Technical Report 2016-2

MIGRATION BEHAVIOR AND SPAWNING SUCCESS OF SPRING CHINOOK SALMON IN FALL CREEK, THE NORTH FORK MIDDLE FORK WILLAMETTE, AND THE SANTIAM RIVERS: RELATIONSHIPS AMONG FATE, FISH CONDITION, AND ENVIRONMENTAL FACTORS, 2015

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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 sub-basin populations, the cause(s) and relationships are not well defined. In 2015 we continued to survey the 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.

A total of 93 Chinook salmon were sampled at Fall Creek Dam in 2015. Fish were collected, assessed for energetic content and overall condition, PIT-tagged and then transported above the dam and allowed to spawn naturally. Five PIT-tagged salmon were recovered during spawning ground surveys on Fall Creek, a recapture rate of 5.4% that was similar to the rate in 2014 (5.6%) but lower than in all previous years (10-12%) except 2013 where record rainfalls precluded surveys during peak spawning activity. None of the five PIT-tagged fish recovered on the Fall Creek spawning grounds in 2015 were females in suitable condition and thus we were unable to estimate prespawn mortality for this group. Overall, 30 unmarked fish were recovered on the spawning grounds (recovery rate =18.1%). Of the 11 unmarked females recovered, 4 (36.4%) were prespawn mortalities. The average water temperature during the study period was 16.0 °C with a peak of 22.8 °C on 2 July. In Fall Creek, across the six study years (2009-2014), PSM estimates of PIT and radio-tagged females combined were 46.7% (range 6-100%).

A total of 241 Chinook salmon collected and tagged (*n* = 75 radio, *n* = 166 PIT) at the Dexter Dam trap were outplanted into the North Fork Middle Fork Willamette River (NFMF) in 2015. The 2015 PSM estimate for PIT- and radio-tagged fish in the NFMF (57%) was the highest among study years (range 13-57% from 2009-2015). Overall, 32 (13%) of the PIT and radio-tagged fish were recovered in carcass surveys, a recovery rate within the range recovered in previous years (7-20%). Female prespawn mortality of NFMF outplants was 57% (four out of 7 females recovered) for PIT and radio-tagged fish combined. The prespawn mortality rate for unmarked females was 35.5% (*n* = 76). Mean water temperature in the NFMF during the study period was 12.2 °C with a peak of 15.8 °C in early July.

In 2015, we continued the early-season outplanting into the NFMF initiated in 2013. Of the 241 PIT and radio-tagged fish released in the NFMF, 73 (30%) were released between 20 May and 3 June (early release group, hereafter). The remaining 168 fish (70%) were released between 11 June and 30 July (standard release group, hereafter). Overall, 3% from both the early (2/73) and standard release groups (5/168) were recovered on the spawning grounds. All three of the females recovered from the standard release group were prespawn mortalities. No females were recovered from the early release group. Prespawn mortality rates were higher in the late release group in 2013 (50%) but higher in the early release group in 2014 (33%).

We estimated prespawn mortality in the South Fork Santiam River upstream of Foster Dam and evaluated behavior of adult salmon released into Foster Reservoir. We collected and tagged 304 (*n* = 37 radio, *n* = 267 PIT) adult Chinook salmon at Foster Dam on the South Santiam River in 2015. Fish were released at two locations in the South Santiam River (Gordon Road and River Bend) and one location in Foster Reservoir (Calkins Park; radio-tagged salmon

only). Recovery rates for PIT-tagged salmon were 26% (*n* = 69) for fish released at Gordon Road and River Bend. The recovery rate of radio-tagged salmon was 13% for fish released at Gordon Road. No radio-tagged fish released at Calkins or River Bend were recovered on the spawning grounds. Prespawn mortality estimates for females released at Gordon Road and River Bend was 38% (*n* = 9) for PIT-tagged fish. No radio-tagged females released at Gordon Road were recovered on the spawning grounds in suitable condition to assess prespawn mortality.

We monitored movements and determined final locations of radio-tagged salmon released to Foster Reservoir and the South Santiam River. Of the 37 radio-tagged fish, 14 (38%) were released at Calkins Park in Foster Reservoir; 4 (29%) of the 14 fish were last recorded in the South Santiam, 5 (36%) were last recorded in the Middle Fork Santiam, and 2 (14%) fell back downstream past Foster Dam. Median reservoir residence times were 79.0 d (range 0.04-85.6 d) for fish last recorded on the South Fork Santiam receiver (SFR), 98.7 d (range 0.05-39.4 d) for fish last recorded on the Middle Fork Santiam receiver (MSR). Mean water temperature in the South Santiam upstream from Foster Reservoir during the study period was 15.6 °C with a peak of 20.8 °C on 1 August. Comparison of the thermal history of fish released in the reservoir (*n* = 8) versus their estimated degree days per day if they would have been released in directly into the South Santiam suggested that reservoir-released fish were exposed to an average of 3.3 fewer degrees per day (DD/d) than fish released in the river and 99 fewer total degree days (DD) than those released into the river, representing a 16% reduction in thermal exposure after outplanting. The potential thermoregulatory benefits of reservoir releases will need to be weighed against the risk of fallback at Foster Dam (14% of reservoir-released fish compared to 1.4% of the PIT and radio-tagged fish).

Multi-year summaries

We tested for associations between salmon 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 tagged females recovered over six years (2009-2014). 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 [(higher PSM in the early (2009-2010) and later years (2013-2014)] and tag date (increasing PSM with later tag date). Several additional models had statistical support, including all models that included either year or tag date. The models for the NFMF included 84 tagged females recovered over seven years (2009-2015). 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 PSM in Fall Creek or the NFMF. No difference in Ni, Pb, Cd, total DDT and total PCB concentrations in carcasses collected in 2013 and 2014 was observed between PSM and successful spawners in the NFMF (*n* = 37) or S. Santiam (*n* = 20). While specific causes of prespawn mortality were difficult to identify, we identified several contributing factors and best management practices that should be considered in future outplanting efforts.

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 sub-basins. 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. However, average PSM 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 (Benda et al. 2015), and poor energetic condition (Bowerman et al. 2016). 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 exhibit 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 Oregon State University (OSU) researchers (e.g., Schreck et al. 2013; Benda et al. 2015).

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; Naughton et al. 2015). 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 upstream from a reservoir (e.g., Foster and Detroit reservoirs).

The origin of adult salmon collected for outplanting is uncertain in some cases, particularly for individuals without hatchery fin clips, and this is a consideration for 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 fall back over Minto Dam and attempt to spawn downstream. No unclipped adults were passed above Detroit Dam because of uncertainty about origin and concerns over depleting the downstream spawning population in 2014. However, in an attempt to evaluate homing of these groups, a subsample of unclipped adults collected at Minto were released in the North Santiam arm of Detroit Reservoir in 2015. Warm water conditions prevented radio-tagging of this group.

The primary goal of this study has been to evaluate factors 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. In 2015, 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 in 2015 we continued a feasibility study to evaluate releasing fish into Foster Reservoir. We also collected samples for a small-scale evaluation of toxins concentrations in carcasses of successful and unsuccessful adult Chinook salmon from several spawning locations in 2013-2015. In 2014, we estimated fallback rates and duration of holding of unclipped Chinook salmon at Minto Dam on the North Santiam River.

Specific 2015 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) Evaluate the feasibility of releasing adults in Foster Reservoir on the South Fork Santiam River.
5) Evaluate inter-annual 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.

7) Collect tissue samples from Chinook salmon in Fall Creek, the NFMF and South Santiam River for toxicology analysis.
8) Evaluate homing of unclipped Chinook salmon released in the North Santiam arm of Detroit Reservoir.

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, 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 fish ladder that led to a finger weir in front of a large collection area. USACE personnel operated a mechanical sweep to crowd trapped salmon 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 to a site approximately 3 km upstream from the head of Fall Creek Reservoir and released at rkm 505.4 for a total transport distance of approximately 10 km.

The Dexter trap was operated by ODFW and sampled salmon were provided to UI by ODFW. ODFW primarily uses the Dexter facility to collect broodstock for the Willamette Hatchery (WH) in Oakridge, OR. In 2009-2015, 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, and then transferred to an anesthetic tank with AQUI-S 20E (AquaTactics Fish Health, Kirkland, WA; 5-17 mg/L) where they were assessed and tagged. In 2015, fish were sedated with AQUI-S 20E (17 mg/L) in the elevator and then transferred to the secondary tank. Fish were transferred to a transportation truck for recovery and then transported above Lookout Point Dam into the NFMF (67 km transport distance). No fish were held for late outplant at the Willamette Hatchery in 2013-2015 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 2013-2015, we evaluated outplanting into the NFMF approximately a month earlier than in previous years to reduce residence time of adults in the Dexter tailrace. Figure 2 outlines the 2015 study design for Fall Creek and NFMF.

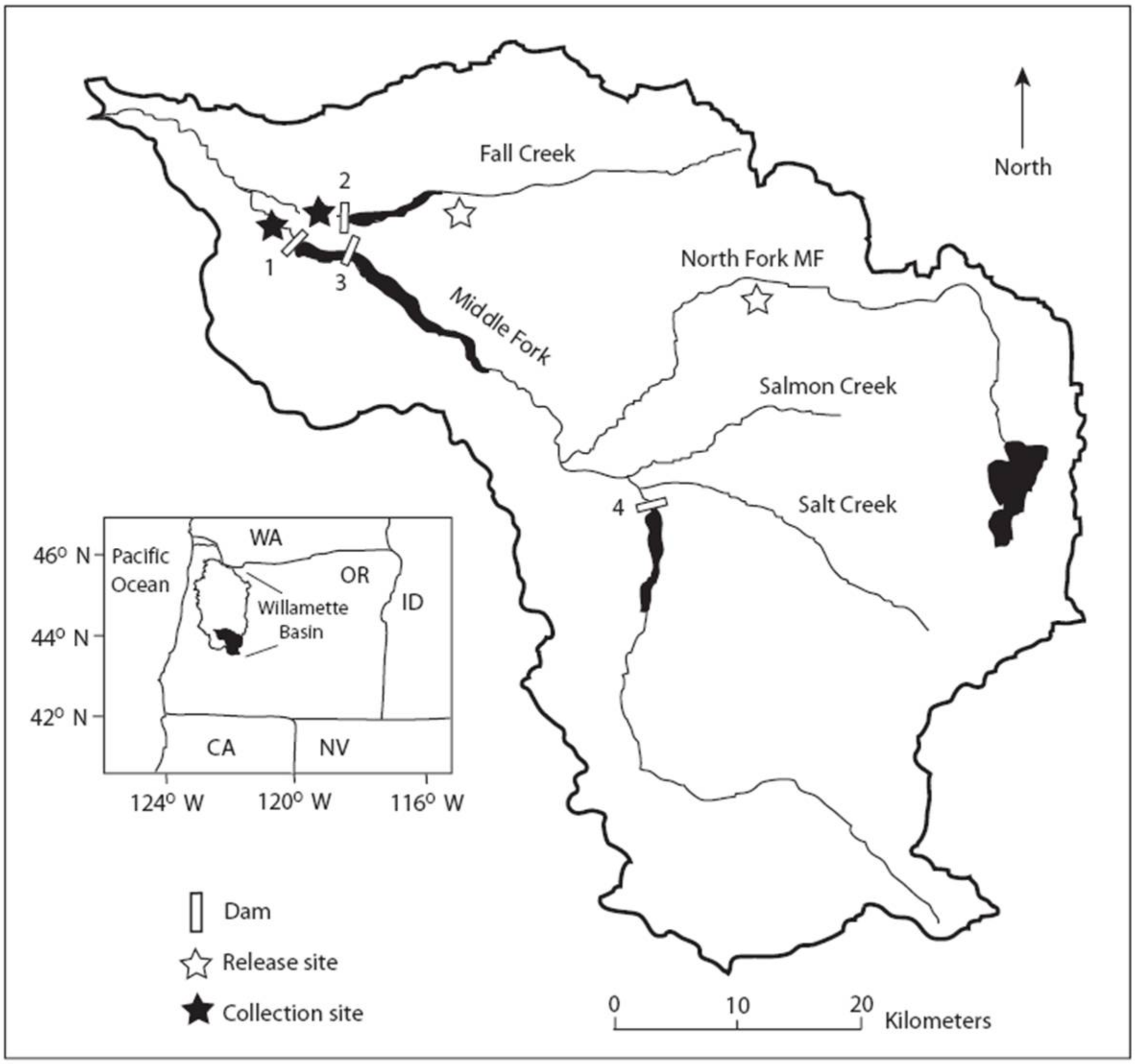

Figure 1. Map of the Middle Fork Willamette River basin showing Chinook salmon collection sites (solid stars) and outplant sites (open stars). Dams are numbered: 1 = Dexter Dam, 2 = Fall Creek Dam, 3 = Lookout Point Dam, and 4 = Hills Creek Dam.

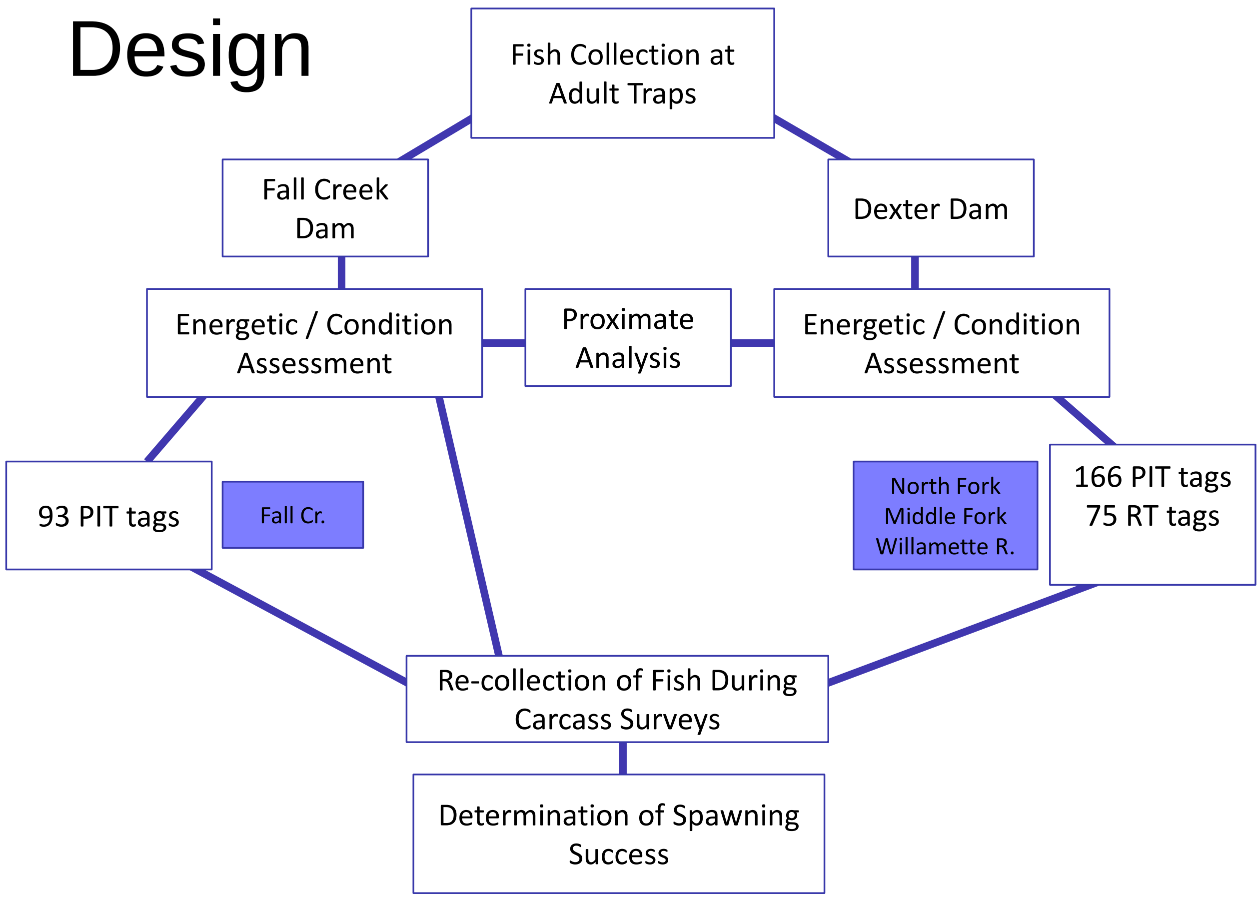

Figure 2. Middle Fork Willamette River study design for 2015. All salmon tagged at Fall Creek trap were immediately outplanted into Fall Creek. Salmon collected and tagged at Dexter Dam were immediately outplanted into the NFMF Willamette River.

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 because fish were previously anesthetized). 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 (range 8-12 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 facilities.

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 75 fish was radio-tagged prior to outplanting in the NFMF in 2015. 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, to estimate distribution during holding (Naughton et al. 2012; Roumasset 2012), and to evaluate residence time and fate. Additionally, the use of radio transmitters aided in the collection of carcasses for PSM assessments.

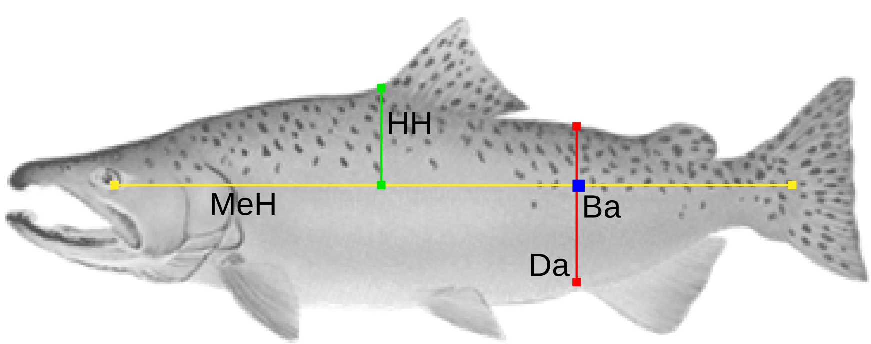

Figure 3. Diagram of morphometrics collected. MeH = Mid-eye to hypural length, HH = Hump height, Da = Depth at anus, Ba = Breadth at anus.

