body somatic energy density (kJ/kg) using tissue samples, which standardized energy content for differences in fish size. We used an arcsine transformation on the fatmeter percentages because the data were not normally distributed. Although the relationship was weak, we found a positive relationship between fatmeter readings and energy density in 2014 (Figure 8). Overall the results suggest that the fatmeter provides a non-lethal and unbiased method to estimate a relative index of lipid reserves and energy content among individuals within years, but does not provide adequate precision to predict absolute values for individual adult Chinook salmon lipid or energy content.

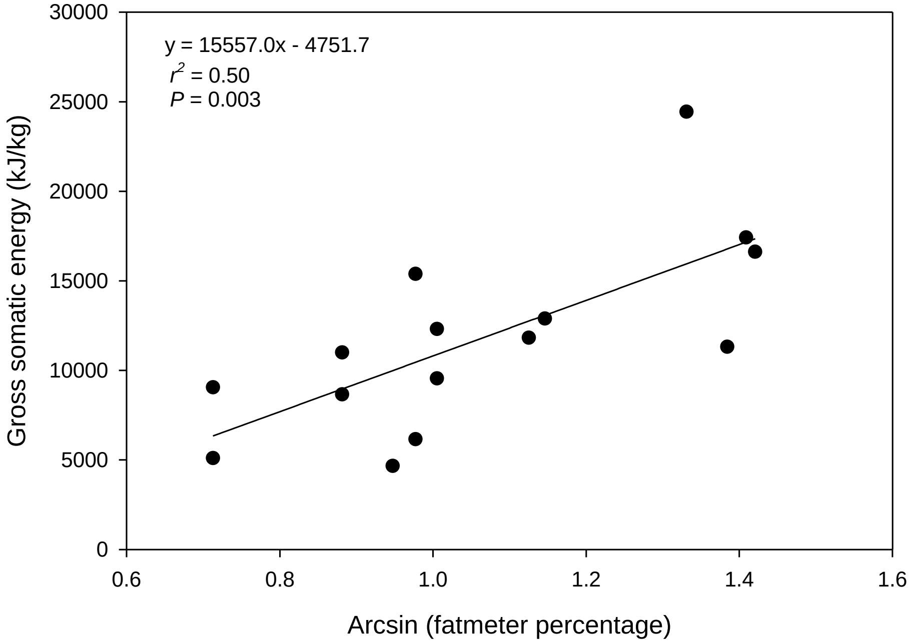

Figure 8. Relationship between Chinook salmon energy density (kJ/kg) estimated using proximate analysis and arcsine square root transformed raw fatmeter percentages, 2014.

River Conditions

The 2014 Chinook salmon migration season in Fall Creek was characterized by low base flow in July and August followed by a slight increase during the September spawning period (Figure 9). Water temperatures at the release site throughout the monitoring period were higher in 2014 than most study years (Figure 10). The average water temperature at the Fall Creek release site during the 2014 study period was 16.7 °C with a peak of 21.8 °C in late July (Figure 11). Mean daily water temperatures in Fall Creek exceeded 20 °C on 25 of the 144 monitored days, a threshold that is generally unfavorable for Chinook salmon holding as it exceeds the thermal preferendum of this species (Orsi 1971; Coutant 1977; Jobling 1981; Richter and Kolmes 2005). Temperatures increased at downstream locations and were highest at the release site in 2014 (Figure 11) as in previous study years (2009-2013).

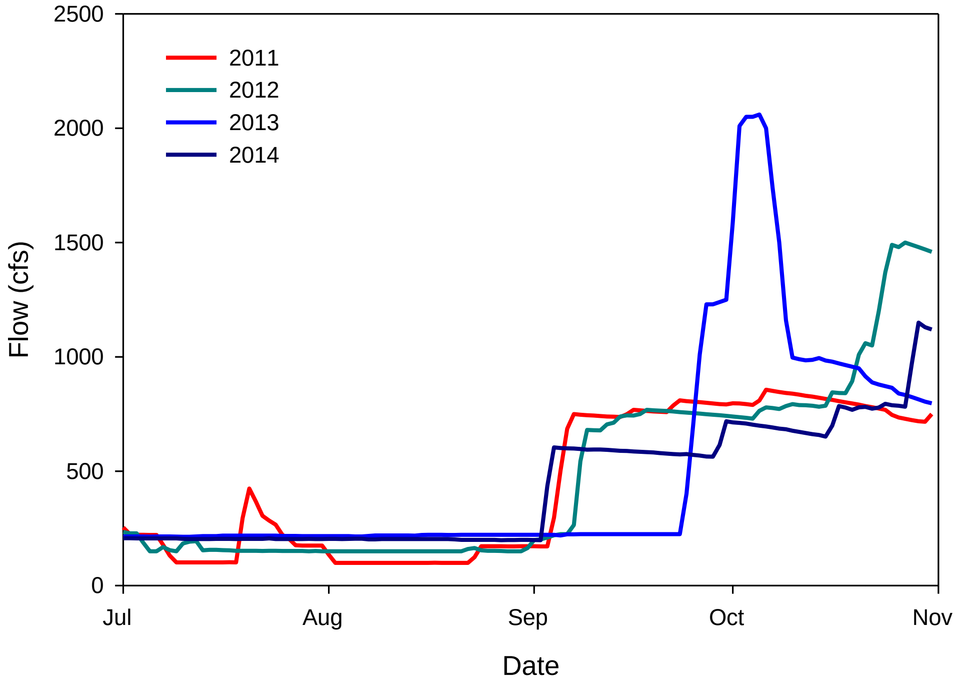

Figure 9. Mean daily discharge (cfs) at Fall Creek 2011-2014. Data is from the USGS Fall Creek gage below Winberry Creek.

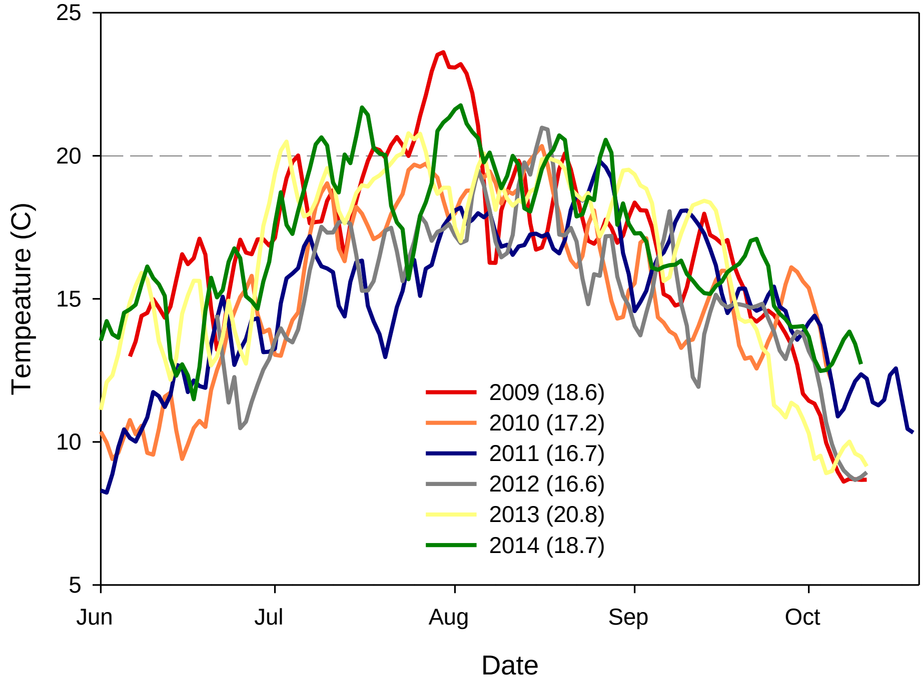

Figure 10. Mean daily water temperatures in Fall Creek in 2009-2014 near the release site (rkm 505.4). Mean temperature for the study period shown in parentheses.

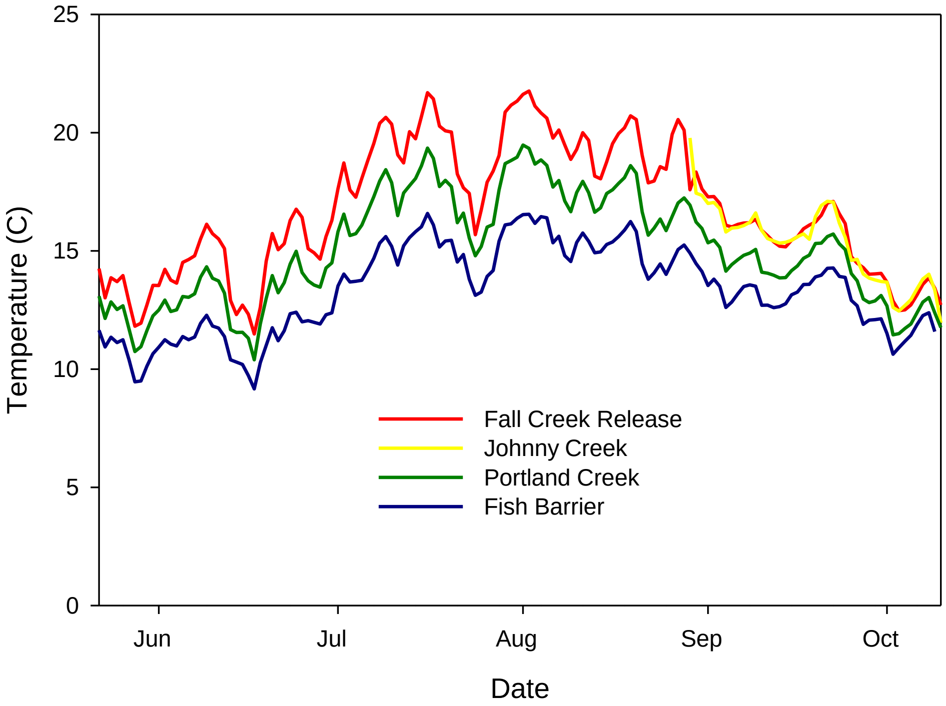

Figure 11. Daily mean water temperatures in 2014 at the sites in Fall Creek. The loggers represent a progression upstream from the release site (rkm 505.4) to the fish barrier (rkm 529.6). Data gaps at the Johnny Creek resulted from a stolen logger.

Water temperatures in the NFMF in 2014 were generally similar to previous study years (Figure 12). In the NFMF, daily means did not exceed 15°C at the release site during the monitoring period in 2014 and ranged from 8.4 to 14.5 °C from June through mid-October (Figure 12). NFMF temperatures were generally near or below the Chinook salmon thermal preferendum. Temperatures generally were higher at downstream locations in all years (Figure 13).

Although the release sites at Fall Creek and the NFMF Willamette were located ~27 km from each other, the NFMF was consistently cooler than Fall Creek (Figure 14) due to differences in elevation, underlying geology, and watershed characteristics. Mean water temperature in the NFMF during the 2014 study period was 11.5 °C with a peak of 14.5 °C in mid-July. Daily mean river temperatures in the NFMF averaged about 4.0 °C lower than in Fall Creek at the release sites throughout the monitoring period and about 5.0 °C lower during the July and August salmon holding period.

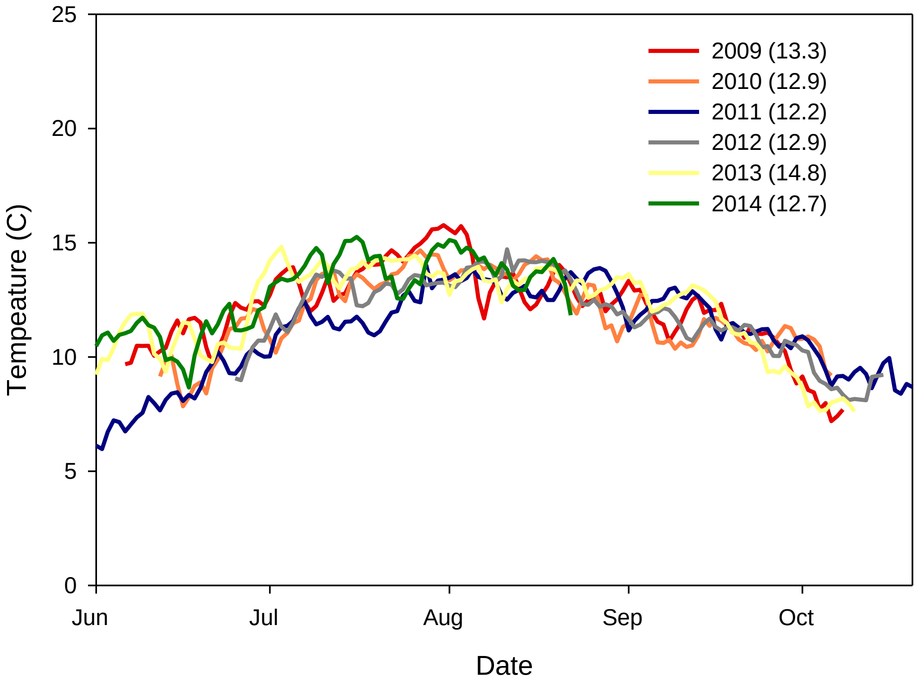

Figure 12. Comparison of mean daily water temperatures collected in the NFMF in 2009-2014 near the release site (rkm 557.9). Mean temperature for the study period shown in parentheses.

