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IDAHO COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT

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, 2011

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Department of Fish and Wildlife Resources
University of Idaho, Moscow, ID 83844-1136

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

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Executive Summary

In recent years, high percentages (80-90%) of adult Chinook salmon transported above dams in some Willamette River tributaries have died prior to spawning. In 2011, 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. The research occurred in the Middle Fork Willamette River sub-basin and was a continuation of projects completed in 2008 through 2010.

A total of 200 Chinook salmon were sampled at Fall Creek Dam in 2011. Fish were collected, assessed for energetic condition, PIT-tagged and/or radio-tagged, and then transported above the dam and allowed to spawn. A total of 49 of the outplanted salmon were recovered during Fall Creek spawning ground surveys, a recapture rate of 24.5%. Prespawn mortality estimates were 15% for PIT-tagged fish and 18% for radio-tagged fish. Fall Creek water temperatures in 2011 were higher than recorded in 2008, but lower than in 2009 and 2010. Daily mean temperature at the release site only exceeded 20°C on August 16th and 17th.

A total of 259 Chinook salmon were sampled at Dexter Dam, with 180 immediately outplanted into the North Fork Middle Fork Willamette River (NFMF) and 79 transported to Willamette Hatchery; 72 of the 79 were later outplanted. Overall prespawn mortality of NFMF outplants was relatively low and was estimated to be 10.3% and was similar between the immediate outplant (10%) and hatchery-held (11.1%) groups. Holding in the hatchery did not appear to reduce prespawn mortality. 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 transportation effects, overall fish condition effects and experience prior to collection, and density-dependent factors including disease and parasites.

In 2011, a subsample of radio- and PIT-tagged fish \( n_{\text{radio}} = 18 \) and \( n_{\text{PIT}} = 1 \) were released in Fall Creek reservoir to determine if the opportunity for cool water holding during the summer would improve survival. Chinook salmon in both release groups remained in the reservoir less than eight hours on average 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 during 2011. A single fish released in the reservoir was recovered on the spawning grounds and was scored a prespawn mortality. 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.

Results from our on-going 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 mortality; 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 Coastal 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) 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.

The migration corridors of many rivers in the WVP 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 indirectly 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 consumption rate 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, including environmental stressors, maturation status, disease, parasites, and initial energetic condition. Adults were collected at Dexter and Fall Creek dams, assessed and tagged, and released above the dams into spawning habitats. A subsample of adults was also released in Fall Creek reservoir. In 2011, 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 from Salmon Creek would decrease prespawn mortality rate upon release into spawning habitats. We released a small number of adults to Fall Creek Reservoir to evaluate whether these adults would successfully spawn in Fall Creek. 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. 2012). 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.
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 to reservoirs during warm summer months with a pilot-scale study at Fall Creek Reservoir.

Methods

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. 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. 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, they were sorted and loaded into a hauling truck for transportation to either WH or to release above the dams into the North Fork of the Middle Fork of the Willamette River (NFMF). 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 above the Dexter and Lookout Point Dams for natural spawning.

To study the effects of 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 2011. 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 both Fall Creek and the NFMF were 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 CO₂ 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. 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 both 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 that held at Willamette Hatchery 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 2011 (Fall Creek: \( n = 75 \); NFMF: \( n = 71 \)). A 3-volt transmitter (Lotek Wireless Inc., New Market, Ontario; MCFT-3A, 43 mm \( \times \) 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 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.
Proximate Analysis

A small sub-sample of fish was lethally sampled 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 4 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 °C for 12 hours and reweighing (AOAC 1965; Craig et al. 1978). The percent moisture in the samples was obtained by placing a weighed sample in a freeze drier at -40°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 2011 were also collected from fish tagged at Willamette Falls and compared with readings from fish tagged at Fall Creek and the Dexter Dam trap.