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 -40 º 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, the parameter 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 fish tagged at Willamette Falls in 2012-2014 were (see Jepson et al. 2015) 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 2015 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 a tagged 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 may have caused mortality). In addition, otoliths and scales were collected from non-marked fish (presumed natural origin fish with no fin clips).

In 2015, 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. 2016). 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 (see below) 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 Fall Creek, NFMF, and Santiam 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.

We treated tagdate as composite proxy variable for both arrival timing and seasonal environmental conditions because these variables were intercorrelated with tagdate each year (see Results). In addition to statistical analyses we summarized PSM rates across study years and streams. We also used logistic regression to compare PSM rates among PIT-tagged, 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 salmon 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 into Foster Reservoir near the Calkins Park boat launch (rkm 421.7; measured from mouth of the Columbia River) and into the South Fork Santiam River upstream from the reservoir 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, MN; 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 2015, we 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- and 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 were processed using established toxicological screening methods (e.g., Greenfield et al. 2008; Hwang et al. 2009a, 2009b; McGourty et al. 2009). We used general linear model procedure (SAS, Inc. Cary, NC) to test for mean differences in concentrations of major metals (Ni, Pb, Cd) and organic classes (DDT, PCBs) between adults scored as prespawn mortalities versus successful spawners, among tributaries and between years.

Methods: Minto Fish Facility tagging

In 2015 we continued a study initiated in 2014 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 for tagging as part of routine trap operations. The trap consists of a ladder and a collection area and an anesthetic tank. ODFW personnel sorted and transferred fish into an anesthetic tank 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). Fish were either released at the fish facility directly into the river Minto Dam or transferred to a truck and transported approximately 25 km upstream and released in the North Santiam River arm of Detroit Reservoir.

Results: Middle Fork Willamette River

Fall Creek

Tagging at Fall Creek occurred from 4 May to 25 June, 2015. A total of 93 fish (58 females, 35 males) were PIT tagged (Figure 4). Tagging was representative of the overall timing of the run, which peaked in early June (Figure 4) but was protracted due to low numbers (93 PIT, 166 unmarked) of fish in 2015. All fish transported above the dam had intact adipose fins (i.e., were presumed wild origin). The mean condition score in 2015 was 2.4, mean fork length was 73.1 cm, mean weight was 4.4 kg, and mean lipid percentage was 5.0% (Table 1).

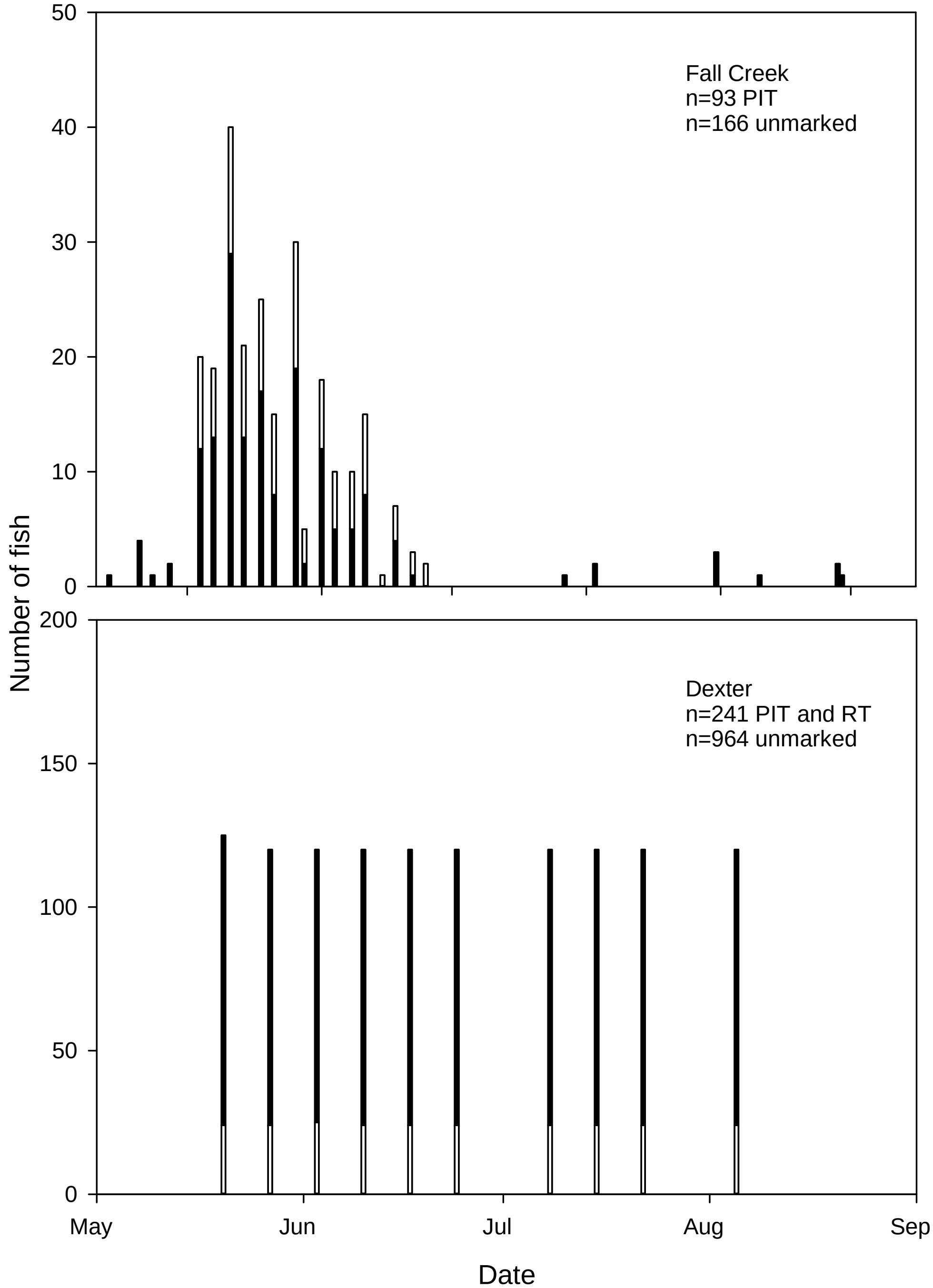

Figure 4. Numbers of adult Chinook salmon collected and tagged in 2015. Top panel: distributions of Chinook salmon that were tagged (open bars) and not tagged (black bars) at Fall Creek trap. Fall Creek fish were immediately outplanted above Fall Creek Dam and Reservoir. Bottom panel: distributions of Chinook salmon tagged (open bars) and not tagged (black bars) at Dexter Dam and immediately outplanted to the NFMF on the date of tagging.

Table 1. Adult Chinook salmon size, lipid content, and condition metrics for fish sampled at Fall Creek trap in 2015. 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* = 93)	Fork Length (cm)	Weight (kg)	MeH (cm)	Da (cm)	Ba (cm)	HH (cm)	% Lipid	Condition Score
Mean	73.1	4.4	61.5	11.8	6.2	8.0	5.0	2.4
St. Deviation	8.5	1.5	7.2	1.5	0.9	1.1	1.5	0.7
Max	91	8.5	77	15.5	8.5	10.6	9.4	3
Min	57	0	48	7.3	4.3	5.7	1.9	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 in 2014 (*mean* ~ 7.1%; Figure 5). Lipid estimates for the Fall Creek sample also decreased through the 2014 season (Figure 5 and 6). This seasonal decline was similar to results in previous years.

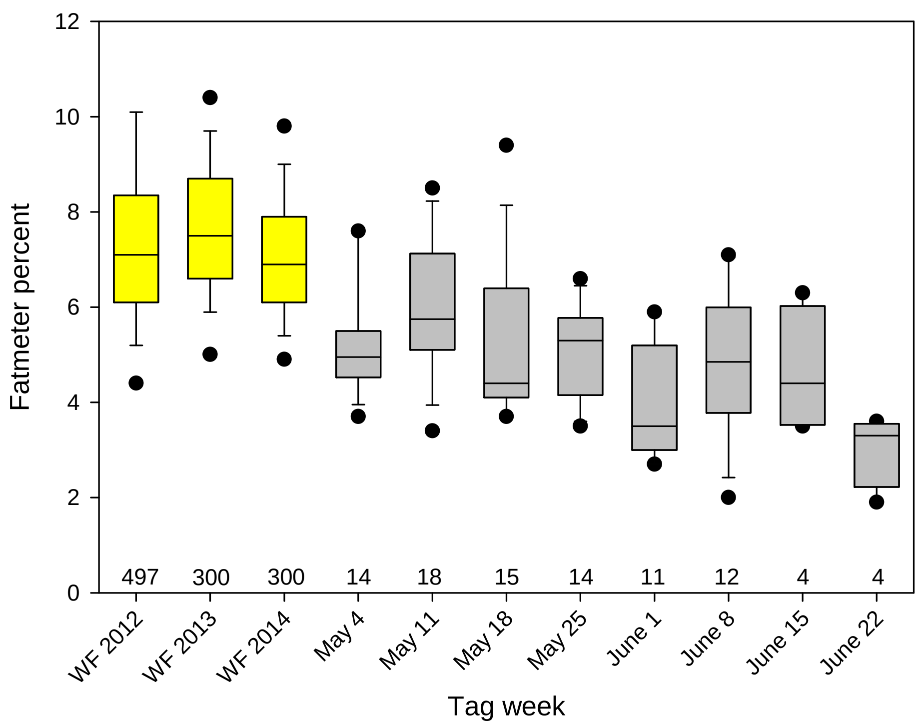

Figure 5. Weekly distributions of fatmeter estimates for Chinook salmon tagged at Fall Creek trap in 2015. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (●). Sample size for each weekly start date shown below each box. Boxes on left show data for Chinook salmon sampled at Willamette Falls Dam (WF) in 2012-2014 from Jepson et al. (2015).

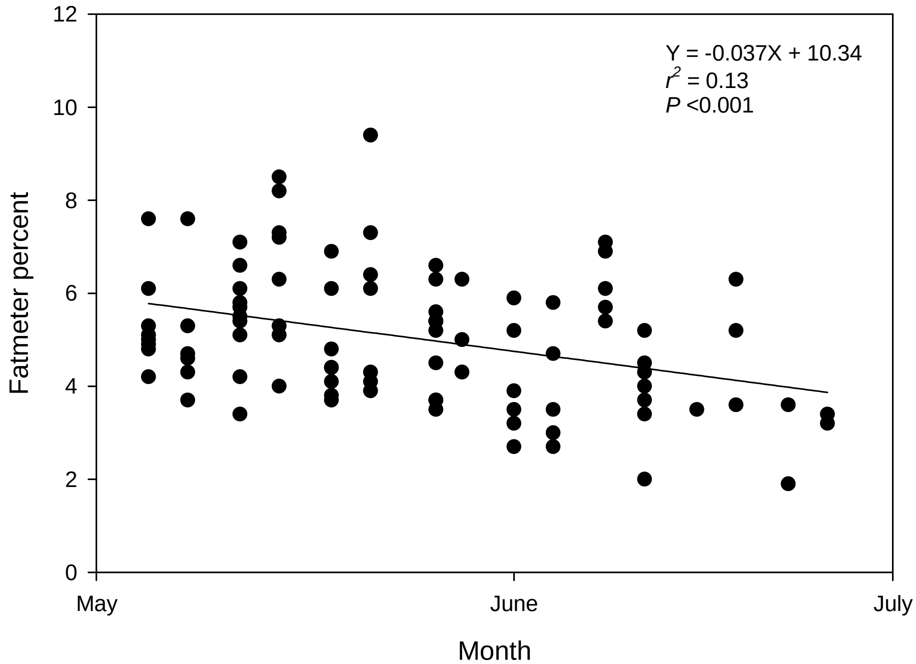

Figure 6. Fatmeter percentages for all Chinook salmon tagged at arrival at Fall Creek trap in 2015.

North Fork Middle Fork Willamette River

As in 2013 and 2014, we initiated outplanting into the NFMF in 2015 approximately a month earlier than in years prior to 2013 in an attempt to reduce the residence time of adult salmon in the Dexter Dam tailrace. Tagging began on 20 May and continued until 5 Aug (Figure 4). The tagged group included 241 fish (114 females, 127 males), and had mean length of 72.0 cm, mean weight of 4.3 kg, mean condition score of 2.5, and mean lipid percentage of 4.0% (Table 2). Mean fatmeter readings from fish tagged at the Dexter Dam trap (4.0%) were about 42% lower than those for fish tagged at Willamette Falls in 2014 (7.1%) and decreased across the ten tagging days (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 2015. 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 = 241)	Fork Length (cm)	Weight (kg)	MeH (cm)	Da (cm)	Ba (cm)	HH (cm)	% Lipid	Condition Score
Mean	72.0	4.3	60.6	11.1	6.2	7.8	4.0	2.5
St. Deviation	5.4	1.0	4.9	1.1	0.6	0.7	1.3	0.7
Max	89	7.8	76	13.7	8	9.7	7.2	3
Min	59	2.14	49	7.4	4.3	6.2	1.3	1

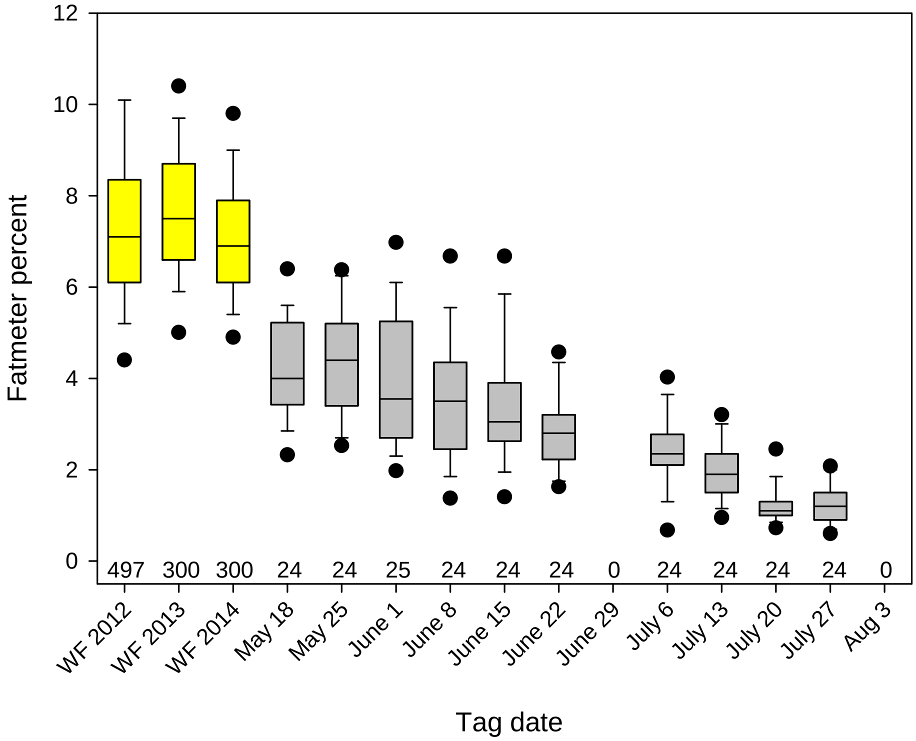

Figure 7. Weekly distributions of fatmeter results for Chinook salmon tagged at Dexter trap in 2015. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (solid circles). Boxes on left show data for Chinook salmon sampled at Willamette Falls Dam (WF) in 2012-2014 from Jepson et al. (2015).

Proximate Analysis

In 2015, proximate analysis was performed on 15 (8 males and 7 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 17 June (n = 5), 22 July (n = 5), and 5 August (n = 5). The average muscle lipid level was 4.9% (Table 3) and ranged from 2-9%. Average gonadal lipid composition was 12.5% for females and 1.2% for males (Table 4). Individual lipid concentrations as estimated with the fatmeter during 2015 were positively correlated with the values estimated from proximate analysis taken from lethally sampled adults (adj. $r^2 = 0.72$, $P < 0.001$, $n = 15$; Table 5).

Table 3. Mean tissue composition of 15 Chinook salmon collected at Dexter trap and used in proximate analysis in 2015.

Tissue	% Moisture	% Crude Lipid	% Total Ash	% Protein
Gonads	70.6	5.7	2.4	21.3
Muscle	75.6	4.9	1.1	18.5
Skin	65.0	4.5	1.2	29.3
Viscera	80.2	2.1	1.2	16.5

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

Tissue	% Moisture	% Crude Fat	% Total Ash	% Protein
Males (n = 8)				
Gonads	79.3	1.2	3.1	16.5
Muscle	75.9	4.7	1.0	18.3
Skin	65.4	4.1	1.1	29.4
Viscera	80.1	2.5	1.2	16.2
Females (n = 7)				
Gonads	57.6	12.5	1.4	28.5
Muscle	75.0	5.1	1.1	18.7
Skin	64.3	5.0	1.4	29.3
Viscera	80.3	1.5	1.2	17.0

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 statistical 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	$adj\ r^2$
2015	15	-0.247	0.520	<0.001	0.72
2014	15	0.372	0.364	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. We found a positive relationship ($r^2 = 0.84$) between fatmeter readings and energy density in 2015 (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.