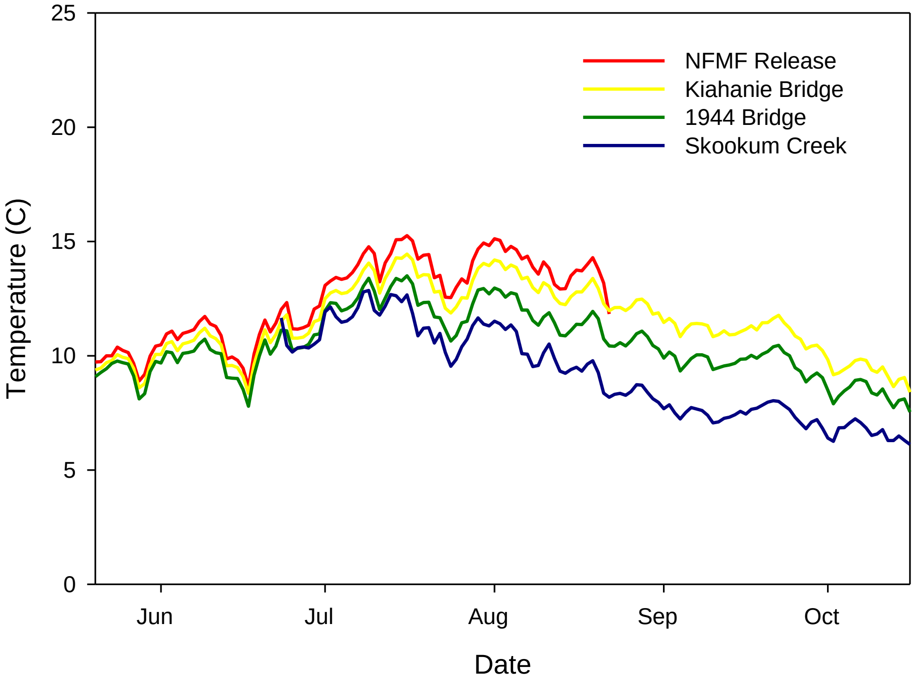

Figure 13. Daily mean water temperatures in 2014 at four NFMF sites. The loggers represent a progression upstream from the release site (rkm 557.9) to Skookum Creek (rkm 585.9). Data gaps at the release site resulted from lost/stolen loggers.

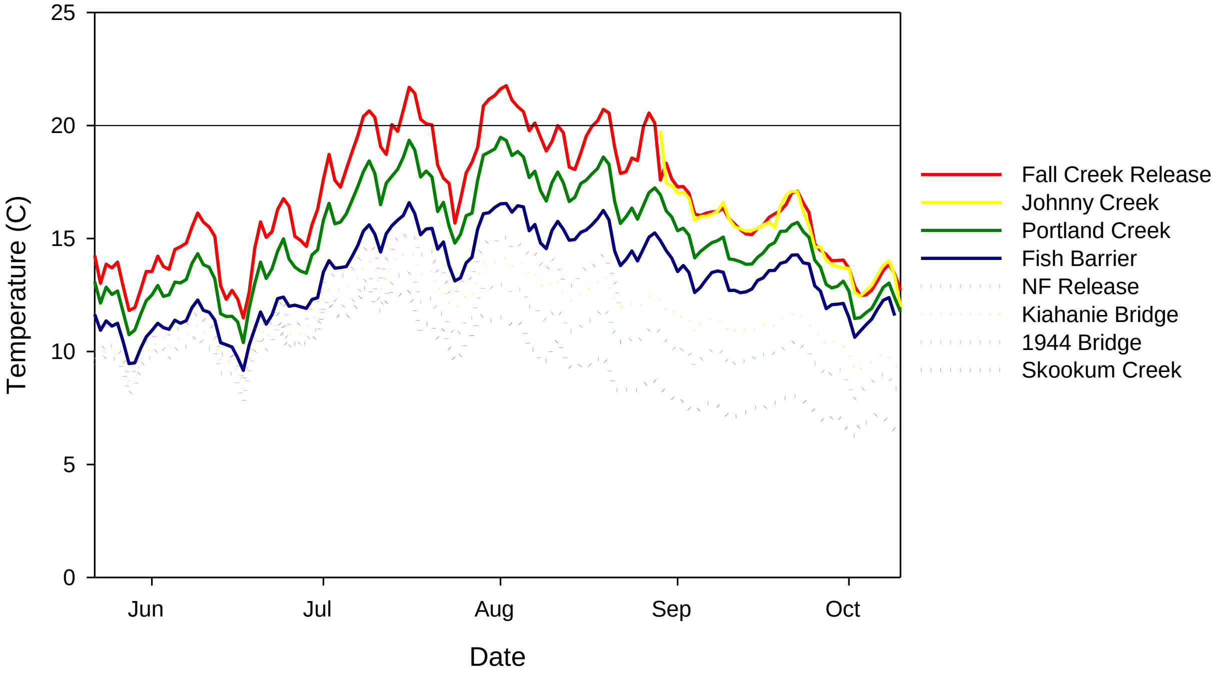

Figure 14. Daily mean water temperatures in Fall Creek (solid lines) and the NFMF Willamette River (dotted lines) in 2014. Solid line at 20 °C represents temperature considered to be physiologically stressful for adult salmonids.

Spawning Ground Surveys and Spawning Success: Fall Creek

Carcasses were recovered in Fall Creek from 16 July until 1 October with the first redd observed on 16 September. The recovery rate for the PIT-tagged sample was 5.6% (9 out of 160 fish). We recovered a higher proportion of unmarked fish in 2014 (23%) than PIT-tagged fish (Table 6). The PSM estimate for PIT-tagged fish was 100% (5 of 5 females recovered) and 65% for untagged female carcasses (11 of 17; Table 6) or 72.7% across both samples (n = 22 recovered females). The 2014 PSM estimate was among the highest in the study period (2008-2014) for Fall Creek (Table 6).

Table 6. Recovery rates and final estimated fates of Chinook salmon that were PIT-tagged or double-tagged (PIT and radio-tagged) and unmarked fish in Fall Creek, 2008-2014. Prespawning mortality (PSM) rates were only calculated for females.

Year	Group	# released	# recovered	% recovered	Females # recovered	Females %PSM
2008	PIT	188	30	16	0	N/A
	Double	7	1	14	0	N/A
	Unmarked	N/A	19	N/A	0	N/A
2009	PIT	175	22	13	10	80
	Double	25	11	44	6	100
	Unmarked	N/A	66	N/A	15	87
2010	PIT	124	30	24	12	42
	Double	75	32	43	15	73
	Unmarked	N/A	148	N/A	46	43
2011	PIT	125	27	22	12	17
	Double	75	22	29	9	44
	Unmarked	128	33	26	13	54
2012	PIT	78	20	26	11	0
	Double	40	11	28	5	20
	Unmarked	192	67	35	28	18
2013	PIT	96	16	17	2	100
	Unmarked	371	31	8	13	100
2014	PIT	160	9	5.6	5	100
	Unmarked	296	69	23	17	65

The final distribution of PIT-tagged fish indicated that the majority of spawning occurred 15-25 km upstream from the release site (Figure 15). Four of five (80%) PIT-tagged prespawn mortalities were recovered between the 1828 Bridge and the barrier falls.

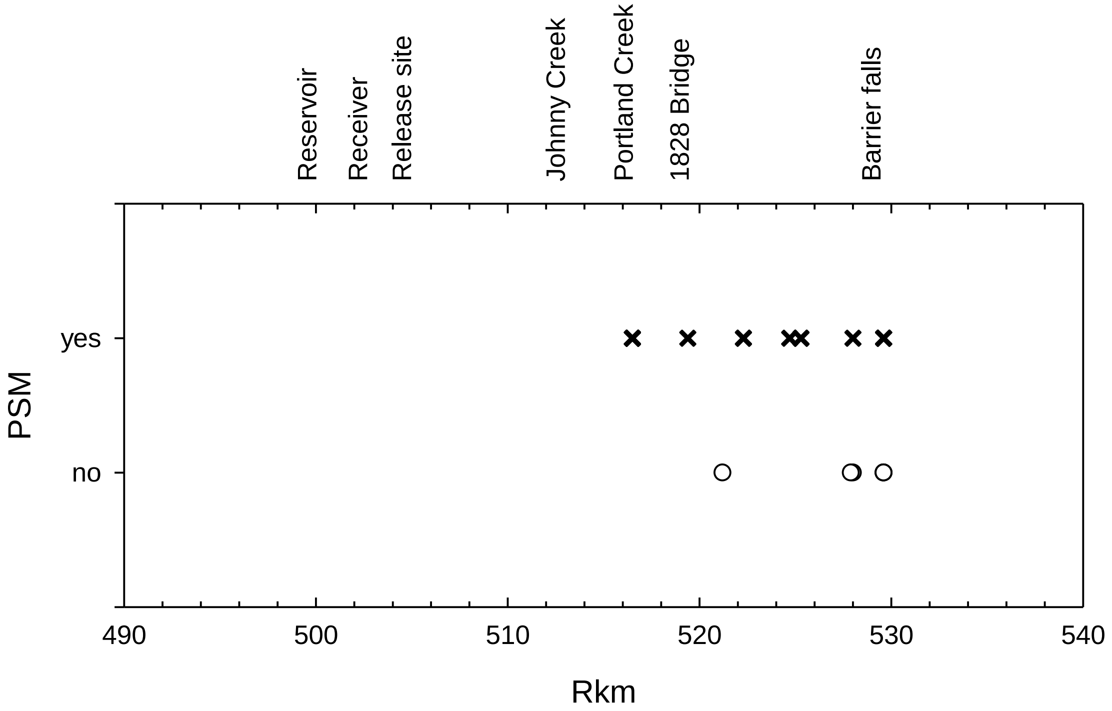

Figure 15. Distribution of 5 PIT-tagged and 17 untagged female Chinook salmon carcasses that were recovered in Fall Creek spawning ground surveys in 2014, by their PSM status.

Spawning Ground Surveys and Spawning Success: NFMF

Carcasses were recovered in the NFMF from 4 August to 2 October from two groups of tagged adults. The recovery rate was 19.3% (29/150) for adults tagged only with at PIT-tag and released immediately (Table 7), which was slightly higher than the recovery rate for radio-tagged adults (16.0%, 8/50). Approximately 24% (208/865) of the unmarked fish released in the NFMF were recovered on the spawning grounds.

The prespawning mortality estimates in 2014 were 23.5% (4 of 17 females recovered) for PIT-tagged fish, 0% (0 of 3 females) for radio-tagged fish, and 9.5% (7 of 74 females) for unmarked fish (Table 7), or 11.7% across all tag groups (n = 94).

Table 7. Final fates of PIT-tagged, double-tagged (PIT and radio), and unmarked subsets of the Chinook salmon outplanted in the NFMF Willamette River in 2009-2014. Prespawning mortality (PSM) rates were only calculated for females. DEX = fish tagged at the Dexter Dam trap and immediately outplanted into the NFMF Willamette River. HH = fish held at the Willamette Hatchery and later outplanted into the NFMF Willamette River.

Year	Group	# released	# recovered	% recovered	Females #recovered	Females %PSM
2009 (DEX)	PIT	124	6	5	3	0
	Double	12	3	25	1	100
	Unmarked	N/A	66	N/A	19	47
2009 (HH)	PIT	103	1	1	1	0
2010 (DEX)	PIT	148	30	20	15	47
	Double	43	8	18	3	67
	Unmarked	N/A	266	N/A	102	64
2010 (HH)	PIT	81	8	10	7	0
	Double	18	7	39	6	33
2011 (DEX)	PIT	109	7	6	5	0
	Double	71	11	15	5	60
	Unmarked	1,366	186	14	98	38
2011 (HH)	PIT	79	8	10	5	40
2012 (DEX)	PIT	104	14	13	10	10
	Double	50	11	22	6	17
	Unmarked	2,441	387	16	192	23
2012 (HH)	PIT	71	17	24	10	10
2013	PIT	106	11	10.4	6	50
	Double	59	6	10.2	3	33.3
	Unmarked	2,031	336	16.5	153	28.8
2014	PIT	150	29	19.3	17	23.5
	Double	50	8	16.0	3	0.0
	Unmarked	865	208	24.0	74	9.5

In the NFMF, spawning activity was concentrated in a 20 km reach just upstream from the release site (Figure 16), a pattern similar to spawning distributions observed in previous years (Mann et al. 2011; Naughton et al. 2013).

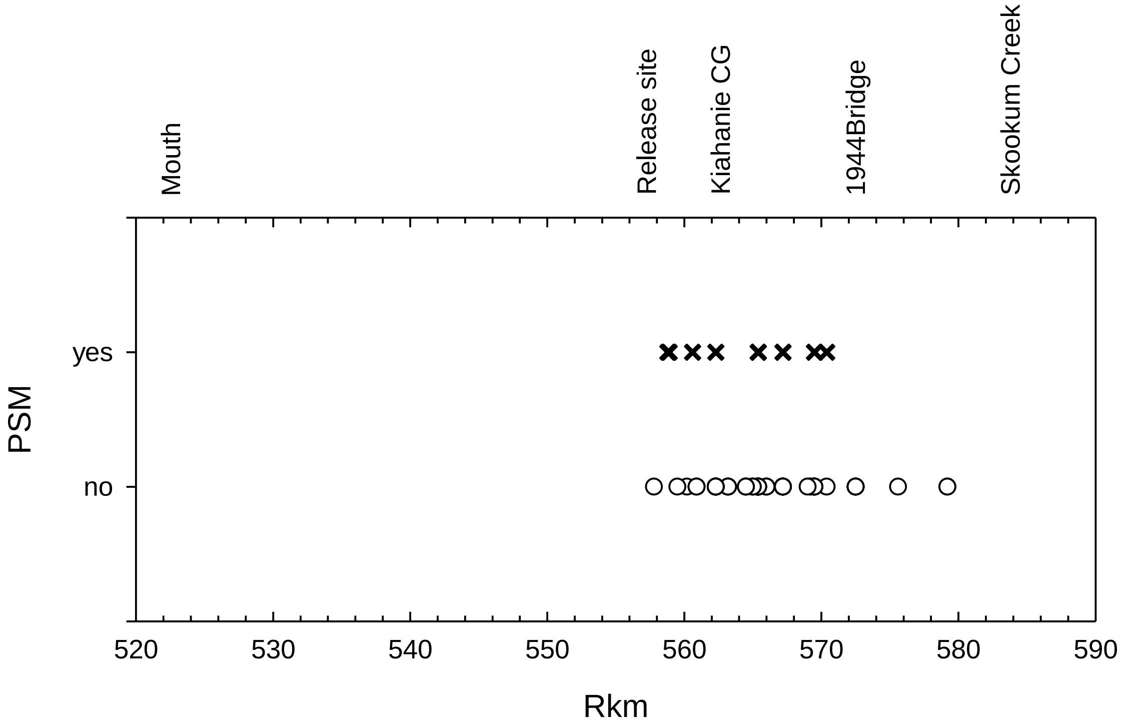

Figure 16. Distribution of 17 PIT-only and 3 radio-tagged and 74 untagged female Chinook salmon carcasses that were recovered in the NFMF Willamette River spawning ground surveys in 2014, by their spawning status.

