Technical Report 2013-2

MIGRATION BEHAVIOR AND SPAWNING SUCCESS OF SPRING CHINOOK SALMON IN FALL CREEK AND THE NORTH FORK MIDDLE FORK WILLAMETTE RIVER: RELATIONSHIPS AMONG FATE, FISH CONDITION, AND ENVIRONMENTAL FACTORS, 2012

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G.P. Naughton, C.C. Caudill, T.S. Clabough, M.L. Keefer, M.J. Knoff, and M.A. Jepson

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

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Executive Summary

In recent years, variable and sometimes high percentages (80-90%) of adult Chinook salmon (*Oncorhynchus tshawytscha*) transported above dams in Willamette River tributaries have died prior to spawning. In 2012, we surveyed the energetic status and survival rates of two 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 including disease assessment in collaboration with Oregon State University (OSU) researchers. The research occurred in the Middle Fork Willamette River sub-basin and was a continuation of projects completed in 2008 through 2011.

A total of 118 Chinook salmon were sampled at Fall Creek Dam in 2012. Fish were collected, assessed for energetic condition, PIT-tagged and/or radio-tagged, and then transported above the dam and allowed to spawn. Prespawn mortality estimates were 20% for radio-tagged fish (n = 1 of 5 females recovered) and 18% (n = 5 of 28 females recovered) for untagged carcasses; none of 11 PIT-tagged fish were considered prespawn mortalities. Fall Creek water temperatures in 2012 were relatively cool and similar to 2011, higher than recorded in 2008, but lower than in 2009 and 2010. Daily mean temperature at the release site only exceeded 20°C on three days in mid-August.

A total of 154 (104 PIT, 50 radio) Chinook salmon were sampled at Dexter Dam and were then immediately outplanted into the North Fork Middle Fork Willamette River (NFMF). An additional 95 were PIT-tagged at Dexter Dam and then transported to Willamette Hatchery where 71 were late outplanted to the NFMF. Overall prespawn mortality of NFMF outplants was 10% for PIT-tagged fish, 17% for radio-tagged fish and 23% for unmarked fish. These rates were among the lowest from the four study years on the NFMF. Prespawn mortality rates for the hatchery-held fish released into the NFMF was 10% (one of ten females recovered). However, holding may have been a substantial contributor to mortality because only 71 of the 95 released into the hatchery pond were eventually recovered. Water temperatures recorded in the NFMF were cooler than in Fall Creek and were in the range preferred by Chinook salmon. Movements by successful spawners after release were short compared to Fall Creek suggesting adequate spawning habitat was available near the release site. Therefore, other factors presumably contributed to prespawn mortality in NFMF fish, including possible collection and transportation effects, fish condition, experience prior to collection, and density-dependent factors including disease and parasites.

As part of the 2012 project we evaluated potential predictors of prespawn mortality across all study years using a series of logistic regression models. The ‘best’ model for Fall Creek (2009-2012 data) included sex, fish collection date, and fish body shape. Females were more likely than males to be prespawn mortalities. The date effect indicated that salmon tagged later in the summer were less likely to spawn, perhaps indicating negative effects of holding downstream or lowered fish condition later in the run. The body shape effect showed that fish that were thin for their length were less likely to be successful spawners. Year effects were in almost all other Fall Creek models with statistical support, presumably reflecting the wide variability in Fall Creek water temperatures; mortality was highest in the warmest years. The ‘best’ model for the NFMF (2008-2012) had salmon condition variables, but models for the NFMF were generally not

statistically significant. There was, however, a modest year effect that reflected higher mortality in 2010 (a relatively warm year) and lower mortality in 2012 (a relatively cool year). There was also a date effect that was similar to that in Fall Creek: salmon tagged later in the run were more likely to be prespawn mortalities. We note that differences in collection timing across years may have been a confounding factor for both populations.

In 2012, a subsample of radio-tagged fish (n = 8) were released in Fall Creek reservoir to determine if the opportunity for cool water holding during the summer would improve survival. As in 2011, Chinook salmon remained in the reservoir less than eight hours (*means* = 5.0 h in 2011 and 4.1 in 2012) before entering Fall Creek, perhaps because temperatures in Fall Creek remained cool (< 20 °C) throughout the migration season and thus there was no thermal advantage to remaining in the reservoir in either year. The rapid movement of adults into the spawning tributary suggests reservoir outplanting can be used to provide the opportunity for a summer thermal refuge in warm years and the opportunity for adults to select natal streams in reservoirs with spawning populations in multiple upstream tributaries.

We also initiated a pilot study at Foster Dam and the South Fork (SF) of the Santiam River in 2012. A total of 134 fish were PIT tagged and/or radio-tagged at Foster Dam in 2012 and released upstream, including 33 fish released into Foster Reservoir. Thirty-one of the 33 fish (94%) were recorded at receivers upstream from the Calkins boat launch release site. The remaining two fish moved downstream and were recorded at the Foster trap. Median reservoir residence times were 5.5 d for fish recorded on the SF Santiam receiver, 8.1 d for fish last recorded on the Middle Fork (MF) Santiam receiver, and 3.3 d for fish last recorded by mobile tracking in the SF Santiam River. Some fish were detected on both the South Fork and Middle Fork the receivers, and others made multiple trips between receivers.

Results from our ongoing Willamette River Chinook salmon studies suggest that prespawn mortality is caused by an interaction of environmental factors (particularly water temperature), disease, fish condition, and energetic status. Multi-year sampling of adult energetic status, disease and parasite prevalence, and other condition metrics will: 1) provide insights into the factors causing prespawn morality; 2) determine how mean salmon condition varies from year to year in response to environmental factors such as main stem and ocean conditions; and 3) will assist in the development of effective management strategies to reduce prespawn mortality in Willamette River spawning tributaries including regulation of flow and/or temperature, and holding of adults under pathogen-free conditions prior to outplanting.

Introduction

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

Due to impassable dams on tributaries, returning adults in many WVP populations cannot reach much of their historic spawning habitat. Therefore an adult transportation 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 observed in adults in some years since the start of the adult transportation 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. Factors most likely to contribute to adult prespawn mortality include environmental stressors (especially water temperature), infectious disease, and poor energetic condition. Importantly, demographic modeling suggests that observed levels of prespawn mortality (e.g. > 50-70%) may strongly negatively affect population growth rates and hinder salmon recovery (Keefer et al. 2010). The importance of prespawn mortality 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) 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 more consistent 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 Columbia and Snake rivers, peak main stem water temperatures occur earlier in the year and warm temperatures persist later in the fall, compared to historic patterns (Quinn and Adams 1996; Quinn et al. 1997). 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. 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.

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. 2008, 2010; Mann et al. 2010) has been associated with higher probability of prespawn mortality.

Release of adults to reservoirs downstream of outplant streams is being considered as a management alternative that may reduce exposure to stressful 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 tributaries in fall for spawning. Release to reservoirs could also reduce transport distances and handling time.

The primary goal of this study was to evaluate factors potentially associated with prespawn mortality 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. 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 2012, a subsample of adults collected at Dexter Dam were held at the ODFW Willamette Hatchery prior to outplanting to test the hypothesis that holding in cool, parasite-free water would decrease prespawn mortality rate upon release into spawning habitats. We released a small number of adults to Fall Creek Reservoir to evaluate whether they would successfully spawn in Fall Creek. We also initiated a pilot study at Foster Dam on the South Fork Santiam River to evaluate the feasibility of releasing fish into Foster Reservoir. Additionally, subsamples of adults from both populations were transported to Oregon State University to assess holding benefits and disease prevalence, as reported in a companion report (Schreck et al. *in review*).

Carcasses were collected from spawning grounds and evaluated for spawning success and potential mortality sources. This included data collected from fish morphometrics, lipid content, and gross signs of disease and injury. We also examined patterns across years for Fall Creek (five years: 2008-2012) and the North Fork Middle Fork Willamette River (NFMF; four years: 2009-2012).

Specific objectives were to:

1) Estimate prespawn mortality 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 ODFW).
2) Test for associations between prespawn mortality, individual adult traits evaluated at the time of collection, and environmental conditions encountered during holding.
3) Continue evaluating whether holding adults collected at Dexter Dam in a hatchery (Willamette Hatchery, Oak Ridge, OR) prior to outplanting reduces prespawn mortality.
4) Evaluate the feasibility of releasing adults into reservoirs during warm summer months with a continuation of a pilot-scale study at Fall Creek Reservoir.
5) Initiate a pilot study to evaluate the feasibility of releasing adults in Foster Reservoir on the South Fork Santiam River.
6) Evaluate interannual patterns in prespawn mortality.

Methods: Middle Fork Willamette River

Study Sites and Facilities

Chinook salmon collection and tagging for this study took place at two sites in the upper Willamette Valley, west of Eugene, OR (Figure 1). 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 Fall Creek trap included a small ladder that led to a finger weir in front of a large collection area. A mechanical sweep was used to crowd trapped fish and raise them into a chute that dropped the fish into an anesthetic tank containing eugenol. The tank was lifted using a fixed crane and placed on the ground to facilitate fish tagging. Tagging and assessment of energy condition occurred at the Fall Creek trap.

The Dexter trap was operated by Oregon Department of Fish and Wildlife (ODFW) and sampled fish were provided by ODFW as part of trap operations. ODFW uses the Dexter facility to collect broodstock for the Willamette Hatchery (WH) in Oakridge, OR. In 2009-2011, 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 transfer to a secondary tank with MS-222 where they were assessed and tagged. Fish were then transferred to a hauling truck for recovery and transport to either WH or to release above the dams into the North Fork of the Middle Fork of the Willamette River (NFMF). In 2012, fish were directly netted out of the ladder using sanctuary nets and transferred to an anesthetic tank containing MS-222. Tagging and assessment of energy condition occurred at both the Dexter Trap and the WH for this population. Only fish above the hatchery's broodstock quota were transported and released for natural spawning.

To study the effects of hatchery versus tributary summer holding on prespawn mortality, Chinook salmon tagged at Dexter Dam were included in one of two experimental groups. One group was transported to WH, tagged, and held in the hatchery's adult holding pond until a release date just prior to spawning in the NFMF. The second group was released into the NFMF immediately following tagging. Figure 2 outlines the 2011 study design.

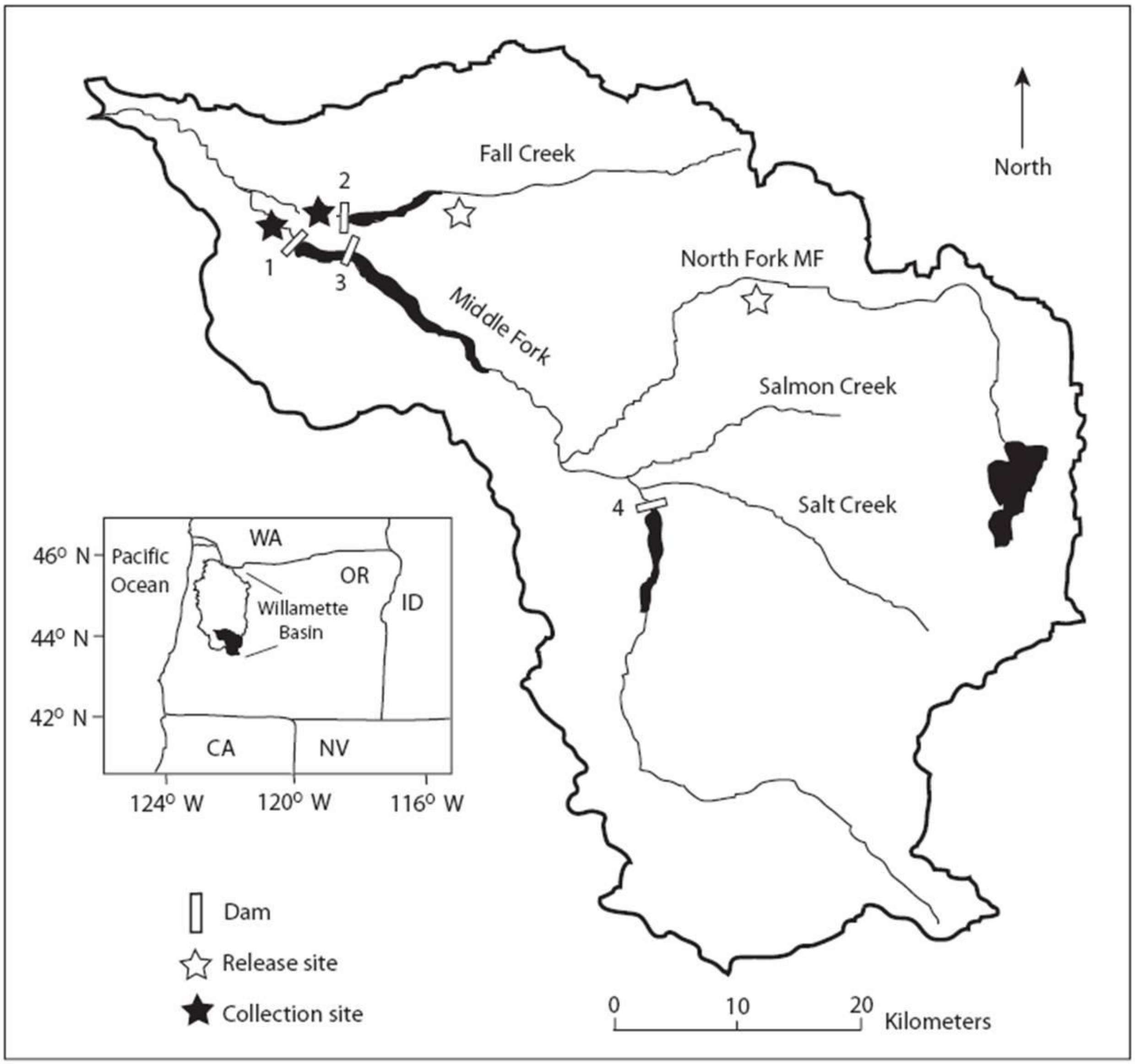

Figure 1. Map of the Middle Fork Willamette River basin showing Chinook salmon collection and outplant sites. Dams are numbered: 1 = Dexter Dam, 2 = Fall Creek Dam, 3 = Lookout Point Dam, and 4 = Hills Creek Dam.