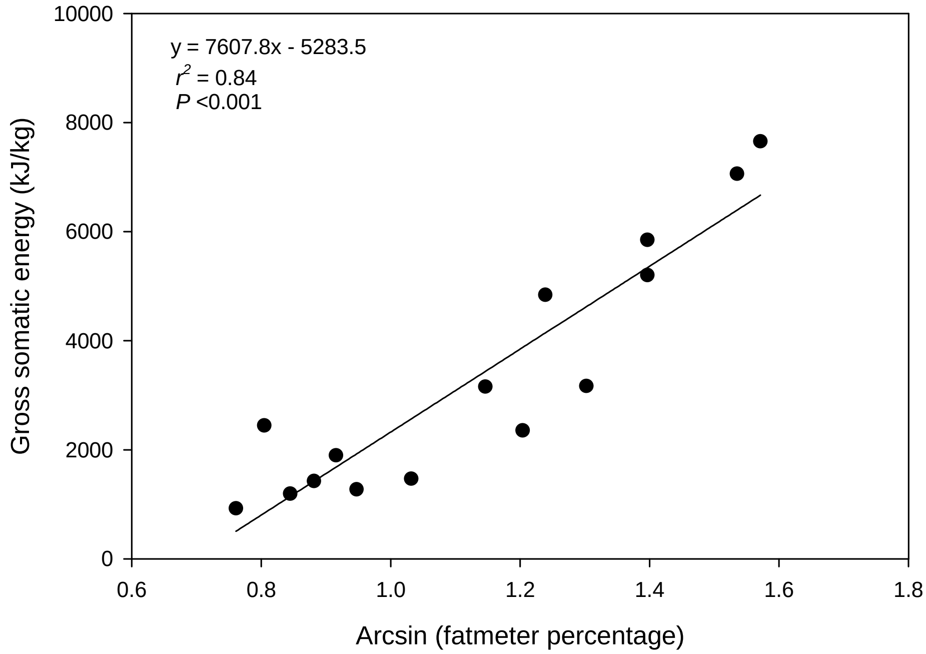

Figure 8. Relationship between Chinook salmon energy density (kJ/kg) estimated using proximate analysis and arcsine square root transformed raw fatmeter percentages, 2015.

River Conditions

The 2015 Chinook salmon migration season in Fall Creek was characterized by base flow from July through September followed by a slight increase in early October (Figure 9). Water temperatures at the release site throughout the monitoring period were higher in 2015 than in most study years (Figure 10). The average water temperature at the Fall Creek release site during the 2015 study period was 16.0 °C with a peak of 22.8 °C on 2 July (Figure 11). Mean daily water temperatures in Fall Creek exceeded 20 °C on 33 of 189 (17%) monitored days in 2015, 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). Within Fall Creek, temperatures were highest at the release site and were lowest at the most upstream site in 2015 (Figure 11), as in previous study years (2009-2014).

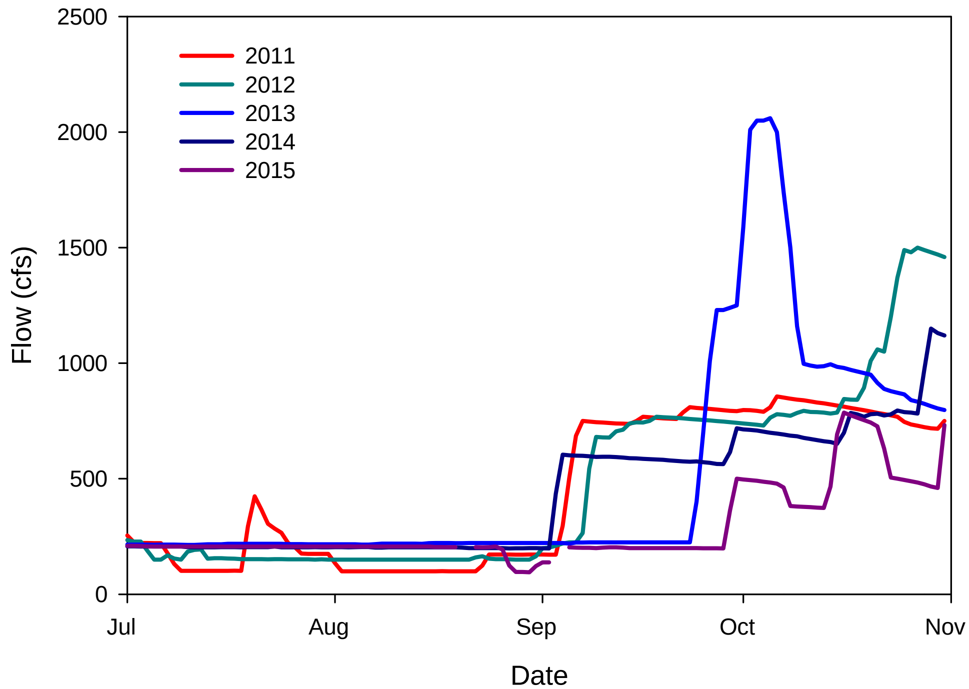

Figure 9. Mean daily discharge (cfs) at Fall Creek 2011-2015. Data are from the USGS Fall Creek gage below Winberry Creek.

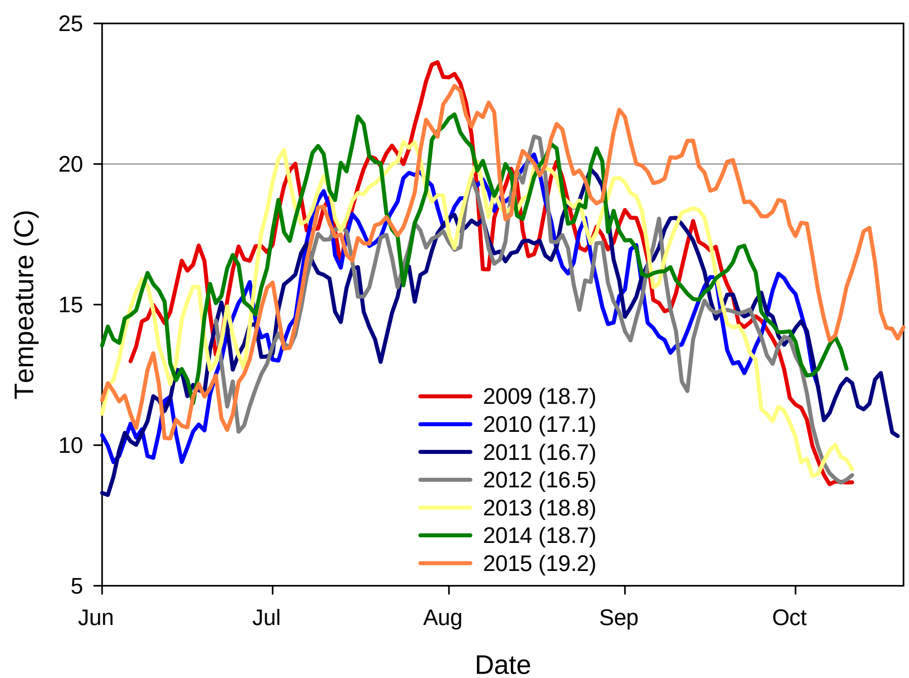

Figure 10. Mean daily water temperatures in Fall Creek in 2009-2015 near the release site (rkm 505.4). Mean temperature for the study period shown in parentheses. Solid line at 20 °C represents temperature considered to be physiologically stressful for adult salmonids.

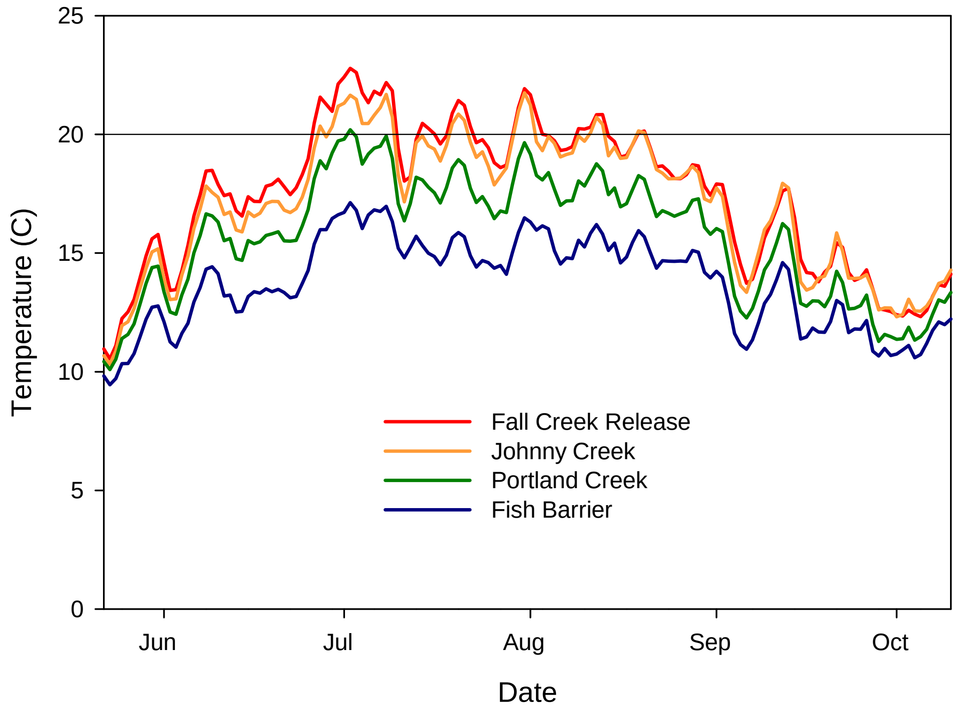

Figure 11. Daily mean water temperatures in 2015 at the sites in Fall Creek. The loggers represent a progression upstream from the release site (rkm 505.4) to the fish barrier (rkm 529.6). Solid line at 20 °C represents temperature considered to be physiologically stressful for adult salmonids.

Water temperatures in the NFMF in 2015 were generally similar to those in previous study years (Figure 12). In the NFMF, daily means did not exceed 16°C at the release site during the monitoring period in 2015 and ranged from 7.9 to 15.8 °C from May through late October (Figure 12). NFMF temperatures were generally near or below the Chinook salmon thermal preferendum and were typically 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 2015 study period was 12.2 °C with a peak of 15.8 °C in early-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 5.7 °C lower during the July and August salmon holding period.

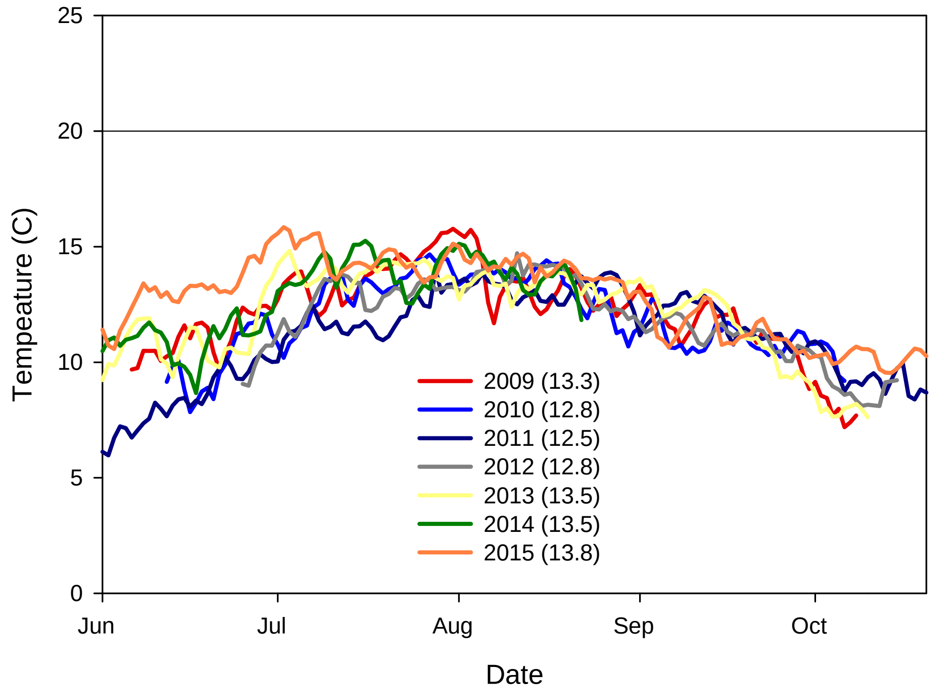

Figure 12. Comparison of mean daily water temperatures collected in the NFMF in 2009-2015 near the release site (rkm 557.9). Mean temperature for the study period shown in parentheses. Solid line at 20 °C represents temperature considered to be physiologically stressful for adult salmonids.

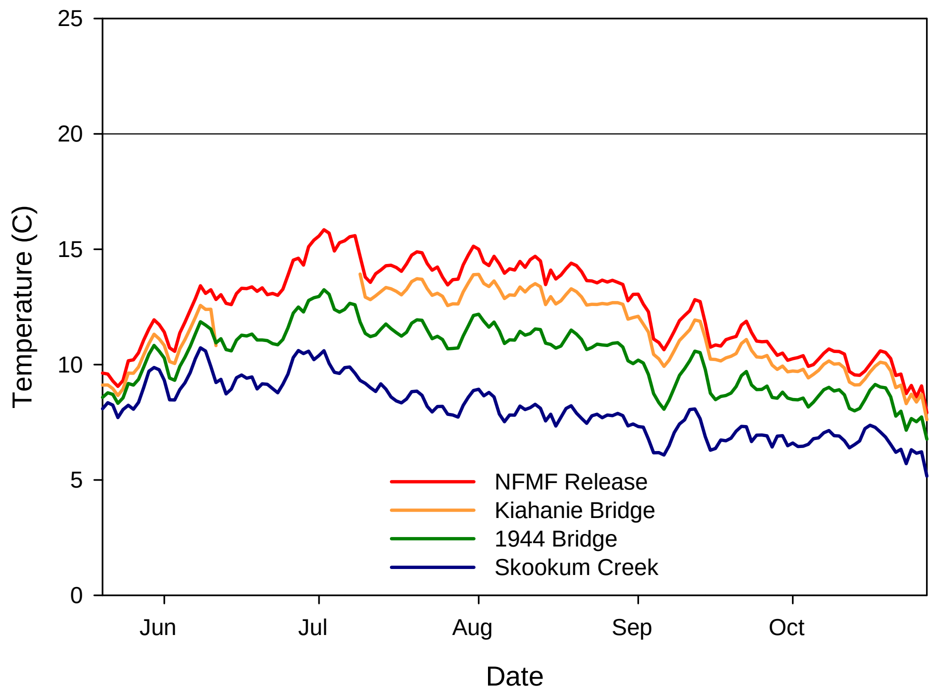

Figure 13. Daily mean water temperatures in 2015 at four NFMF sites. The loggers represent a progression upstream from the release site (rkm 557.9) to Skookum Creek (rkm 585.9). Data gaps at the Kiahanie site resulted from lost/stolen loggers. Solid line at 20 °C represents temperature considered to be physiologically stressful for adult salmonids.

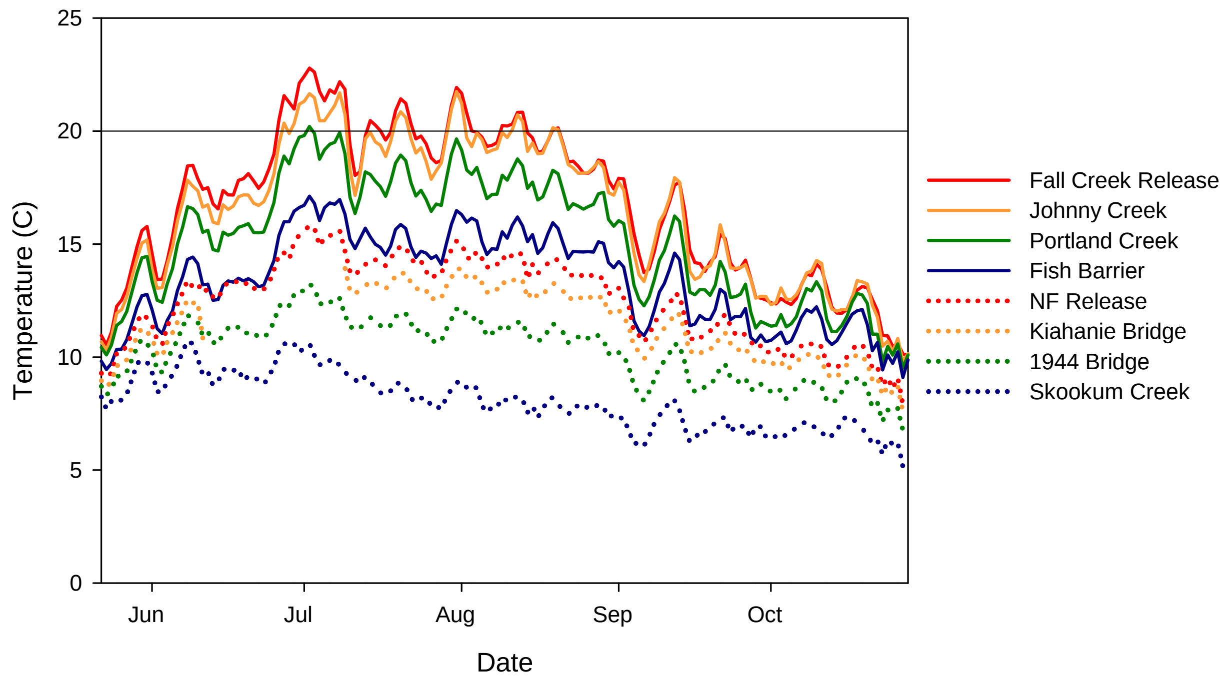

Figure 14. Daily mean water temperatures in Fall Creek (solid lines) and the NFMF Willamette River (dotted lines) in 2015. Solid line at 20 °C represents temperature considered to be physiologically stressful for adult salmonids.

Spawning Ground Surveys and Spawning Success: Fall Creek

Carcasses were recovered in Fall Creek from 30 July until 1 October with the first redd observed on 10 September. The recovery rate for the PIT-tagged sample was 5.5% (5 out of 93 fish). We recovered a higher proportion of unmarked fish in 2015 (18%) than PIT-tagged fish (Table 6). Because we did not recover any females with known spawn status we could not calculate a PSM estimate for PIT-tagged fish. The PSM estimate for untagged female carcasses (4 of 11; Table 6) was 36.4% and was the second lowest in the study period (2008-2015) for Fall Creek (Table 6).

Table 6. Recovery rates of Chinook salmon that were PIT-tagged, double-tagged (PIT- and radio-tagged), and unmarked subsets outplanted in Fall Creek, 2008-2015. Prespawning mortality (PSM) rates were only calculated for females with known spawning status

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
2015	PIT	93	5	5.4	0	N/A
	Unmarked	166	30	18.1	11	36

The final distribution of recovered, unmarked female salmon indicated that the majority of spawning occurred 15-30 km upstream from the release site (Figure 15). The four unmarked prespawn mortalities were recovered between Portland Creek and the barrier falls.