In 2014, we continued the early outplanting of PIT- and radio-tagged fish into the NFMF initiated in 2013. Overall, recovery rates were higher in 2014 than 2013 (Table 8), largely because a flooding during the spawning season in 2013 reduced recovery. Although sample sizes were small and 2013 estimates are challenging to interpret because of the flood, PSM estimate were the same (33%) for the early release group in both years. PSM rates were higher in the late release group in 2013 (50%) than in the late group in 2014 (18%).

Table 8. Prespawn (PSM) percentages for two groups of spring Chinook salmon tagged at the Dexter trap and released in in the NFMF in 2013-2014.

Year	Release Date	Number Released	Number Recovered	Percent Recovered	Females Recovered	PSM	Percent PSM
2013	22 May-5 June	64	6	9.4	3	1	33
	19 Jun-17 Jul	101	11	10.9	6	3	50
2014	21 May-4 June	60	8	13.3	3	1	33
	11 Jun-30 Jul	140	28	20.0	17	3	18

Fall Creek and NFMF Multi-year Summary

We tested for associations between fate and a suite of factors potentially related to PSM across study years using univariate and multiple logistic regression models and multi-model selection techniques. The models for Fall Creek included 87 females over 6 years (2009-2014). Among the univariate logistic regression models, year, fork length and standardized mideye-to-hypural length (StdMeH) were significantly ($P < 0.05$) associated with PSM (Table 9). The fork length effect indicated higher PSM rate in larger salmon and the StdMeH relationship indicated fish relatively short tails and heads (i.e., relatively large-bodied) had higher PSM. In the multi-model logistic regression evaluation, the most parsimonious model included year and tag date (Table 9). The tag date effect reflected higher PSM among the later migrants, on average, while the year effect indicated higher PSM in the early (2009 and 2010) and latest study years (2013 and 2014). Several additional models had statistical support, with ΔAIC < 4.0, all of which included year or tag date. These models included various combinations of condition score, fork length, Fulton's K, weight, and shape.

The models for the NFMF included 77 females over 6 years. Among the univariate predictor variables, PSM was only significantly associated with tag date ($P = 0.016$), which reflected an increase in PSM with increasing tag date (Table 10). In the multivariate models, year plus tag date was the model with the lowest P value ($P = 0.120$) and the model with tag date, condition score, and fatmeter was the most parsimonious (Table 10).

Table 9. Selection statistics for logistic regression models of PSM in Fall Creek from 2008-2014 that included a variety of predictor variables and mortality as the dependent variable. AIC = Akaike information criteria, $\Delta\text{AIC} = \text{AIC}_{\text{current}}\text{-AIC}_{\text{best}}$. Models in shaded grey had statistical support ($\Delta\text{AIC} < 4$ in multivariate model, $P < 0.05$ in univariate models), and the model in bold text was most parsimonious. Variable definitions: Condition = overall physical condition score; TagDate = release date; Fatmeter = fatmeter percentage; StdMeH = standardized mideye to hypural length; StdHH = standardized hump height; StdDa = standardized depth at anus; StdBa = standardized breadth at anus; FL = fork length; Weight, and K = Fulton's K (10^5*weight/L^3).

Model type							
Univariate	Variables				AIC	ΔAIC	*P*-value
Timing	Year				93.761	3.22	0.004
	Tag date				121.386	30.845	0.080
Condition	Condition				126.274	35.733	0.817
	Fatmeter				119.916	29.375	0.084
	Fulton's K				121.939	31.398	0.119
Shape	STDMeH				118.531	27.99	0.021
	STDHH				122.515	31.974	0.157
	STDDa				120.74	30.199	0.062
	STDBa				121.179	30.638	0.078
Size	FL				119.637	29.096	0.035
	Weight				122.876	32.335	0.199
Multivariate	Variables				AIC	ΔAIC	*P*-value
Timing	**Year**	**Tagdate**			**90.541**	**0**	**0.003**
Condition	Condition	Fatmeter			123.636	33.095	0.449
	Year	Condition	Fatmeter		97.057	6.516	0.047
	Condition	Fatmeter	K		123.578	33.037	0.354
	Year	Condition	Fatmeter	K	98.033	7.492	0.066
	Condition	Fatmeter	tagdate		122.588	32.047	0.299
	Year	Fatmeter	tagdate	K	93.996	3.455	0.013
Shape	StdMeH	StdHH	StdDA	StdBA	123.389	32.848	0.194
	Year	Shape			94.276	3.735	0.033
	Condition	Fatmeter	Shape		126.172	35.631	0.452
	Year	Condition	Fatmeter	Shape	98.923	8.382	0.173
	Shape	Tag date			121.533	30.992	0.107
	Year	shape	Tag date		91.887	1.346	0.046
Size	FL	Weight			118.907	28.366	0.045
	Year	FL	Weight		93.032	2.491	0.017
	FL	Weight	Shape		123.254	32.713	0.233
	Year	FL	Weight	Shape	96.902	6.361	0.076
Full					34.1		1.0

Table 10. Selection statistics for logistic regression models of PSM in NFMF from 2009-2014 that included a variety of predictor variables and mortality as the dependent variable. AIC = Akaike information criteria, ΔAIC = AIC$_{current}$-AIC$_{best}$. Models in shaded grey had statistical support (ΔAIC < 4 in multivariate model, $P < 0.05$ in univariate models), and the model in bold text was most parsimonious. Variable definitions: Condition = overall physical condition score; TagDate = release date; Fatmeter = fatmeter percentage; StdMeH = standardized mideye to hypural length; StdHH = standardized hump height; StdDa = standardized depth at anus; StdBa = standardized breadth at anus; FL = fork length; Weight, and K = Fulton's K (10^5*weight/L^3).

Model type Univariate	Variables				AIC	ΔAIC	*P*-value
Timing	Year				98.107	6.96	0.216
	Tag date				**91.147**	**0**	**0.016**
Condition	Condition				97.143	5.996	0.272
	Fatmeter				92.232	1.085	0.298
	Fulton's K				96.378	5.231	0.372
Shape	STDMeH				97.888	6.741	0.902
	STDHH				97.773	6.626	0.720
	STDDa				97.903	6.756	0.991
	STDBa				97.903	6.756	0.995
Size	FL				97.821	6.674	0.775
	Weight				97.179	6.032	0.927
Multivariate	Variables						
Timing	Year	Tagdate			94.745	3.598	0.120
Condition	Condition	Fatmeter			94.131	2.984	0.404
	Year	Condition	Fatmeter		99.478	8.331	0.540
	Condition	Fatmeter	K		95.336	4.189	0.575
	Year	Condition	Fatmeter	K	100.997	9.85	0.669
	Condition	Fatmeter	tagdate		93.744	2.597	0.311
	Year	Fatmeter	tagdate	K	96.525	5.378	0.419
Shape	StdMeH	StdHH	StdDA	StdBA	103.404	12.257	0.974
	Year	Shape			105.925	14.778	0.619
	Condition	Fatmeter	Shape		101.498	10.351	0.841
	Year	Condition	Fatmeter	Shape	106.764	15.617	0.834
	Shape	Tag date			95.658	4.511	0.181
	Year	shape	Tag date		100.725	9.578	0.354
Size	FL	Weight			98.989	7.842	0.906
	Year	FL	Weight		101.609	10.462	0.442
	FL	Weight	Shape		105.622	14.475	0.956
	Year	FL	Weight	Shape	106.849	15.702	0.658
Full					108.39	17.243	0.844

Overall, PSM rates for PIT- and radio-tagged female Chinook salmon were highly variable in Fall Creek ranging from about 6% in 2012 to 100% in 2013 and 2014 (Figure 17). PSM rates for PIT- and radio-tagged females combined in the NFMF were the highest in 2010 (50%; Figure 17) versus 13-44% in previous years. In most years, a majority of prespawn mortalities occurred prior to the first redd count in each stream (Figures 18 and 19). PSM rates were higher for PIT and radio-tagged fish in Fall Creek compared to untagged fish in 2009 and 2010 but rates were similar for tagged and untagged groups in 2011-2014 (Figure 20). In the NFMF, there were no consistent year-to-year patterns in PSM rates among untagged, PIT-tagged or radio-tagged groups (Figure 21). Tag type (PIT, radio, and untagged) was not a significant predictor of PSM rates at NFMF ($P = 0.440$) in multinomial logistic regression when controlling for the effects of year ($P < 0.001$). In a similar analysis controlling for year effects ($P < 0.001$) at Fall Creek, radio+PIT-tagging was associated with significantly higher PSM at Fall Creek compared to PIT-tagging only ($P = 0.016$), but the probability of PSM was not significantly different between radio+PIT-tagged and untagged samples when the analysis was restricted to years with all three tag types (2009-2012), and this effect was marginally significant when including all years ($P = 0.054$) and non-significant ($P = 0.773$) when comparing radio+PIT samples to untagged samples. Thus, while there was some weak evidence that double-tagged fish had higher PSM rate than PIT-only tagged fish, this effect was not observed with untagged controls. Overall, we conclude that radio+PIT-tagging had no or minimal additional tagging effects on the probability of PSM compared to PIT-tagging only or untagged samples in Fall Creek and the NFMF.

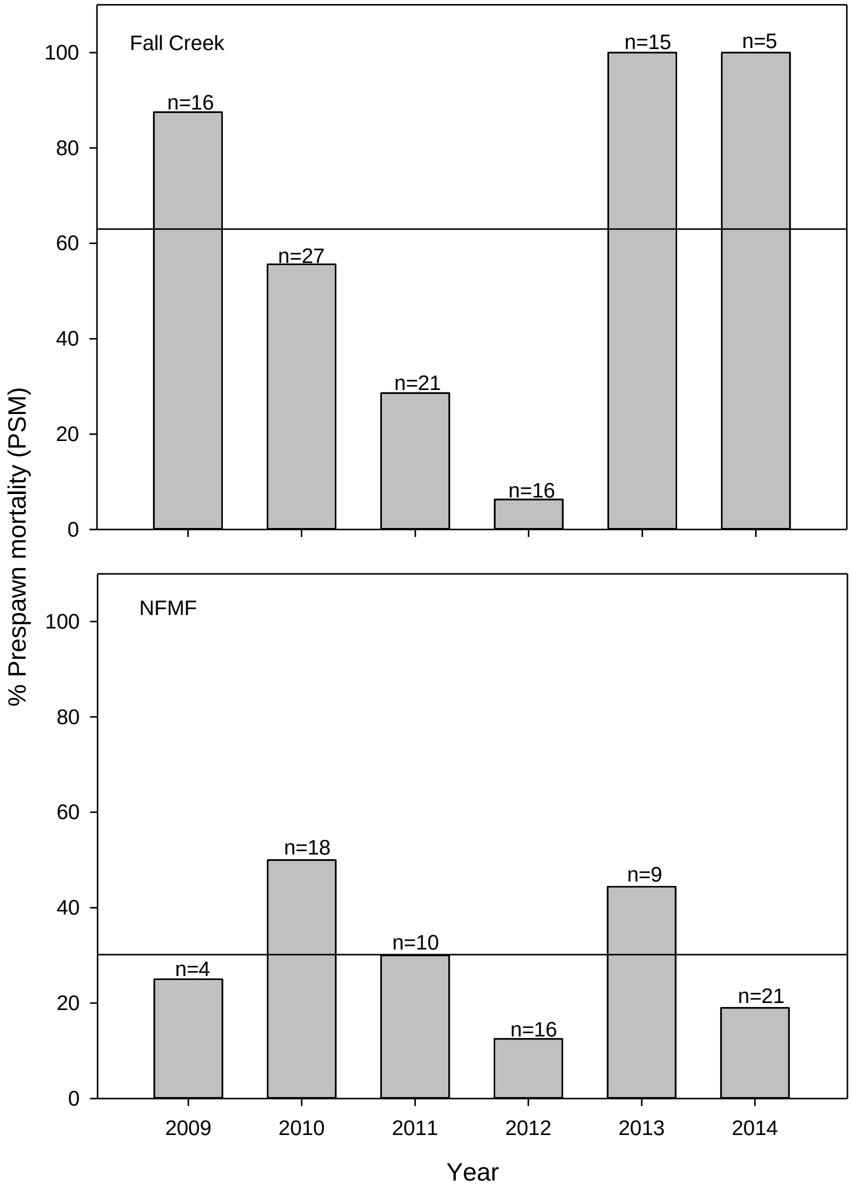

Figure 17. Annual percent PSM for combined PIT- and radio-tagged female Chinook salmon recovered in Fall Creek (top panel) and the NFMF (bottom panel) in 2009-2014. Horizontal line is the mean PSM rate across study years.