**Temperature Monitoring**

Temperature recorders were installed in 2011 at a total of eight locations in Fall Creek and the NFMF Willamette River. In Fall Creek, loggers were located at the release site (rmk 505.4), the bridge near Johnny Creek (rmk 30.6), near the mouth of Portland Creek (rmk 513), and at the unnamed falls that act as a fish barrier (rmk 529.6). In the NFMF Willamette River, loggers were placed at the release site (rmk 557.9), below the bridge near Kiaharie campground (rmk 565.4), at the forest road 1944 bridge (rmk 572.5), and above Skookum Creek (rmk 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 sealed in parafilm 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 Oregon State University, and tissue samples were collected for histology.
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). Survival to the first day of spawning activity was also used in analyses as a metric of reproductive success because the proportion of remaining gametes could not be reliably estimated in most males or in some carcasses that had been scavenged. Multi-model selection (Burnham and Anderson 2002), including univariate and fifteen multiple logistic regression models with adult fate (spawned, prespawn mortality) as the dependent variable were used to evaluate potential correlates with prespawn mortality when sample size was adequate \(n \geq 30\). Predictors included sex, overall physical condition score, tag date, sex, temperature at release site on tag date, estimated standardized lipid, estimated gross somatic energy, mideye to hypural length, hump height, depth at anus, breadth at anus, fork length, mass, and \(K = \text{Condition Factor (}10^{5}\times W/L^3\).\)

Results

Tagging

*Fall Creek*

Tagging occurred from 19 May to 26 September, 2011. A total of 200 fish (94 females, 104 males, 2 unknown) were PIT tagged, and 75 of these were also radio-tagged (Figure 4). Tagging was representative of the overall timing of the run, which peaked in early June (Figure 5). All fish transported above the dam were non-adipose clipped fish. Although 16 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 2011 was 2.2, mean fork length was 75.7 cm, mean weight was 5.0 kg, and mean lipid percentage was 3.2% (Table 1).
Figure 4. Numbers of adult Chinook salmon tagged in 2011. All fish at Fall Creek were immediately outplanted above Fall Creek Dam (top panel). On the bottom panel, black bars represent fish transported to Willamette Fish Hatchery and held until outplanting on 30 August and gray bars represent fish immediately outplanted to the NFMF on the date of tagging. Open bar on bottom panel represents number of hatchery-held fish outplanted to the NFMF on 30 August.
Figure 5. Distributions of Chinook salmon that were (black bars) and were not (gray bars) tagged at Fall Creek trap.

Table 1. Adult Chinook salmon size, lipid content, and condition metrics for fish sampled at Fall Creek trap in 2011. 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.

<table>
<thead>
<tr>
<th>Fall Creek (n = 200)</th>
<th>Fork Length (cm)</th>
<th>Weight (kg)</th>
<th>MeH (cm)</th>
<th>Da (cm)</th>
<th>Ba (cm)</th>
<th>HH (cm)</th>
<th>% Lipid</th>
<th>Condition Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>75.7</td>
<td>5.0</td>
<td>64.1</td>
<td>12.1</td>
<td>6.0</td>
<td>8.1</td>
<td>3.2</td>
<td>2.2</td>
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<tr>
<td>St. Deviation</td>
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<td>5.9</td>
<td>1.4</td>
<td>1.1</td>
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<tr>
<td>Max</td>
<td>97</td>
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<td>79.0</td>
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<td>11.1</td>
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</tr>
<tr>
<td>Min</td>
<td>59</td>
<td>2.0</td>
<td>49.0</td>
<td>8.4</td>
<td>1.4</td>
<td>5.2</td>
<td>0.52</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Individual lipid concentrations as estimated with the Fatmeter were poorly correlated with the values estimated from proximate analysis taken from lethally sampled adults (adj. $R^2 = 0.168$, $P = 0.072$, $N = 15$ see Proximate Analysis section below). Mean estimated standardized lipid content of tagged adults arriving to Fall Creek trap was similar to lipid estimated for adults at Willamette Falls and decreased through the 2011 season (Figure 6). A similar decline in
estimated lipid at the time of arrival to Fall Creek Dam trap through the migration season was observed in 2008-2010 (Figure 7).