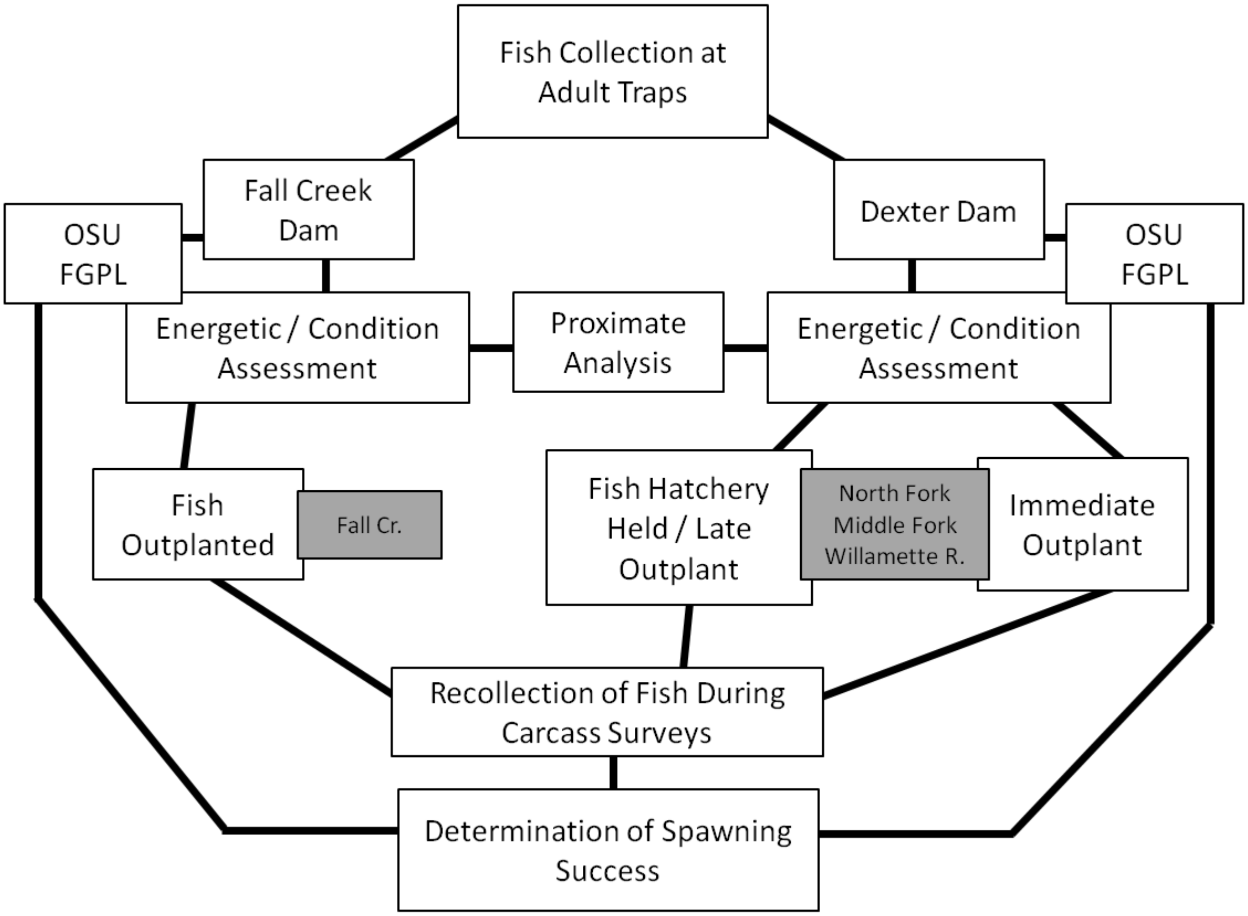

Figure 2. Study design for 2012. All fish tagged at Fall Creek trap were immediately outplanted into Fall Creek or Fall Creek reservoir. Fish collected and tagged at Dexter Dam were either immediately outplanted or were transported to Willamette Hatchery and held and outplanted later in the summer into the NFMF Willamette River. Additionally, a sub-sample of fish from the NFMF was sent to Oregon State University after tagging and assessment.

Tagging and Assessment of Condition

Salmon were fully anesthetized prior to handling at both trap sites. Adults were anesthetized in approximately 60 ppm eugenol at Fall Creek trap. Sampling at Dexter trap and the WH used CO_2 during initial trapping followed by MS-222 according to ODFW protocols (approximately 50 ppm). Following tagging, fish were loaded into a truck filled with fresh river water and transported to an upstream release site. Fish held at WH were tagged on site (typically the day after collection at the Dexter trap) using the same methods as at the dam traps and were also Floy-tagged. Oxygen was monitored during transportation with a target concentration of 10 ppm. 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 all sites.

While anesthetized, fish 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 a large number of 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 half centimeter were taken as well as four morphological measures previously used to estimate energetic status (Figure 3) (Mann et al. 2010). 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 washdown 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. Adults held at WH were reassessed using the fatmeter at the time of collection from hatchery ponds prior to outplanting.

A sub-sample of fish was radio-tagged in 2012 (Fall Creek: n =40; NFMF: n =50). 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 latex band was placed on each transmitter to reduce regurgitation (Keefer et al. 2004). Fish > 63 cm were randomly selected for radio tagging. The purpose of radio tagging was to verify that fish were moving upstream after release, estimate distribution during holding (Naughton et al. 2011; Roumasset 2012), evaluate residence time and fate of reservoir-released adults, and to determine if fish migrated back into the reservoir. In past years, the latter behavior has been linked with prespawn mortality (Keefer et al. 2010). Additionally, the use of radio tags aided in the collection of carcasses for prespawn mortality assessments.

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

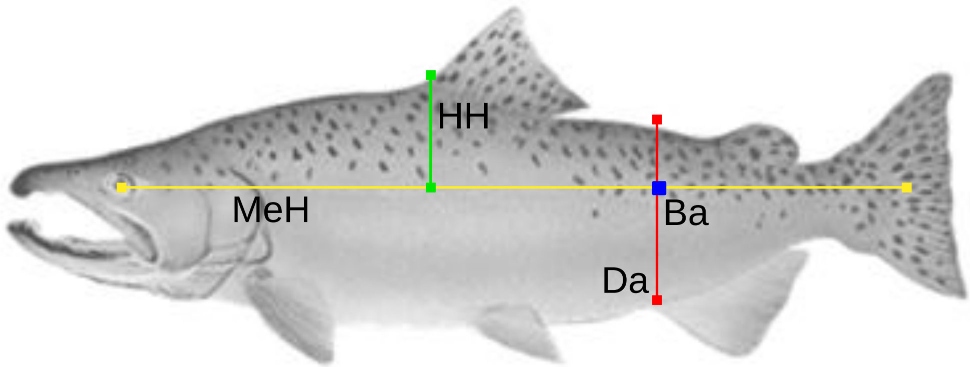

Figure 3. Diagram of morphometrics collected. MeH = Mid-eye to hypural length, HH = Hump height, Da = Depth at anus, Ba = Breadth at anus.

Proximate Analysis

A small sub-sample (n = 15) of fish was 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 gram subsample of the homogenate was taken. The samples were frozen and later transported to Washington State University where they underwent proximate analysis.

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

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

We used linear regression to estimate the relationship between muscle lipid content and fatmeter readings. The relationship was then used to estimate muscle lipid content for each outplanted fish by inverse prediction (Sokal and Rohlf 1995) using fatmeter measurements taken at the time of tagging. Henceforth, we refer to the corrected lipid estimates for outplanted fish as "standardized lipid percentage". The relationship between fatmeter readings and proximate analysis results and standardized fatmeter values were also compared among study years to evaluate interannual variation in the accuracy and precision of the fatmeter in predicting lipid content and patterns of standardized lipid levels among years, respectively. Fatmeter readings from 2012 were also collected from fish tagged at Willamette Falls (see Jepson et al. 2013) and compared with readings from fish tagged at Fall Creek and the Dexter Dam trap. We evaluated the relationships between lipid values of fish collected for proximate analysis and morphometrics using multiple regression.

Temperature Monitoring

Temperature recorders were installed in 2012 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 30.6), near the mouth of Portland Creek (rkm 513), and at the unnamed falls that act as a fish barrier (rkm 529.6). 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). Temperatures were logged at 15 minute intervals from early June to mid-October.

We used IBT submersible temperature loggers (Embedded Data Systems, LLC, Lawrenceburg, KY; 17.35x5.89 mm, 3.3g in air) to record internal temperatures on a subsample of radio-tagged fish. The tags were waterproofed (Plasti Dip multipurpose rubber coating; Plasti Dip International, Blaine, Minnesota, see Donaldson et al. 2009) and attached to the bottom the radio tags with electrical tape then inserted gastrically. The temperature recorders were recovered during carcass surveys and were downloaded.

Spawning Ground Surveys and Spawning Success

After translocation to spawning areas 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 on a regular basis from the beginning of releases through the spawning period (June through early October). Fish encountered during spawning ground surveys were inspected by UI and/or ODFW personnel for radio and PIT tags. When the carcass of an individual from this study was located, it was inspected to determine spawning status and its general condition was noted (how recently it died, obvious wounds, fungus levels, or other apparent visual cues that caused mortality). In addition, otoliths and scales were collected from non-marked fish. If a fish had recently died (gills were pink), the fish was transported on ice to OSU, and tissue samples were collected for histology.

In 2012 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). Prespawn mortality rates were calculated only for female fish in most cases because the proportion of remaining gametes could not be reliably estimated in most males and in some carcasses that had been scavenged. Survival to the first day of spawning activity was also used in some analyses as a metric of reproductive success.

Multi-year summary

We performed several statistical analyses to test for associations between prespawn mortality and a suite of potential causative factors for both Fall Creek and the NFMF fish 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 sex, year, tag date, condition, fatmeter percent, Fulton's K ($K = 100\ (\text{weight}/FL^3)$, fork length(FL), weight, mid-eye-to-hyperl (MeH), depth at anus (Da), breadth at anus (Ba) and hump height (HH). We calculated standardized morphometric measurements for the four morphometric parameters to control for differences in body size by dividing each estimate by fork length.

Males were included in multi-model selection analyses to test for possible sex-related differences in survival. Males made up a minority of the fish in the models, however, because their prespawn mortality status was often ambiguous and many males were therefore censored prior to modeling. The model set included all univariate models plus fifteen multiple logistic regression models with adult fate (spawned, prespawn mortality) as the dependent variable. The full logistic regression model was:

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

Methods: South Santiam River

Adult Chinook salmon were collected and tagged at the Foster Dam trap on the South Santiam River from 1 June to 11 September 2012. The trap was operated by ODFW and sampled fish were provided as part of the trap operations. The Foster trap consisted of a ladder that led to a large collection area. A mechanical sweep was used to crowd trapped fish. ODFW personnel sorted fish and transferred fish into an anesthetic tank where they were anesthetized with CO_2 before transfer to a secondary tank containing MS-222. Tagging, handling, and proximate analysis methods were similar to those reported above for salmon trapped in the MF Willamette River. Salmon were released in Foster Reservoir near the Calkins boat launch.

Results: Middle Fork Willamette River

Tagging

Fall Creek

Tagging occurred from 17 May to 10 August, 2012. A total of 118 fish (56 females, 60 males, 2 unknown) were PIT tagged, and 40 of these were also radio-tagged (Figure 4). Tagging was representative of the overall timing of the run, which peaked in early June followed by another peak in late-July (Figure 4). All fish transported above the dam were non-adipose clipped fish. Although three adipose-clipped fish did return to Fall Creek Dam, they were presumed to be hatchery-origin strays from other basins and were not transported above the dam by USACE personnel. The mean condition score in 2012 was 2.6, mean fork length was 75.4 cm, mean weight was 4.9 kg, and mean lipid percentage was 5.3% (Table 1).

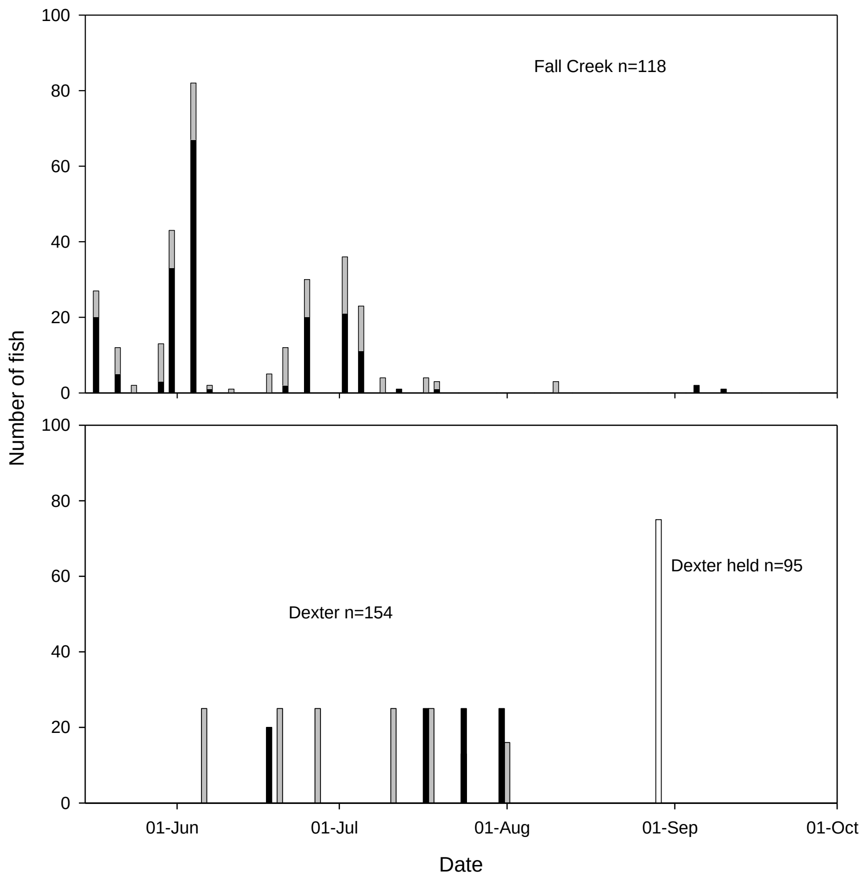

Figure 4. Numbers of adult Chinook salmon tagged in 2012. Top panel: distributions of Chinook salmon that were (gray bars) and were not (black bars) tagged at Fall Creek trap. Fall Creek fish were immediately outplanted above Fall Creek Dam. Bottom panel: distributions of Chinook salmon collected at Dexter Dam that were transported to Willamette Fish Hatchery and held until outplanting on 29August (black bars) and fish that were immediately outplanted to the NFMF on the date of tagging (gray bars). Open bar on bottom panel represents number of hatchery-held fish outplanted to the NFMF on 29 August.

Table 1. Adult Chinook salmon size, lipid content, and condition metrics for fish sampled at Fall Creek trap in 2012. MeH = Mid-eye to hypural length, Da = Depth at anus, Ba = Breadth at anus, HH = Hump height, % Lipid = Standardized % lipid in muscle tissue, wet weight.

Fall Creek (n = 118)	Fork Length (cm)	Weight (kg)	MeH (cm)	Da (cm)	Ba (cm)	HH (cm)	% Lipid	Condition Score
Mean	75.4	4.9	63.8	12.0	6.2	8.2	5.3	2.6
St. Deviation	5.9	1.1	5.0	1.3	0.8	0.8	3.7	0.6
Max	89.0	8.5	76.0	15.5	8.0	10.0	17.8	3.0
Min	55.0	1.8	47.0	7.8	4.0	5.7	0.9	1.0

Individual lipid concentrations as estimated with the Fatmeter during 2012 were poorly correlated with the values estimated from proximate analysis taken from lethally sampled adults (adj. r^2 = 0.614, P = 0.408, n = 15 see Proximate Analysis section below). Mean estimated standardized lipid content of tagged adults arriving to Fall Creek trap was lower than lipid estimated for adults at Willamette Falls (Figure 5) and decreased through the 2012 season (Figure 6). This seasonal decline was similar to results in previous years (Figure 7).

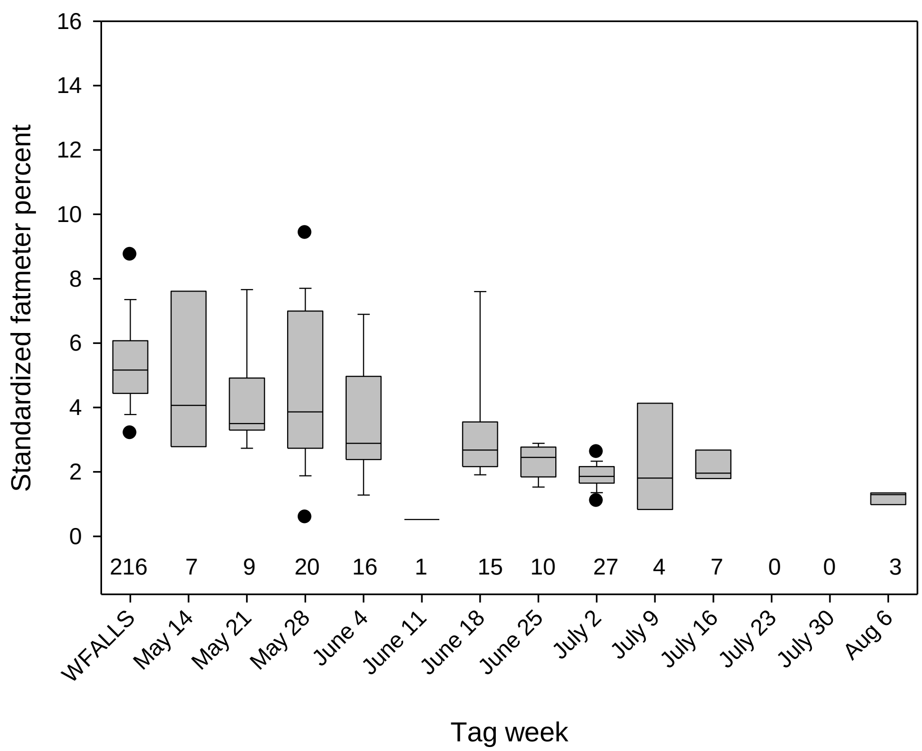

Figure 5. Weekly distributions of standardized fatmeter results for Chinook salmon tagged at Fall Creek trap in 2012. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (solid circles). Sample size for each date given below each distribution. First box on left shows data for Chinook salmon sampled at Willamette Falls Dam (WFALLS) from Jepson et al. 2013. (Note: the Willamette Falls data were not validated using the same equation as the tributary fish.)