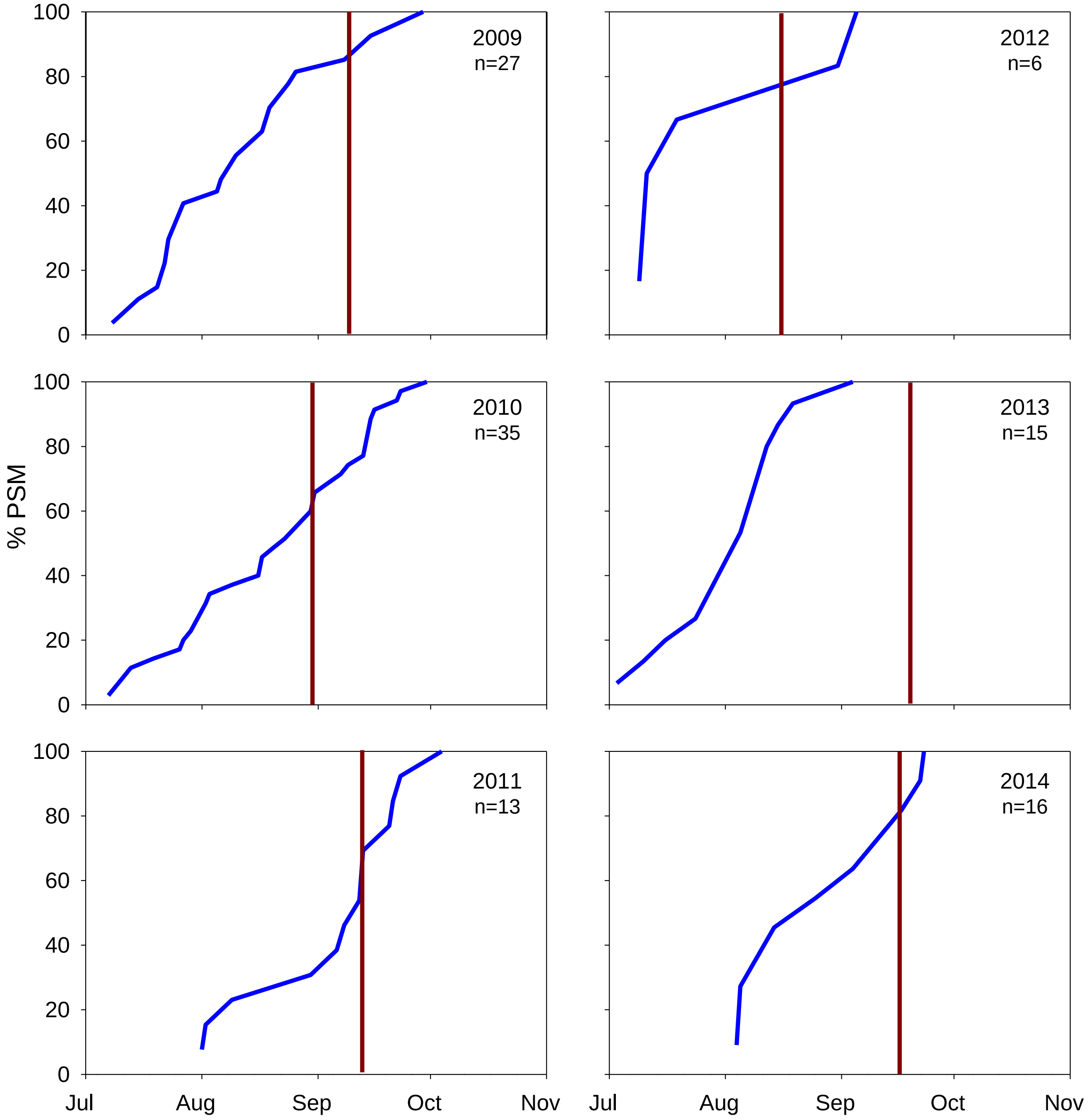

Figure 18. Cumulative percent PSM events of Chinook salmon in Fall Creek in 2009-2014 by date of carcass recovery. Vertical red lines indicate the date that the first redd was observed.

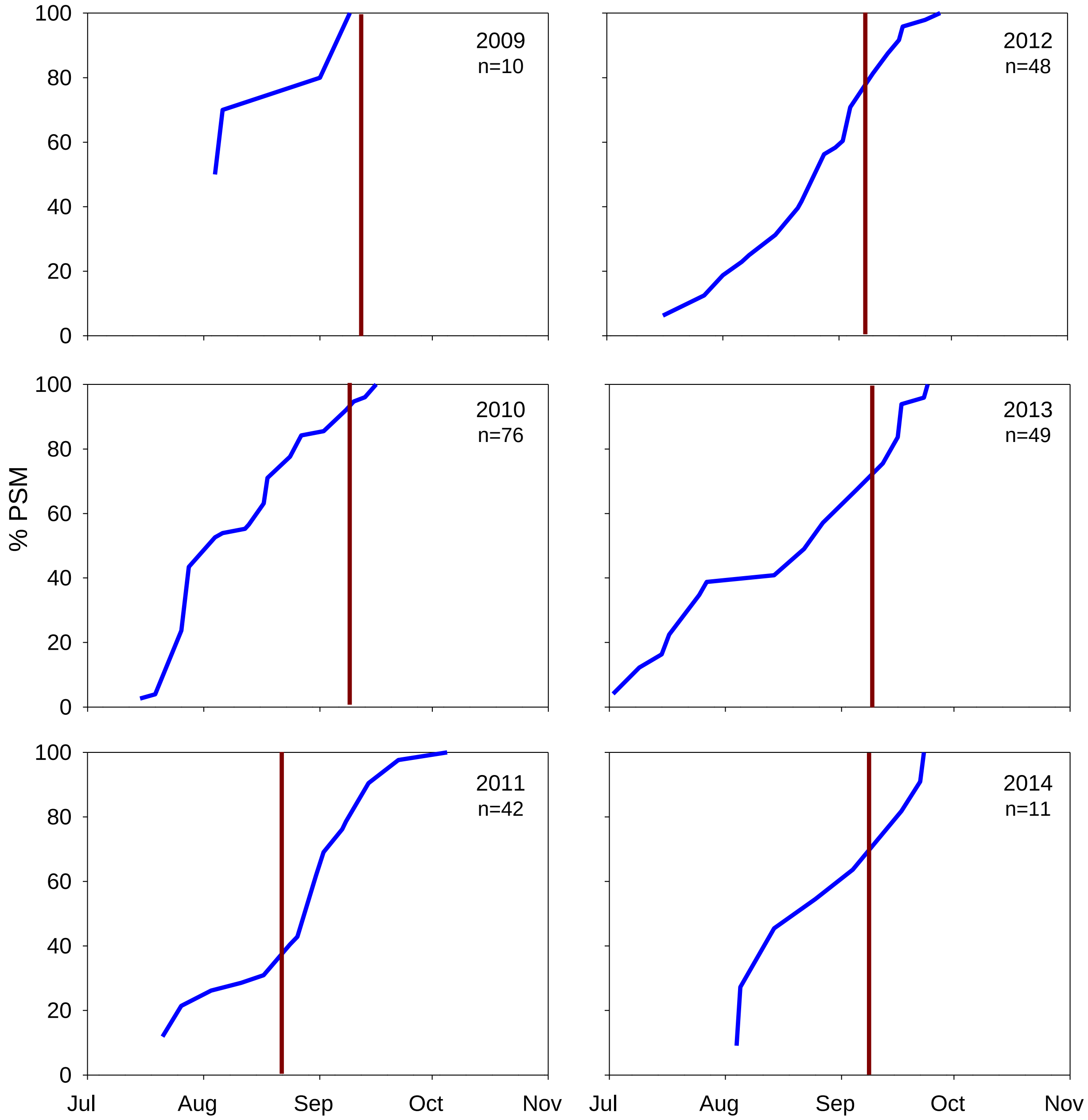

Figure 19. Cumulative frequency of PSM events of Chinook salmon in the NFMF of the Willamette River in 2009-2014. Vertical red lines indicate the date that the first redd was observed.

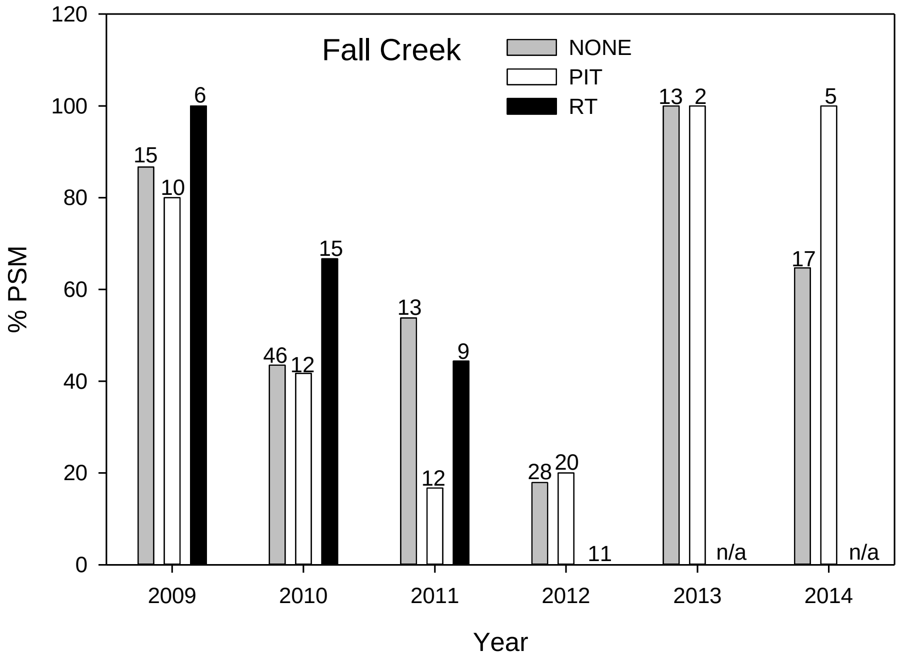

Figure 20. PSM rates for tagged and untagged female Chinook salmon recovered in Fall Creek in 2009-2014. Sample sizes shown above each bar are total number of females recovered.

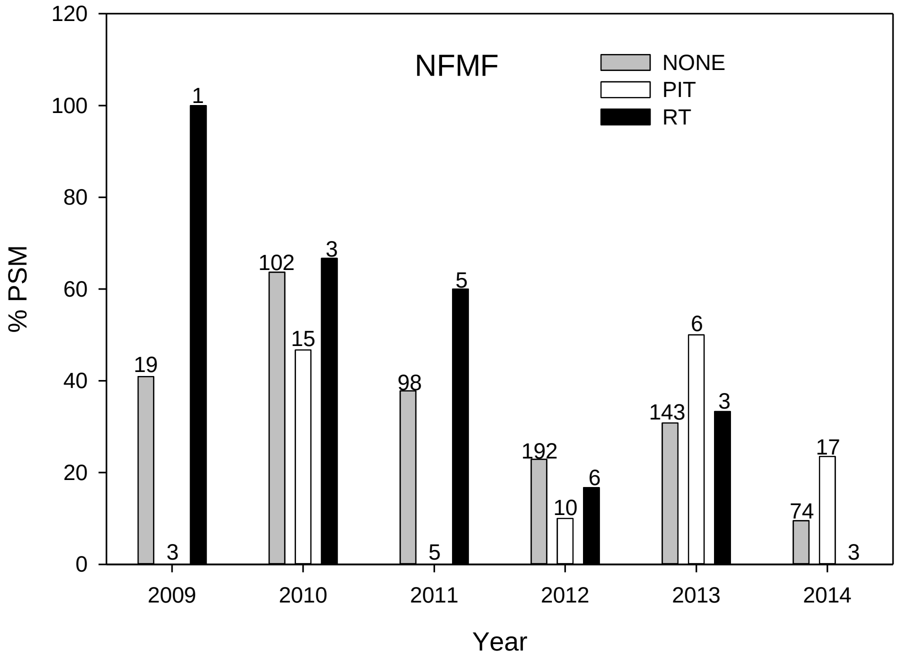

Figure 21. PSM rates for tagged and untagged female Chinook salmon recovered in the NFMF in 2009-2014. Rates do not include hatchery held fish released in the NFMF in 2009-2012. Sample sizes shown above each bar are total number of females recovered.

We examined the interannual relationship between water temperature and PSM in the two study areas (Figure 22). In Fall Creek, annual female PSM was strongly associated with mean daily water temperature from 1 July to 15 September (r^2 = 0.76) and positively but weakly correlated with the maximum 7-d moving average temperature (r^2 = 0.34). The first metric was an indicator of the overall thermal environment in each year and the second metric was an index of potential acute thermal stress. There was less evidence for a temperature effect in the NFMF, where neither the seasonal mean (r^2 = 0.19) nor the 7-d moving average (r^2 = <0.01) was strongly associated with PSM (Figure 22).

Results: South Fork Santiam

Adult Chinook salmon were collected and tagged at the Foster Dam trap on the South Santiam River from13 June to 16 September 2014. A total of 174 Chinook salmon (82 females, 92 males) were PIT tagged, and 75 of these were also radio-tagged at Foster Dam and released into the South Fork Santiam River or Foster Reservoir (Figure 23). All fish transported above the dam had intact adipose fins. The 99 PIT-tagged fish were released at Gordon Road. The 75 radio-tagged fish were released at three sites (Figure 24): River Bend (*n* = 4), Calkins (*n* = 44) and Gordon Road (*n* = 27). Fish released at the Calkins Park site were used to evaluate the efficacy of reservoir releases. The mean fork length for all PIT and radio-tagged fish (n = 174) was 78.4 cm in 2014, mean condition score in 2014 was 2.4, mean weight was 5.7 kg, and mean lipid percentage was 1.9% (Table 11). Mean estimated lipid content of tagged adults arriving at the Foster trap in June were lower than lipid content estimated for adults at Willamette Falls and generally decreased through the 2014 season (Figure 25).

The recovery rate for PIT-tagged fish was 32.3% (32/99). The recovery rates for radio-tagged salmon ranged from 11.4% (5/44) for fish released at Calkins Park to 37.3% (10/27) for fish released at Gordon Road. PSM estimates for fish released at Gordon Road were 11% (2 of 18 females recovered) for PIT-tagged fish and 40% (2 of 5 females recovered) for radio-tagged fish (Table 12). Two out of four recovered radio-tagged females released at Calkins were prespawn mortalities. Of the 49 (44 at Calkins, 5 at Gordon Road) radio-tagged fish released with thermographs, 22 (45%) were recovered on the spawning grounds (either before or after spawning had ceased). Eight thermographs recovered from reservoir released fish were used to compare actual degree days with estimated degree days if they would have been released in directly into the South Santiam upstream from the reservoir.