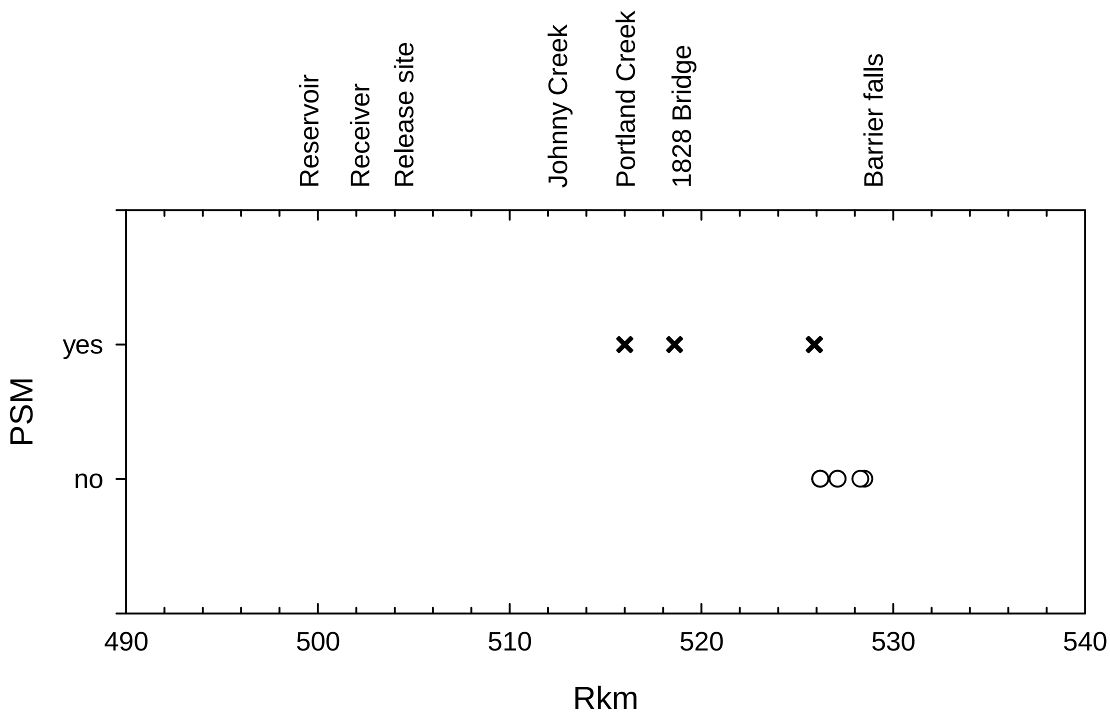

Figure 15. Distribution of 11 untagged female Chinook salmon carcasses that were recovered in Fall Creek spawning ground surveys in 2015, by their PSM status.

Spawning Ground Surveys and Spawning Success: NFMF

Carcasses were recovered in the NFMF from 24 July to 1 October from two groups of tagged adults. The recovery rate for both PIT-only and double-tagged (radio and PIT) fish was 13.3% (Table 7). The recovery rate was 18.9% (182/964) for the unmarked fish released in the NFMF.

The prespawning mortality estimates in 2015 were 75% (3 of 4 females recovered) for PIT-tagged fish, 33% (1 of 3 females) for double-tagged fish, and 35.5% (27 of 76 females) for unmarked fish (Table 7).

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 2009-2015. 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. Prespawning mortality (PSM) rates were only calculated for females with known spawning status.

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
	Unmarked	2,031	336	16.5	153	29
2014	PIT	150	29	19.3	17	24
	Double	50	8	16.0	3	0
	Unmarked	865	208	24.0	74	10
2015	PIT	166	22	13.3	4	75
	Double	75	10	13.3	3	33
	Unmarked	964	182	18.9	76	36

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. 2014).

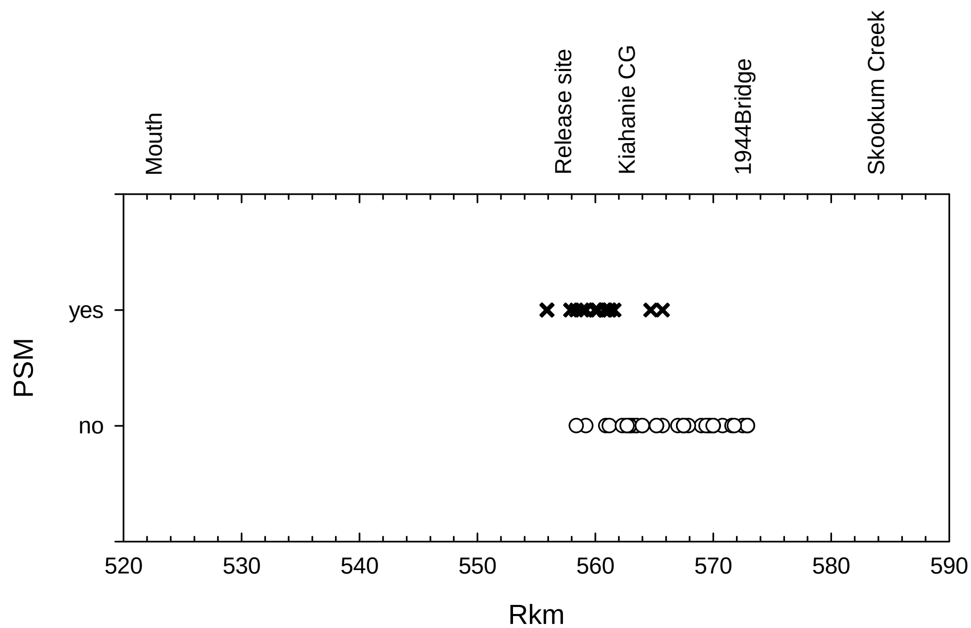

Figure 16. Distribution of 4 PIT-only, 3 double-tagged, and 76 untagged female Chinook salmon carcasses that were recovered in the NFMF Willamette River spawning ground surveys in 2015, by their spawning status.

In 2015, we continued the early outplanting of PIT- and radio-tagged fish into the NFMF initiated in 2013. Overall, recovery rates were substantially lower in 2015 than in 2013 and 2014 (Table 8). Although sample sizes were small and 2015 estimates are therefore challenging to interpret, all the observed PSM occurred in the late release group. PSM rates were also higher in the late (50%) than the early (33%) release group in 2013, but the pattern was reversed in 2014 (33% PSM for the early group versus 18% for the late group

Table 8. Prespawn (PSM) percentages for two groups of spring Chinook salmon tagged at the Dexter trap and released in in the NFMF in 2013-2015.

Year	Release Date	Number Released	Number Recovered	Percent Recovered	Females Recovered	PSM	Percent PSM
2013	22 May-5 Jun	64	6	9.4	3	1	33
	19 Jun-17 Jul	101	11	10.9	6	3	50
2014	21 May-4 Jun	60	8	13.3	3	1	33
	11 Jun-30 Jul	140	28	20.0	17	3	18
2015	20 May-3 Jun	73	2	2.9	0	n/a	n/a
	10 Jun-5 Aug	168	5	3.0	3	3	100

Fall Creek and NFMF Multi-year Summary

We tested for associations between female PSM 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). No females meeting criteria for scoring PSM were recovered during spawning ground surveys in 2015. 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 in larger salmon and the StdMeH relationship indicated fish with 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 later study years (2013 and 2014) which were warmer than 2011-2012. Two multivariate models had statistical support, with ΔAIC < 4.0, both of which included tag date.

The models for the NFMF included 84 females over 7 years. Among the univariate predictor variables, PSM was only significantly associated with tag date ($P = 0.008$), 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 ($P = 0.0904$) and the full model 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 female mortality as the dependent variable. No suitable females were recovered in 2015. 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	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

Table 9. Continued.

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	56.441	1.0

Table 10. Selection statistics for logistic regression models of PSM in NFMF from 2009-2015 that included a variety of predictor variables and female 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 and $P < 0.05$ 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	103.926	38.5	0.202
	Tag date	**94.889**	29.5	**0.008**
Condition	Condition	103.143	37.7	0.760
	Fatmeter	96.644	31.2	0.186
	Fulton's K	100.616	35.2	0.163
Shape	STDMeH	102.026	36.6	0.251
	STDHH	97.774	32.4	0.720
	STDDa	102.301	36.9	0.321
	STDBa	103.191	37.8	0.668
Size	FL	103.361	37.9	0.909

Table 10. Continued.

	Weight				102.443	37.0	0.676
Multivariate	Variables						
Timing	Year	Tagdate			97.977	32.6	0.094
Condition	Condition	Fatmeter			100.131	34.7	0.819
	Year	Condition	Fatmeter		105.478	40.1	0.801
	Condition	Fatmeter	K		101.336	35.9	0.894
	Year	Condition	Fatmeter	K	106.997	41.6	0.876
	Condition	Fatmeter	tagdate		99.744	34.3	0.687
	Year	Fatmeter	tagdate	K	99.526	34.1	0.329
Shape	StdMeH	StdHH	StdDA	StdBA	103.404	38.0	0.974
	Year	Shape			105.925	40.5	0.619
	Condition	Fatmeter	Shape		101.498	36.1	0.841
	Year	Condition	Fatmeter	Shape	106.764	41.3	0.834
	Shape	Tag date			95.958	30.5	0.181
	Year	shape	Tag date		100.725	35.3	0.354
Size	FL	Weight			103.954	38.5	0.722
	Year	FL	Weight		107.282	41.9	0.410
	FL	Weight	Shape		105.622	40.2	0.956
	Year	FL	Weight	Shape	106.849	41.4	0.658
Full					65.424	0.0	0.852

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). No female prespawn mortalities were recovered in Fall Creek in 2015. PSM rates for PIT- and radio-tagged females combined in the NFMF were the highest in 2015 (57.1%; Figure 17) versus 13-50% in previous years. In most years, a majority of prespawn mortalities occurred prior to the first identified redd 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). The PSM rate for untagged fish in Fall Creek in 2015 was 36.4% which was at the lower end of the estimates for the unmarked group during the study period (*range* = 17.9% [2012] to 100% [2013]).

Comparison of PSM rates among tag groups (PIT, PIT+radio, none) revealed differences among types within year, but these differences were not consistent across years. At Fall Creek, an analysis controlling for year effects, radio+PIT-tagging was associated with significantly higher PSM than PIT-tagging only (Chi-square 6.4, df = 2, $P = 0.040$) when restricted to years with all three tag types (2009-2012). While there was some evidence that double-tagged fish had higher PSM rate than PIT-only tagged fish, this effect was not observed when tagged fish were compared to untagged controls. The odds of being classified as a PSM were 1.8 (95% CI = 0.7-4.2, $P = 0.726$) times more likely for double-tagged versus untagged fish and 4 (95% CI = 1.4-11.5), $P = 0.016$) times more likely for double-tagged versus PIT-tagged fish. In the NFMF, there were no consistent year-to-year patterns in PSM rates among untagged, PIT-only or double-tagged groups (Figure 21). Tag type (PIT, radio, and untagged) was not a significant predictor of PSM rates at NFMF ($\chi^2 = 0.6$, df = 2, $P = 0.729$) in multinomial logistic regression when controlling for the effects of year ($P < 0.001$). 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 to outplanting without tagging in Fall Creek and the NFMF.

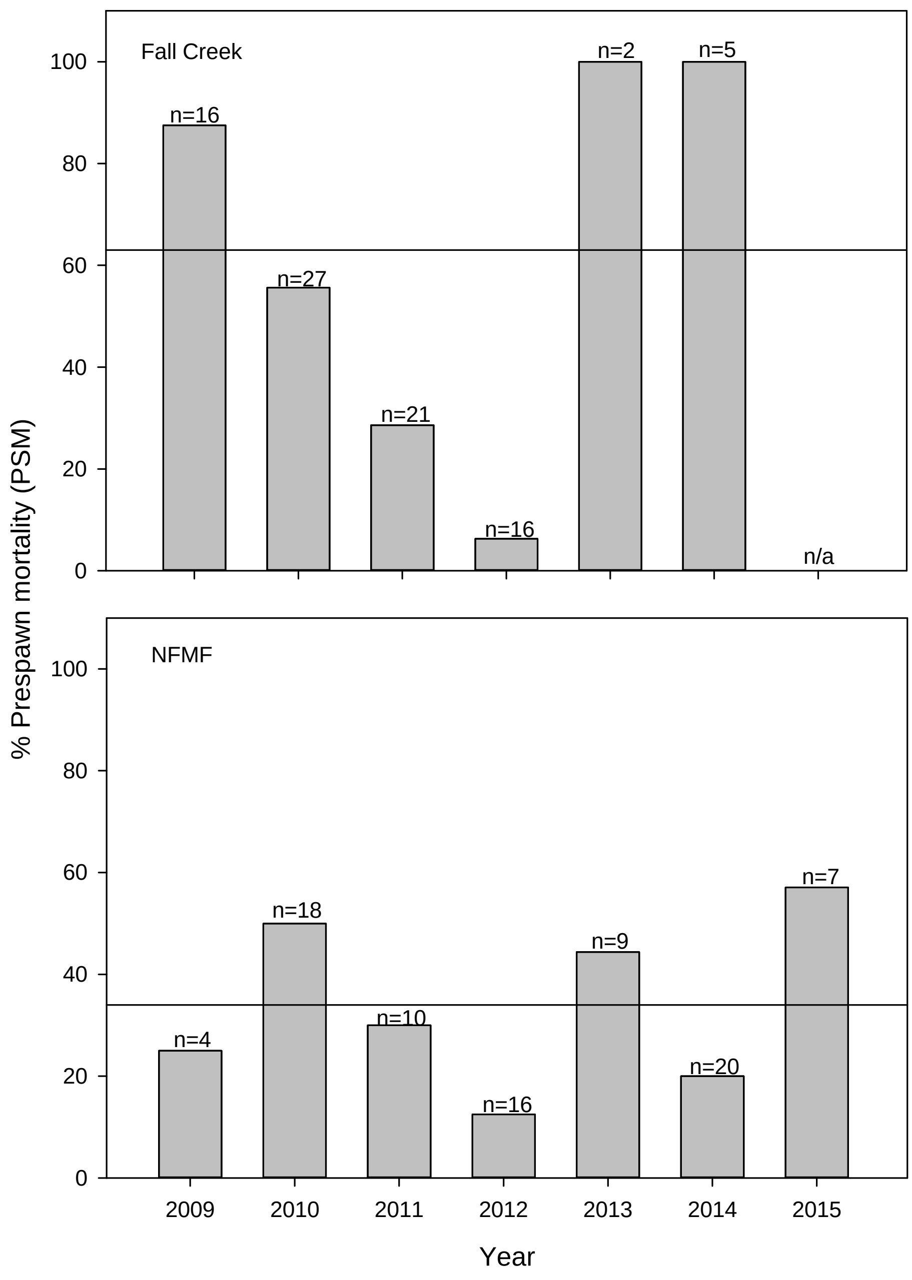

Figure 17. Annual percent PSM for combined PIT-only and double-tagged (radio+PIT) female Chinook salmon recovered in Fall Creek (top panel) and the NFMF (bottom panel) in 2009-2015. Horizontal line is the mean PSM rate across study years.

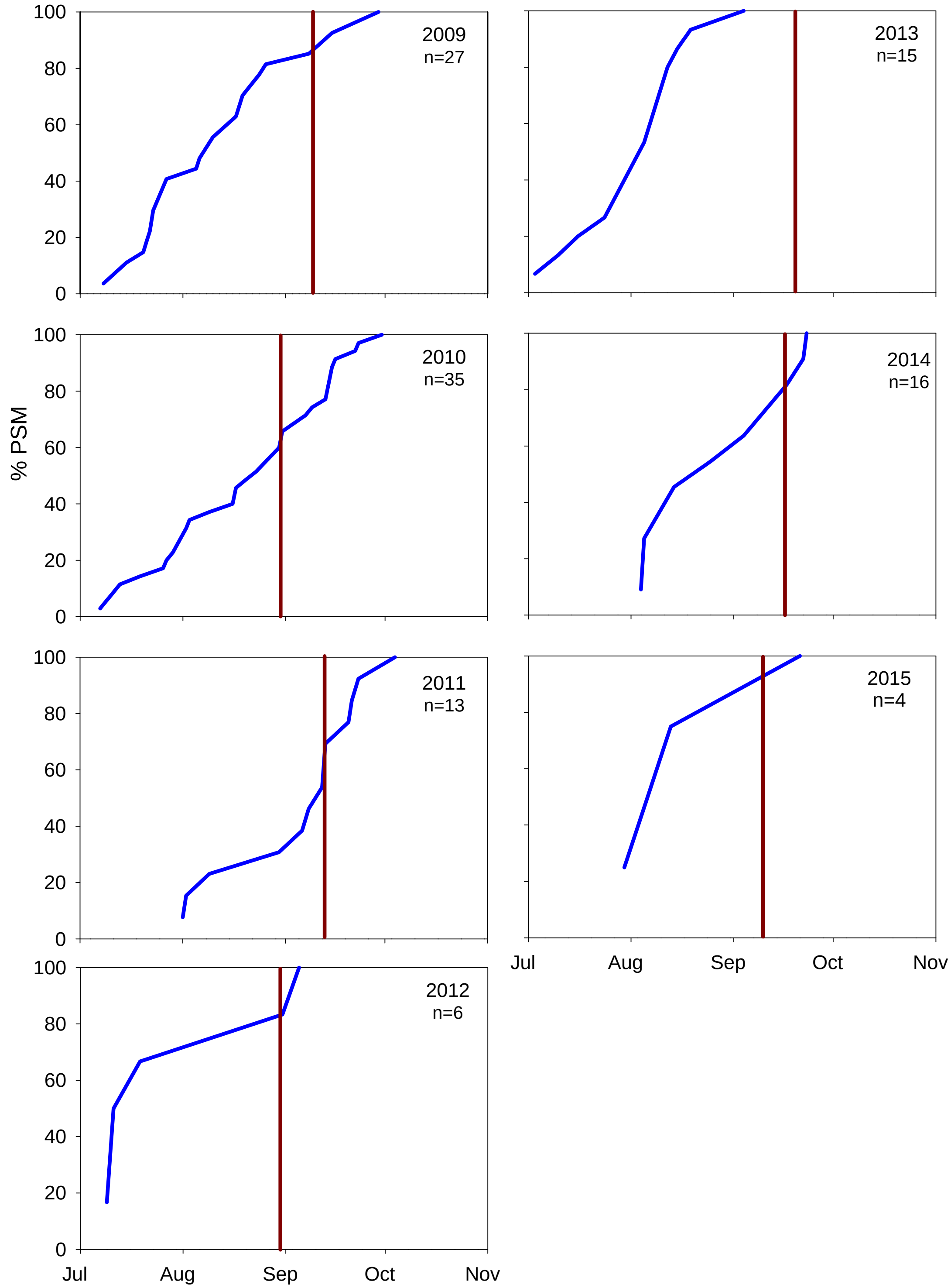

Figure 18. Cumulative percent of PSM carcass recoveries of PIT-tagged, double-tagged (radio+PIT), and untagged Chinook salmon in Fall Creek in 2009-2015 by date of carcass recovery. No fish were radio-tagged in Fall Creek in 2013-2015. Vertical red lines indicate the date that the first redd was observed.