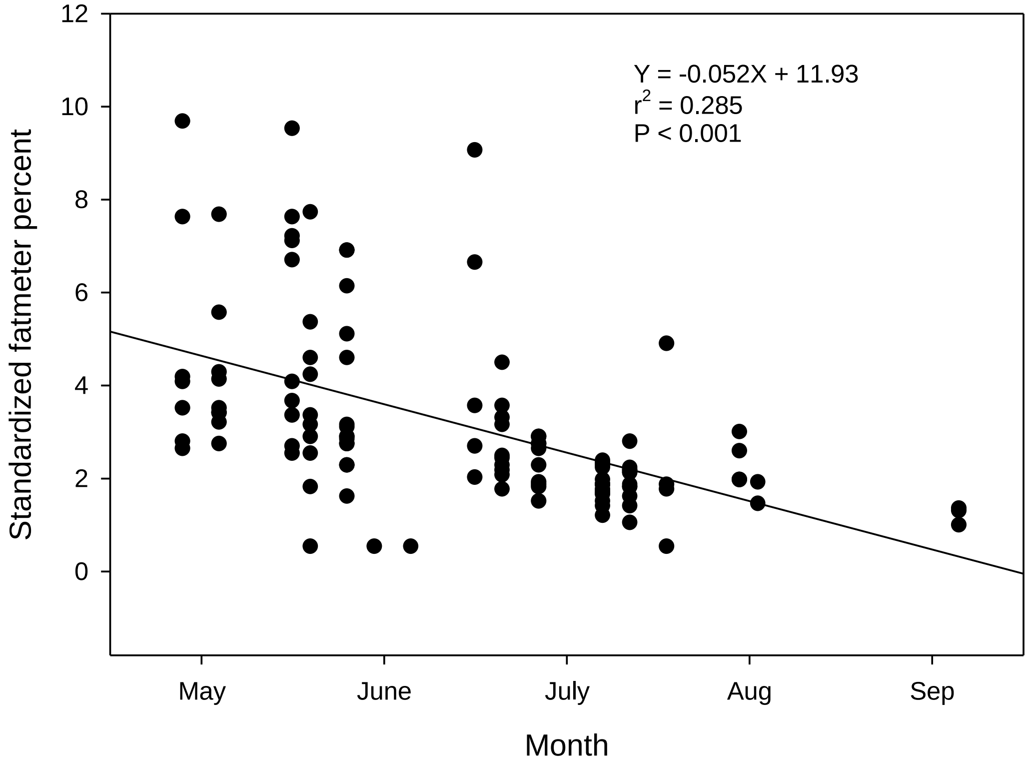

Figure 6. Standardized fatmeter percentages for all fish tagged at arrival at Fall Creek Dam in 2012.

North Fork Middle Fork Willamette River

In 2012, tagging of the immediate outplant group began on 6 June and continued until 1 August (Figure 6). This group included 154 fish (80 males, 74 females), and had mean length of 73.8 cm, mean weight of 4.5 kg, mean condition score of 2.5, and mean standardized lipid percentage of 2.4% (Table 2). Adult salmon held at WH before outplanting were collected and tagged on four separate days from 19 June to 1 August in accordance with ODFW's operation of the Dexter trap for collection of broodstock (Figure 8). This group had 95 fish (51 males, 44 females). The mean condition score was 2.3, mean fork length was 74.1 cm, mean weight was 4.5 kg, and mean standardized lipid percentage was 4.4% (Table 3).

On 29 August, 2012, 71 of the 95 adults held at WH were recaptured in the pond and outplanted into the NFMF (two were confirmed mortalities and an additional 22 were not recaptured). Mean fatmeter readings from fish tagged at the Dexter Dam trap were lower than those for fish tagged at Willamette Falls and remained relatively constant across the six tagging events (Figure 7). Mean lipid content at recollection from the WH pond was lower than at initial collection at Dexter. Mean lipid content of 49 fish with fatmeter readings at initial collection was 4.83% compared to 0.46% on the day of outplanting (Figure 8).

Table 2. Adult Chinook salmon size, lipid content, and condition metrics for fish collected and sampled at Dexter trap and then immediately outplanted in 2012. MeH = Mid-eye to hypural length, Da = Depth at anus, Ba = Breadth at anus, HH = Hump height, % Lipid = Standardized % lipid in muscle tissue, wet weight.

Dexter (*n* = 154)	Fork Length (cm)	Weight (kg)	MeH (cm)	Da (cm)	Ba (cm)	HH (cm)	% Lipid	Condition Score
Mean	73.8	4.5	61.7	11.4	5.9	7.8	2.4	2.5
St. Deviation	5.7	1.1	4.9	1.1	0.8	0.8	1.7	0.7
Max	86.0	7.23	72.0	14.1	9.6	10.1	11.7	3.0
Min	54.0	1.69	45.0	7.8	3.6	5.6	0.4	1.0

Table 3. Adult Chinook salmon size, lipid content, and condition metrics for fish collected and sampled at Dexter trap and held at Willamette Hatchery in 2012. MeH = Mid-eye to hypural length, Da = Depth at anus, Ba = Breadth at anus, HH = Hump height, % Lipid = Standardized % lipid in muscle tissue, wet weight.

Willamette hatchery (*n* = 95)	Fork Length (cm)	Weight (kg)	MeH (cm)	Da (cm)	Ba (cm)	HH (cm)	% Lipid	Condition Score
Mean	74.1	4.5	62.0	11.4	6.0	7.8	4.4	2.3
St. Deviation	4.8	1.1	4.1	1.1	0.7	1.0	5.5	0.8
Max	92.0	9.3	75.0	14.8	8.2	11.8	25.1	3.0
Min	65.0	2.8	53.0	9.4	4.4	5.2	0.2	1.0

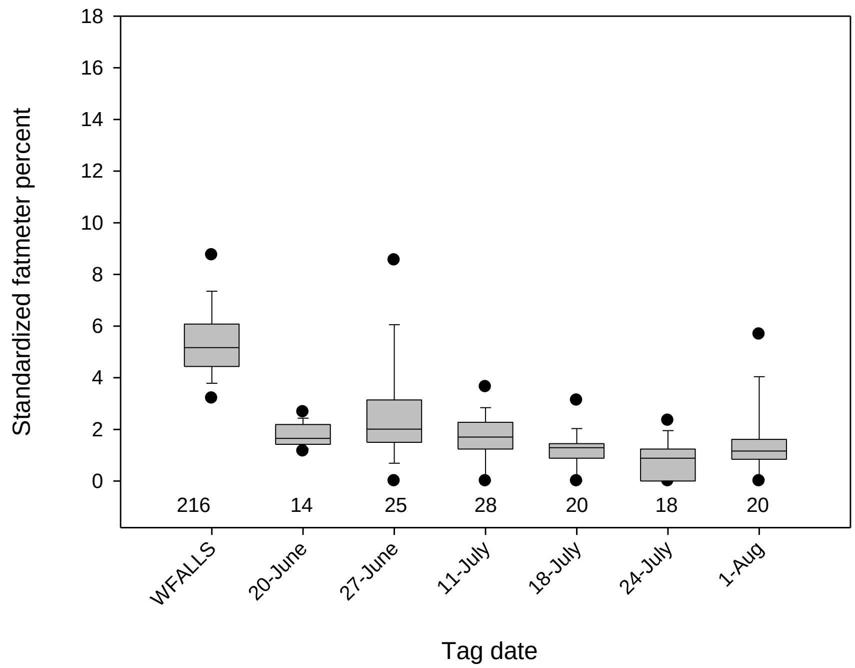

Figure 7. Weekly distributions of standardized fatmeter results for Chinook salmon tagged at Dexter trap in 2012. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (solid circles). First box on left shows data for Chinook salmon sampled at Willamette Falls Dam (WFALLS) from Jepson et al. 2013. (Note: the Willamette Falls data were not validated using the same equation as the tributary fish.)

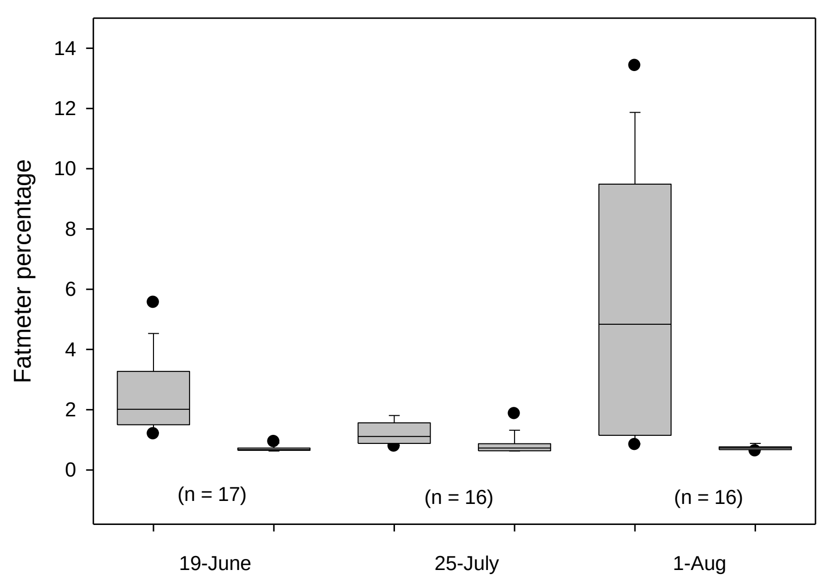

Figure 8. Distributions of standardized fatmeter results for Chinook salmon held at Willamette Hatchery and then outplanted in 2012. Tagging data were collected on the dates fish were tagged (left box of each pair), and outplant data were for when fish were reassessed and outplanted on 29 August (right box). 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).

Proximate Analysis

In 2012, proximate analysis was performed on 15 salmon collected at Dexter (9 males and 6 females). No fish were sampled from Fall Creek (Table 4) because of concerns over lethally sampling unclipped (presumed natural origin) adults from this location. Lethal takes for proximate analysis were conducted on 6 June (n = 8) and 3 August (n = 7). The average muscle lipid level was 4.7% and ranged from 2-11% (Table 4). Females had gonadal lipid compositions of 7.0%, while males were 1.3%, on average (Table 5).

Table 4. Mean tissue composition of Chinook salmon collected at Dexter and used in proximate analysis in 2012.

Tissue	% Moisture	% Crude Lipid	% Total Ash	% Protein
Gonads	74.1	3.6	1.7	20.6
Muscle	74.5	4.7	1.1	19.7
Skin	63.1	6.1	1.1	29.7
Viscera	80.6	2.3	1.1	16.0

Table 5. Tissue composition of Chinook salmon used in proximate analysis by sex.

Tissue	% Moisture	% Crude Fat	% Total Ash	% Protein
Males (n = 9)				
Gonads	81.8	1.3	2.0	14.9
Muscle	74.2	5.0	1.1	19.8
Skin	62.4	5.2	0.9	31.5
Viscera	80.1	2.4	1.2	16.4
Females (n = 6)				
Gonads	62.5	7.0	1.3	29.2
Muscle	75.1	4.3	1.1	19.5
Skin	64.2	7.3	1.5	13.5
Viscera	81.3	2.3	0.9	15.5

Fatmeter readings were taken on proximate analysis fish at the time of trapping to simultaneously assess the accuracy of the fatmeter readings and provide regression equations to calculate standardized values across years. Preliminary multiple regression models provided no evidence of a difference between sexes in the relationship between uncorrected fatmeter and proximate analysis lipid estimates ($P > 0.1$ in all years), but did suggest differences in the relationship among years ($P < 0.05$). Consequently, we performed regression analyses for each year with combined sexes. In all years the relationship was positive. However, the significance and strength of the relationship varied among years, and was highest in 2009 and 2010, years with the largest sample sizes (Table 6).

Table 6. Linear regression results that show the relationships between fatmeter percentages (FM) and percent lipid in wet weight muscle tissue 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
2012	15	0.523	0.5137	0.408	0.61
2011	15	1.854	0.46	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 found a positive relationship between fatmeter readings and energy density in 2012 (Figure 9). Overall the results suggest that the fatmeter provides a non-lethal method to estimate a relative index of lipid reserves and energy content among individuals within years, but may not provide adequate precision to predict absolute values for individual adult Chinook salmon lipid or energy content.

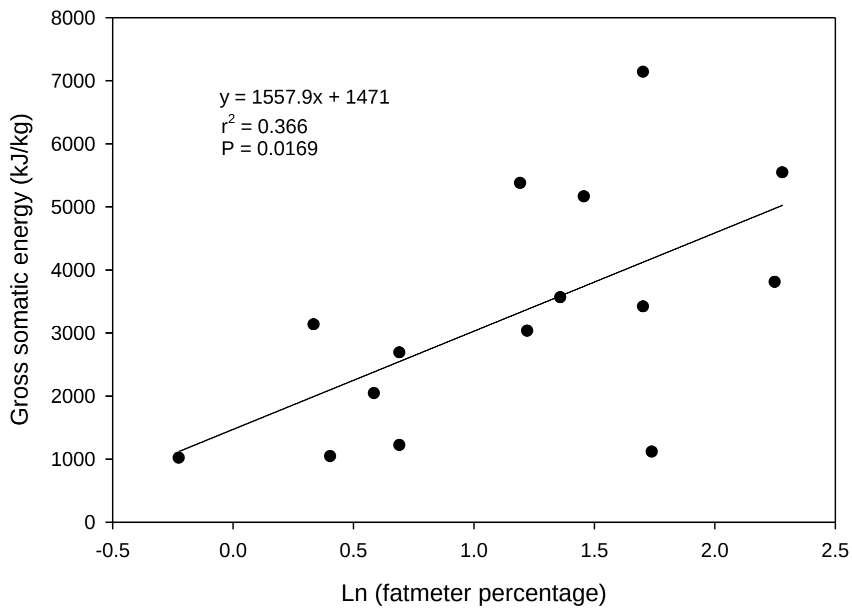

Figure 9. Relationship of Chinook salmon energy density (kJ/kg) to $\log_e$ transformed raw fatmeter percentages, 2012. Energy density data were calculated from proximate analysis.

Comparison of standardized morphometric values to lipid values indicated associations between body shape and lipid content, where adults with thicker bodies for a given length had higher lipid at both Fall Creek (Figure 10) and the NFMF (Figure 11). However, there was substantial variability among individuals in all three associations (N = 144, df = 4, P < 0.001, r^2 = 0.22). Length of the mid-body relative to tail and head (stdMEH) was not associated with LIPID (Figures 10 and 11). These results indicate shape could be used to evaluate relative lipid level and energy condition, but similar to the fatmeter readings, morphometery provides insufficient resolution to predict individual lipid values.