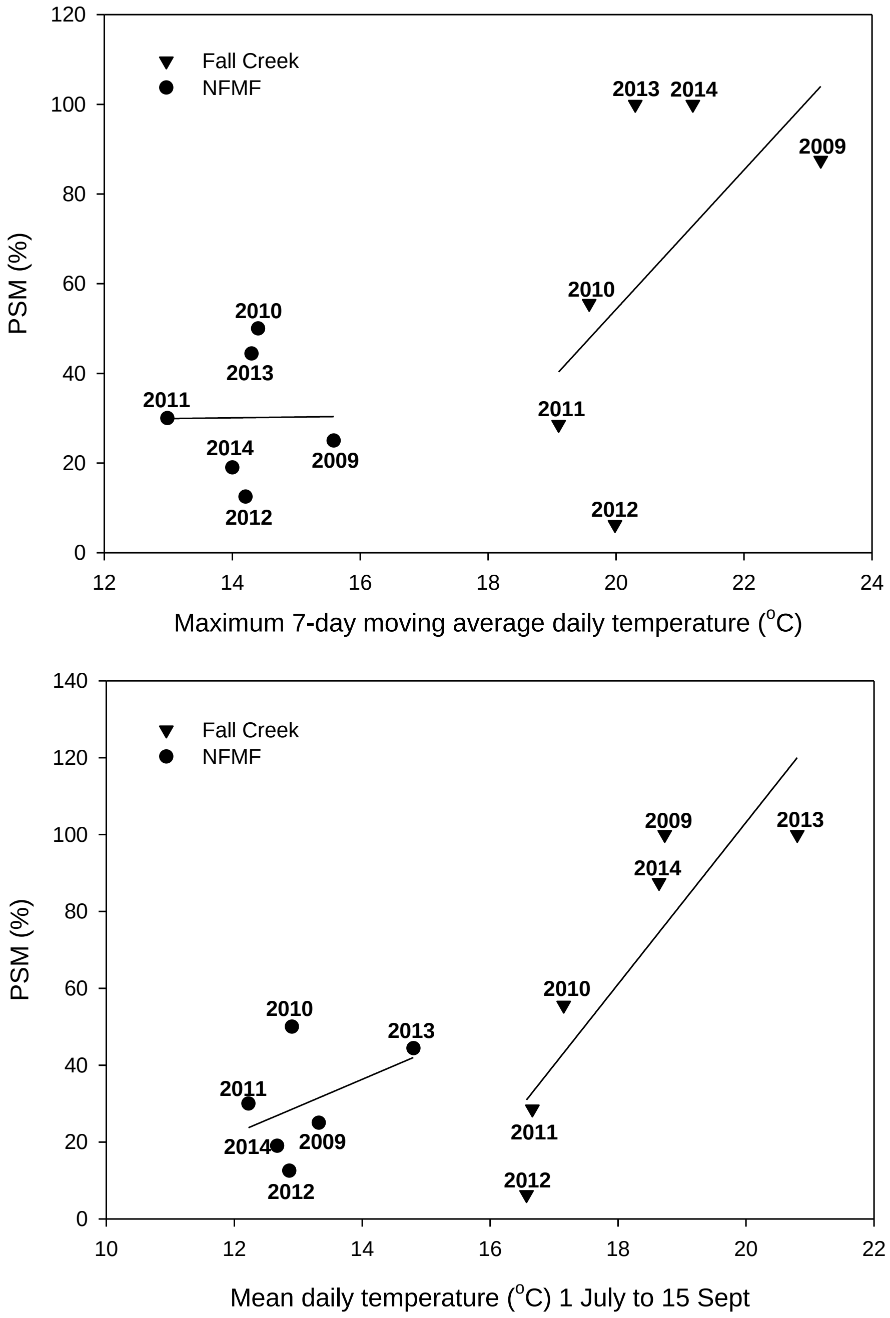

Figure 22. Prespawning mortality rates of female PIT- and radio-tagged Chinook salmon in Fall Creek and the NFMF in relation to the maximum 7-d moving average daily temperatures (top panel) and the mean daily temperature from 1 July to 15 September (bottom). Temperatures were recorded at the release sites.

Figure 23. Map of Foster Reservoir including South Fork and Middle Fork Santiam river arms, radiotelemetry monitoring antennas (●) and Chinook salmon release sites (●). Note: Gordon Road release site is approximately 16.4 river kilometers upstream of River Bend and is not shown on the map.

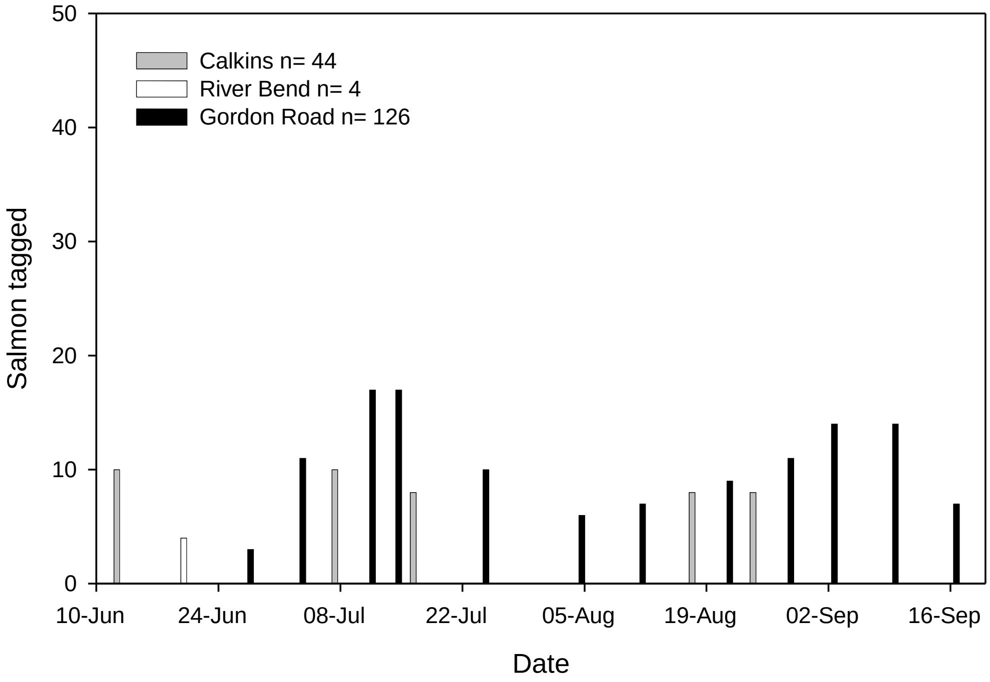

Figure 24. Numbers of adult Chinook salmon PIT- and radio-tagged at Foster Dam in 2014. Fish were immediately outplanted at three locations above Foster Dam. A total of 414 adults Chinook salmon were collected at the Foster trap.

Table 11. Adult Chinook salmon size, lipid content, and condition metrics for fish collected and sampled at Foster trap on the South Fork of the Santiam River and then immediately outplanted in 2014 (*n* = 174). MeH = Mid-eye to hypural length, Da = Depth at anus, Ba = Breadth at anus, HH = Hump height, % Lipid = % lipid in muscle tissue, wet weight.

SF Santiam (*n* = 174)	Fork Length (cm)	Weight (kg)	MeH (cm)	Da (cm)	Ba (cm)	HH (cm)	% Lipid	Condition Score
Mean	78.4	5.7	64.8	12.5	5.9	8.3	1.9	2.4
St. Deviation	8.1	1.8	6.8	1.5	1.0	1.2	1.4	0.7
Max	93	10	77	15.9	8.4	11.8	7.2	3
Min	57	1.9	46	8.4	3.3	5.2	0.3	1

Table 12. Recovery rates and final estimated fates of Chinook salmon that were PIT-tagged or double-tagged (PIT- and radio-tagged) at Foster Dam, 2013-2014. Prespawning mortality (PSM) rates were only calculated for females with known spawning status. Release sites were Gordon Road (GDR), River Bend (RVB) and Calkins Park (CKP).

Year	Release Site	Group	# released	# recovered	% recovered	#Females recovered	Females %PSM
2013	GDR	PIT	107	12	11.2	6	16.7
		Double	21	4	19.0	3	100
	RVB	PIT	18	1	5.6	1	100
		Double	4	1	25.0	0	n/a
	CKP	Double	50	4	8.0	1	100
2014	GDR	PIT	99	32	32.3	18	11.1
		Double	27	10	37.0	5	40.0
	RVB	PIT	0	n/a	n/a	n/a	n/a
		Double	4	1	25.0	1	100
	CKP	Double	44	5	11.4	4	50.0

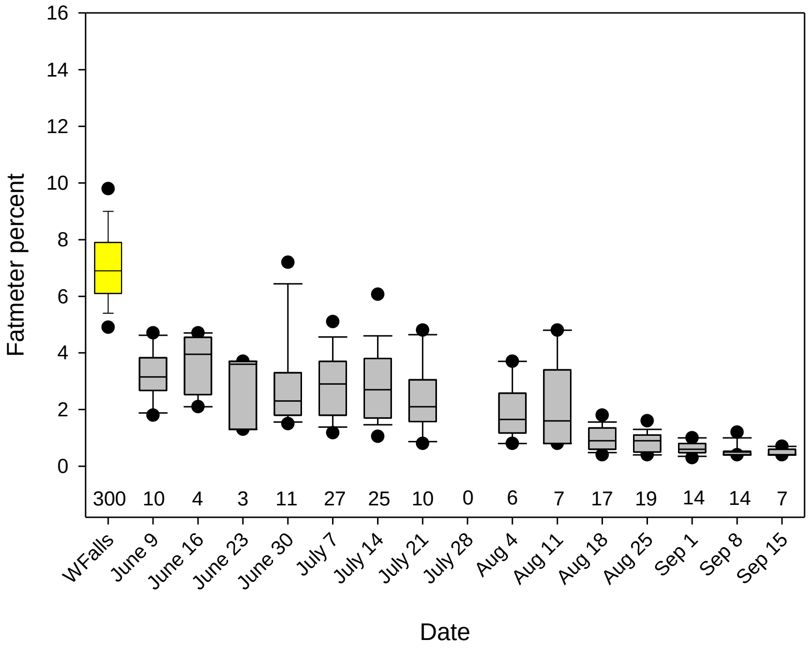

Figure 25. Distributions of fatmeter results for Chinook salmon tagged at the Foster Dam trap in 2014. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (●). Sample size for each week given below each distribution. Fatmeter readings from Willamette Falls (WFALLS) are from Jepson et al. (*in review*).

Proximate Analysis

In 2014, proximate analysis was performed on 15 Chinook salmon collected at Foster trap (7 males and 8 females). Lethal takes for proximate analysis were conducted on 27 June (*n* = 5), 24 July (*n* = 5) and 21 August (*n* = 5). The average muscle lipid level was 4.7% (Table 13) and ranged from 1.4-8.9%. Average gonadal lipid composition was 6.5% for females and 1.5% for males (Table 14). Individual lipid concentrations of fish collected at Foster Dam as estimated with the fatmeter were poorly correlated with the values estimated from proximate analysis taken from lethally sampled adults (adj. r^2 = -0.074, *P* = 0.854, *n* = 15).

Table 13. Mean tissue composition of 15 Chinook salmon collected at the Foster Dam trap and used in proximate analysis in 2014.

Tissue	% Moisture	% Crude Lipid	% Total Ash	% Protein
Gonads	70.2	4.1	1.9	23.8
Muscle	75.5	4.7	1.2	18.6
Skin	65.1	4.2	0.8	29.9
Viscera	78.9	2.1	1.1	17.9

Table 14. Tissue composition of 15 Chinook salmon collected at Foster used in proximate analysis by sex.

Tissue	% Moisture	% Crude Fat	% Total Ash	% Protein
Males (*n* = 7)				
Gonads	76.7	1.5	2.3	19.6
Muscle	74.6	5.1	1.1	19.1
Skin	66.2	1.4	0.6	31.8
Viscera	79.1	2.9	1.1	17.0
Females (*n* = 8)				
Gonads	64.5	6.5	1.6	27.4
Muscle	76.3	4.4	1.2	18.1
Skin	64.2	6.7	0.8	28.2
Viscera	78.7	1.4	1.1	18.7

South Fork Santiam River and Foster Reservoir Environment

Mean water temperature in the South Santiam (measured at the Gordon Road release site) during the 2014 study period was 15.2 °C with a peak of 19.3 °C on 1 August and tended to be progressively warmer downstream (Figure 26). Water temperatures in the Middle Fork Santiam were approximately 3 degrees cooler (*mean* = 12.8 °C) than in the South Fork with a maximum temperature of 14.3 °C on 20 July due to the thermal influence of Green Peter Reservoir. Mean water temperatures collected by USACE at 11 depths in Foster Reservoir ranged from 18.7 °C at 0.2 m from the surface to about 8.4 °C at 24 m, with a maximum of 23.9 °C in early August (Figure 27). The thermocline was at approximately 4-6 m and temperatures below 6 m remained <= 15 °C throughout the summer.

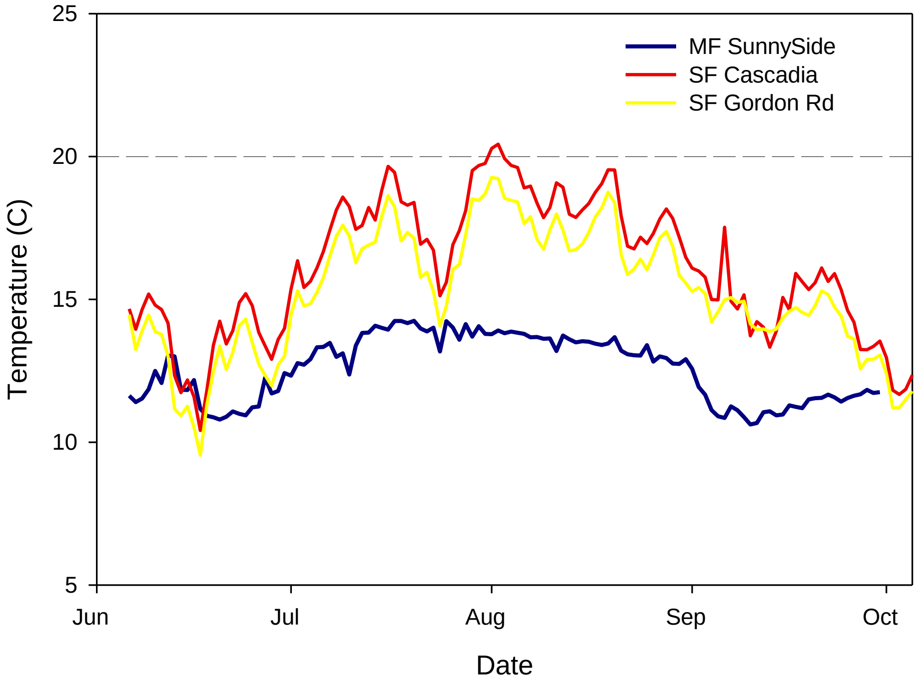

Figure 26. Daily mean water temperatures in 2014 in the Middle Fork Santiam River and at three sites in the South Fork Santiam River. The loggers in the South Fork Santiam represent a progression upstream from the Cascadia Bridge (rkm 437.3) to the Gordon Road release site (rkm 444.7). The River Bend release site logger located at rkm 428.3 was stolen in 2014.