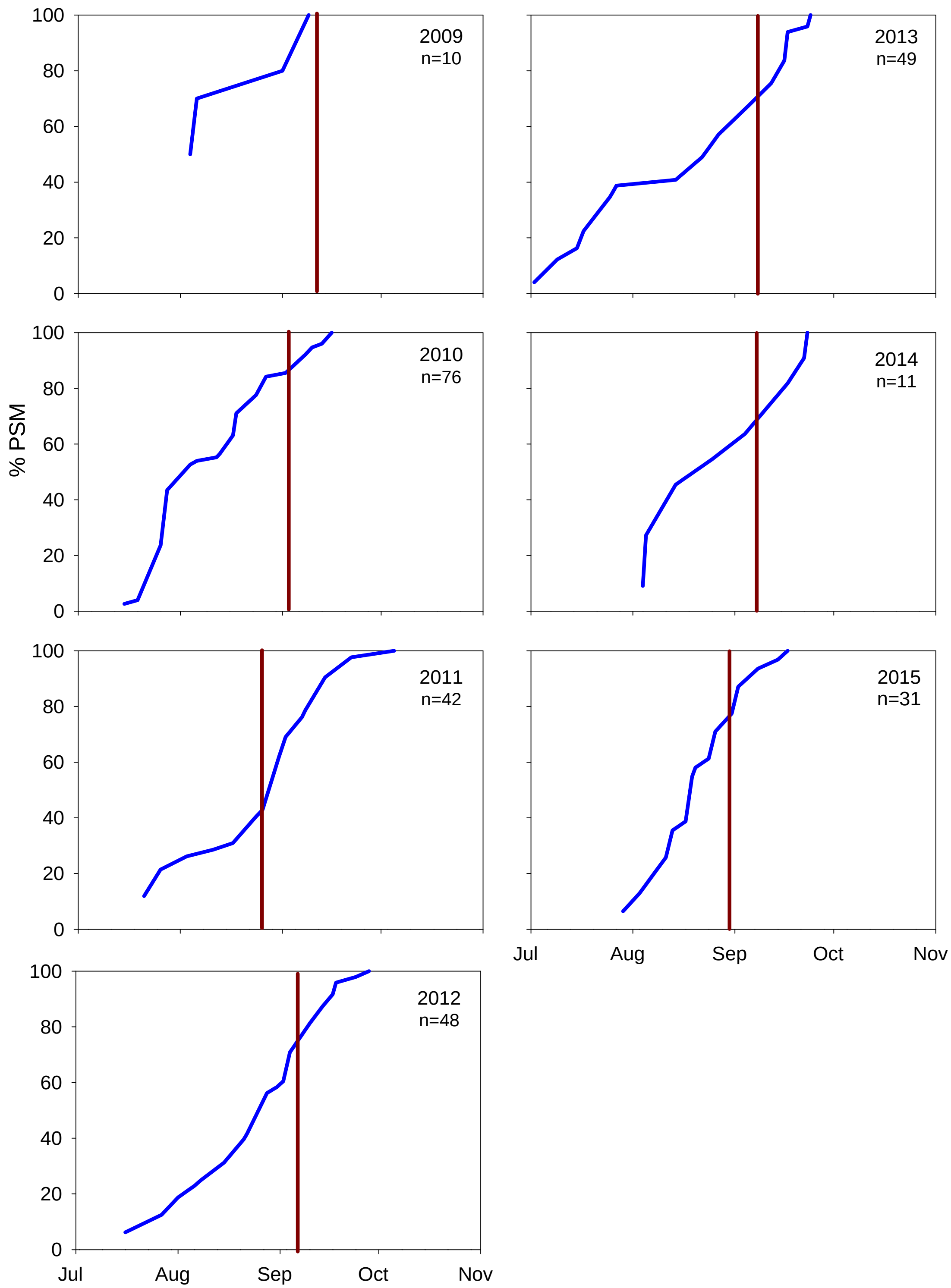

Figure 19. Cumulative frequency of PSM events of PIT, radio and untagged Chinook salmon in the NFMF of the Willamette River in 2009-2015. Vertical red lines indicate the date that the first redd was observed.

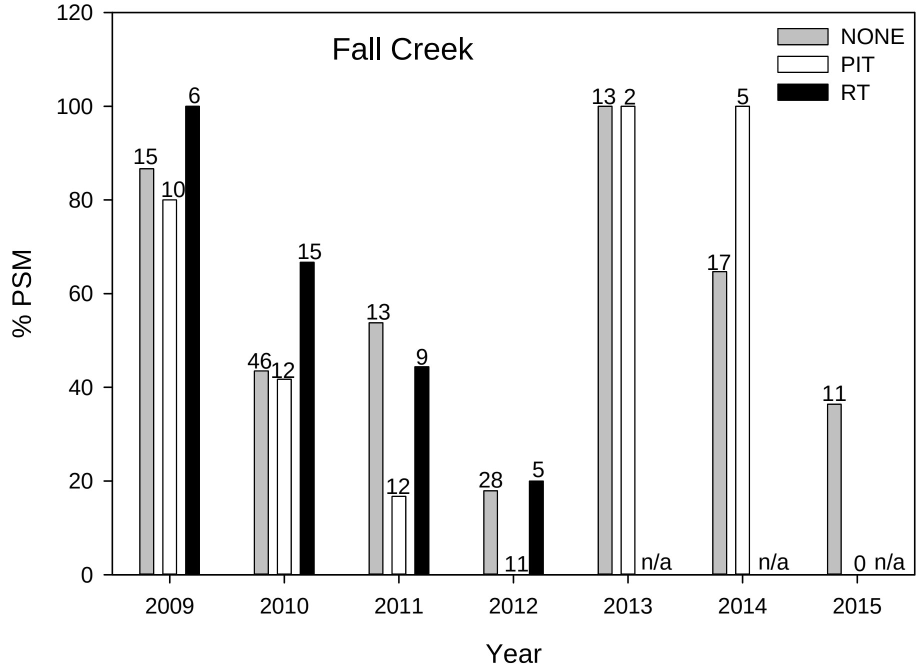

Figure 20. PSM rates for tagged (PIT = PIT-only, RT = radio+PIT) and untagged (NONE) female Chinook salmon recovered in Fall Creek in 2009-2015. Sample sizes above each bar are total number of females recovered; n/a indicates no radio-tagged fish in study year.

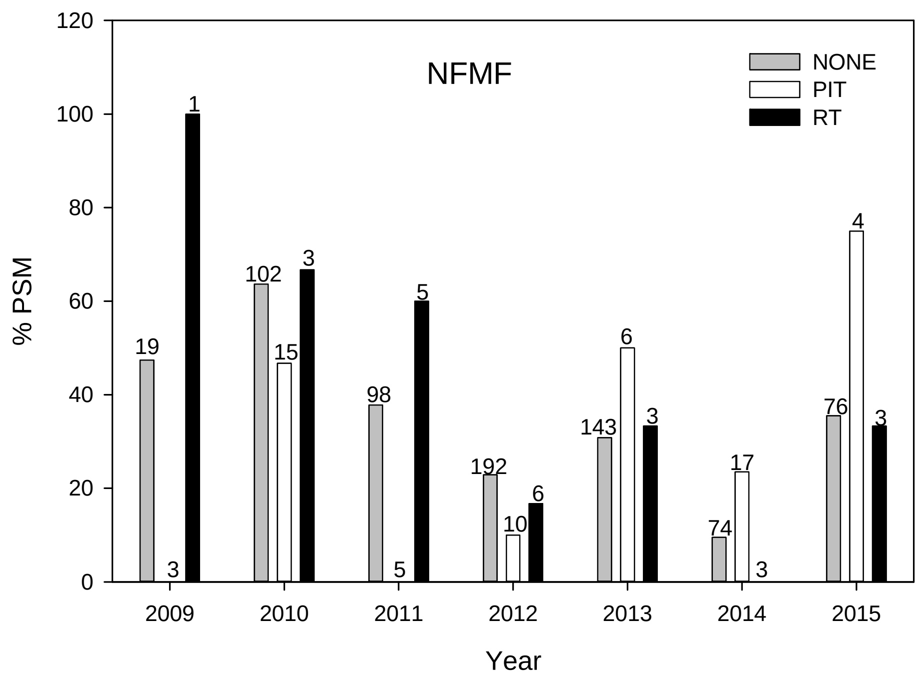

Figure 21. PSM rates for tagged (PIT = PIT-only, RT = radio+PIT) and untagged (NONE) female Chinook salmon recovered in the NFMF in 2009-2015. Rates do not include hatchery-held fish released in the NFMF in 2009-2012. Sample sizes above each bar are total number of females recovered.

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 and potential accumulation of thermal load 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), but where temperatures remained well below those considered stressful to salmonids.

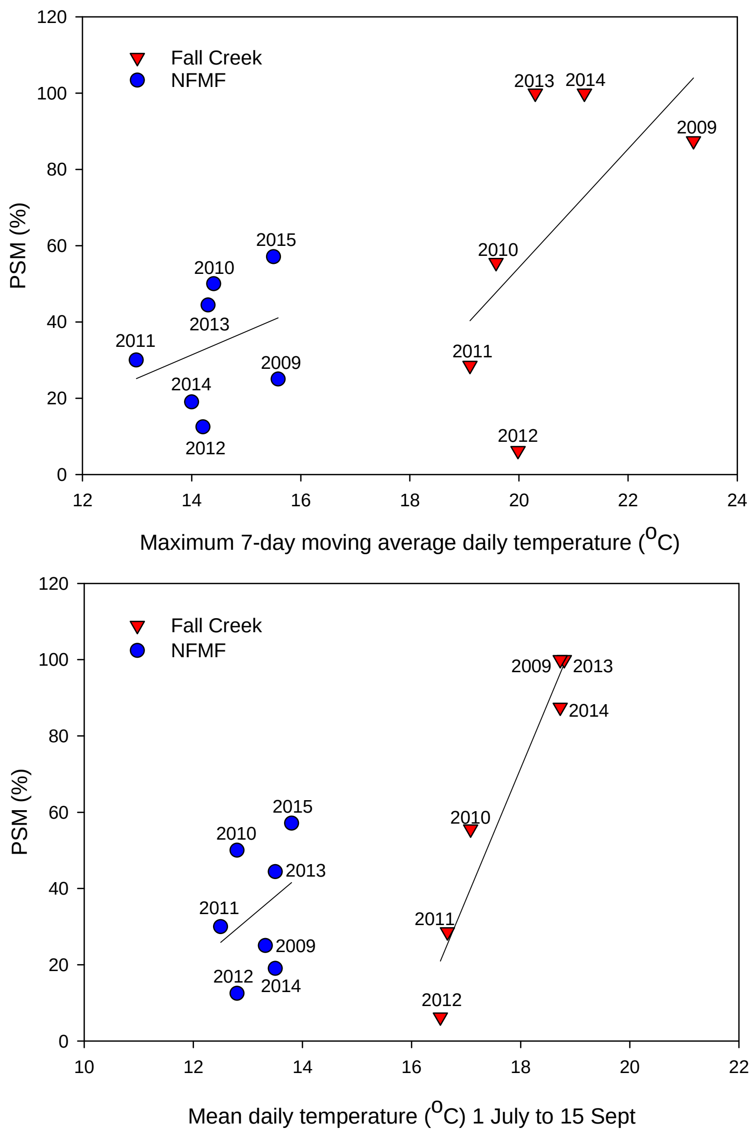

Figure 22. Annual prespawning mortality rates of female PIT- and radio-tagged Chinook salmon in Fall Creek and the NFMF in relation to the maximum 7-d moving average daily temperatures (top panel) and the mean daily temperature from 1 July to 15 September (bottom). Temperatures were recorded at the release sites. Note: no tagged females were recovered in Fall Creek in 2015.

Results: South Fork Santiam

Salmon collection at Foster

Adult Chinook salmon were collected and tagged at the Foster Dam trap on the South Santiam River from 19 May to 15 September 2015. A total of 322 Chinook salmon (135 females, 187 males) were PIT tagged, and 47 of these were also radio-tagged (Figure 23).

All fish transported above the dam had intact adipose fins. Overall, 203 PIT-tagged fish were released at Gordon Road and 64 were released at River Bend. The 37 radio-tagged fish were released at three sites (Figure 24): River Bend (n = 10), Calkins (n = 14) and Gordon Road (n = 13). Fish released at the Calkins Park site were used to evaluate the efficacy of reservoir releases. No fish were fish released at River Bend or Calkins after the Foster pond holding period. The mean fork length for all PIT- and radio-tagged fish (n = 322) was 75.3 cm,, mean condition score was 2.5, mean weight was 5.4 kg, and mean lipid percentage was 4.5% (Table 11). Mean estimated lipid content of tagged adults arriving at the Foster trap in May were lower than lipid content estimated for adults at Willamette Falls in previous years and generally decreased through the 2015 season (Figure 25).

Changes to study protocols and mortality associated with high water temperature

Due to concern about high water temperatures in the South Santiam River (approximately 19 °C on 2 July at the Gordon Road release site) and the difference between temperatures at the release site versus the cooler temperatures below Foster Dam, UI, ODFW, and NOAA Fisheries agreed that outplanting fish was too risky. This prompted a decision to hold fish in the Foster ponds which were substantially cooler (10.6 °C) than the river. The first ponding of radio- and PIT-tagged fish occurred on 10 July and continued weekly until 1 September. All ponded fish were outplanted on 7 September. A total of 104 fish (92 PIT-tagged, 12 double-tagged) were ponded during the holding period. A total of 18 (17.3%) fish died during holding of which 45% (n = 8) were PIT-tagged fish and 55% (n = 10) were radio-tagged. However, mortality rates of ponded PIT-tagged fish were approximately 9% (8/92) compared to 83% (10/12) for ponded radio-tagged fish. Mortalities were distributed among tag dates with at least one fish from each tagging event (except 4 August) dying after release into the holding pond. Fifty percent of the mortalities (n = 9) were from fish tagged in the first two days of tagging during the holding period: 10 July (n = 5) and 14 July (n = 4). Mortalities were collected by ODFW personnel and placed in a freezer until transferred by UI personnel to the Dexter Dam freezer where they were stored until processed for proximate analysis.

Intestine and kidney samples from 14 of the Foster pond mortalities were collected during proximate analysis processing and were immediately frozen then transported to the ODFW Fish Health Services laboratory at OSU where they were tested for *Ceratomyxa shasta*, bacteriology and ELISA for bacterial kidney disease (BKD) (Sarah Bjork, ODFW, Fish Health Services, pers. comm.). Three tissue samples tested positive for *C. shasta* while both *Aeromonas* spp. and *Psuedomonas* spp. grew on all samples (common on compromised or degraded fish). No fish tested positive for BKD. Based on observation of numerous PSM fish from Minto, ODFW suggested that *Columnaris* on the gills may have been a significant contributing factor to mortalities. However, because fish were immediately frozen after they were recovered from the holding ponds fresh gill samples were not available for testing.