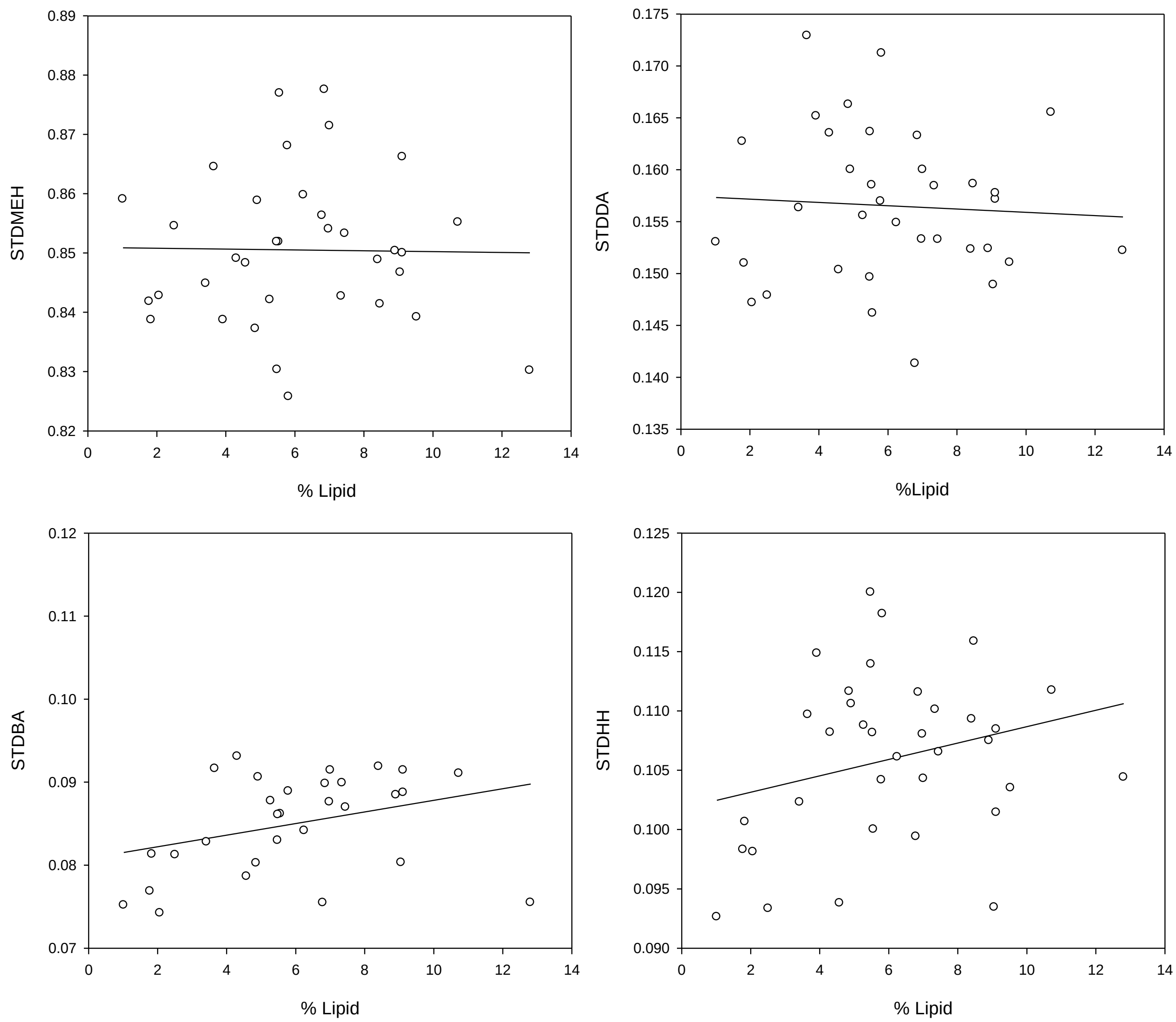

Figure 10. Relationships between four morphometric measurements and percent lipid values from Chinook salmon collected at Fall Creek in 2008-2010.

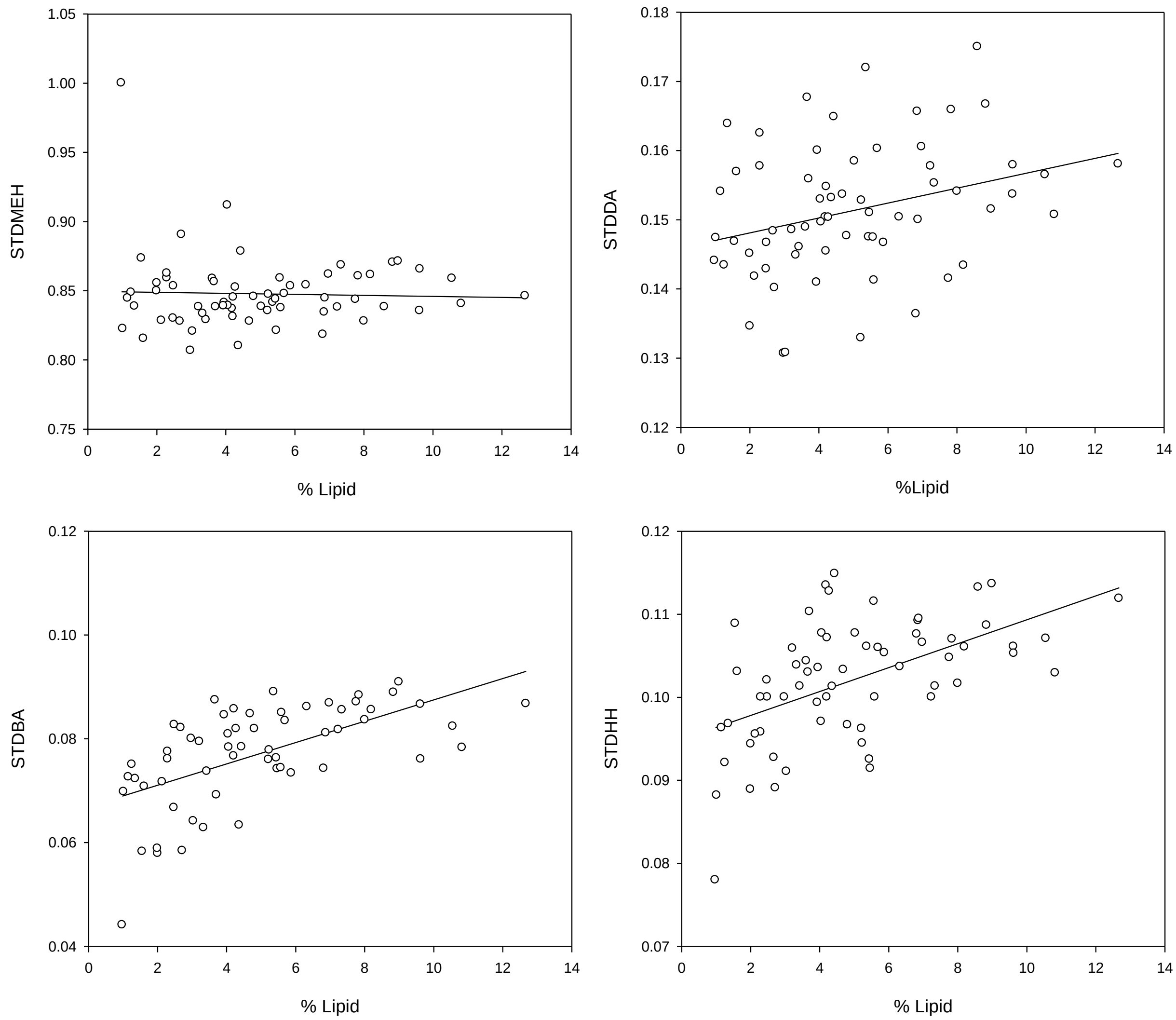

Figure 11. Relationships between four morphometric measurements and percent lipid values from Chinook salmon collected at NFMF in 2009-2012.

River Conditions

Temperature loggers were deployed to record ambient temperatures at multiple sites in Fall Creek and the NFMF Willamette River during 2009-2012 (Figure 12). The 2012 migration year was characterized by above average flows and generally below average temperatures through June. Daily mean temperatures at the release site in Fall Creek only exceeded 20°C for three days in mid- August (Figure 13). These temperatures were favorable for Chinook salmon migration as they were within the thermal preferendum of this species and were 3-4°C lower than incipient lethal temperatures (Orsi 1971; Coutant 1977; Jobling 1981; Richter and Kolmes 2005). Overall, water temperatures in Fall Creek in 2011 and 2012 were cooler than observed in 2009 and 2010. Temperatures increased at downstream locations and were highest at the release site in all study year (2009-2012). Mean daily temperatures during 2008 remained below 19°C at a single site monitored by USFS (Mann et al. 2010).

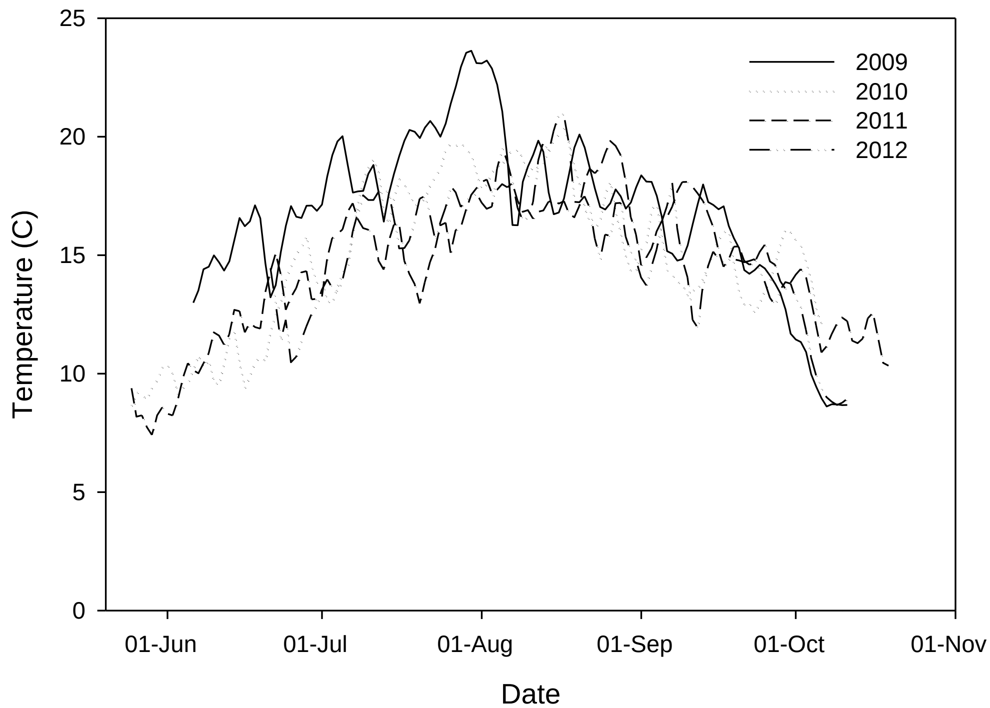

Figure 12. Comparison of mean daily water temperatures collected in Fall Creek in 2009-2012 near the release site (rkm 505.4).

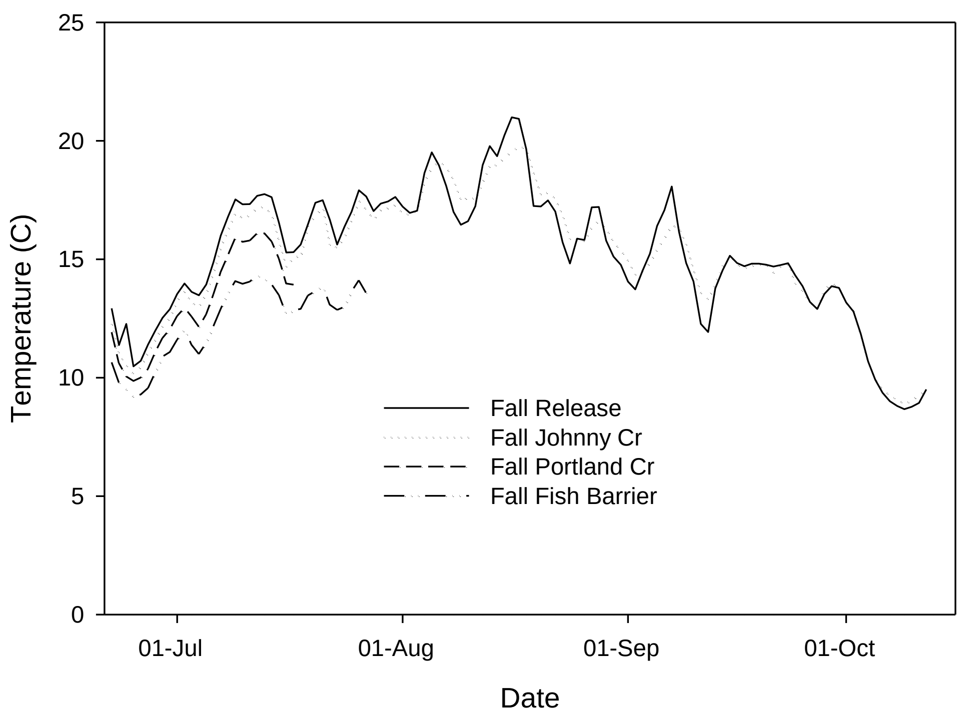

Figure 13. Daily mean water temperatures in 2012 at four sites in Fall Creek. The loggers represent a progression upstream from the release site (rkm 505.4) to the fish barrier (rkm 529.6). Data gaps resulted from missing or malfunctioning loggers.

In the NFMF, daily means did not exceed 15°C at the release site during the monitoring period in 2012 and ranged from 8.1 to 14.7 C from June through mid-October (Figure 14). NFMF temperatures were generally near or below the Chinook salmon thermal preferendum. Temperatures generally were higher at downstream locations in all years.

Although the release sites at Fall Creek and the NFMF Willamette were located 16.5 miles from each other, the NFMF was consistently cooler than Fall Creek due to differences in elevation and watershed characteristics (Figure 15). Daily mean river temperatures in the NFMF averaged 3.0 °C lower than in Fall Creek at the release sites throughout the monitoring period and about 4.0 °C lower during the July and August holding period. Peak water temperature recorded by USGS gauges occurred on 16 August in Fall Creek (21.0°C) and 11 August in the NFMF (14.7°C). The USGS gauge at Fall Creek is located at the release site while the NFMF gauge is located near the mouth (approximately 30 km downstream from the release site).

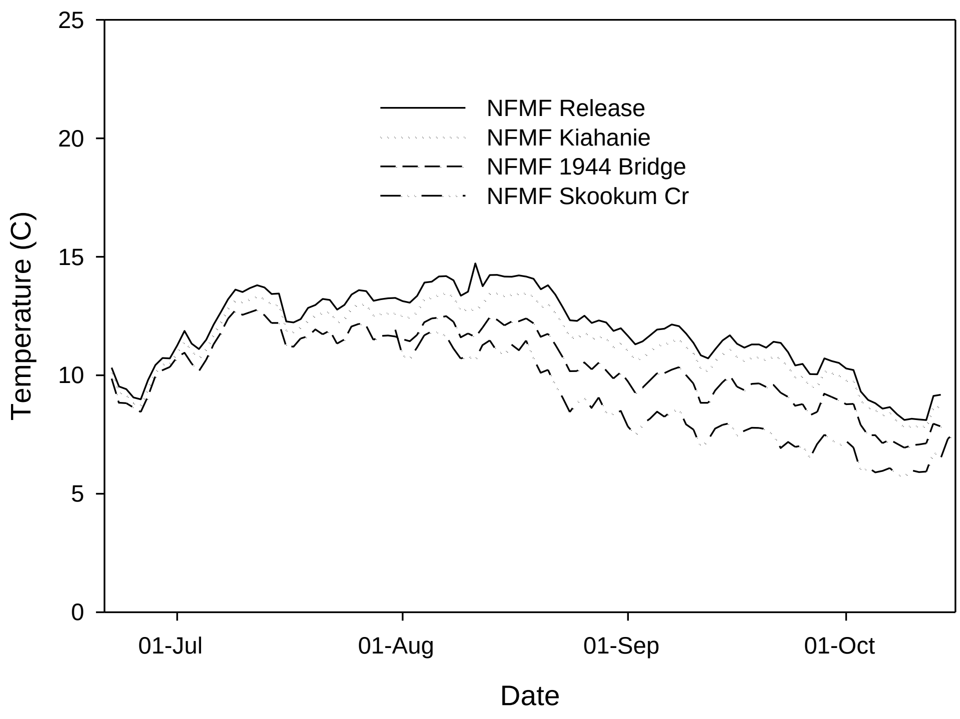

Figure 14. Daily mean water temperatures in 2012 at four sites in the North Fork Middle Fork Willamette River. The loggers represent a progression upstream from the release site (rkm 557.9) to Skookum Creek (rkm 585.9). Data gaps at the release site resulted from lost/stolen loggers.