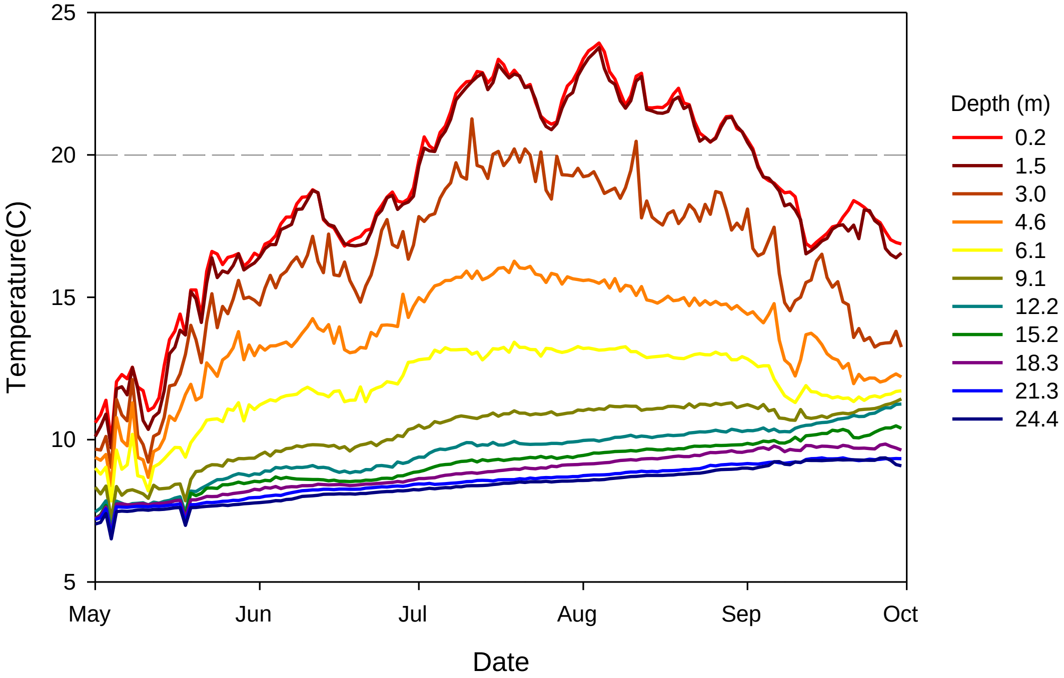

Figure 27. Foster Reservoir mean daily water temperatures collected at 11 depths between 1 May and 30 September 2104 (U.S. Army Corps of Engineers).

Reservoir Releases

Forty-four radio-tagged salmon were released into Foster Reservoir in 2014 and 27 (61%) of these were recorded at receivers upstream from the Calkins release site. Median reservoir residence times were 11.4 d (range 0.04-85.6 d) for fish last recorded on the South Fork Santiam receiver (SFR), 12.8 d (range 0.05-39.4 d) for fish last recorded on the Middle Fork Santiam receiver (MSR; Figure 28). Fish last recorded at the SFR site also included some fish that were detected on the MSR site, including fish that made multiple trips between receiver sites. Two of the four (50%) females released in Foster Reservoir and recovered on the spawning grounds were prespawn mortalities. Ten (23%) of the 44 fish released in the reservoir fell back through the dam with a median release-to-fallback time of 3.2 d (*range* = 0.6-31.6 days).

Comparison of the thermal history of fish released in the reservoir (Calkins Park releases) versus those released in river (at Gordon Road release site) suggested that reservoir-released fish were exposed to an average of 2.8 fewer degrees per day than fish released in the river (Figure 29). Estimates of the total accumulated degree days between release and spawning for reservoir residents were lower compared to estimated values for release into the South Santiam and the magnitude of the difference depended on the residence time in the reservoir (Figure 30). The average relative reduction in the total accumulated degree days was 16% (range = 14-23%).

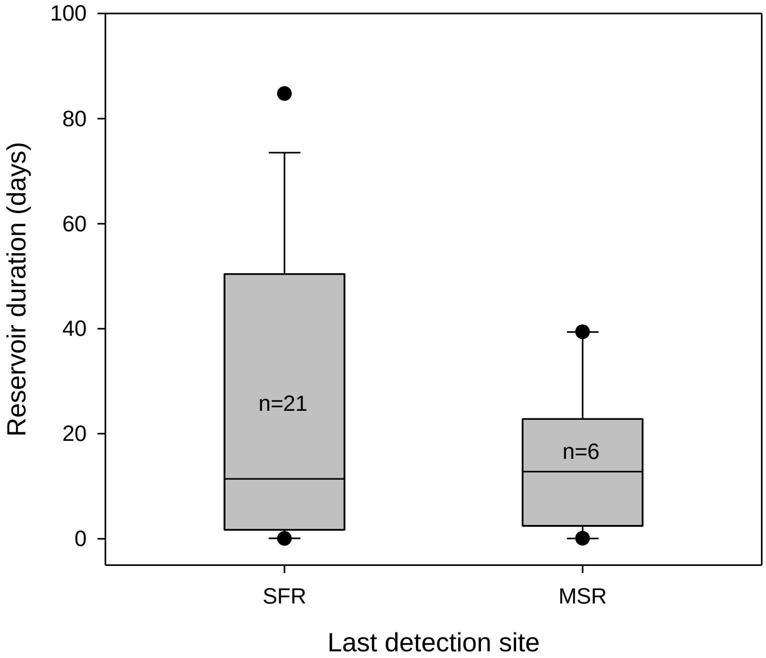

Figure 28. Reservoir residence times (d) of radio-tagged adult Chinook salmon released into Foster reservoir in 2014 by final detection location. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (●). SFR = South Fork Santiam River, MSR = Middle Fork Santiam River.

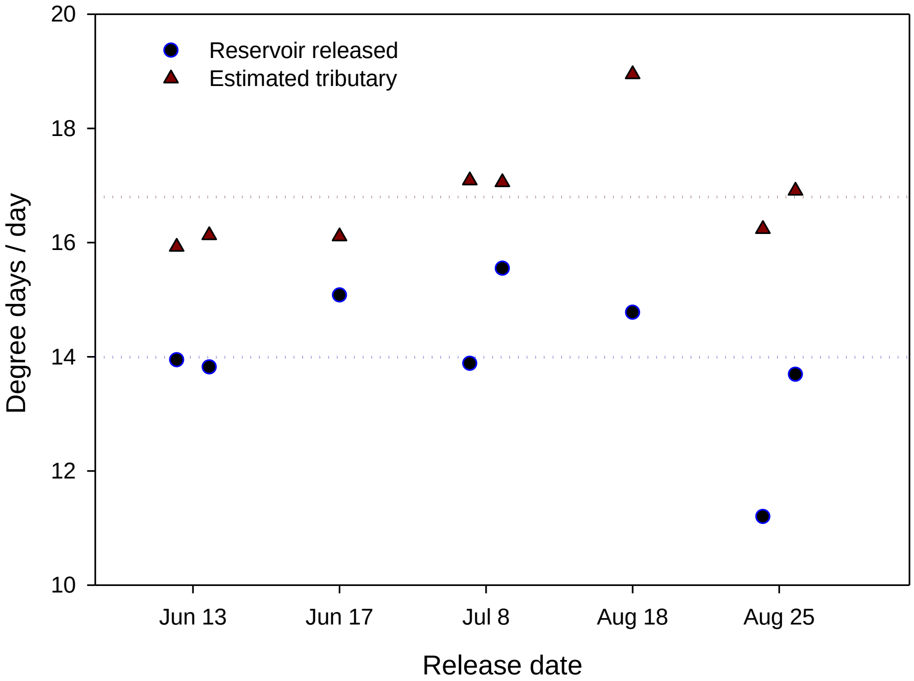

Figure 29. Numbers of degree days per day calculated for reservoir-released Chinook salmon (n = 8) that had archival temperature loggers (●), and their estimated degree days per day if they would have been released in directly into the South Santiam upstream from the reservoir (▲).

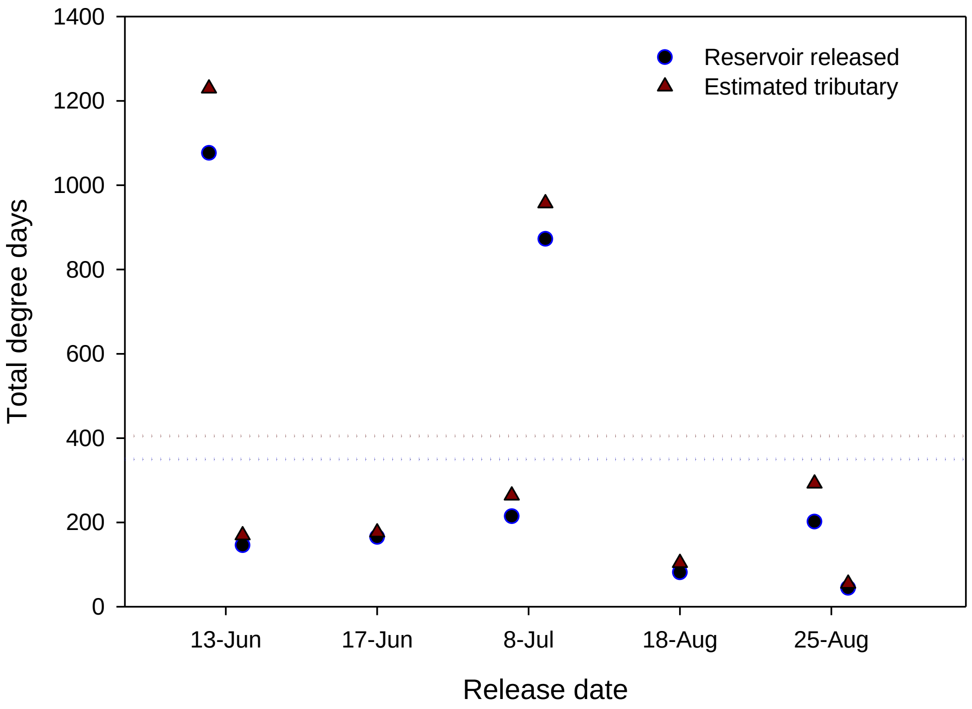

Figure 30. Total accumulated degree days for reservoir-released Chinook salmon (n =8) with archival temperature loggers (●) and their estimated total degree days between release and spawning if they would have been released directly into the South Santiam River upstream from the reservoir (▲).

Results: Minto Fish Facility tagging

Overall, we collected and radio-tagged 50 spring Chinook salmon at the Minto trap between 10 June and 28 July (Figure 31). All were released at the Minto Fish Facility, approximately 100 m upstream from the dam. The average fork length was 77.5 cm and average weight was 5.5 kg. Of the 50 fish, 30 (60%) moved upstream and remained there during the spawning period, while 20 (40%) had upstream movement (based on detections at the Big Cliff tailrace receiver) and then fell back downstream from the dam (based on detections at Minto Dam receivers; Figure 31). The median time from release to fallback was 53.2 d (*range* = 0-115 d). Nine out the 20 fish that fell back did so before the first redd was observed on 9 September while the other 11 fish remained upstream during the spawning period. Of the 20 fish that fell back, one was recaptured in the Minto trap but all other fish were last recorded downstream from the dam. During the spawning period, 8 adults remained downstream from Minto, 22 were recorded between Minto and the Big Cliff tailrace receiver and 10 in the Big Cliff tailrace (Figure 32).

Of the 300 spring Chinook salmon radio-tagged at Willamette Falls in 2014 (Jepson et al. *in review*), 14 were detected at Minto. A similar proportion of the Willamette Falls-tagged salmon were recorded falling back past Minto Dam (6 of 14; 43%) and ten were detected at the Big Cliff tailrace site. The median time from detection at the Big Cliff tailrace to fallback was 90 d. All six of the fallback events were after 28-September, in contrast to the fallbacks by the group collected at Minto (Figure 31).

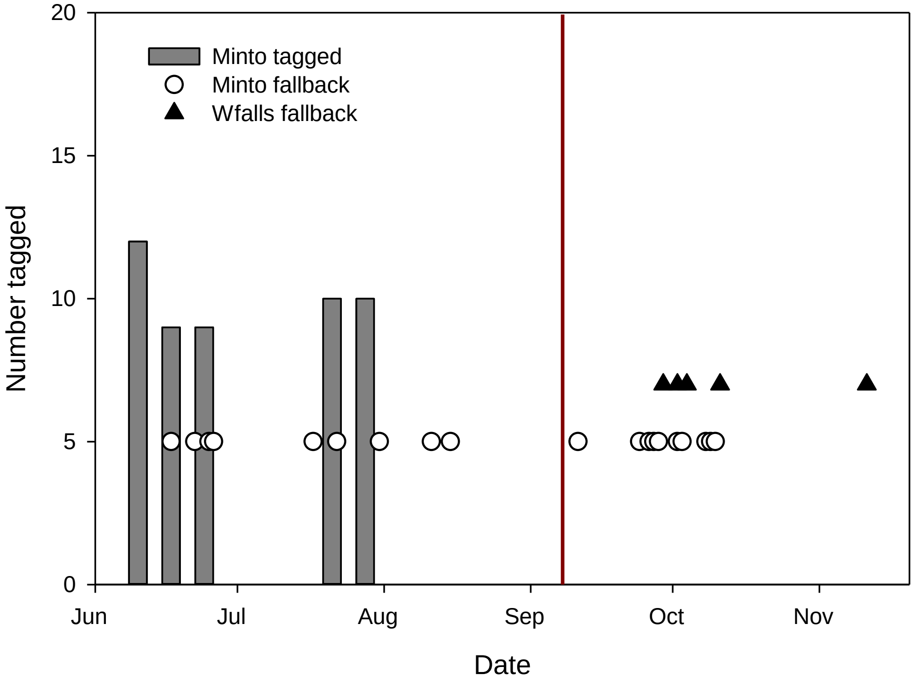

Figure 31. Number of Chinook salmon radio-tagged at Minto Fish Facility and number that fellback. Red line indicates first redd date in Big Cliff Tailrace.