Figure 6. Weekly distributions of standardized Fatmeter results for Chinook salmon tagged at Fall Creek trap in 2011. 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.
Figure 7. Standardized fatmeter percentages for all fish tagged based on the date of arrival at Fall Creek Dam. Study year is indicated.
Middle Fork Willamette

In 2011, tagging of the immediate outplant group began on 26 May and continued until 24 August. This group included 180 fish (91 males, 89 females), and had mean length of 75.8 cm, mean weight of 4.9 kg, mean condition score of 2.33, and mean standardized lipid percentage of 3.1% (Table 3). Adult salmon held at WH before outplanting were collected and tagged on five separate days from 15 June to 18 August in accordance with ODFW’s operation of the Dexter trap for collection of broodstock (Figure 4). This group had 79 fish (42 males, 37 females). The mean condition score was 2.4, mean fork length was 75.0 cm, mean weight was 4.7 kg, and mean standardized lipid percentage was 4.0% (Table 2).

On 30 August, 2011, sixty adults of the 79 adults held at WH were recaptured and outplanted (7 were confirmed mortalities and an additional 12 were not recaptured). Mean lipid content at recollection was lower than at initial collection and was 1.97% including 13 (22%) individuals with lipid percentages greater than 4.0% on reassessment (Figure 8). Mean fatmeter readings from fish tagged at the Dexter Dam trap were lower than those for fish tagged at Willamette Falls and tended to decline throughout the season until the last three tagging events where estimated percentages increased (Figure 9).

Table 2. Adult Chinook salmon size, lipid content, and condition metrics for fish collected and sampled at Dexter trap and held at Willamette Hatchery in 2011. 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.

<table>
<thead>
<tr>
<th>Dexter (n = 79)</th>
<th>Fork Length (cm)</th>
<th>Weight (kg)</th>
<th>MeH (cm)</th>
<th>Da (cm)</th>
<th>Ba (cm)</th>
<th>HH (cm)</th>
<th>% Lipid</th>
<th>Condition Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>75.0</td>
<td>4.7</td>
<td>63.3</td>
<td>11.5</td>
<td>5.9</td>
<td>8.0</td>
<td>4.0</td>
<td>2.4</td>
</tr>
<tr>
<td>St. Deviation</td>
<td>6.8</td>
<td>1.4</td>
<td>5.9</td>
<td>1.5</td>
<td>1.0</td>
<td>1.2</td>
<td>5.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Max</td>
<td>89.0</td>
<td>8.4</td>
<td>77.0</td>
<td>15.0</td>
<td>8.2</td>
<td>12.3</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>55.0</td>
<td>1.9</td>
<td>48.0</td>
<td>7.5</td>
<td>3.6</td>
<td>5.4</td>
<td>0.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table 3. Adult Chinook salmon size, lipid content, and condition metrics for fish collected and sampled at Dexter trap and then immediately outplanted in 2011. 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.

<table>
<thead>
<tr>
<th>Dexter (n = 180)</th>
<th>Fork Length (cm)</th>
<th>Weight (kg)</th>
<th>MeH (cm)</th>
<th>Da (cm)</th>
<th>Ba (cm)</th>
<th>HH (cm)</th>
<th>% Lipid</th>
<th>Condition Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>75.8</td>
<td>4.9</td>
<td>63.7</td>
<td>11.6</td>
<td>5.9</td>
<td>7.9</td>
<td>4.5</td>
<td>2.3</td>
</tr>
<tr>
<td>St. Deviation</td>
<td>7.4</td>
<td>1.4</td>
<td>6.4</td>
<td>1.4</td>
<td>0.8</td>
<td>0.9</td>
<td>6.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Max</td>
<td>93.0</td>
<td>9.1</td>
<td>78.0</td>
<td>15.3</td>
<td>7.7</td>
<td>10.0</td>
<td>31.8</td>
<td>3</td>
</tr>
<tr>
<td>Min</td>
<td>55.0</td>
<td>1.8</td>
<td>46.0</td>
<td>7.8</td>
<td>3.7</td>
<td>5.4</td>
<td>0.0</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 8. Distributions of standardized Fatmeter results for Chinook salmon held at Willamette Hatchery and then outplanted in 2011. Tagging data were collected on the dates fish were tagged, and outplant data were for when fish were reassessed and outplanted on 30 August. 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).
Figure 9. Weekly distributions of standardized Fatmeter results for Chinook salmon tagged at Dexter trap in 2011. 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 2011, proximate analysis was performed on 15 salmon at Dexter (9 males and 6 females). No fish were sampled from Fall Creek (Table 4) because of concerns over lethally sampling unclipped adults from this location. Lethal takes for proximate analysis were conducted on 26 May ($n = 7$), 20 July ($n = 4$) and 27 September ($n = 4$). The average muscle lipid level was 4.7% (Table 4) and ranged from 1.0-9.6%. Females had mean gonadal lipid compositions of 11.4%, while males were much lower averaging 1.3% (Table 5). This was expected because eggs have high lipid content. Males need less energy for gamete production, but potentially store more energy in muscles than females for use in spawning activity, which was supported by our results.
Table 4. Mean tissue composition of Chinook salmon collected at Dexter and used in proximate analysis in 2011.