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

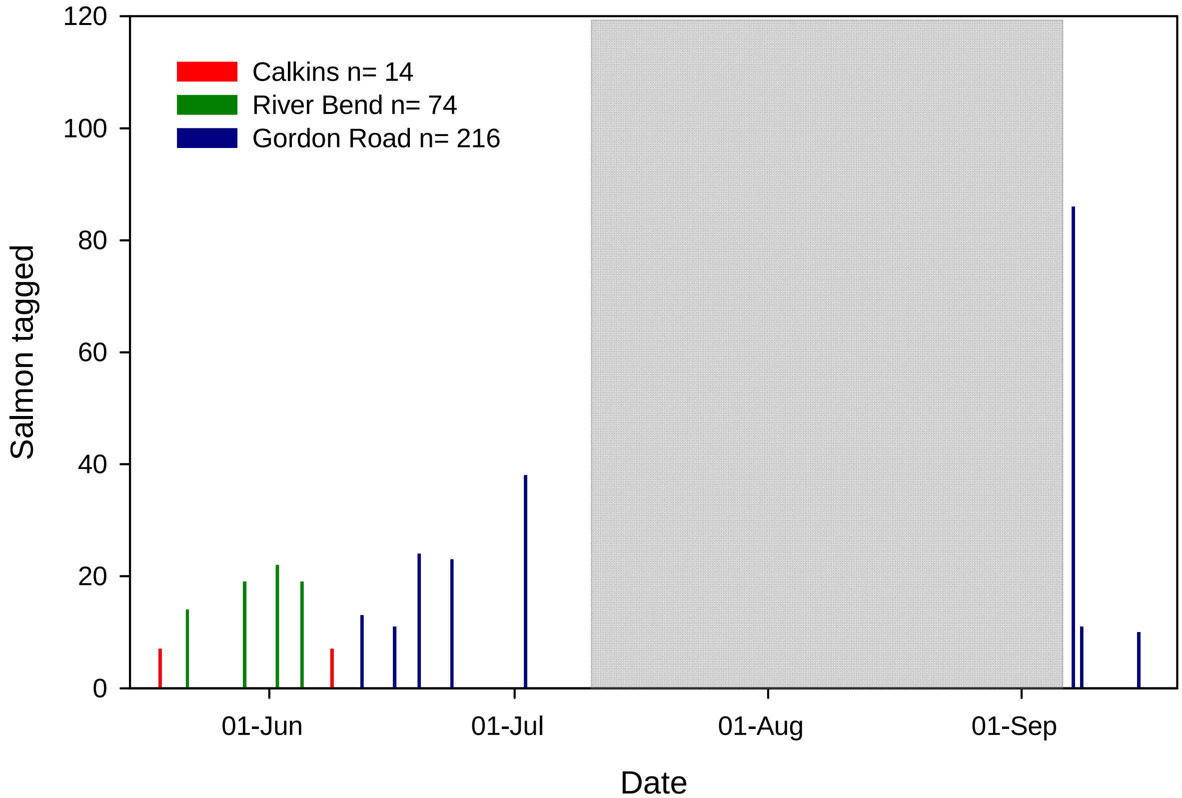

Figure 24. Numbers of adult Chinook salmon PIT- and radio-tagged at Foster Dam in 2015. Fish were released at three locations above Foster Dam. A total of 636 adult Chinook salmon were collected at the Foster trap. Fish were held in the Foster pond during the warm temperature period shaded in gray, from 10 July to 7 September (including 92 PIT-only, 12 double-tagged).

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 2015 (*n* = 322). 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* = 322)	Fork Length (cm)	Weight (kg)	MeH (cm)	Da (cm)	Ba (cm)	HH (cm)	% Lipid	Condition Score
Mean	75.3	5.4	63.1	12.1	6.6	8.4	4.5	2.5
St. Deviation	7.0	1.6	5.7	1.5	0.8	1.1	1.6	0.7
Max	89	9.8	75	16.1	8.7	11.2	11.6	3
Min	56	2.2	48	7.4	4.7	6.2	1.6	1

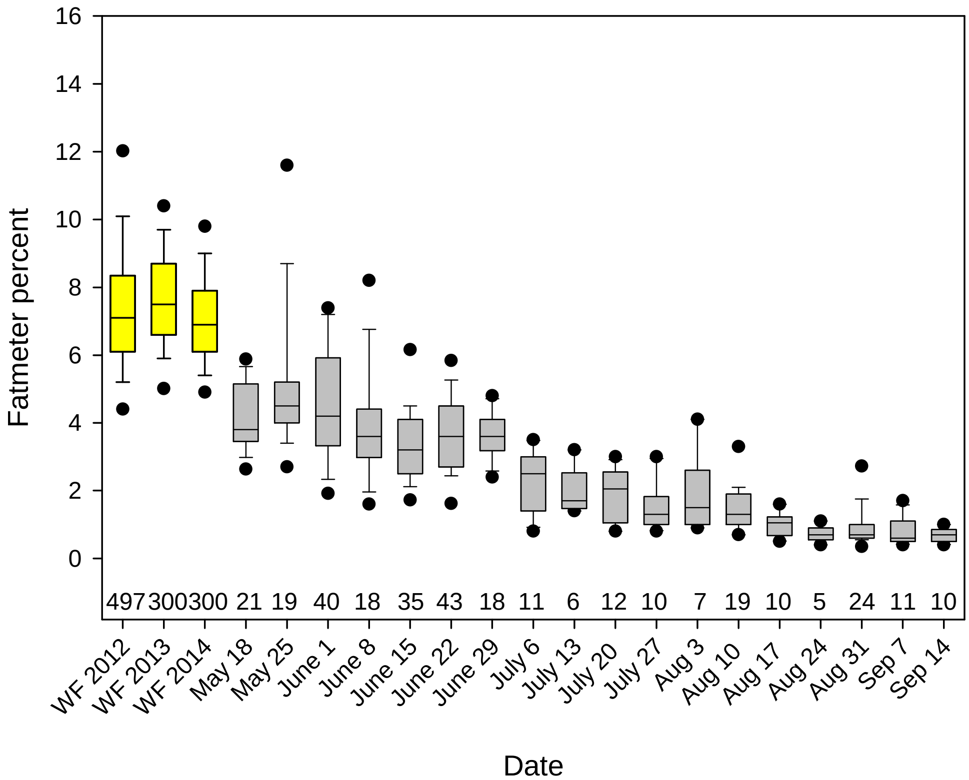

Figure 25. Distributions of fatmeter results for Chinook salmon tagged at the Foster Dam trap in 2015. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (●). Sample size for each week given below each distribution. Boxes on left show data for Chinook salmon sampled at Willamette Falls Dam (WF) in 2012-2014 from Jepson et al. (2015).

Salmon recovery rates

The recovery rate for PIT-tagged fish was 25.8% (69/267). Three of 23 (13%) radio-tagged fish released upstream of Foster Dam were subsequently recovered in spawning ground surveys and only from the group released at Gordon Road (i.e., none were recovered from the reservoir release group or the group released at River Bend). The PSM estimate for PIT-only fish released at Gordon Road was 37.5% (9 of 24 females recovered) whereas only one female radio-tagged fish was recovered and it was not a PSM (Table 12). The final distribution of PIT- and radio-tagged fish indicated that the majority of spawning occurred between the Gordon Road release site and the barrier falls (Figure 26).

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, 2013-2015. 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). No estimates for untagged fish were calculated because all fish released upstream from Foster Dam were either PIT or double-tagged.

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
2015	GDR	PIT	203	69	25.8	20	35
		Double	13	3	13.0	1	0
	RVB	PIT	64	7	10.9	4	50
		Double	10	0	0.0	0	n/a
	CKP	Double	14	0	0	n/a	n/a

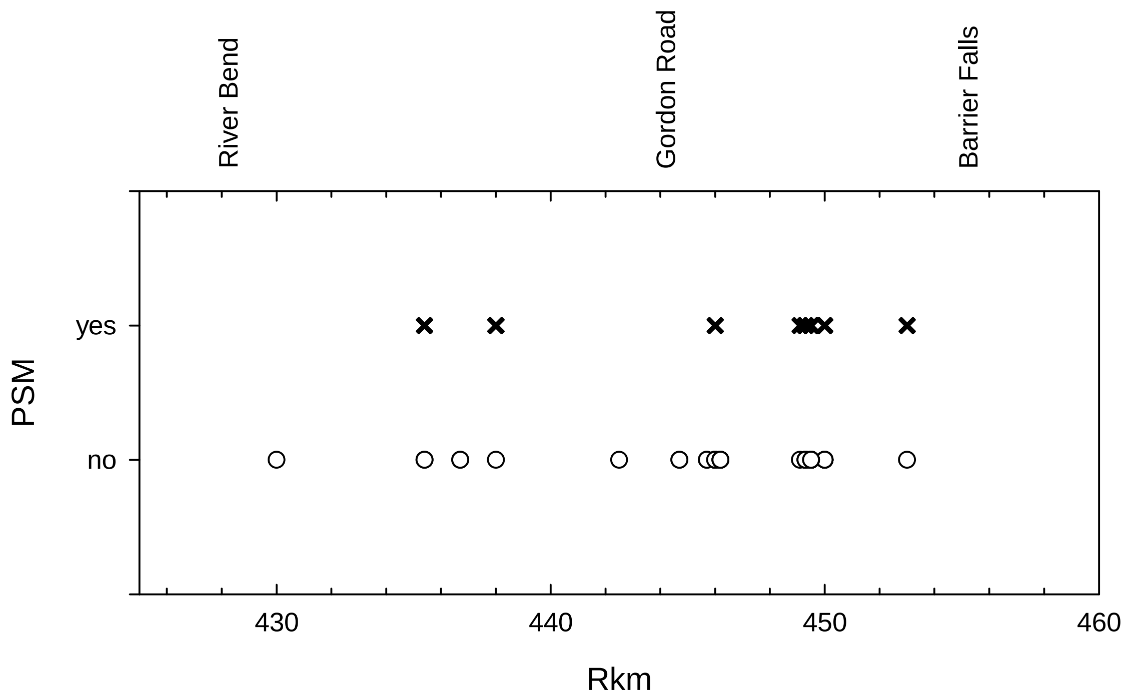

Figure 26. Distribution of 57 PIT-only, 1 double-tagged, and 7 untagged female Chinook salmon carcasses that were recovered in the South Santiam River spawning ground surveys in 2015, by their spawning status. Note: ‘untagged’ group may have shed PIT tags as all were theoretically tagged at release.

Proximate Analysis

In 2015, proximate analysis was performed on 15 Chinook salmon collected at Foster trap (3 males and 12 females). Lethal takes for proximate analysis were conducted on 23 June (n = 5), 21 July (n = 2), 8 September (n = 4), and 15 September (n = 4). The average muscle lipid level was 3.8% (Table 13) and ranged from 1.4-8.9%. Average gonadal lipid composition was 9.6% for females and 1.6% for males (Table 14). Individual lipid concentrations of fish collected at Foster Dam as estimated with the fatmeter were correlated with the values estimated from proximate analysis taken from lethally sampled adults (adj. $r^2 = 0.48$, $P = 0.003$, n = 15).

Table 13. Mean tissue composition of 15 Chinook salmon collected at the Foster Dam trap and used in proximate analysis in 2015.

Tissue	% Moisture	% Crude Lipid	% Total Ash	% Protein
Gonads	62.3	8.0	2.8	26.8
Muscle	77.6	3.8	1.1	17.6
Skin	69.6	2.2	0.9	27.3
Viscera	80.1	1.4	1.3	17.1

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

Tissue	% Moisture	% Crude Fat	% Total Ash	% Protein
Males (n = 3)				
Gonads	76.4	1.6	4.6	17.4
Muscle	78.7	3.4	1.1	16.8
Skin	72.9	0.5	0.7	25.9
Viscera	80.8	1.5	1.3	16.4
Females (n = 12)				
Gonads	58.8	9.6	2.4	29.2
Muscle	77.3	3.9	1.1	17.7
Skin	68.8	2.6	1.0	27.6
Viscera	80.0	1.4	1.3	17.3

South Fork and Middle Fork Santiam River and Foster Reservoir Environment

Mean water temperature in the South Santiam (measured at the Gordon Road release site) during the 2015 study period was 15.6 °C with a peak of 20.8 °C on 2 July; temperatures tended to be progressively warmer downstream (Figure 27). Water temperatures in the Middle Fork Santiam were approximately 3.5 degrees warmer (*mean* = 19.1 °C) than in the South Fork Santiam with a maximum temperature of 22.7 °C on 13 August. Mean seasonal water temperatures collected by USACE at 11 depths in Foster Reservoir ranged from 20.6 °C at 0.2 m from the surface to ~10.4 °C at 24 m, with a maximum of 24.8 °C on 5 July (Figure 28). The thermocline was at approximately 6-9 m and temperatures below 9 m generally remained <= 15 °C throughout the summer. The thermocline was also less clearly defined and deeper after mid-July.

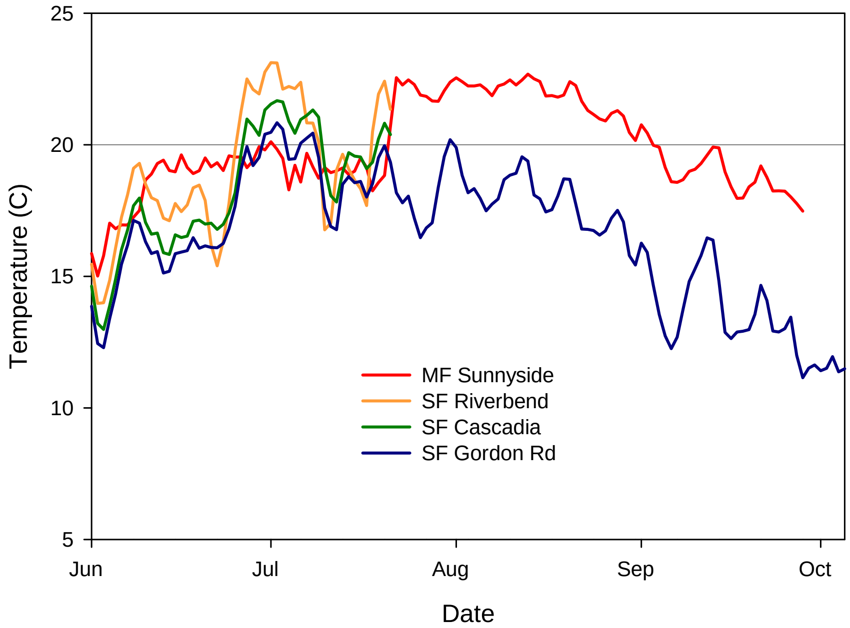

Figure 27. Daily mean water temperatures in 2015 in the Middle Fork (MF) Santiam River and at three sites in the South Fork (SF) Santiam River. The loggers in the South Fork Santiam represent a progression upstream from the River Bend release site (rkm 428.3) to the Gordon Road release site (rkm 444.7). The River Bend and Cascadia (437.3) loggers were stolen in 2015. Solid line at 20 °C represents temperature considered to be physiologically stressful for adult salmonids.

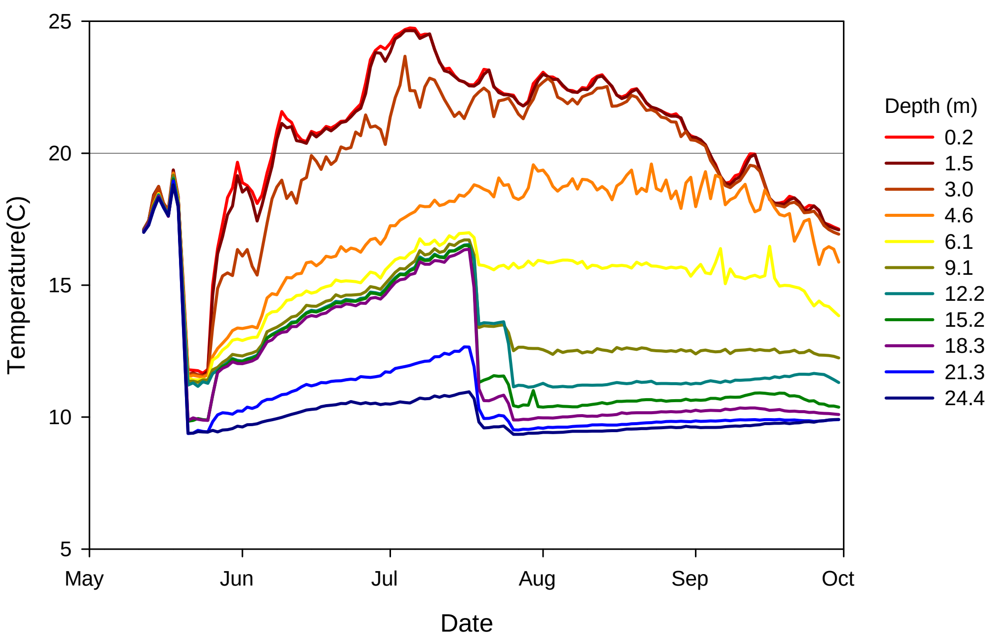

Figure 28. Foster Reservoir mean daily water temperatures collected at 11 depths between 1 May and 30 September 2015 (U.S. Army Corps of Engineers). Solid line at 20 °C represents temperature considered to be physiologically stressful for adult salmonids.

Reservoir-released fish

Fourteen radio-tagged salmon were released into Foster Reservoir in 2015 and 9 (64%) of these were recorded at receivers upstream from the Calkins release site. Median salmon residence times in the reservoir were 79.0 d (range 7.7-110.1 d) for fish last recorded on the South Fork Santiam receiver (SFR) and 94.7 d (range 79.7-141.3 d) for fish last recorded on the Middle Fork Santiam receiver (MSR; Figure 29). Fish last recorded at the SFR site also included some fish that were detected at the MSR site, including fish that made multiple trips between receiver sites. None of the radio-tagged fish released in Foster reservoir in 2015 were recovered on the spawning grounds. Two (14%) of the 14 fish released in the reservoir were recorded falling back through the dam with release-to-fallback times of 13-16 d. In contrast, only 1.4% (4/290) of the PIT and radio-tagged fish released in the river fell back.

Although no reservoir-released fish were found on the spawning grounds, we recovered several radio-archival tag pairs without carcasses (n = 8 in 2014; n = 3 in 2015)) which allowed us to estimate thermal histories. Comparison of the thermal history of fish released in the reservoir (Calkins Park releases) versus thermal history if fish would have been released in river (at Gordon Road release site) suggested that reservoir-released fish were exposed to an average of 3.3 fewer degrees per day (DD/d) than fish released in the river (Figure 30) in 2015 compared to 2.8 fewer DD/d) in 2014. Estimates of the total accumulated degree days (DD) were lower compared to estimated values for release into the South Santiam and the magnitude of the difference depended on the fish residence time in the reservoir (Figure 31). The average relative reduction in the total accumulated DD was 16% (range = 14-23%) in 2014 and 39% (range 20-45%) in 2015.