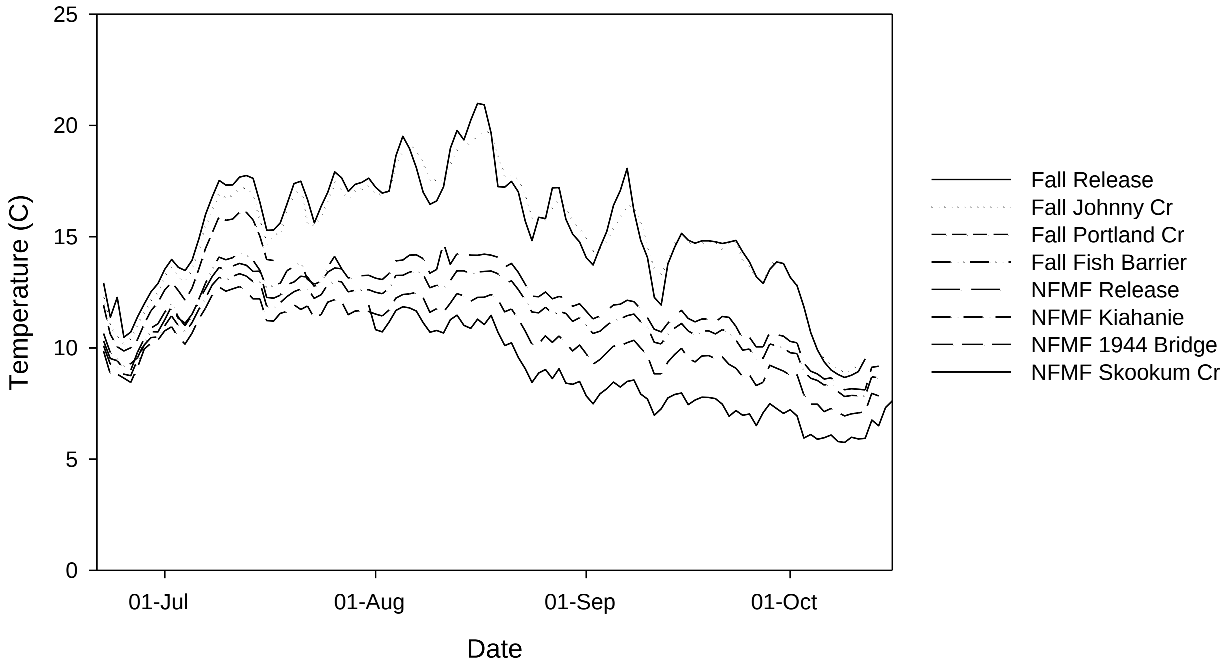

Figure 15. Daily mean water temperatures in Fall Creek and the NFMF Willamette River in 2012.

Spawning Ground Surveys and Spawning Success

Fall Creek

Carcasses were recovered in Fall Creek from 9 July until 12 October. The recovery rate was 26% of the PIT-tagged fish and 28% of the double-tagged fish (PIT and radio). We recovered a higher proportion of unmarked fish in 2012 (35%) than either PIT or double-tagged fish (Table 7).

Prespawn mortality estimates in Fall Creek in 2012 were the lowest in the 2008-2012 period (Table 7). We calculated prespawn mortality using several samples including PIT-tagged fish only, double-tagged fish only, and untagged carcasses. Some carcasses or double-tagged fish were excluded from the analyses because spawning success could not be determined or because the fish presumably died from unnatural means (i.e., poaching). None of the 11 PIT-tagged females recovered were considered pre-spawn mortalities (Table7). Prespawn mortality estimates were 20.0% for radio-tagged females (1 of 5 recovered), and 18% (5 of 28 recovered) for untagged carcasses.

Table 7. Recovery rates and final estimated fates of Chinook salmon that were PIT-tagged or double-tagged (PIT and radio-tagged) and unmarked fish in Fall Creek, 2008-2012. Prespawning mortality (PSM) rates were only calculated for females.

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

The final distribution of PIT-tagged fish indicated that the majority of spawning occurred upstream from the 1828 Bridge (rkm 519.4; Figure 16). All prespawn mortalities were recovered upstream from the release site. The distribution of successful spawners in Figure 15 represents the primary spawning habitat in Fall Creek. Fish outplanted:redd, ratios were 3.1, 9.5, 7.9, 7.2 and 18.6 for 2008, 2009, 2010, 2011 and 2012 respectively (G. Taylor, pers. communication).

Prespawn mortality was not clearly associated with tagging date in 2012 (Figure 16). We did not see an association between rising temperatures and prespawn mortality as was observed in 2009 and 2010 (Mann et al. 2011), likely because mean daily temperatures rarely exceeded 20° in Fall Creek in 2012.

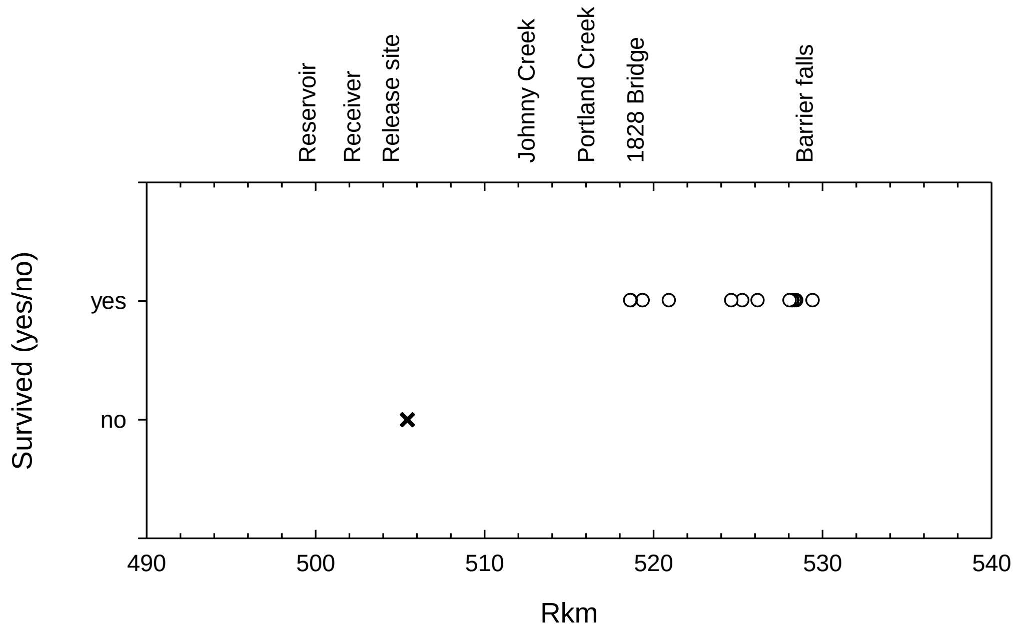

Figure 16. Distribution of PIT-tagged Chinook salmon carcasses that were recovered in Fall Creek spawning ground surveys in 2012, including their spawning status.

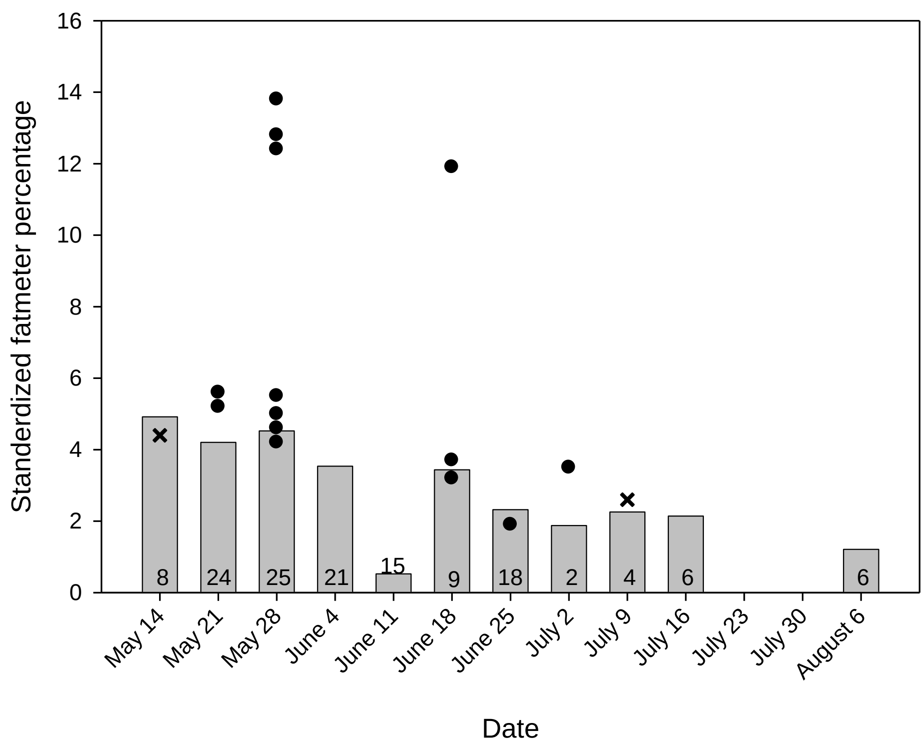

Figure 17. Weekly mean standardized lipid levels of Fall Creek Chinook salmon as calculated from fatmeter readings collected at the time of tagging in 2012. Circles represent the lipid percentage for successfully spawned fish, crosses represent prespawn mortalities. The points were included in the week that they were tagged. Tagged sample sizes shown for reference.

North Fork Middle Fork Willamette River

Carcasses were recovered in the NFMF from 16 July to 9 October from three groups of tagged adults. The recovery rate was 13% for adults tagged only with at PIT-tag and released immediately (Table 8), a proportion similar to the recovery rate for unmarked adults (16%). A higher proportion of double-tagged adults was recovered (28%). Seventeen of 71 PIT-tagged adults released after holding at Willamette Hatchery were recovered (24%).

The prespawning mortality rates of directly released PIT-tagged fish in the NFMF in 2012 was 10% (1 of 10 females recovered), which was the same as for PIT-tagged fish held at WH and then released into the NFMF. Prespawn mortality of radio-tagged fish in the NFMF was estimated to be 17% (1 of 6 females recovered) (Table 8). The overall prespawn mortality rate for both immediate outplant (PIT and radio-tagged) samples was 12.5% (three of 16 females recovered). The prespawn mortality rates for all groups were among the lowest from the four study years on the NFMF.

Table 8. Final fates of PIT-and radio-tagged and unmarked subsets of the Chinook salmon outplanted in the NFMF Willamette River. 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 then later outplanted into the NFMF Willamette River.

Year	Group	# released	# recovered	% recovered	Females #recovered	Females %PSM
2009 (DEX)	PIT	124	6	5	3	0
	Double	12	3	25	1	100
	Unmarked	N/A	66	N/A	19	47
2009 (HH)	PIT	103	1	1	1	0
2010 (DEX)	PIT	148	30	20	15	47
	Double	43	8	18	3	67
	Unmarked	N/A	266	N/A	102	64
2010 (HH)	PIT	81	8	10	7	0
	Double	18	7	39	6	33
2011 (DEX)	PIT	109	7	6	5	0
	Double	71	11	15	5	60
	Unmarked	1,366	186	14	98	38
2011 (HH)	PIT	79	8	10	5	40
2012 (DEX)	PIT	104	14	13	10	10
	Double	50	11	22	6	17
	Unmarked	2,441	387	16	192	23
2012 (HH)	PIT	71	17	24	10	10

In the NFMF, spawning activity was concentrated in a 10 km reach just upstream from the release site (Figure 18), a pattern similar to spawning distributions observed in previous years (Mann et al. 2011; Naughton et al. 2011). We recovered a single carcass at 23 km upstream from the release site at ~rkm 580. A total of 167 redds were counted in 2012 and all were upstream from the release site.

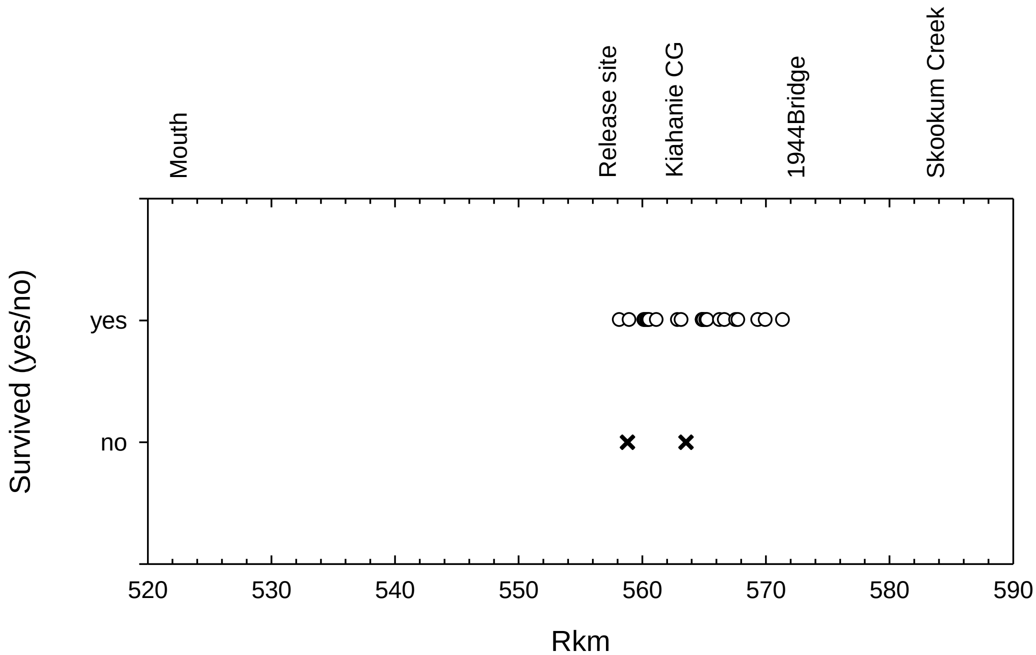

Figure 18. Distribution of PIT-tagged (including radio-tagged) Chinook salmon carcasses that were recovered in the NFMF Willamette River spawning ground surveys in 2012, including their spawning status.

Multi-year Summary

We tested for associations between fate and a suite of factors potentially related to prespawn mortality across study years using univariate and multiple logistic regression models and multi-model selection techniques. At Fall Creek, qualitative examination of univariate comparisons between fate and predictors indicated PSM mortalities arrived later, had lower lipid (uncontrolled for arrival timing), lower condition score, lower condition factor (K), were relatively longer and narrower in shape for a given body size (higher standardized MEH, lower standardized DA and HH), and were larger overall (see Figures 19 and 20). At NFMF, prespawn mortalities tended to arrive later than survivors, had lower condition factor and lipid scores, had slightly lower masses, and tended to be thinner for a given length (smaller standardized DA and HH) (Figure 21 and 22).

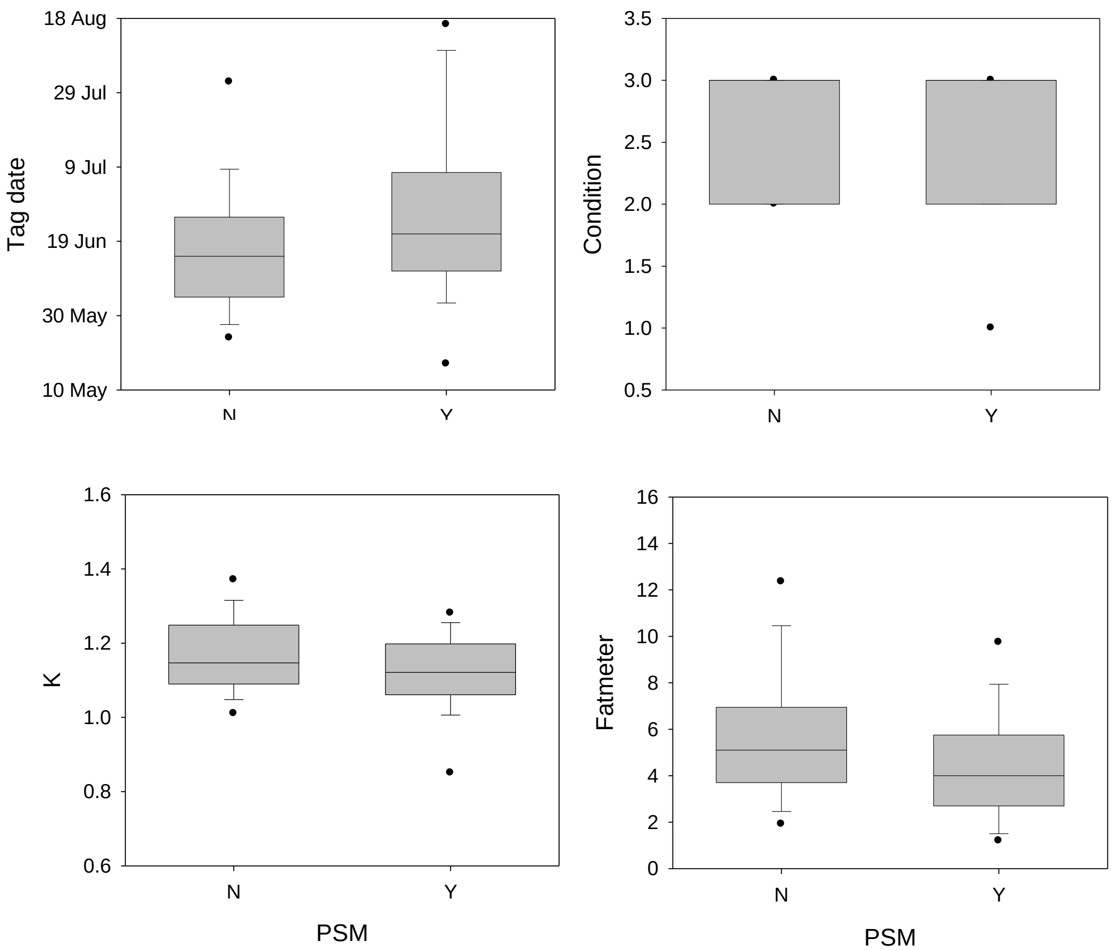

Figure 19. Distributions of Chinook salmon tag date, Condition, Condition Factor (K), and fatmeter estimates for survivors (N) and prespawn mortalities (Y) across years at Fall Creek.