<table>
<thead>
<tr>
<th>Tissue</th>
<th>% Moisture</th>
<th>% Crude Lipid</th>
<th>% Total Ash</th>
<th>% Protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonads</td>
<td>70.55</td>
<td>5.33</td>
<td>2.77</td>
<td>21.36</td>
</tr>
<tr>
<td>Muscle</td>
<td>74.42</td>
<td>4.72</td>
<td>1.12</td>
<td>19.73</td>
</tr>
<tr>
<td>Skin</td>
<td>59.44</td>
<td>10.67</td>
<td>1.05</td>
<td>28.84</td>
</tr>
<tr>
<td>Viscera</td>
<td>78.80</td>
<td>2.49</td>
<td>1.50</td>
<td>17.20</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Tissue</th>
<th>% Moisture</th>
<th>% Crude Fat</th>
<th>% Total Ash</th>
<th>% Protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males (n = 9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gonads</td>
<td>78.3</td>
<td>1.3</td>
<td>3.5</td>
<td>16.9</td>
</tr>
<tr>
<td>Muscle</td>
<td>75.7</td>
<td>4.0</td>
<td>1.1</td>
<td>19.2</td>
</tr>
<tr>
<td>Skin</td>
<td>60.3</td>
<td>8.0</td>
<td>1.1</td>
<td>30.6</td>
</tr>
<tr>
<td>Viscera</td>
<td>79.3</td>
<td>2.5</td>
<td>1.5</td>
<td>16.7</td>
</tr>
<tr>
<td>Females (n = 6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gonads</td>
<td>58.9</td>
<td>11.4</td>
<td>1.7</td>
<td>28.0</td>
</tr>
<tr>
<td>Muscle</td>
<td>72.5</td>
<td>5.9</td>
<td>1.2</td>
<td>20.5</td>
</tr>
<tr>
<td>Skin</td>
<td>58.2</td>
<td>14.7</td>
<td>1.0</td>
<td>26.2</td>
</tr>
<tr>
<td>Viscera</td>
<td>78.1</td>
<td>2.5</td>
<td>1.5</td>
<td>17.9</td>
</tr>
</tbody>
</table>

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 for in 2009 and 2010, years with the highest sample sizes (Table 6).

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), which standardizes energy content for differences in fish size. We found a modest positive relationship between Fatmeter readings and energy density in 2011 (Figure 11). 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 individual values or estimate levels among years.
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.

<table>
<thead>
<tr>
<th>Year</th>
<th>n</th>
<th>Intercept</th>
<th>Slope</th>
<th>P</th>
<th>adj $r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>15</td>
<td>1.854</td>
<td>0.46</td>
<td>0.072</td>
<td>0.168</td>
</tr>
<tr>
<td>2010</td>
<td>30</td>
<td>0.703</td>
<td>0.413</td>
<td>&lt;0.001</td>
<td>0.647</td>
</tr>
<tr>
<td>2009</td>
<td>29</td>
<td>3.097</td>
<td>0.758</td>
<td>&lt;0.001</td>
<td>0.375</td>
</tr>
<tr>
<td>2008</td>
<td>11</td>
<td>3.738</td>
<td>0.387</td>
<td>0.090</td>
<td>0.206</td>
</tr>
</tbody>
</table>

Figure 11. Relationship of Chinook salmon energy density (kJ/kg) to log$_e$ transformed raw Fatmeter percentages. Energy density data were calculated from proximate analysis.
River Conditions