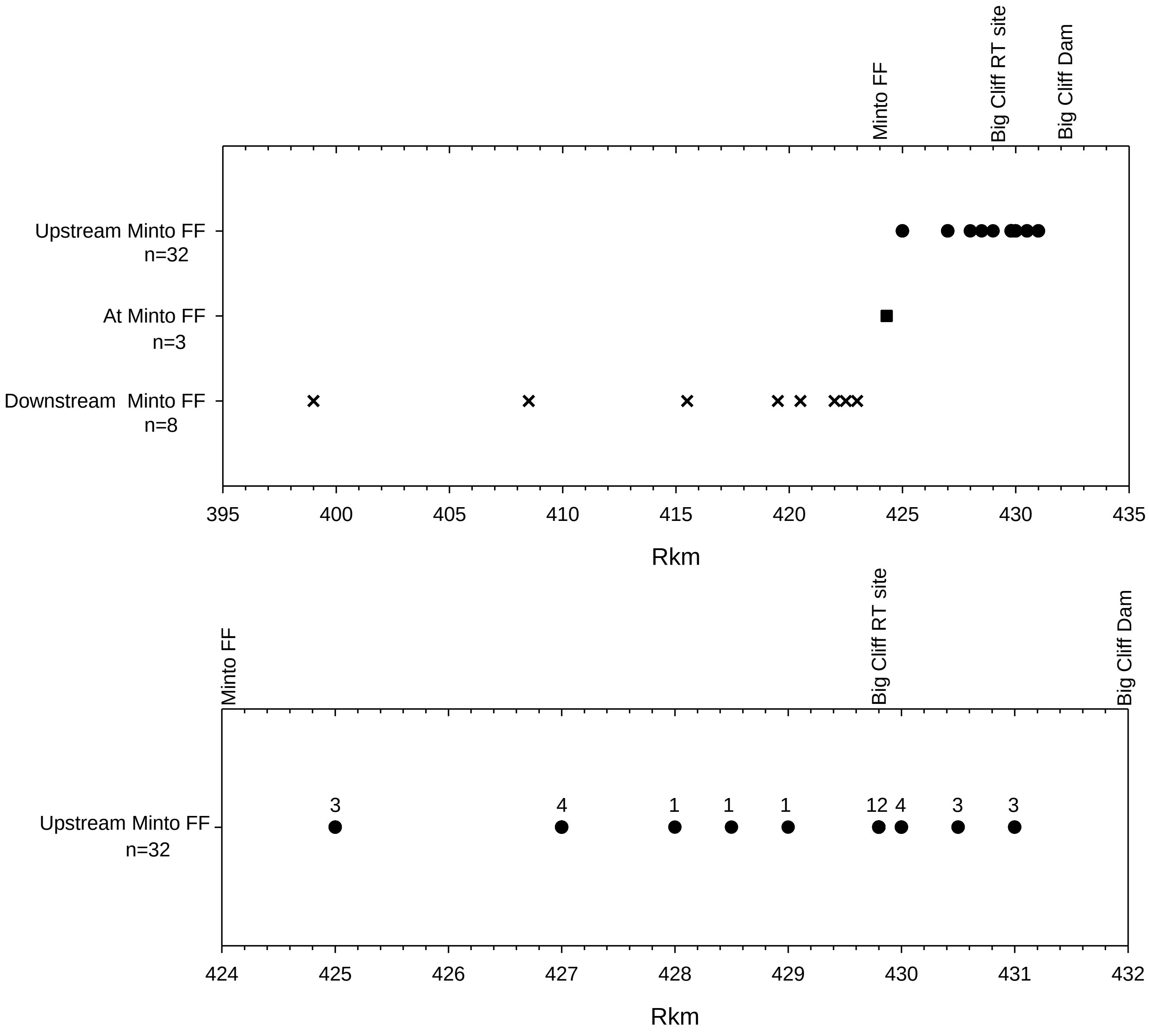

Figure 32. Distribution of radio-tagged Chinook salmon downstream of Minto Fish Facility to Big Cliff Dam during spawning (top panel). Distribution and number (above each point) of radio-tagged Chinook salmon during spawning between Minto Fish Facility and Big Cliff Dam (bottom panel).

Discussion

The primary study objectives for the Middle Fork Willamette River sites were to estimate PSM rates in the Fall Creek and NFMF Chinook salmon populations and to examine relationships between PSM and potential causative agents. Additional objectives in 2014 included continued examination of PSM patterns across years, evaluation of the behavior and distribution of reservoir-released Chinook salmon at Foster Reservoir, and a pilot study examining fallback behavior and spawning distribution in Chinook salmon released above Minto Dam.

Across years at all study sites, PSM rates did not differ systematically between groups that were untagged, tagged with PIT tags only, or double-tagged with PIT tags and radio transmitters, suggesting that tagging had minimal effect on fate (or at least was not systematically worse than the standard handling protocols for outplanted salmon). Notably this result contrasts with a recent study of Chinook salmon in the Yakima River where adults were also radio-tagged relatively late in their migration and displayed strong negative tagging effects (Corbett et al. 2012). The disparity between locations indicates possible population-specific differences in response to methods, differences in prior experience of salmon including exposure to pathogens, toxins, high water temperatures or other carry-over effects prior to tributary entry and tagging, differences in environment during holding, or a combination of these factors. Moreover, lower PSM rates of marked groups relative to unmarked salmon in recent years may reflect more careful handling, tagging and transport. Regardless, the results for the WVP suggest that carefully executed tagging studies can provide reliable estimates of PSM and fate within the study areas.

Sample sizes were small because carcasses are difficult to recover due to difficult stream conditions, scavenging, and limited frequency of surveys (about once/week) and sample sizes are further reduced due to female-only PSM estimates. Although the sample sizes were small, PSM rates in Fall Creek in 2013 and 2014 were the highest among all study years and this result was consistent with the high water temperature observed there in both years (and see below). In 2014, all five PIT-tagged females recovered on the spawning grounds were prespawn mortalities. The PSM rates for unmarked females were 65% (17 of 21 females recovered) in 2014. High rates have been reported in previous studies and thus the 2014 rates reported here are plausible, but clearly must be interpreted cautiously (i.e., mortality as high as 90%, Schroeder et al. 2007; Kenaston et al. 2009; Keefer and Caudill 2010). It remains unknown if the 2013 estimates were biased high because the carcasses of late-spawning adults could not be recovered due to flooding. Nonetheless, evaluation of the seasonal timing of PSM events (Figures 18 and 19) indicate that much of the mortality occurs prior to the onset of spawning, suggesting the true rate in 2013 was high relative to past years.

In contrast to the Fall Creek results, the 2014 PSM estimate of 23.5% for PIT- and radio-tagged fish combined in the NFMF was among the lowest in the time series (2009-2014). The 2014 rate was substantially lower than in 2013 when high water levels precluded surveys during the peak of spawning activity. Because we were able to survey throughout the spawning season in 2014, the rates we observed were likely more representative than those in 2013. The moderate

NFMF temperatures (*mean* = 11.5 °C) throughout the spawning period likely contributed to the lower rates observed in 2014 and other years.

As in 2013, we initiated trapping at Dexter Dam approximately three weeks earlier than previous years (2009-2012) in an effort to reduce potential residence time of adults in the tailrace and achieve a sample more representative of the actual run timing in the Middle Fork of the Willamette (See Appendix tables 1 and 2). In previous years, sampling at Fall Creek was more representative of the timing of the run than sampling at Dexter. This was due to limitations in the operation of the Dexter Trap, which is primarily used for broodstock collections for Willamette Hatchery. With the assistance of ODFW the collection of adults at Dexter Dam began on 21 May (approximately two weeks earlier than in 2012), with collections every week thereafter until the last week in July. Data from our 2012 study indicated that adult salmon tagged at Willamette Falls spent about two weeks on average (*range* <1-22 days) in the Dexter Dam tailrace prior to collection (Jepson et al. 2013), suggesting an effect of trapping interval on tailrace residence time. Poor attraction flow from the Dexter trap entrance compared to turbine discharge may also contribute somewhat to tailrace residence time irrespective of trap operations. In 2013, operations were modified to allow adults to enter the trap throughout the run season, which could potentially reduce both tailrace residence time and salmon density in the trap during collection of broodstock and adults for outplanting. 2014 was a year with relatively early run timing and trap records from 2014 indicate that opening the trap early likely reduced tailrace residence time and densities for a relatively large group of salmon because 487 adults were collected before 5 June (6% of total collected) and 3,507 before 18 June (43.4% of total). Interestingly, the prespawn mortality rate in 2014 was the lowest recorded to date, suggesting the modified collection protocols may have contributed to the reduced PSM. However, this mechanism remains speculative and factors including a switch from MS-222 to AQUI-SE between 2013 and 2014 or other factors contributing to interannual variation also likely contributed to the 2014 result. Continued early operation in future years is needed to confirm that early collection reduces overall PSM. Additional improvements to collection and handling protocols reducing density and reducing other stressors such as discontinuing use of CO_2 as an anesthetic (Gilderhus and Marking 1987) could also reduce the PSM rate for this population, though these would require investments in facilities and personnel.

Fish Condition, Environmental Conditions, and Spawning Success: Middle Fork

The energetic condition of two populations of Middle Fork Willamette River spring Chinook salmon was assessed (Fall Creek and NFMF). The percentage of lipid in the muscle tissue was used as the measure of energetic condition. The mean lipid content at the time of tagging in 2014 was 5.0% and 2.9% for Fall Creek and Dexter fish, respectively. These measurements were nearly the same as in 2013 where mean lipid content was 5.2% at Fall Creek and 2.9% at Dexter.

The lipid levels of fish tagged at Fall Creek and Dexter Dam in 2012-2014 were generally lower than in 2009-2011 (Mann et al. 2011). Differences in the locations and timing of these sampling events likely explain some of the among-year and population differences in lipid levels. Lipid levels in Chinook salmon collected at Willamette Falls in 2013 and 2014 were about 2-4%

higher (2014 mean lipid level at Willamette Falls = 7.1%), on average, than those collected at Fall Creek or the Dexter Dam trap. This was not surprising because significant energy is required to migrate the more than 250 km from Willamette Falls to these upstream sites.

Although sample sizes were too low to detect a significant association between physical condition and spawning success in 2014 in Fall Creek, salmon were in generally good condition in 2014 (*mean condition score* = 2.4). The mean condition in 2014 was similar to 2013 (*mean* = 2.5). The condition of fish tagged at Dexter in 2014 was also not a factor associated with prespawn mortality in 2014 (mean condition score = 2.4). These relatively high condition scores suggest initial composite condition and previous injury was not a major factor contributing to the apparently high PSM in 2014. We note that this index was somewhat subjective because there may be some interannual variability in scores because different personnel collected data in some years.

When combining the results from all six study years, we found an association between annual PSM rate and summer water temperatures in Fall Creek. However, this conclusion should be with caution because it is largely driven by results from three years (Figure 21 & 22) including one year with low sample size (2009) and the 2013 estimate likely affected by flooding. We have also observed PSM that directly coincided with increases in water temperatures within year (Mann et al. 2010 and 2011). The 2014 Fall Creek temperatures were generally warmer than in previous years except 2009, with daily maximums exceeding 20°C, approximately 17% of the time (*n* = 25 of 144 days). We observed lower mortality rates for salmon collected and outplanted in Fall Creek in May 2010, when water was cooler than later in the summer. In 2011 and 2012, river temperatures rarely exceed 20 °C throughout the run and lower temperature exposures likely contributed in part to lower PSM rates. In 2013, temperatures were similar to 2011 and 2012, but spawning ground recoveries in 2013 were too low to make meaningful comparisons among study years. In contrast to Fall Creek, there was less evidence for a seasonal temperature effect on the annual PSM rate in the NFMF across study years, where temperatures remained much cooler through the summer and spawning period. Overall, the associations reported here within and across the Fall Creek and NFMF populations are consistent with analyses of larger data sets from the Willamette Valley (Roumassett 2012) and on-going analyses for Chinook salmon across the Columbia Basin (Bowerman et al. 2014). The analyses are collectively revealing a non-linear increase in PSM rates at temperatures above ~17 °C (Figure 22).

As in 2013, the majority of prespawn mortalities in Fall Creek in 2014 (15/16, 94%) occurred prior to the observation of the first redd (16 September) which was approximately two weeks later than in 2012 (2012 first redd date = 30 August) and one week later than in 2011 (first redd date = 8 September). The low numbers of early redds observed in 2013 and 2014 at Fall Creek may be partially explained by changes in the distribution of fish in Fall Creek related to warmer late summer and fall temperatures. Fish were observed on several occasions holding in large pools downstream from typical spawning areas two to three weeks after the typical onset of spawning (late August/early September) but the lack of radio-tagged fish made it difficult to effectively monitor their distributions. Temperatures during this period were among the warmest in the time series. The large proportion of PSM occurring prior to the onset of spawning highlights the importance of monitoring for PSM during the entire outplant season rather than just during the spawning season.

Because water temperatures remained cool throughout in the NFMF, it is more likely that PSM rates in the NFMF were affected by additional factors, including transportation stress, long holding times downstream from Dexter Dam and at the facility, unmeasured factors affecting condition at arrival, and density-dependent issues that were not quantifiable in this study but were potentially important based on field observations (large concentrations of fish were observed stacking up in the tailrace). These factors should be a management concern for salmon released into the NFMF, but may be of less importance at Fall Creek where transportation times are shorter and densities are lower.

South Fork Santiam and Foster Reservoir Releases

In 2014, we continued evaluating the feasibility of releasing adults into Foster Reservoir. Release into a reservoir would allow unmarked (presumably natural-origin) adults collected below dams to select and home to their natal tributary. Thus from 2012-2014, we conducted reservoir and in-stream releases to evaluate the use of reservoir release for both thermal and homing benefits. In contrast to the relatively short residence times (< 1 d) observed in Fall Creek reservoir in 2011 and 2012 (Naughton et al. 2013), the typical salmon residence time in Foster reservoir ranged from 3 to 8 days in 2012, from 16 to 32 days in 2013, and from 11 to 12 days in 2014. Comparison of the thermal history of fish released into the Foster reservoir versus estimated degree days if they would have been released in the river upstream from the reservoir suggested that reservoir-released fish were exposed to an approximately 3 fewer degrees per day than fish released in the river and an average of 55 total degree days fewer per individual than those released in the river. This suggests that releasing fish into the reservoir may be a viable way of reducing temperature exposure prior to spawning. However, nearly one-quarter (10 of 44; 22.7%) of fish released in the reservoir in 2014 fell back (compared to 12% in 2013) through the dam potentially offsetting any thermal or homing benefits. Telemetry records also indicated that there was some evidence for tributary selection, including fish that made multiple trips between tributary Middle and South Santiam receiver sites. While these behaviors suggest natal site selection, selection could not be confirmed because fish were not of known origin. We are currently investigating whether assignments from an on-going genetic pedigree analysis can be used to determine if the ten adults that fell back originated from below Foster Dam or upstream tributaries. We hypothesize that adults originating downstream would be more likely to actively seek downstream routes and fall back (e.g., functional overshoot and downstream movement; Keefer et al. 2008b). Distinguishing between active fallback by adults originating downstream vs. “accidental” fallback via entrainment would be useful for assessing the relative mortality costs of fallback vs. thermal and homing benefits of reservoir outplanting.