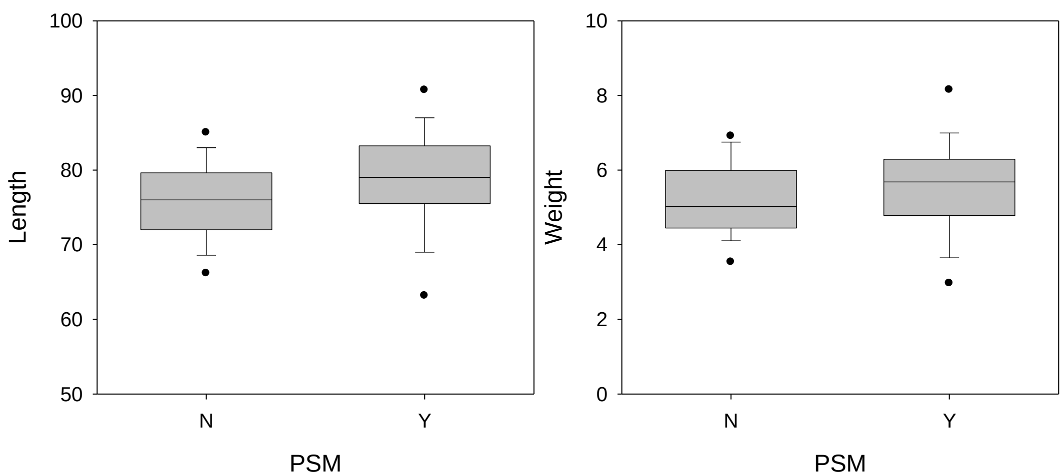

Figure 20. Distributions of Chinook salmon body morphometry metrics, length, and weight for survivors (N) and prespawn mortalities (Y) across years at Fall Creek.

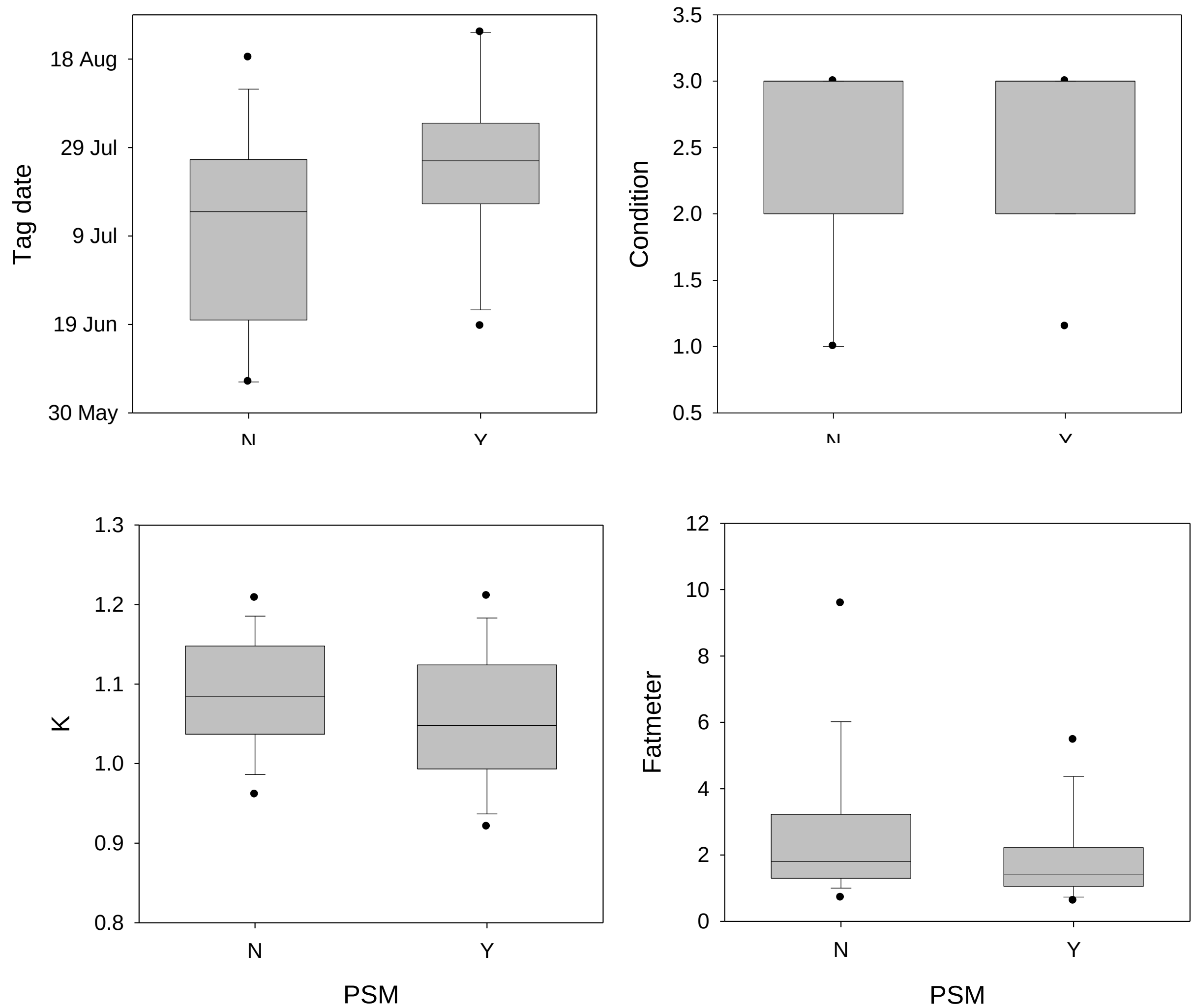

Figure 21. Distributions of Chinook salmon tag date, Condition, Condition Factor (K), and fatmeter estimates for survivors (N) and prespawn mortalities (Y) across years at Dexter Dam.

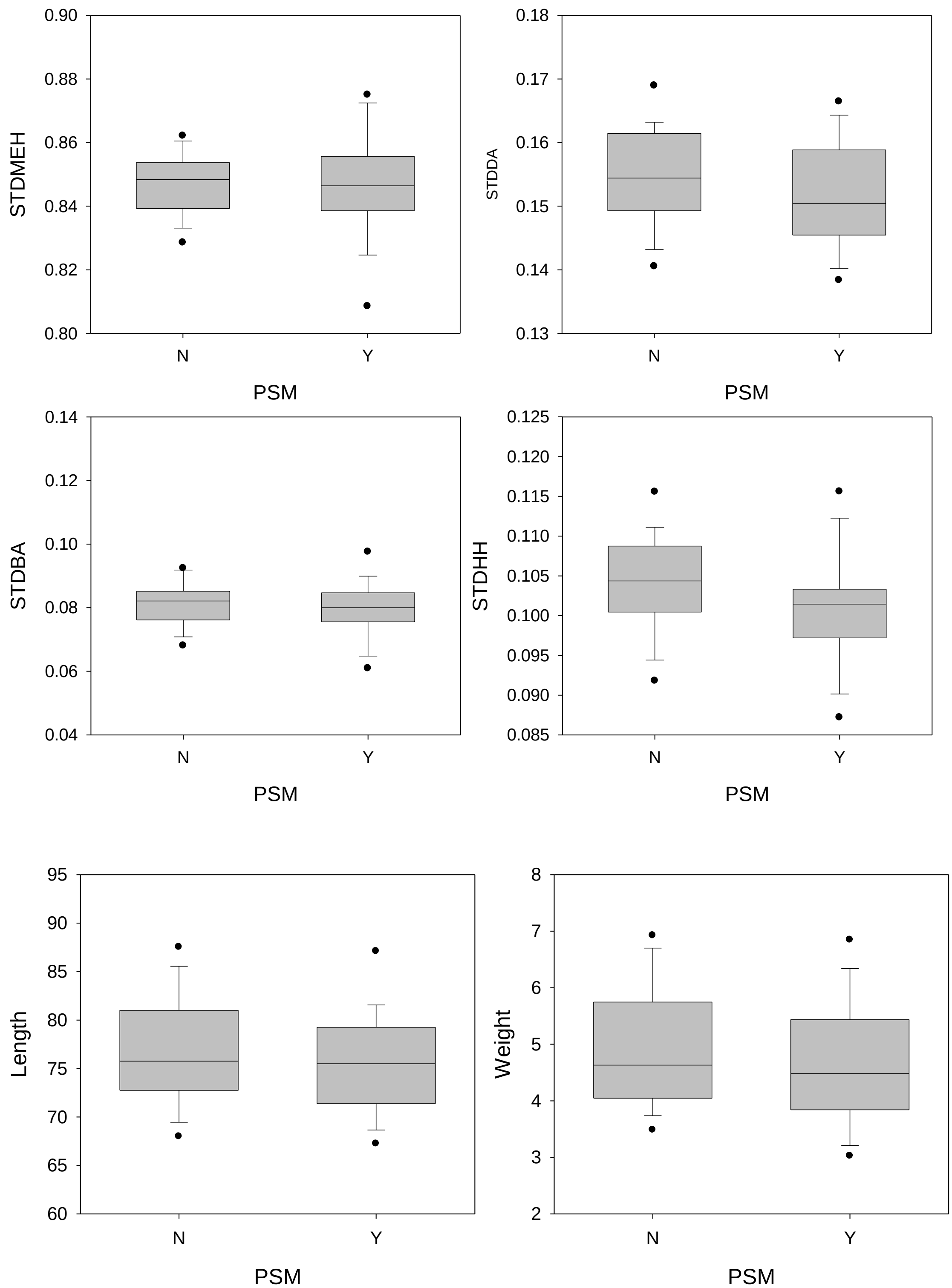

Figure 22. Distributions of Chinook salmon body morphometry metrics, length, and weight for survivors (N) and prespawn mortalities (Y) across years at Dexter Dam.

The models for Fall Creek included 75 females and 32 males (*n* = 107 fish over 4 years). Among the univariate logistic regression models, year, fatmeter, Fulton's K, and fork length were significantly associated with prespawn mortality at $P < 0.05$ (Table 9). In the multi-model logistic regression comparison, the most parsimonious model included sex, shape (MeH, Da, Ba, HH) and tag date (Table 9). The tag date effect reflected the higher prespawn mortality among later migrants, on average, and the shape effect indicated higher mortality among relatively thinner salmon. Females had higher mortality than males. Several additional models had statistical support, with ΔAIC < 4.0. These models included various combinations of fish shape, tag date, sex, tag date, year and condition. That multiple models produced similar results was not surprising given the inter-correlations among predictor variables.

The models for the NFMF included 72 females and 8 males (*n* = 80 fish over 4 years). Prespawn mortality was not significantly associated with any univariate predictors (all model $P \geq 0.056$), although the fatmeter-only model was the most parsimonious among all models tested Table 10). In the multivariate models, year plus tag date was the model with the lowest *P* value ($P = 0.091$; Table 10), but the model with condition, fatmeter, and K was the most parsimonious. Prespawn mortality was higher for later-arriving fish in this model. The year effect reflected relatively high mortality in 2010 and relatively low mortality in 2012

Table 9. Selection statistics for logistic regression models of prespawn mortality in Fall Creek from 2008-2012 that included a variety of predictor variables and mortality as the dependent variable. AIC = Akaike information criteria, $\Delta AIC = AIC_{current}\text{-}AIC_{best}$. 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; 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
	Sex	147.388	37.043	0.142
Timing	Year	117.276	6.931	<0.001
	Tag Date	148.941	38.596	0.411
Condition	Condition	150.893	40.551	0.695
	Fatmeter	143.023	32.678	0.027
	Fulton's K	143.374	33.029	0.019
Shape	StdMeH	145.255	34.910	0.057
	StdHH	149.039	38.694	0.448
	StdDA	149.614	39.269	0.935
	StdBA	125.772	15.427	0.214

Table 9. Continued.

Size	FL					145.211	34.866	0.043
	Mass					147.890	37.545	0.194
Multivariate	Variables							
Timing	Year	Tag Date				117.419	7.074	<0.001
Condition	Condition	Fatmeter				146.793	36.448	0.166
	Sex	Condition	Fatmeter			147.550	37.205	0.185
	Year	Condition	Fatmeter			121.021	10.676	0.002
	Condition	Fatmeter	K			146.246	35.901	0.116
	Sex	Condition	Fatmeter	K		147.731	37.386	0.171
	Year	Condition	Fatmeter	K		122.956	12.608	0.003
	Condition	Fatmeter	tagdate			147.653	37.308	0.218
	Year	Fatmeter	tagdate	K		120.367	10.022	0.001
Shape	StdMeH	StdHH	StdDA	StdBA		128.998	18.653	0.4373
	Sex	Shape				128.213	17.868	0.3578
	Year	Shape				113.988	3.643	0.015
	Year	Sex	Shape			112.919	2.574	0.015
	Sex	**Shape**	**Tag date**			**110.345**	**0.000**	**0.005**
	Year	Shape	Tag date			111.602	1.257	0.012
	Year	Sex	Tag date	Shape		111.826	1.481	0.015
	Sex	Condition	Fatmeter	Shape		128.742	18.397	0.390
	Year	Condition	Fatmeter	Shape		116.444	6.099	0.070
	Sex	Year	Condition	Fatmeter	Shape	115.575	5.230	0.074
Size	FL	Mass				145.246	34.901	0.059
	Sex	FL	Mass			146.701	36.356	0.104
	Year	FL	Mass			120.471	10.126	<0.001
	FL	Mass	Shape			127.376	17.031	0.325
	Sex	FL	Mass	Shape		126.111	15.766	0.234
	Year	Sex	FL	Mass	Shape	114.087	3.742	0.047
Full						117.889	7.544	0.134

Table 10. Selection statistics for logistic regression models of prespawn mortality in NFMF from 2009-2012 that included a variety of predictor variables and mortality as the dependent variable . AIC = Akaike information criteria, ΔAIC = $AIC_{current}$-AIC_{best}. Models in shaded grey had statistical support (ΔAIC < 4 in multivariate model, $P < 0.05$ in univariate models), and the model in bold text was most parsimonious. Variable definitions: Condition = overall physical condition; 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					AIC	ΔAIC	P-value
Univariate	Variables				AIC	ΔAIC	P-value
	Sex				97.685	7.649	0.508
Timing	Year				99.559	9.523	0.495
	Tag date				97.301	7.265	0.372
	Condition				98.397	8.361	0.446
	Fatmeter				**90.036**	**0.000**	**0.182**
	Fulton's K				94.235	4.199	0.079
Shape	StdMeH				99.107	9.071	0.993
	StdHH				94.220	4.184	0.056
	StdDA				95.529	5.493	0.116
	StdBA				97.154	7.118	0.351
Size	FL				97.616	7.580	0.487
	Mass				95.811	5.775	0.211
Multivariate							
Timing	Year	Tag date			94.266	4.230	**0.091**
Condition	Condition	Fatmeter			92.036	2.000	0.411
	Sex	Condition	Fatmeter		94.485	4.449	0.497
	Year	Condition	Fatmeter		98.006	7.970	0.746
	Condition	Fatmeter	K		93.794	3.758	0.495
	Sex	Condition	Fatmeter	K	95.069	5.033	0.532
	Year	Condition	Fatmeter	K	99.005	8.969	0.797
	Condition	Fatmeter	Tag date		95.166	5.130	0.483
	Year	Fatmeter	Tag date	K	93.814	3.778	0.332

Table 10. Continued.