Temperature loggers were deployed to record ambient temperatures at multiple sites in Fall Creek and the NFMF Willamette River during 2009-2011 (Figure 12). The 2011 migration year was characterized by above average flows and generally cooler temperatures through June. Daily mean temperatures at the release site in Fall Creek only exceeded 20°C for four days in late August. 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 were cooler than observed in 2009 and 2010. Temperatures were increased at downstream locations and were highest at the release site during 2009-2011. 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 2009-2011 near the release site (rkm 505.4).
In the NFMF, daily means exceeded 15°C at the release site in early July and fluctuated between 15 and 19°C from July through August (Figure 14). NFMF temperatures were generally near or below the Chinook salmon thermal preferendum. Temperatures increased 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 5.0°C lower than in Fall Creek at the release sites during the July and August holding period. Peak water temperature recorded by USGS gauges occurred on the same day (26 August) in Fall Creek (20.7°C) and the NFMF (19.9°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 2011 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 missing loggers.
Movement and Distribution

Radio tracking was conducted approximately once a week through the 2011 migration season. As in previous years, Chinook salmon movements differed in the NFMF Willamette River compared to Fall Creek in that we observed less movement immediately after release in the NFMF. Several factors may have contributed to the behavioral difference observed between locations. The release site for the NFMF was in a reach with ideal spawning habitat, and fish were released much later in the spawning season than they were in Fall Creek due to the broodstock collection protocols at Dexter Dam/WH. Additionally, there are two large holding pools immediately upstream and downstream of the NFMF release site. Finally, temperatures at the release site were generally cooler in the NFMF than in Fall Creek where upstream locations had more suitable temperatures during warm periods. Overall, distributions of radio-tracked fish were similar to those of carcass recoveries (see Figures 18 and 22).

Temperatures recorded on internal temperature loggers paralleled in-stream temperature data when matched with mobile tracking locations (see Figures 16 and 17 for two examples), suggesting adults could behaviorally thermoregulate by moving longitudinally, particularly in Fall Creek where temperatures were consistently cooler. We found no evidence that adults used small cool-water refugia, e.g., that adult body temperatures differed from water temperatures recorded on nearby loggers.
Figure 16. Internal temperature recorder data collected after outplanting in Fall Creek of the Chinook salmon with radio transmitter 1-117. The blue line shows the hour body temperature including diel fluctuations paralleling hour fluctuations in stream temperature (not shown). Mean daily fish body temperature is given by the black line. Daily means of the in-stream temperature logger sites are shown with corresponding mobile tracking locations on the secondary y-axis. Green line indicates fish position as obtained by mobile tracking. At release, mean body temperature was similar to the release site water temperature and then decreased relative to temperature at the release site as the salmon moved upstream. For instance, mean body temperature nearly identical to temperatures recorded at Fish Barrier during early July during a period when the adult was located a short distance downstream. Similarly, body temperature was intermediate to that recorded at Portland Creek and Fish Barrier during early September.
Figure 17. Internal temperature recorder data collected after outplanting in NFMF of the Chinook salmon with radio transmitter 1-90. The light blue line background shows hourly body temperature, while the black line is the daily mean body temperature. Daily means of the in-stream temperature logger sites are shown with corresponding locations on the secondary y-axis. Green line indicates fish position as obtained by mobile tracking. At release, body temperature was similar to the release site and this individual remained between the release site and Kiahanie until spawning. The body temperature was similar to water temperatures at the nearest logger available site (Kiahanie; the release site logger was not recovered during 2011)) and the salmon did not utilize cooler temperatures found upstream, nor was there evidence that the salmon used small cool-water refugia.
Spawning Ground Surveys and Spawning Success

Fall Creek

Carcasses were recovered in Fall Creek from 21 July until 7 October. The recovery rate was 21.6% of the PIT-tagged fish and 29.3% of the double-tagged fish (PIT and radio). As we have observed in previous years, a number of carcasses had been scavenged prior to recovery, and it is possible that PIT tags were lost from fish before they were scanned. This hypothesis was supported by the observation that in 2011 the proportion of released adults with PIT tags (34% of those outplanted) was higher than the proportion of carcasses with PIT-tags (21.6%). Carcasses were primarily scavenged by turkey vultures and bald eagles during the day (based on observations) and likely by raccoons at night (based on scat).