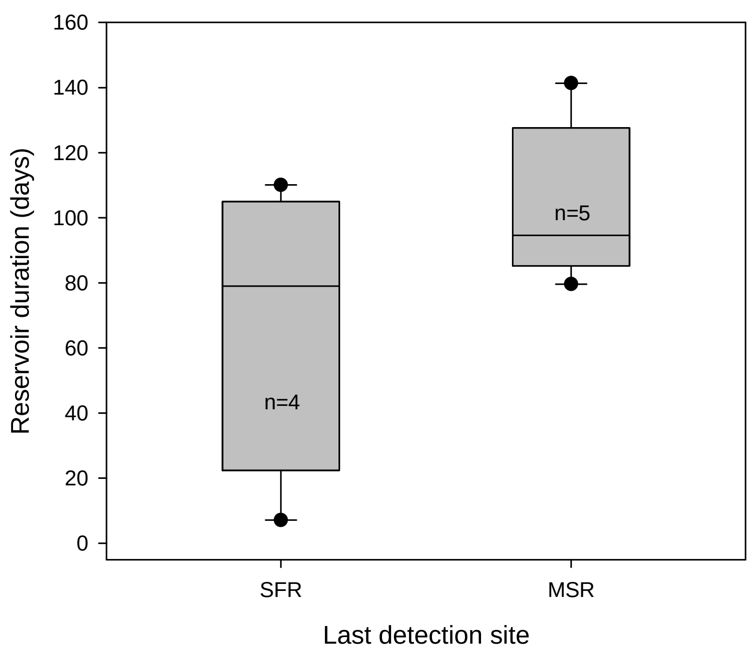

Figure 29. Reservoir residence times (d) of radio-tagged adult Chinook salmon released into Foster reservoir in 2015 by final detection location. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (●). SFR = South Fork Santiam River, MSR = Middle Fork Santiam River.

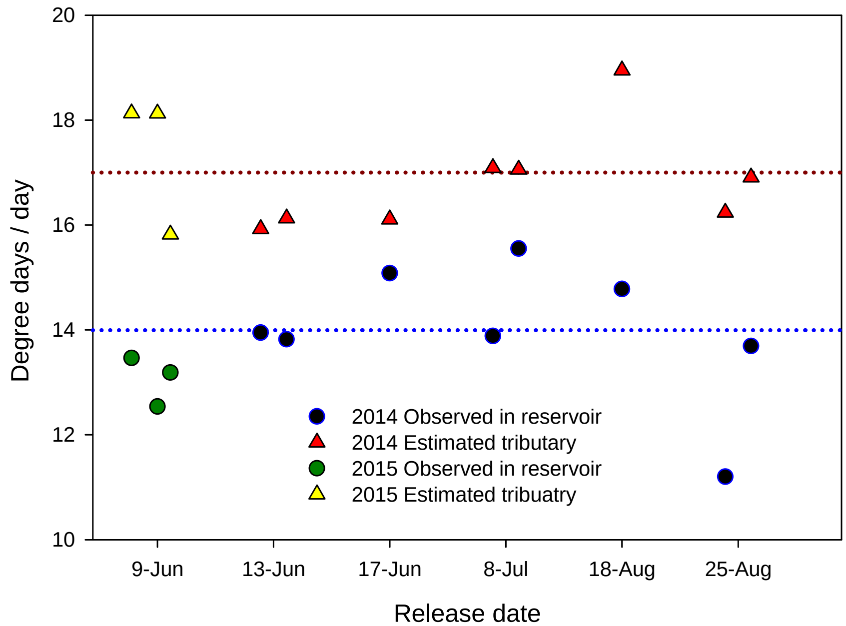

Figure 30. Numbers of degree days per day calculated for reservoir-released Chinook salmon (n = 8 in 2014; n = 3 in 2015) that had archival temperature loggers (●), and their estimated degree days per day if they would have been released in directly into the South Santiam upstream from the reservoir (▲). Red dotted line is estimated tributary mean degree days per day and blue dotted line is reservoir mean degree days per day across years.

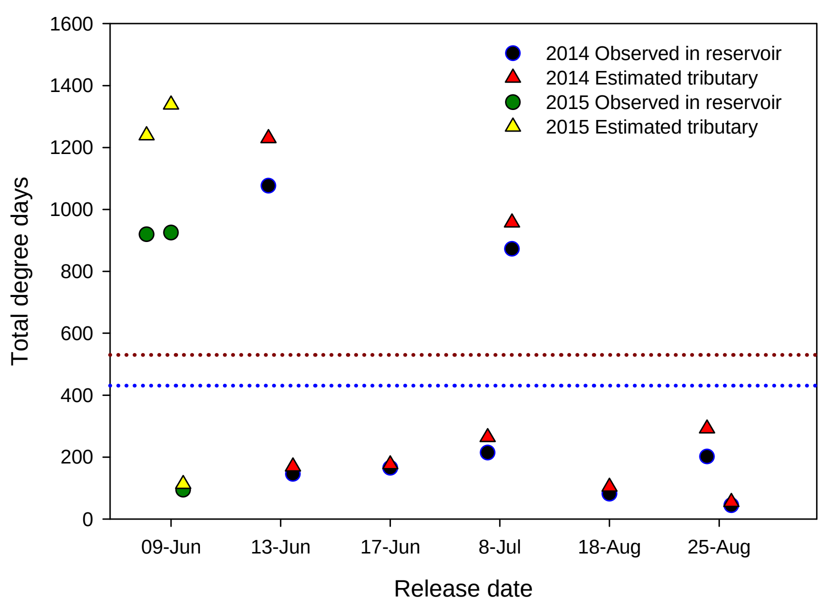

Figure 31. Total accumulated degree days for reservoir-released Chinook salmon (n =8 in 2014; n = 3 in 2015) with archival temperature loggers (●) and their estimated total degree days between release and spawning if they would have been released directly into the South Santiam River upstream from the reservoir (▲). Red dotted line is estimated tributary mean total degree days and blue dotted line is reservoir mean total degree days across years.

South Santiam River multiyear summary

We tested for associations between female PSM and a suite of factors potentially related to PSM across study years using univariate and multiple logistic regression models and multi-model selection techniques in the South Santiam River. The models included 64 females over 3 years (2013-2015). Fish that died during Foster pond holding in 2015 were excluded from the analysis. Among the univariate logistic regression models, tag date, fat percent, Fulton's K and breadth at anus were significantly ($P < 0.05$) associated with PSM (Table 15). The tag date effect indicated that earlier-arriving fish had higher PSM rates. Higher fat percentage, increased breadth, and higher Fulton's K values were all associated with higher PSM. In the multi-model logistic regression evaluation, the most parsimonious model included fork length, weight, and shape but was not statistically significant (Table 15). Models with year and tag date were significant and largely driven by tag date, indicating higher PSM among the early migrants. While the model with FL, weight, and shape was the most parsimonious (lowest AIC value), no other models had statistical support, with ΔAIC < 4.0. We also tested for the effect of release location on PSM and while the overall model was not significant ($P = 0.11$) the estimate for the Gordon Road release site was ($P = 0.034$).

Table 15. Selection statistics for logistic regression models of PSM in the South Santiam River from 2013-2015 that included a variety of predictor variables and mortality as the dependent variable. AIC = Akaike information criteria, $\Delta AIC = AIC_{current}-AIC_{best}$. 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 ($10^5 \times weight/L^3$).

Model type Univariate	Variables		AIC	ΔAIC	*P*-value
Timing	Year		85.32	21.1	0.227
	Tag date		78.66	14.5	0.012
Condition	Condition		87.488	23.3	0.643
	Fatmeter		81.733	17.5	0.038
	Fulton's K		80.472	16.3	0.030
Shape	STDMeH		86.364	22.2	0.995
	STDHH		83.344	19.2	0.093
	STDDa		86.242	22.1	0.724
	STDBa		77.516	13.3	0.0064
Size	FL		86.35	22.2	0.8970
	Weight		84.47	20.3	0.1769
Multivariate	Variables		AIC	ΔAIC	*P*-value
Timing	Year	Tagdate	78.264	14.1	0.035

Table 15. Continued.

Condition	Condition	Fatmeter			84.959	20.8	0.176
	Year	Condition	Fatmeter		85.572	21.4	0.194
	Condition	Fatmeter	K		82.19	18.0	0.131
	Year	Condition	Fatmeter	K	83.524	19.3	0.215
	Condition	Fatmeter	tagdate		83.594	19.4	0.135
	Year	Fatmeter	tagdate	K	79.826	15.6	0.113
Shape	StdMeH	StdHH	StdDA	StdBA	78.644	14.5	0.050
	Year	Shape			77.165	13.0	0.056
	Condition	Fatmeter	Shape		82.918	18.7	0.183
	Year	Condition	Fatmeter	Shape	80.616	16.4	0.210
	Shape	Tag date			80.162	16.0	0.088
	Year	shape	Tag date		77.864	13.7	0.101
Size	FL	Weight			80.951	16.8	0.053
	Year	FL	Weight		82.213	18.0	0.100
	FL	**Weight**	**Shape**		**64.184**	**0.0**	**0.102**
	Year	FL	Weight	Shape	78.039	13.9	0.114
Full					83.313	19.1	0.499

Carcass recoveries among basins

Overall, carcass recoveries of Chinook salmon (PIT, RT and unmarked fish combined) were proportional to outplant abundance among the Fall Creek, NFMF, and South Santiam basins during the three years when collections occurred in all three basins (Figure 32). Carcass recoveries per survey ranged from 1.6 (259 outplants) to 2.4 fish/survey (467 outplants) in Fall Creek, from 6.0 (1200 outplants) to 15.4 (2267 outplants) in the NFMF, and from 2.0 (200 outplants) to 5.4 (457 outplants) in the South Santiam.

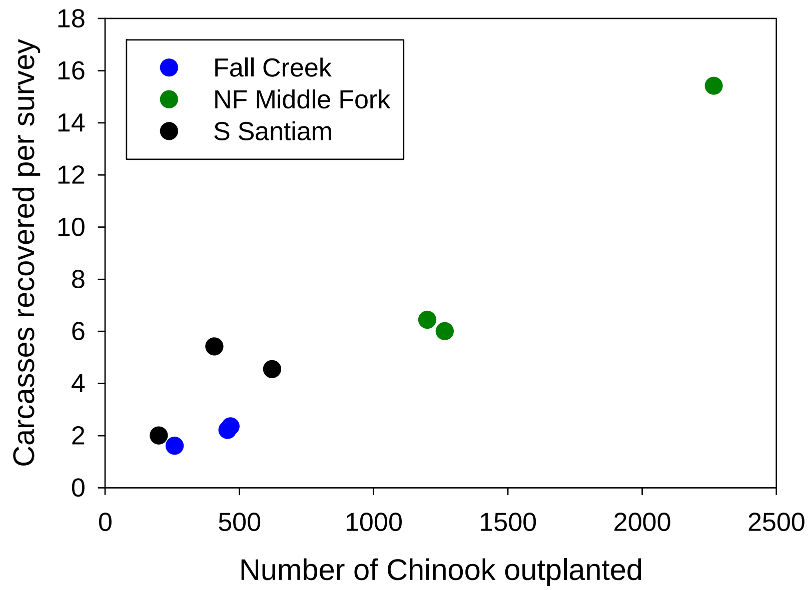

Figure 32. Carcasses recovered per survey versus the number of Chinook salmon outplanted in 2013-2015.

Results: Toxicology sampling

In 2013, we collected 28 tissue samples from adult Chinook salmon recovered on the spawning grounds: 19 (68%) from the NFMF, 7 (25%) from the South Fork Santiam, and 2 (7%) from Fall Creek (Table 16). Of the nineteen collected in the NFMF 10 (53%) were from prespawn mortalities and 9 (47%) were from fish that spawned. Four of the seven (57%) samples collected in the South Fork Santiam were from prespawn mortalities and three were from fish that spawned. Both of the Fall Creek samples were from prespawn mortalities.

In 2014, we collected 35 tissue samples from adult Chinook salmon recovered on the spawning grounds: 18 (51%) from the NFMF, 13 (37%) from the South Fork Santiam and 4 (11%) from Fall Creek (Table 16). Of the eighteen collected in the NFMF 4 (22%) were from prespawn mortalities and 14 (78%) were from fish that spawned. Three of the 13 (23%) samples collected in the South Fork Santiam were from prespawn mortalities and 10 were from fish that spawned. Three of the four fish from Fall Creek samples were from prespawn mortalities. Samples were also collected in 2015 but data has not been analyzed due to cost constraints.

Table 16. Number of Chinook salmon and spawning status collected for toxicology analysis from three Willamette River tributaries.

			Prespawn mortality	
Year	Tributary	# Collected	Yes	No
2013	Fall Creek	2	2	0
	NFMF	19	10	9
	SF Santiam	7	4	3
2014	Fall Creek	4	3	1
	NFMF	18	4	14
	SF Santiam	13	3	10
2015	Fall Creek	4	0	4
	NFMF	13	4	9
	SF Santiam	8	3	5

Mean concentrations across 2013 and 2014 samples were: Ni: 91.6 ng/g; Cd: 4.2 ng/g; Pb 10.1 ng/g; PCBs 13.0 ng/g; DDT 12.5 ng/g in 2013 and Ni: 57.9 ng/g; Cd: 4.3 ng/g; Pb 10.1 ng/g; PCBs 15.9 ng/g; DDT 19.0 ng/g in 2014 (Figure 33). General linear model results suggested there was no statistical difference in concentrations of individual metals (Ni, Cd, and Pb) and organic compounds (PCBs and DDT) between PSM fish and successful spawners, among tributaries, or between years (3-way ANOVAs for each toxin: P_{psm} range = 0.389-0.784, P_{trib} range = 0.282-.852; P_{year} range = 0.282-0.920).

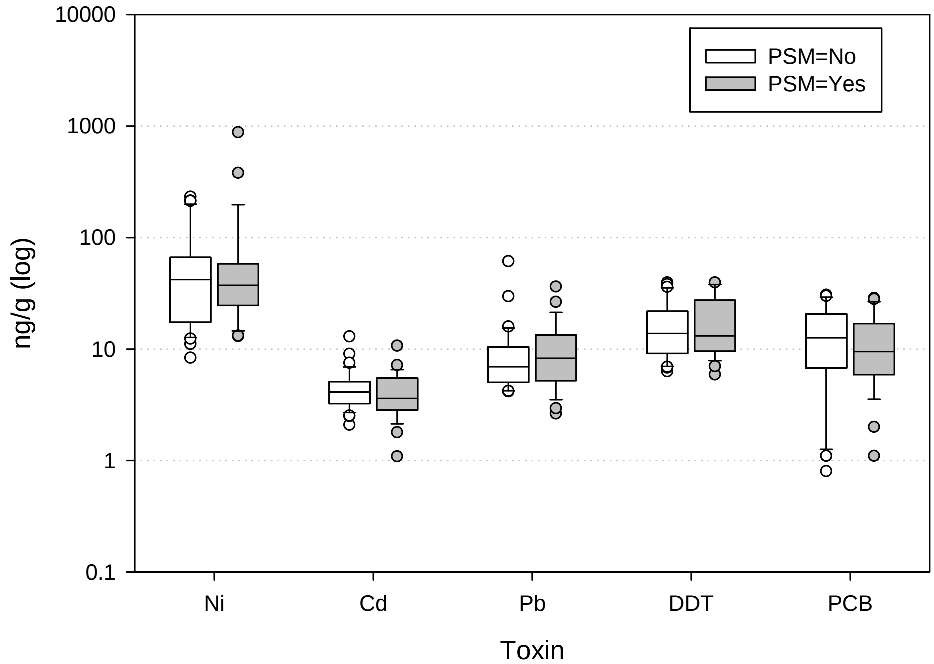

Figure 33. Concentrations of heavy metals and organic compounds in Chinook salmon classified as prespawn or non prespawn mortalities collected from Fall Creek, NFMF and the South Santiam River in 2013 and 2014.

Results: Minto Fish Facility tagging

We collected and radio-tagged 20 spring Chinook salmon at the Minto trap on 13 July (*n* = 9) and 22 July (*n* = 11). Five of the fish tagged on 13 July were released in the North Santiam River (rkm 449.4) upstream from Detroit Reservoir. The other four fish tagged on 13 July were released near the Minto Fish Facility, approximately 100 m upstream from the tagging location. Of the 11 fish radio-tagged on 22 July, 6 were released near the Minto Fish facility while the other five were held at the facility for release the following week. On 30 July the five fish held at the facility were found dead or moribund. Three fish were immediately taken to the OSU Fish Pathology Lab for examination; collection and tagging at Minto was immediately stopped. The visual examination indicated that the kidneys were liquefied and muscle was separating from the ribs on three fish. Test results later indicated that the fish had either BKD or furunculosis. There was no exact diagnosis for the fourth fish, but a bacterial infection was expected (Sarah Bjork, ODFW Fish Health Service Summary 14-436). Examination of the stomachs of the radio-tagged fish revealed that the tags perforated the stomach lining which likely hastened mortality of the already compromised fish.

The average fork length of the fifteen fish that were released was 78.9 cm and average weight was 5.3 kg. Of the 10 fish released near the Minto Fish Facility, 7 (70%) moved upstream and remained there during the spawning period, and 3 (30%) 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). The median time from release to fallback was 9.9 d (*range* = 6.1-15.6 d). All three of the fish that fell back did so before the first redd was observed on 24 August. The seven fish that remained upstream did so through the spawning period. The three fish that fell back were last recorded downstream of the Minto facility.

Discussion

Middle Fork: Carcass Recovery Rates and PSM Estimates

Overall, carcass recovery rates in Fall Creek and the NFMF were substantially lower in 2015 than in the previous two years. Low discharge conditions may have contributed to the low recovery rates in 2015, but we note that carcass recovery rates tend to be low for a variety of reasons, including difficult stream conditions, carcass scavenging, and limited frequency of surveys (about 1-2 times /week). Moreover, carcass recoveries were generally proportional to the number of fish outplanted in Fall Creek and the NFMF as well as the South Santiam in 2013-2015.

Although the sample sizes for tagged fish were small, PSM rates in Fall Creek in 2013 (100%) and 2014 (65%) were the highest among all study years and this result was consistent with the high water temperature observed there in both years (see below). While no PIT-tagged females were recovered in Fall Creek in 2015, 36% of the unmarked females recovered in Fall Creek were prespawn mortalities This rate was lower than the 2014 rate for unmarked fish and at the lower end of the range for the 2009-2015 study period (18-87%). High rates have been reported in previous studies (i.e., mortality as high as 90%, Schroeder et al. 2007; Kenaston et al. 2009; Keefer and Caudill 2010) and thus the 2013-2014 rates reported here are plausible, but clearly must be interpreted cautiously given the small sample size. It remains unknown if the 2013 estimates were biased high because the carcasses of late-spawning adults could not be recovered due to flooding in that year. Nonetheless, evaluation of the seasonal timing of PSM events (Figures 18 and 19) indicates that much of the mortality occurs prior to the onset of spawning, suggesting the true rate in 2013 was high relative to other study years.