Shape	StdMeH	StdHH	StdDA	StdBA		99.894	9.858	0.418
	Sex	Shape				100.619	10.583	0.436
	Year	Shape				104.614	14.578	0.664
	Year	Sex	Shape			105.258	15.492	0.658
	Sex	Condition	Fatmeter	Shape		100.1738	10.137	0.706
	Year	Condition	Fatmeter	Shape		104.602	14.566	0.895
	Sex	Year	Condition	Fatmeter	Shape	105.455	15.419	0.884
	Year	Sex	Shape			105.258	15.222	0.658
	Sex	Shape	Tag date			102.265	12.229	0.5259
	Year	shape	Tag date			100.950	10.914	0.372
	Year	sex	Tag date	shape		101.218	11.182	0.378
Size	FL	Mass				95.919	5.883	0.191
	Sex	FL	Mass			97.642	7.606	0.311
	Year	FL	Mass			97.227	7.191	0.271
	FL	Mass	Shape			102.195	12.159	0.510
	Sex	FL	Mass	Shape		103.659	13.623	0.645
	Year	Sex	FL	Mass	Shape	105.266	15.230	0.710
Full						107.628	17.592	0.845

We examined the relationship between water temperature and prespawn mortality in the two study areas (Figure 23). In Fall Creek, female mortality was positively associated with mean daily water temperature from 1 July to 15 September (r^2 = 0.84) and with the maximum 7-d moving average temperature (r^2 = 0.53), though in both cases this result was contingent on inclusion of a single study year (2009) The first metric was an indicator of the overall thermal environment in each year and the second metric was an index of potential acute thermal stress. There were no clear patterns in the NFMF (Figure 23). Neither the seasonal mean (r^2 = 0.01) nor the 7-d moving average (r^2 = 0.00) was associated with prespawn mortality.

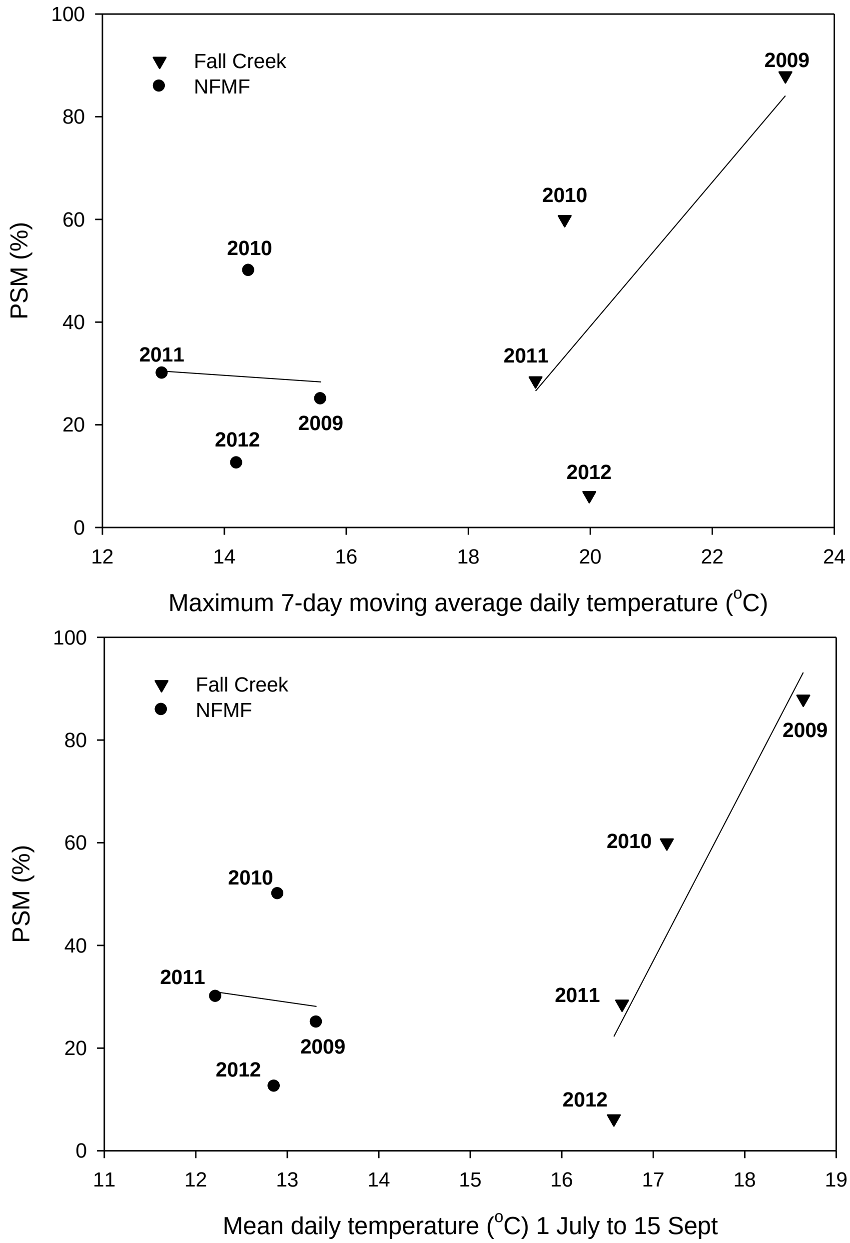

Figure 23. Prespawning mortality rates of female PIT and radio-tagged Chinook salmon in Fall Creek and the NFMF in relation to the maximum 7-d moving average (top) daily temperatures and the mean daily temperature from 1 July to 15 September (bottom). Temperatures were recorded at the release sits.

Fall Creek Reservoir Releases

Eight radio-tagged Chinook salmon were released into Fall Creek Reservoir on 21-June at 9:30 AM. Eight of the 10 (80%) fish were recorded upstream from the receiver above the reservoir. Two of the radio-tagged fish were recovered on the spawning grounds and neither was considered a prespawn mortality. Median reservoir residence time was less than a day for both the 2011 (5.0 h) and 2012 (4.1 h) reservoir release groups (Figure 24).

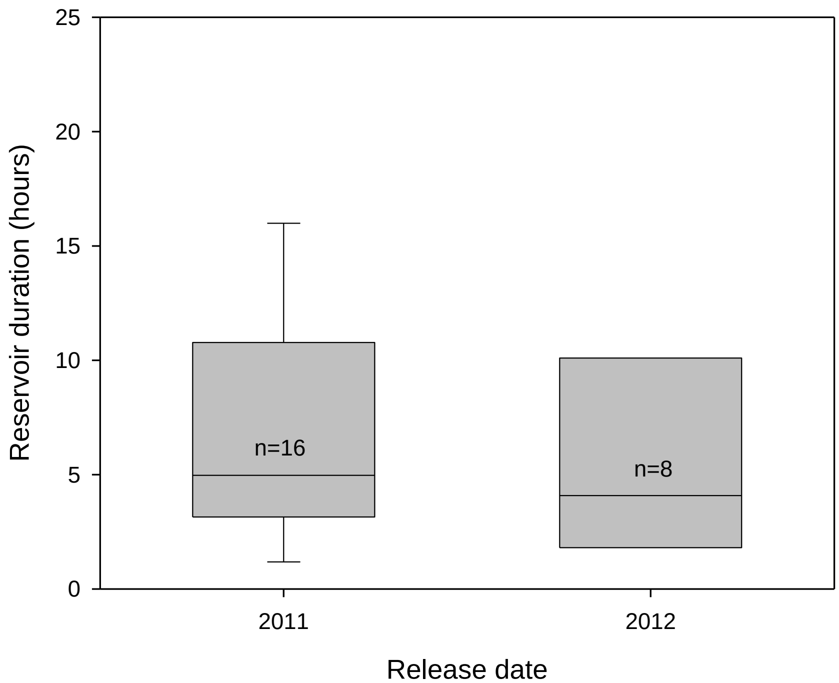

Figure 24. Reservoir residence times of radio-tagged adult Chinook salmon released into Fall Creek reservoir in 2011 and 2102. In 2011, fish were released on 13 June, 25 July, and 11 August. In 2012, all fish were released on 21-June. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), and 10th and 90th percentiles (whiskers).

Results: South Fork Santiam

A total of 134 fish (55 females, 79 males) were PIT tagged, and 74 of these were also radio-tagged (Figure 25). All fish transported above the dam were non-adipose clipped fish. Fish were released at three sites: River Bend (*n* = 75), Calkins (*n* = 33) and Gordon Road (*n* = 26). Fish released at the Calkins site were used to evaluate reservoir releases. The mean condition score in 2012 was 2.6, mean fork length was 78.3 cm, mean weight was 5.6 kg, and mean lipid percentage was 3.0% (Table 11).

Figure 25. Map of Foster Reservoir including Calkins release site and South Fork and Middle Fork Santiam river arms.

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 2012. MeH = Mid-eye to hypural length, Da = Depth at anus, Ba = Breadth at anus, HH = Hump height, % Lipid = Standardized % lipid in muscle tissue, wet weight.

SF Santiam (n = 134)	Fork Length (cm)	Weight (kg)	MeH (cm)	Da (cm)	Ba (cm)	HH (cm)	% Lipid	Condition Score
Mean	78.3	5.6	65.3	12.4	5.9	8.5	3.0	2.6
St. Deviation	6.7	1.5	5.5	1.4	1.0	1.3	3.2	0.6
Max	96.0	10.4	83.0	16.5	8.3	12.1	19.4	3.0
Min	59.0	2.42	49.0	8.7	4.0	4.4	0.2	1.0

Individual lipid concentrations as estimated with the fatmeter were poorly correlated with the values estimated from proximate analysis taken from lethally sampled adults (adj. r^2 = 0.503, P = 0.998, N = 15 see Proximate Analysis section below). Mean estimated standardized lipid content of tagged adults arriving at the Foster trap in June were similar to lipid content estimated for adults at Willamette Falls and then generally decreased through the 2012 season (Figure 26).

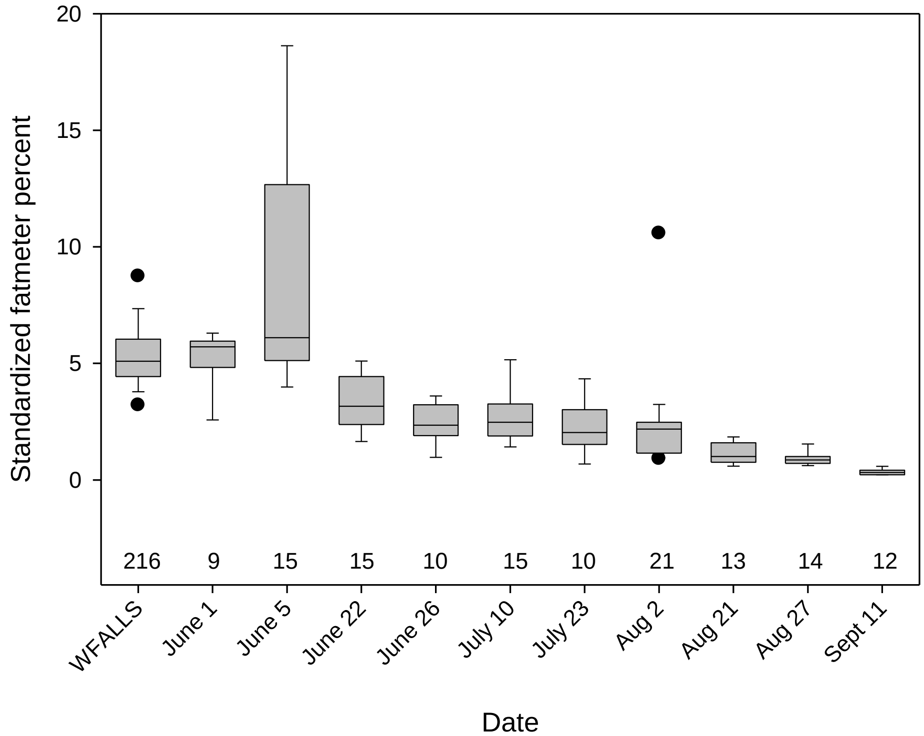

Figure 26. Distributions of standardized fatmeter results for Chinook salmon tagged at the Foster Dam trap in 2012. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (solid circles). Sample size for each date given below each distribution. Fat meter readings from Willamette Falls (WFALLS) are from Jepson et al. 2013. (Note: the Willamette Falls data were not validated using the same equation as the tributary fish.)

Proximate Analysis

In 2012, proximate analysis was performed on 15 salmon at Foster (6 males and 9 females). Lethal takes for proximate analysis were conducted on 5 June (n = 8) and 2 August (n = 7). The average muscle lipid level was 5.9% (Table 9) and ranged from 1.1-14.5%. Females had gonadal lipid compositions of 4.8%, while males were 0.7%, on average (Table 11).

Table 11. Mean tissue composition of Chinook salmon collected at the Foster Dam trap and used in proximate analysis in 2012.

Tissue	% Moisture	% Crude Lipid	% Total Ash	% Protein
Gonads	71.7	3.2	1.6	23.5
Muscle	72.5	5.9	1.1	20.5
Skin	57.9	10.8	1.0	30.3
Viscera	77.9	3.0	1.0	18.0

Table 12. Tissue composition of Chinook salmon collected at Foster used in proximate analysis by sex.

Tissue	% Moisture	% Crude Fat	% Total Ash	% Protein
Males (*n* = 6)				
Gonads	80.6	0.7	2.1	16.6
Muscle	73.0	4.8	1.1	21.0
Skin	58.2	10.7	1.3	29.8
Viscera	77.6	3.4	1.2	17.9
Females (*n* = 9)				
Gonads	65.8	4.8	1.3	28.0
Muscle	72.1	6.6	1.1	20.2
Skin	57.7	10.8	0.9	30.6
Viscera	78.2	2.8	0.9	18.1

Reservoir Releases

Thirty-three radio-tagged salmon were released into Foster Reservoir in 2012, and 31 (94%) of these were recorded at receivers upstream from the Calkins release site. The remaining two fish moved downstream and were recorded at the Foster trap. Median reservoir residence times were 5.5 d for fish last recorded on the South Fork Santiam receiver (SFR), 8.1 d for fish last recorded on the Middle Fork Santiam receiver (MSR), and 3.3 d for fish last recorded by mobile tracking in the SF Santiam River (Figure 27). Fish last recorded at the SFR site also included some fish that were detected on the MSR site, including fish that made multiple trips between receivers. Prespawn mortality estimates for fish released upstream from Foster Dam were reported by ODFW (see Sharpe et al. *in review*).