In addition to evaluating Foster Reservoir releases we also estimated PSM rates of adults released into the South Fork Santiam River. Overall, our PIT tag recovery rate was higher in the South Fork Santiam River (32%) than in the NFMF (19%), and Fall Creek (6%). Radio-tag recovery rates ranged from 37% for fish released in-river (Gordon Road release site) to 11% for fish released in the reservoir (note that the recovery rate would have been approximately 15% if the 10 fish that fell back over the dam were excluded from the release group). PSM rates for fish released at Gordon Road were 45.5% for PIT-tagged and 50% for radio-tagged fish in 2014. The PSM rate for reservoir-released fish was also 50% but the low number of recoveries (*n* = 4) makes conclusions about the efficacy of reservoir releases speculative, particularly since only one reservoir released female was recovered in 2013

Minto Fish Facility

In 2014, we initiated a radio-tagging study at the Minto Fish Facility to estimate fallback rates and holding times of natural-origin spring Chinook salmon upstream from the dam and to evaluate the distribution of unclipped salmon passed above Minto during the spawning period. Overall, 20 (40%) of the 50 radio-tagged fish fell back over the spillway with 9 of these falling back prior to the onset of spawning (based on the observation of the first redd on 9 September). While the median time from release to fallback was approximately 53 days, several fish fell back within hours of being released. Fallback rates at Minto Dam for salmon tagged at Willamette Falls were also high with 6 (60%) of the 10 fish recorded at Minto or Big Cliff falling back. However, all of the Falls-tagged fish fell back after 29 September when spawning activity had nearly ceased and thus likely represented movement of spawned out adults or carcasses. The high fallback rate for fish tagged at the Minto Fish Facility is not surprising due to the close proximity of the release site to the dam (approximately 100 m). Moreover, while fish radio-tagged at Minto Dam were allowed to fully recover and release themselves volitionally, it is possible that lingering tagging effects may have contributed to the relative rapid fall back for some fish compared to those tagged at Willamette Falls. Regardless, fish radio-tagged at Minto that fell back prior to the onset of spawning could have spawned in the suitable habitat downstream from the dam. The distribution of adults during the spawning period suggested potential natal origin below Minto Dam (8 adults remaining downstream of Minto Dam during the spawning period), in the reach between Minto Dam and Big Cliff Dam (~22 adults observed only between Minto and the Big Cliff tailrace receiver), and ten adults in the tailrace of Big Cliff during spawning that may have overshoot their natal reach or have originated above Big Cliff. These assignments are highly speculative and assume homing with very high precision. Regardless of true origin, the telemetry data suggest that the majority of unclipped adults passed above Minto Dam attempt spawning in the Minto-Big Cliff reach.

Management Implications

The apparent impact that water temperatures had on spawning success across study years and sites suggests that strategies that minimize Chinook salmon exposure to high water temperatures should be considered to increase survival of outplanted fish. Nearly three quarters of the total thermal accumulation between passage of Willamette Falls and spawning occurs in tributaries (Keefer et al. 2015). Development of structured management plans for years with different anticipated river conditions could be used to ensure minimum impacts to outplanted fish, with the costs and benefits depending on biological benefit and economic costs (e.g., Schreck et al 2013). Without the ability to directly manipulate water temperatures in the rivers above impoundments, managers may have to manipulate the timing or location of outplanting, or use cool water holding strategies during summer (Naughton et al. 2013). Such manipulation may be particularly important in years with poor water availability or climate forecasts.

If salmon that die before spawning do so because of conditions in the Willamette River main stem or in tributaries, then holding them in high quality conditions may increase survival, particularly in years with predicted low discharge and/or high temperatures. Upon trapping, the fish could be held in cool water until river temperatures have dropped to a more favorable level. Results from our previous holding studies (2009-2012) at Willamette Hatchery suggest that this strategy could be useful, particularly in warm years, although this approach entails added risks associated with additional transport and longer holding times. Schreck et al. (2013) reported that PSM rates of fish captured at Willamette Fall, Dexter Dam, and Foster Dam and held until sexual maturity in cool water (~13 C) were lower for fish collected earlier (0-6%) compared to fish collected later (10-32%) in the run. However, we note that there are potentially serious concerns with extended holding that need to be considered before implementation, including disease transmission, maturation effects, and reduction of condition, as well as logistical issues concerning facility use and personnel demand. Similarly, conditions encountered at collection facilities and during transport and at outplanting may affect PSM rates. The relatively high PSM (30% PIT and RT combined 2009-2014) in the consistently cool-water NFMF compared to Fall Creek in cool years suggests (6%, 2012; 29% 2011) differences in experience prior to outplanting may contribute to PSM in the NFMF. Potential factors include Dexter tailrace residence time, collection density, physical differences in the collection and trap facilities, handling procedures including differences in anesthetics (i.e., use of CO_2 at Dexter trap), and any differences in transport protocols (densities, travel times, tank structure and conditions, etc.). Improving collection, transport, and release of adults from Dexter into the NFMF is likely to be effective at reducing PSM. However, salmon returning the Middle Fork Willamette tributaries also have the longest travel distances among the Willamette basin spring Chinook populations and may already be physiologically stressed or have higher disease loads when they arrive at Fall Creek and Dexter dams. This migration stress may significantly affect their post-outplant survival.

The short movements of adults prior to spawning in the NFMF relative to Fall Creek suggest that habitat conditions in the NFMF are not limiting near the release site. Experimental tests of alternative collection and handling protocols could identify causative agents and effective management strategies. An alternative management strategy may be to use different outplant release sites in years with different in-river conditions in streams such as Fall Creek (Schreck et al. 2013). For example, release sites further upstream, which are generally cooler, could be used during periods of unfavorable water temperatures. The low recovery rate of adult carcasses in 2014 was associated with a longer period of residence in Fall Creek during a low water year, suggesting the potential for increased exposure to predators or poaching.

In contrast to 2010 and 2011 there were no significant mortalities observed following a release event in the NFMF in 2012, 2013 or 2104. There was, however, presumably some delayed mortality associated with collection and transportation to the release site. The mechanism(s) for this mortality is unclear, but may be attributable to the short-term stress of handling and transport and/or to “shipping fever” (combined result of stress and proliferative disease transmitted during high density holding; Schreck et al. 2012a) rather than water quality issues during transportation (which would manifest in minutes to hours and would likely have been evident prior to release from the truck). Schreck et al. (2013) suggested minimizing crowding and duration of the stress and possibly using antibiotics to reduce the severity of "shipping fever". Handling protocols at Dexter Dam Trap require use of CO_2 for anesthetization, which is known to induce higher stress and mortality in fishes than some other forms of anesthesia (e.g., Gilderhus and Marking 1987; Sanderson and Hubert 2007). However, to what degree differences in collection and handling protocols contributed to PSM at either site remains unknown. The effects of handling protocol could be tested explicitly by applying alternative protocols or anesthesia treatments to paired release groups through the outplant season at Dexter Dam or at other locations.

Demonstrating causal links between PSM and mechanism(s) (e.g., disease expression or energy content) could provide guidance and support for other options proposed for the recovery of the Upper Willamette Chinook ESU (ODFW and NMFS 2011) and is an on-going goal of this collaborative project (see Schreck et al. 2012a,b, 2013). For example, if temperature is a controlling factor for pathogenesis, then proposed measures that would prevent warming or reduce temperatures that are in the proposed "Conservation and Recovery Plan" could be even more strongly endorsed. Schreck et al. (2013) found a strong positive association between PSM and accumulated degree days and time in the UWR system and suggested that accumulated degree days provided a simple, biologically-relevant metric since it is associated with thermal exposure, pathogen dynamics, and energetic status. Jepson et al. (2013) and Keefer et al. (2015) indicate that many WVP Chinook salmon accumulate considerable thermal units before and after collection and outplanting. Thermal exposure prior to outplanting can be significant, and results from salmon tagged with archival temperature loggers at Willamette Falls indicate that the warmest exposure is often in the main stem Willamette whereas a majority of degree days accumulate in the tributaries (> 1,000 degree days for many salmon, Keefer et al. 2015).

The possibility of managing water temperatures below the dams during the spring Chinook salmon migration to reduce stress and, disease expression, and PSM should be considered. Active management of temperature regime has been successful below Lost Creek reservoir on the Rogue River, OR (ODFW 1991) and below Dworshak Dam on the Clearwater River, ID (Clabough et al. 2007). Successful management of adult salmon within the WVP and on the spawning grounds above projects will require reliable information on disease prevalence, individual-and population-level energetics, abiotic factors in the migration corridor, and effects of current protocols for handling and transporting fish.

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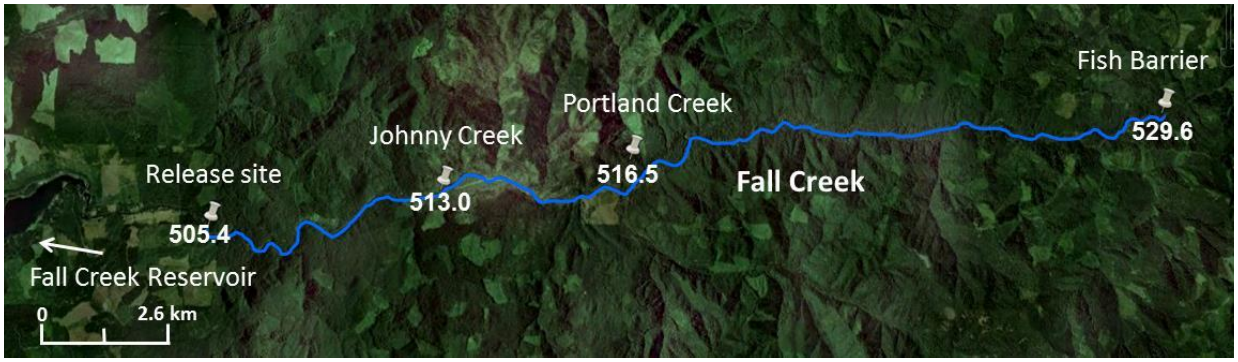
Appendix

Appendix Table 1. Number and date range of Chinook salmon that were PIT-tagged or double-tagged (PIT and radio-tagged) fish in Fall Creek, 2008-2014.

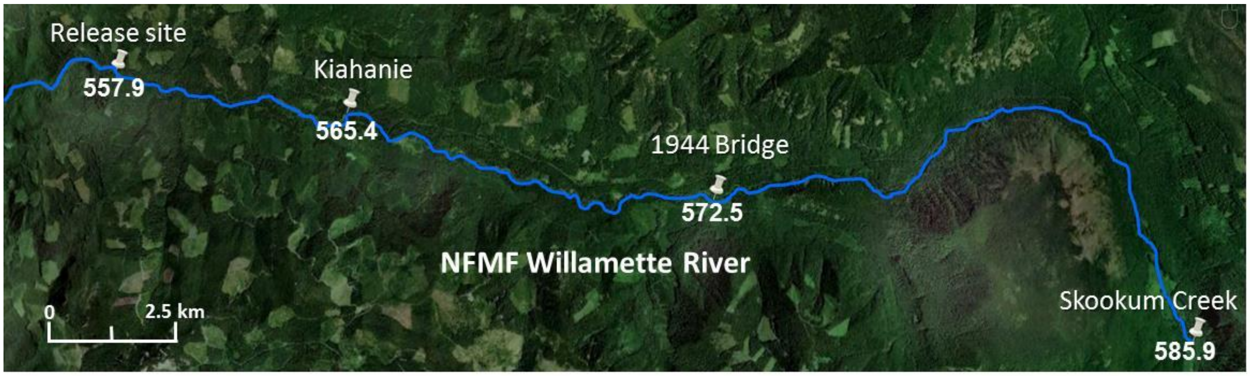
Year	Group	# released	Tag/release date range
2008	PIT	188	15 May – 14 July
	Double	7	26 June – 7 July
2009	PIT	175	26 May – 24 Aug
	Double	25	4-June – 10 Aug
2010	PIT	124	17 May – 26 Aug
	Double	75	7 June – 26 Aug
2011	PIT	125	19 May – 26 Sep
	Double	75	19 May – 26 Sep
2012	PIT	78	17 May – 19 July
	Double	40	17 May – 10 Aug
2013	PIT	96	16 May – 26 Aug
2014	PIT	160	19 May – 10 July

Appendix Table 2. Number and tag date range of PIT-and radio-tagged subsets of the Chinook salmon outplanted in the NFMF Willamette River in 2009-2014. DEX = fish tagged at the Dexter Dam trap and immediately outplanted into the NFMF Willamette River. HH = fish held at the Willamette Hatchery then later outplanted into the NFMF Willamette River with release date shown in parentheses.

Year	Group	# released	Tag/release date range
2009 (DEX)	PIT	124	25-June – 17 Aug
	Double	12	17 July – 17 Aug
2009 (HH)	PIT	103	24 June – 9 July (24 Aug)
2010 (DEX)	PIT	148	13 July – 11 Aug
	Double	43	13 July – 11 Aug
2010 (HH)	PIT	81	18 June – 1 July (1 Sep)
	Double	18	18 June – 1 July (1 Sep)
2011 (DEX)	PIT	109	26 May – 24 Aug
	Double	71	26 May – 24 Aug
2011 (HH)	PIT	79	15 June – 18 Aug (30 Aug)
2012 (DEX)	PIT	104	6 June – 1Aug
	Double	50	6 June – 1Aug
2012 (HH)	PIT	71	19 June – 1Aug (29 Aug)
2013	PIT	106	22 May – 17 July
	Double	59	22 May – 17 July
2014	PIT	150	21 May – 30 July
			21 May – 30 July



Appendix Figure 1. Map of temperature monitoring locations in Fall Creek in 2014.



Appendix Figure 2. Map of temperature monitoring locations in NFMF Willamette River in 2014.