In contrast to the Fall Creek results, the 2015 PSM estimate of 57.1% for PIT- and radio-tagged fish in the NFMF was the highest in the time series (2009-2015). Notably, all of the observed PSM occurred in the late NFMF release group. Water temperatures in the NFMF were similar to temperatures in previous years (and never exceeded 16 °C) and therefore likely did not substantively contribute to high PSM rates observed in the 2015 tagged fish sample. As in Fall Creek in 2015, however, the small sample size (only 7 females recovered) means that the PSM estimate for PIT and radio-tagged fish may not be representative of the population as a whole. The PSM rate for unmarked females (36%, n = 76) may more accurately reflect PSM rates in the NFMF; the 36% estimate was in the middle of the range (10-64%) observed over the study period.

In 2013-2015, we initiated trapping at Dexter Dam approximately three weeks earlier than in 2009-2012 in an effort to reduce 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 and the USACE the collection of adults at Dexter Dam began between 20-22 May (2013-2015), with collections every week thereafter until mid-July to late-August. Data from a 2012 study using salmon radio-tagged at Willamette Falls indicated that fish 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 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 were collected before 18 June (43.4% of total). Interestingly, the prespawn mortality rate of fish outplanted to the NFMF in 2014 was the lowest recorded to date, suggesting that the modified collection protocols may have contributed to the reduced PSM. However, this relationship remains speculative and factors including a switch in anesthetic from MS-222 (2013) to AQUI-S 20E (2014) or other factors contributing to inter-annual variation also likely contributed to the 2014 results. A future study with experimental treatments could be used to identify which trap, collection, handling and transport factors affect PSM rate.

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

As in previous years, we assessed the energetic condition of Fall Creek and NFMF outplants. 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 2015 was 5.0% and 4.0% for Fall Creek and Dexter fish, respectively. The measurements for Fall Creek salmon were nearly the same as in 2013 (5.2%) and 2014 (5.0%). At Dexter, average lipid content was higher in 2015 (4.0%) than estimates at Dexter in 2013 (2.9%) and 2014 (2.9%).

The lipid levels of fish tagged at Fall Creek and Dexter Dam in 2012-2015 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 between-population differences in lipid levels. Average lipid levels in Chinook salmon collected at Willamette Falls in 2012 (7.4%), 2013 (7.7%) and 2014 (7.1%) were about 2-4% higher, on average, than those collected at Fall Creek or the Dexter Dam trap. While no fish were sampled at Willamette Falls in 2015 the mean lipid levels at Fall Creek (5.0%) and Dexter (4.0%) were 2.4-3.4% lower in 2015 than the 2012-2014 average (7.4%) for the samples at Willamette Falls, values in the same range observed in years with sampling at the Falls and in tributaries. This was not surprising because significant energy is required to migrate the more than 250 km from Willamette Falls to the Middle Fork collection sites. Although we have no repeat lipid measurements for any adults in the samples across years, we estimate that in 2015 adults used ~33% to ~46% of their lipid reserves from the time they passed Willamette Falls to the time they were collected at the Middle Fork trapping facilities. These estimates were based on the 2012-2014 average (7.4%) at Willamette Falls and are similar in magnitude to those observed in the Columbia River (Bowerman et al. *in review*) and Snake River (Mann et al. 2009).

Although sample sizes were too low to detect a statistically significant association between physical condition and spawning success in 2015 in Fall Creek, salmon were in generally good condition in 2015 (*mean condition score* = 2.4), similar to salmon condition in 2013 and 2014 (*mean* = 2.5 in both years). The condition of fish tagged at Dexter in 2015 was also not associated with prespawn mortality in 2015 (*mean condition score* = 2.5). These relatively high condition scores suggest that initial composite condition and previous injury was not a major factor contributing to the apparently high PSM in 2015. We note that this index was somewhat subjective and there may be some inter-annual variability in scores associated with personnel changes.

Over the six study years, we found an association between annual PSM rate and summer water temperatures in Fall Creek. However, this conclusion is largely driven by results from three years (Figures 21 and 22), including one year with low sample size (2009) and the 2013 estimate that was likely affected by flooding. We have also observed PSM that directly coincided with increases in water temperatures within year (Mann et al. 2010, 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 those years. 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. No PIT-tagged females were recovered in Fall Creek in 2015, but water temperatures were among the highest during the study period and may have contributed to PSM.

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 than in Fall Creek through the summer and spawning period in all years. 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 River Basin (Bowerman et al. 2014; 2016). The analyses are collectively revealing a non-linear increase in PSM rates at temperatures above ~17 °C (e.g,. Figure 22).

As in 2013-2014, the majority of prespawn mortalities in Fall Creek in 2015 (3/4, 75%) occurred prior to the observation of redd building (first redd date = 10 September) which was about a week earlier than in 2014 (16 September) and 2013 (19 September). The low numbers of early redds observed in 2013-2015 at Fall Creek may be partially explained by changes in the distribution of fish in Fall Creek related to warm 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 distributions. Temperatures during this period were among the warmest in the time series. The large proportion of PSM that occurs 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 are generally 4-5°C degrees cooler throughout the NFMF than in Fall Creek, 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 (i.e., large concentrations of fish were observed in the Dexter tailrace prior to early outplanting efforts). 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: High Water Temperatures and Adult Holding

The unusually warm conditions at Foster Dam in 2015 resulted in a significant change in how adult salmon were collected and ouplanted. The decision to hold fish at the Foster facility started on 10 July and many of the tagged study fish were held for weeks before outplanting on 7 September. Mortality of tagged fish was high (9%) for 92 PIT-tagged fish and very high (83%) for 12 radio-tagged fish. Hatchery-origin Chinook salmon being held for broodstock at Foster also suffered high mortality rates (Brett Boyd, ODFW, *pers. comm*.). Of the 1,293 fish collected for broodstock, 107 (8.3%) mortalities occurred during holding. There were also many visual culls of fish with BKD during hatchery spawning and an additional 19% (n = 246) after ELISA results were finalized; these rates were much higher than the typical ~2% mortality and culling that occurs during holding (Brett Boyd, ODFW, *pers. comm*.). While the combined in-pond PIT/radio mortality rate (17.3%) was higher than the in-pond hatchery mortality rate of (8.3%) when accounting for the known cull rate of 19% the overall hatchery mortality rate was about 27% ([107 morts + 246 culls]/1,293 total collected). The combination of results clearly show that the environmental conditions and disease prevalence combined to produce much higher mortality in 2015 than in most previous years.

Pathology results for the Foster mortalities were incomplete because testing was conducted only on frozen tissue samples. We were limited to using frozen samples because pond mortalities were typically removed and placed in the freezer before our arrival. While tests did reveal the presence of various pathogens on all samples, the results were less conclusive than at Minto because it was difficult to grow sufficient numbers of bacteria for testing.

South Fork Santiam: Foster Reservoir Releases

In 2015, we continued evaluating the tactic 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 above the reservoir. Reservoir release may also provide thermal benefits during warm periods. Thus from 2012-2015, 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 for salmon released into Fall Creek reservoir in 2011 and 2012 (Naughton et al. 2013), the typical salmon residence time in Foster reservoir ranged from 3-8 days in 2012, from 16-32 days in 2013, from 11-12 days in 2014, and from 20-120 days in 2015. Some of the among-year differences were related to release timing, with the 2015 sample released into the reservoir relatively early compared to in other years.

We used the thermal histories of salmon released into the Foster reservoir to estimate potential thermal benefits relative to in-river releases upstream from the reservoir. In 2015, degree day results suggested that reservoir-released fish were exposed to approximately 3.3 fewer degrees per day than fish released in the river and an average of 99 total degree days fewer per individual than those released in the river. This result indicates that releasing fish into the reservoir may be a viable way to reduce temperature exposure prior to spawning. The thermal benefits from releasing fish into the reservoir were also observed in 2014 when fish were exposed to about 2.8 fewer degrees per day than river-released fish.

A concern regarding in-reservoir releases is that some fish may fall back past the dam after release. In 2015, two of fourteen (14%) fish released in the reservoir fell back (compared to 1.4% of fish released in the river). This fallback percentage was lower than in 2014 (25%) and comparable to the 2013 results (12%). 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 from 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. Further, is it possible that some fallbacks in all years were by moribund or dead salmon.

Radiotelemetry records provided some evidence for tributary selection by the reservoir-released fish. Some individuals made multiple trips between the Middle and South Santiam receiver sites before selecting one or the other. While these behaviors suggest natal site selection, selection could not be confirmed because all fish were of unknown origin. However, the movements clearly indicate the potential for sampling and selection between tributaries prior to tributary entry and spawning.

South Fork Santiam: PSM Estimates

Overall, PSM rates for salmon in the South Santiam tended to be higher in 2015 than the two previous study years. The PSM rate for PIT-tagged fish released at Gordon Road in 2015 (35%) was higher than the previous two study years (17% in 2013 and 11%). While the PSM rate of PIT-tagged fish released at River Bend in 2015 was higher (50%) than for Gordon Road the number of recoveries (n = 4) was low. The low number of recoveries at the River Bend site was due in part to the decreasing use of this site as water levels dropped and temperatures increased. No radio-tagged fish released in Foster reservoir or at River Bend were subsequently recovered on the spawning grounds. The PSM rate for reservoir-released fish in 2014 was 50% but only four female carcasses were recovered, and only one female was recovered from the 2013 reservoir release. Thus, any conclusions about the efficacy of reservoir releases in regards to PSM would be speculative.

Minto Fish Facility

In 2015, we continued with a radio-tagging study initiated in 2014 at the Minto Fish Facility to estimate fallback rates and holding times of unclipped (presumed natural-origin) spring Chinook salmon upstream from the dam and to evaluate the distribution of unclipped salmon passed above Minto during the spawning period. Due to mortalities of radio-tagged fish held at the facility in late July, the 2015 study was stopped. However, there is some limited information on the 10 fish released prior to the cessation of the study. Of the 10 fish released at the Minto Fish Facility, 7 (70%) moved upstream and remained there during the spawning period; 3 (30%) moved upstream and were detected at the Big Cliff tailrace receiver, and then fell back downstream from Minto. The median time from release to fallback was about 10 d.

The Minto study component was terminated in 2015 when held fish had high mortality. Pathology results from several mortalities suggested that the effect may have been exacerbated by tagging previously-infected fish. Three of the four fish tested from Minto were infected with either BKD or *Furunculosis.* The visual examination also indicated that the muscles were severely degraded and internal organs were liquefied. Thus, radio-tagging fish with degraded internal organs likely hastened their demise.

In the 2014 study, 20 (40%) of the 50 salmon that were radio-tagged at Minto fell back over the spillway, and with 9 of these 20 fell back prior to the onset of spawning (based on the first redd observation 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 (Naughton et al. 2015).

Tagging and handling effects

Across years at all study sites, PSM rates did not differ systematically between groups that were untagged and tagged with PIT tags only. The only evidence for a statistically significant tag-type effect was in Fall Creek in 2009-2012, when all three tag categories (radio+PIT, PIT-only, no tag) were used. The test indicated that PSM was higher for radio-tagged fish than for PIT-tagged fish, but also that there was no statistical difference between radio-tagged fish and untagged fish and no difference between PIT-tagged fish and untagged fish. In other words, it did not appear that radio-tagging fish resulted in systematically worse outcomes than the standard handling protocols for outplanted salmon. Notably this result contrasts with a 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 inconsistency in results 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. It is also possible that low sample sizes of recovered fish in Fall Creek and the NFMF reduced that statistical power of the test. Moreover, lower PSM rates of marked groups relative to unmarked salmon in recent years may reflect more improved handling, tagging and transport conditions and protocols. Regardless, the results for the WVP suggest that carefully executed tagging studies can provide reliable estimates of salmon PSM and distribution within the study areas.

Toxicology

We collected samples in 2013-2015 for screening of toxins with two goals: 1) to screen concentrations from a broad panel of known toxins to identify “background” loads and potential toxins of concern, and 2) to directly test for associations between concentrations and spawning success in individual salmon. Complete screening included evaluation of more than 25 trace elements and metals and more than 100 organic pollutants for 2013-14 samples. We selected three target elements (Pb, Cd, Ni) for initial reporting because elevated concentrations were observed in these metals in gill tissues of prespawn mortality coho salmon compared to successful spawners in urban watersheds (Scholz et al. 2011). We also evaluated for two organic compound classes (DDT and PCBs) because of their potential concentration in fatty tissues. The concentrations observed in the WVP reported here for the 2013-14 samples were lower or similar than those reported for Fraser River Chinook salmon (Kelly et al. 2008,. 2011) for similar tissues (muscle). Observed values from WVP Chinook salmon were also lower or similar to those reported for coho from both non-urban and urban streams by Scholz et al. (2011). We note differences in species and tissue type (muscle+skin versus gill) between our study and the Scholz et al. (2011) study prevent direct comparison. Nonetheless, metal concentrations observed in the WVP are approaching those observed in prespawn mortality salmon by Scholz et al (2011). While we did not observe a clear association between toxins concentrations and fate in 2013-2014 years, we did observe spatial differences in metal concentrations. The mechanisms resulting in spatial variation in Pb and Cd may be related to underlying geology (the natural source of these elements) or differences in exposure to anthropogenic sources encountered during rearing, migration or holding. Overall, there was little evidence that toxic concentrations of the three metals and the two organic compounds were directly responsible for prespawn morality in 2013 and 2014.

Management Implications and Recommendations

Adult trapping and handling

Unlike Fall Creek where clove oil or AQUI-S 20E is used, 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). Continued early trap operation in future years is needed to confirm that early collection reduces overall PSM in this population. Additional improvements to collection and handling protocols to reduce density and other stressors such as the use of AQUI-S 20E (instead of $CO_{2)}$ as an anesthetic (Gilderhus and Marking 1987) could also reduce the PSM rate for this population. Such changes would likely require investment in facilities and personnel. 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.

Recommendations:
--Only open the Dexter trap when fish are needed for broodstock and outplanting to minimize stress and injuries in the raceway

--Continue to use AQUI-S 20E on fish to be outplanted. Although we didn't conduct a direct comparison with CO_2, the fish appeared to be visibly less stressed.

Transport protocols

In contrast to in 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".

Recommendations:

--More rigorous evaluation of the effects of transportation including the effects of fish density, monitoring salmon stress levels, examining fish for transport-related injuries, etc.

--Increase truck availability for outplanting

Release locations and timing

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. 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, scavengers, or poaching.

Recommendations:

--Although the effects on PSM are somewhat inconclusive, continue with early outplanting to reduce crowding in raceways and removal from warmer tailrace.

--Continue evaluating the use of reservoir releases: More research on the effect of fallback, the origin of fallback fish, thermal benefits and PSM rates

--Consider release sites that require shorting hauling distances and reduced transport times

Fish holding

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 the 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 Falls, 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% PIT and RT combined in 2012; 29% PIT and RT combined in 2011) differences in experience prior to outplanting may contribute to PSM in the NFMF. However, salmon returning to 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 relative to other populations. This migration stress may significantly affect their post-outplant survival.

Recommendation:

--More rigorous evaluation of holding fish. While the Willamette hatchery and other holding locations might have suitable water temperatures, potential benefits could be offset by increases in disease.

Prespawn mortality mechanisms

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 Chinook salmon. 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. .

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 ongoing 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).

Recommendations:

--Tests for PSM predisposition: genetic test, stress hormone test

--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

Additional suggestions

The possibility of managing water temperatures below WVP dams during the spring Chinook salmon migration to reduce stress, 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.

Recommendations:

--Use cool-water releases from project dams to moderate water temperatures in the main stem Willamette River and tributaries.

-- Maintain habitat in the NFMF. Due to the threat of climate change cool-water refuges will become increasingly important for the long term persistence of salmonid populations. The upper NFMF is high quality habitat with cool water temperatures (typically <15 C), well dispersed spawning gravels, and complex habitat with undercut banks, log jams and deep pools to avoid predators and thermoregulate.

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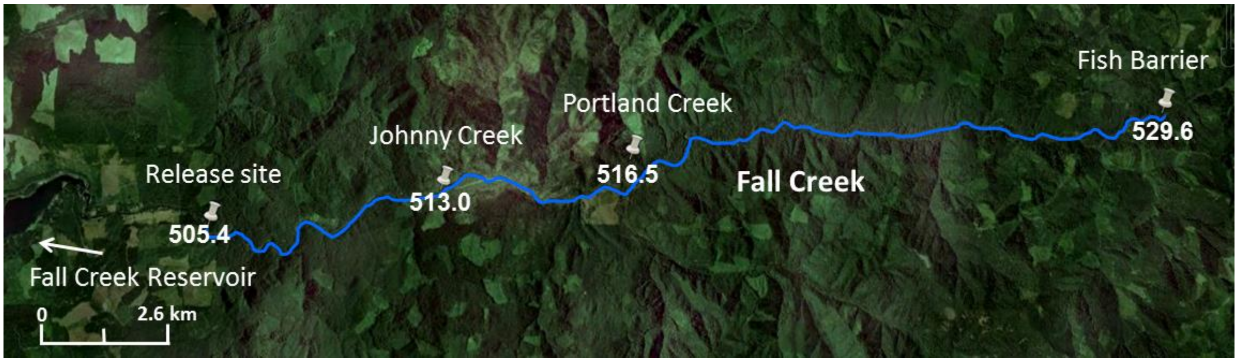
Appendix

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, 2008-2015.

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
2015	PIT	93	4 May – 25 June

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 2009-2015. 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
	Double	50	21 May – 30 July
2015	PIT	166	20 May – 5 Aug
	Double	75	20 May – 22 July



Appendix Figure 1. Map of temperature monitoring locations in Fall Creek in 2015.

Appendix Figure 2. Map of temperature monitoring locations in NFMF Willamette River in 2015.