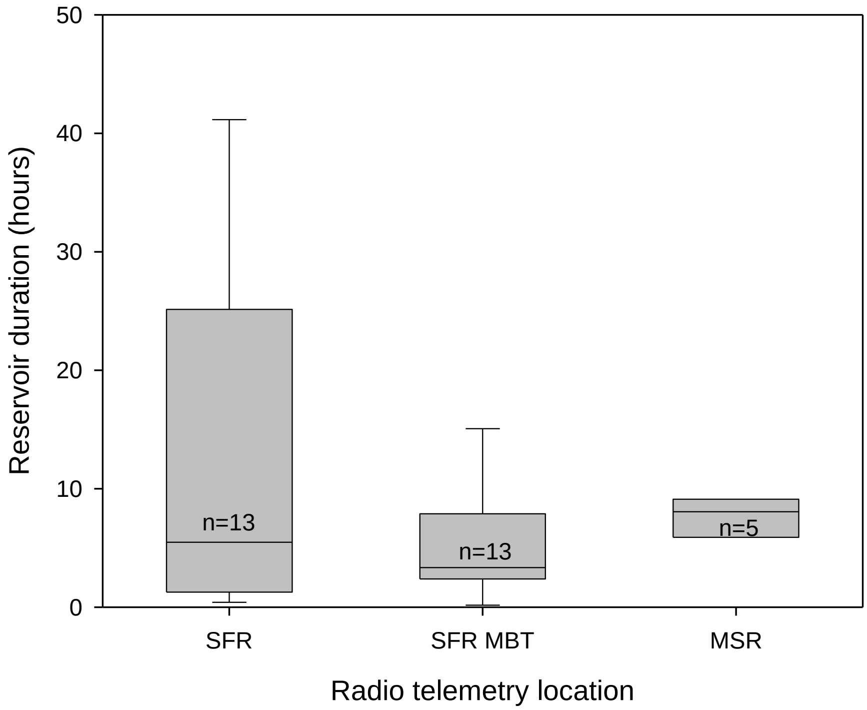

Figure 23. Reservoir residence times of radio-tagged adult Chinook salmon released into Foster reservoir in 2012. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), and 10th and 90th percentiles (whiskers). SFR = South Fork Santiam River, SFR MBT = recorded in the South Fork Santiam River by mobile tracking, MSR = Middle Fork Santiam River.

Discussion

Summary

The primary Middle Fork study objectives were to estimate prespawning mortality rates in the two Middle Fork populations, examine relationships between prespawn mortality and potential causative agents, evaluate the efficacy of hatchery-holding prior to outplanting, and test whether release to reservoirs downstream of spawning tributaries could provide a summer thermal refuge. We were able to address each of these goals in 2012 We also conducted a pilot feasibility study to evaluate releasing adults into Foster Reservoir on the South Fork of the Santiam River.

Sampling at Fall Creek was more representative of the timing of the run than sampling at Dexter. This was due to limitations in the operation of the Dexter Trap, which is primarily used for broodstock collections for Willamette Hatchery. With the assistance of ODFW the collection of adults at Dexter Dam began on 6 June, approximately two weeks later than in 2011, with collections occurring about every two to three weeks thereafter until the first week in August. Data from a concurrent study revealed that radio-tagged adults spent about two weeks (*range* <1-22 days) in the Dexter Dam tailrace prior to collection (Jepson et al. 2013*).* Residence time in the tailrace was probably primarily determined by trapping interval. Poor attraction flow from the Dexter trap entrance compared to turbine discharge may also contribute somewhat to tailrace residence time irrespective of trap operations. In 2013, operations will be modified to allow adults to enter the trap throughout the run season which could potentially reduce tailrace residence time and densities in the trap during collection of broodstock and adults for outplanting to the NFMF. The multi-year analyses suggest that later arriving adults were more likely to be prespawn mortalities. However, we caution that the statistical support for this association was mixed (i.e., the tag date effect was not consistently significant across all models and sampling dates differed across years). This suggests that the effect was weak and/or was not directly related to arrival timing. Regardless, representative sampling across the run at all locations will be important for rigorously evaluating associations between prespawn mortality and potential timing effects that may be associated with holding in the tailrace and trap operations.

As in previous years, sampling at Fall Creek Dam better matched run timing. At Fall Creek Dam, run timing typically peaks in early June followed by a smaller peak in the fall. In 2012, tagging was representative of the overall timing of the run, which peaked in early June and again in late-July, which was slightly earlier than previous years.

Spawning ground recovery rates for PIT-tagged fish in 2012 were higher than the previous years. As in previous years, we focused on areas with the highest concentrations of fish, as well as increased our coordination with ODFW carcass surveyors in order to maximize efficiency. In the NFMF, kayak surveys were used more often (by ODFW) to increase the stream area covered. Use of radio-tags helped with recovery rates in both drainages in 2012, particularly the larger NFMF. Increased personnel and increased survey frequency were largely responsible for the increased tag recovery rates in 2012.

Prespawn mortality rates in Fall Creek observed in 2012 were substantially lower than in 2009 and 2010 and were similar to those in 2011. Prespawning mortality estimates in 2011 were about 15-29% for PIT- and radio-tagged fish compared to 40-90% in 2009 and 2010. The 2012 estimates were 18% for unmarked fish, 20% for radio-tagged fish and 0% for PIT-tagged fish. Moreover, the rates for 2011 and 2012 were substantially lower than the very high mortality recorded in years past (i.e., mortality as high as 90%, Schroeder et al. 2007; Kenaston et al. 2009; Keefer and Caudill 2010). Comparison of PIT only, double tag, and untagged rates in 2012 and other years suggest that prespawn mortality rates were similar in tagged versus untagged and double-tagged versus PIT-tagged in Fall Creek with the exception of 2010. Due to the low number of females recovered the high prespawning mortality rates observed in 2009 must be viewed with caution. It is possible that the rates in Fall Creek were overestimated and conversely rates in the NFMF were underestimated. The higher rate in 2010 for radio-tagged fish may have been due to tag or handling effects. Alternatively, this pattern may have resulted from higher recovery of prespawn mortality carcasses in the radio-tagged group, particularly in the early season (i.e., we were less likely to locate carcasses without transmitters). No consistent pattern was observed in the NFMF among years. Overall, the similarity among prespawn mortality rates among the tagged and unmarked fish in 2012 and other years suggests that tagging procedures and tag burden did not strongly affect observed rates, as has been observed in other systems (Corbett et al. 2012).

In contrast to 2010 and 2011 there were no significant mortalities observed following a release event in the NFMF in 2012. There was presumably delayed mortality associated with collection and transportation to the release site. The mechanism for this mortality is unclear, but may have attributable to short-term stress of handling and transport and/or “shipping fever” (Schreck et al. 2012a) rather than to water quality issues in transportation (which would manifest in minutes to hours and would likely have been evident prior to release from the truck). Handling protocols at Dexter Dam Trap require use of CO_2 for anesthetization. While CO_2 is known to induce higher stress and mortality in fishes during anesthesia (e.g., Sanderson and Hubert 2007), to what degree differences in collection and handling protocols contributed to prespawn mortality 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 other locations. While we did not explicitly compare handling protocols, we did begin collecting fish directly from the ladder in 2012 (after the second tagging event) before they were exposed to CO_2 which may have minimized mortality associated with release events.

Similar to 2011, poaching may have affected the survival of salmon outplanted above Fall Creek Dam in 2012. Any poaching is not accounted for in the reported estimates of prespawn mortality because prespawn mortality rates are based solely on PIT- or radio-tag recoveries on the spawning grounds. While we did not have direct evidence of poaching in 2012, removal of roe from carcasses that may or may not have died naturally, targeted fishing of salmon in restricted waters, recovery of radio tags from unnatural locations (e.g., from under rocks near the stream) and fish spearing have been observed in previous years. The impact these factors have on reproductive success and production of the population is unknown. Although, the percentage of fish directly (e.g., poaching) or indirectly (e.g., stress or energy consumption through harassment) affected could be quite large because ~80% of adults are not recovered and assessed for cause of mortality (Table 8), we have no quantitative information to substantiate this. Given the current fishing regulations and the high use of Fall Creek by recreationists during salmon migration and spawning, it may be difficult to reduce these human impacts without restricting activity of conscientious users.

Fish Condition, Environmental Conditions, and Spawning Success

The energetic condition of two populations of Willamette River spring Chinook salmon was assessed. The percentage of lipid in the muscle tissue was used as the measure of energetic condition. Lipid is the primary source of energy used by migrating salmon and can be non-lethally assessed in bioenergetic studies (Brett 1995; Crossin and Hinch 2005; Pinson 2005). The Distell Fatmeter provided estimates of lipid levels in the muscle tissue, as well as gross somatic energy content. The mean lipid content at the time of tagging in 2012 was 5.3% and 2.4% for Fall Creek and Dexter fish, respectively. Differences in tagging dates made direct comparison of these means difficult, though after standardization using the proximate analyses, we did not observe significant differences in lipid levels between years or locations.

The lipid levels of fish tagged at Fall Creek and Dexter Dam in 2012 were generally lower than in other years (Mann et al. 2011). Differences in the locations and timing of these sampling events likely explain some of the among-population differences in lipid levels. Lipid levels from Chinook salmon collected at Willamette Falls were about 2-5% higher, on average, than those collected at Fall Creek or the Dexter Dam trap. This was not surprising because significant energy is required to migrate the more than 250 km from Willamette Falls to these upstream sites. Although the lipid readings collected during tagging appeared reasonable, the fatmeter malfunctioned in early June and several sampling events were missed. The meter was eventually replaced.

In contrast to 2010, there was no association between lipid levels and spawning success in 2012. The lack of relationship in 2012 (and 2011) may have been due to low sample size (sample sizes were larger in 2012) or a true lack of relationship, a conclusion supported by the multi-year analyses.

We did not observe a significant association between physical condition and spawning success in 2012 in Fall Creek, in contrast to earlier observations (e.g., Keefer et al. 2010). Because salmon were in generally good condition in 2012 (mean condition score = 2.6), there may not have been enough variability in the data to detect a condition effect. The mean condition in 2012 was higher than previous years: 2011 (mean = 2.2), 2010 (mean = 2.5), and 2009 (mean = 2.2). Although the high 2012 condition scores comport with low prespawn mortality, this index was somewhat subjective because there may be some interannual variability in scores because different personnel collected data in some years. The effects of condition may also be stronger in years with stressful environmental conditions. For example, high temperatures in 2009 likely exacerbated the impact of physical injuries by increasing the prevalence of pathogens and depressing the immune response.

When combining the results from all five study years, we found an association between annual prespawn mortality rate and summer water temperatures in Fall Creek, though we note this conclusion should be considered preliminary because it is largely driven by a single year (2009; Figure 23). We have also observed prespawn mortality that directly coincided with increases in water temperatures within year (e.g., in 2009 and 2010). The 2010 river conditions were cooler than in 2009, although daily maximums exceeded 22°C, a range that is considered deleterious to adult Chinook salmon (Richter and Kolmes 2005; Mann 2007). We observed lower mortality rates for fish migrating in May in 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 low prespawn mortality rates. Early-run fish returning to Fall Creek are typically exposed to lower overall temperatures because of the rapid movement upstream after release to relatively cool reaches (Roumasset 2012) and lower relative temperature exposure during mainstem migration.

It is unlikely that water temperatures in NFMF near areas used by outplanted Chinook salmon routinely reach levels that would have large impacts on survival. It is then interesting to note the lower levels of prespawning mortality rates in Fall Creek for PIT and radio-tagged fish combined (6.3%; 1 of 16 PIT and radio-tagged females recovered) compared to the NFMF in 2012 (12.6%; 2 of 16 PIT and radio-tagged females recovered) which was cooler by 4.5-5.0°C in July and August. Although rates were generally low and sample sizes were small, prespawn mortality in the NFMF is more likely to be 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. 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.

Hatchery Holding and Spawning Success

We recovered enough PIT-tagged salmon in 2012 from the NFMF to make a comparison between the two treatment groups at Dexter. Fish held at Willamette Hatchery in 2012 were collected concurrently with fish that were immediately outplanted. We also PIT and Floy-tagged the fish at the Dexter Hatchery prior to transporting them to the Willamette Hatchery. We believed this would reduce the stress of being recaptured a second time at the hatchery (as was done in past years). Our best estimate of prespawn mortality in the hatchery-held group was 10% (1 of 10 females recovered on the spawning grounds) with a worst case scenario of 26.3% based on known mortalities and unrecovered fish in the pond. The 'best estimate' measure was the same prespawn mortality rate (10%) observed for PIT-tagged fish that were immediately outplanted into the NFMF. Thus, the available data suggest that the holding strategy was neutrally beneficial at best in 2012. Moreover, the cool conditions and relatively low prespawn mortality rate observed in the NFMF suggest the potential benefit of hatchery holding in 2012 was low relative to other years with higher temperatures. While known mortalities at the hatchery were low (2 out of 95 fish released into the holding pond) the number of unrecovered fish (22/95) was problematic. Several explanations are possible, including tag loss during transport or at the hatchery, mortalities occurring but carcasses not being recovered, escape from the hatchery, or tags not being identified when fish were being loaded for outplanting. A more rigorous approach to handling and accounting for tagged fish during holding and outplanting will be necessary in future evaluations to accurately separate mortality in the hatchery from missed detections or tag loss.

Fall Creek Reservoir and Foster Reservoir Releases

Radio- and PIT-tagged fish were released in Fall Creek reservoir for the second time in 2012. We hypothesized that fish would use the cooler water in the reservoir as a hypolimnetic thermal refuge before entering Fall Creek when temperatures were suitable for spawning. However, in both 2011 and 2012 adult Chinook salmon moved into Fall Creek on the same day of release. This was not surprising because temperatures in Fall Creek were less than 20 degrees throughout the 2011 and 2012 migration seasons and thus the reservoir probably was not a thermal refuge. However, these releases were valuable because they demonstrated adults released into the reservoir were able to return to Fall Creek and spawn (though we note that the reservoir release site was near the head of reservoir). Releases lower in the reservoir and during a warm year could better establish whether such a practice would be beneficial by reducing transport distances and times, and improve survival to spawning.

The 2011-2012 Fall Creek reservoir releases also suggested a potential application of releases in other reservoirs with multiple tributary spawning populations. Release into a reservoir would allow unmarked (natural-origin) adults collected below dams to select and home to their natal tributary. Thus in 2012, we conducted reservoir and in-stream releases at Foster Dam to evaluate the use of reservoir release for both thermal and homing benefits. In contrast to the relatively short residence times (< 1 d) in Fall Creek reservoir, the typical residence time in Foster reservoir ranged from 3 to 8 days. Telemetry records also indicate that there was some evidence for tributary selection, including fish that made multiple trips between receiver sites. While these behaviors suggest natal site selection, this could not be confirmed because no fish were of known origin. Indeed, there is speculation that most of the natural origin fish were produced below Foster Dam, and thus wandering behavior between the South and Middle forks and long reservoir residency times may the result of a lack of natal homing cues above the dam.

Management Implications

The apparent impact that water temperatures had on spawning success across study years suggests that strategies that minimize exposures to high temperatures in years with above average temperatures should be considered to improve survival of outplanted fish. Development of structured management plans for years with different anticipated river conditions could be used to ensure minimum impacts to outplanted fish. Without the ability to directly manipulate water temperatures in the river above impoundments, managers may have to manipulate the timing or location of outplanting, or use cool water holding during summer.

If fish that die pre-spawning do so because of conditions in the Willamette River 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. However, we note that there are potentially serious concerns with extended holding that need to be considered before implementation, including transmission of disease, 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 outplanting may affect prespawn mortality rate. The relatively high prespawn mortality in the cool NFMF compared to Fall Creek in cool years suggests differences in experience prior to outplanting between populations may contribute to prespawn mortality in the NFMF. Potential factors include tailrace residence time, collection density, physical differences in the collection and trap facilities, handling procedures including differences in anesthetics, and any differences in transport protocols (densities, travel times, tank structure and conditions, etc.). However, salmon returning the Middle Fork Willamette tributaries have the longest travel distances and may already be physiologically stressed when they arrive at Fall Creek and Dexter dams which may significantly affect their survival. The short movements of adults prior to spawning in the NFMF relative to Fall Creek suggest that habitat conditions within the NFMF are not limiting near the release site in the NFMF. Again, experimental tests of alternative collection and handling protocols could identify causative agents and effective management strategies.

Demonstrating causal links between prespawn mortality and mechanism(s) (e.g., disease expression or energy) could provide guidance and support for other recovery 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 and the companion 2012 OSU report on disease). 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. The possibility of managing water temperatures below the dams during the spring Chinook migration to reduce stress, disease and reduce prespawning mortality should be considered. Active management of temperature regime has been successful below Lost Creek reservoir on the Rogue River (ODFW 1991) and below Dworshak Dam on the Clearwater-Snake rivers (Clabough et al. 2007). Successful management of adults 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 fish. Continued monitoring allows managers to have a suite of strategies to address prespawn mortality and population fitness in the face of varying river conditions and dam operations in future years.

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