Prespawn mortality estimates in Fall Creek were the second lowest during the 2008-2011 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). Four of the 27 recovered PIT-tagged carcasses were unsuccessful spawners, for a prespawn mortality estimate of 14.8% (Table 7). Prespawn mortality estimates were 18.2% for radio-tagged fish only (n = 4 of 22 recoveries), and 33.3% (n = 24 of 128 recoveries) for untagged carcasses.

Table 7. Final estimated fates of Chinook salmon that were PIT-tagged or double-tagged (PIT and radio-tagged) in Fall Creek, 2008-2011. Double-tagged fish were only included in the PIT-tagged numbers if the whole carcass was recovered, and not just the radio tag in 2008-2010. Double-tagged and radio-tagged fish were enumerated separately in 2011.

<table>
<thead>
<tr>
<th>Year</th>
<th>Group</th>
<th># released</th>
<th># recovered</th>
<th>% recovered</th>
<th>%PSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>PIT</td>
<td>195</td>
<td>32</td>
<td>29.0</td>
<td>9.4</td>
</tr>
<tr>
<td>2009</td>
<td>PIT</td>
<td>175</td>
<td>33</td>
<td>16.5</td>
<td>84.8</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>25</td>
<td>21</td>
<td>84.0</td>
<td>90.5</td>
</tr>
<tr>
<td>2010</td>
<td>PIT</td>
<td>125</td>
<td>62</td>
<td>31</td>
<td>41.9</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>75</td>
<td>54</td>
<td>72</td>
<td>63.0</td>
</tr>
<tr>
<td>2011</td>
<td>PIT</td>
<td>125</td>
<td>27</td>
<td>21.6</td>
<td>14.8</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>75</td>
<td>22</td>
<td>29.3</td>
<td>18.2</td>
</tr>
<tr>
<td></td>
<td>Unmarked</td>
<td>128</td>
<td>24</td>
<td>18.8</td>
<td>33.3</td>
</tr>
</tbody>
</table>
The final distribution of PIT-tagged fish indicated that the majority of spawning occurred upstream from the 1828 Bridge (rkm 519.4; Figure 18). All prespawn mortalities were recovered upstream from the release site. The distribution of successful spawners in Figure 18 represents the primary spawning habitat in Fall Creek. Fish outplanted: redd ratios were 3.1, 9.5, 7.9 and 7.2 for 2008, 2009, 2010 and 2011 respectively.

Prespawn mortality was clearly associated with the date of tagging (Figure 18). 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 barely exceeded 20° in Fall Creek in 2011 (Figure 19).

Figure 18. Distribution of PIT-tagged Chinook salmon carcasses that were recovered in Fall Creek spawning ground surveys in 2011, including their spawning status.
Figure 19. Release, holding period and date of last observation for Chinook salmon released in Fall Creek in 2011 by fate. Each horizontal bar represents one PIT-tagged fish from the tag date to the recovery date, ranked by release date. Fish that survived to the first spawning day are in solid lines while prespawn mortalities are in dashed. Release site temperatures are plotted for reference.
Figure 20. Release, holding period and date of last observation for Chinook salmon released in Fall Creek in 2011 by fate as in Figure 19, ranked by recovery date. Fate was not as clearly associated with temperatures in 2011.

We also tested for associations between fate and a suite of factors potentially related to prespawn mortality at Fall Creek using logistic regression and multi-model selection techniques; sample size was inadequate for a similar analysis of the NFMF. In univariate models, sex, standardized Fatmeter percentage, tag date, and gross somatic energy were not significantly associated with prespawn mortality ($P > 0.05$). We evaluated a suite of fifteen multiple logistic regression models and compared fit using AIC. However, none of these models provided evidence of associations between prespawn mortality and predictors, perhaps because of the relatively low sample size.
Figure 21. Weekly mean standardized lipid levels of Fall Creek Chinook salmon as calculated from Fatmeter readings collected at the time of tagging in 2011, Fall Creek Dam. Circles represent the lipid percentage for successfully spawned fish, crosses represent pre-spawn 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 21 July to 5 October from three groups of tagged adults. The recovery rate for adults tagged only with a PIT-tag and released immediately was 6.4% (Table 8), a proportion substantially lower than the recovery rate for unmarked adults, suggesting some loss of PIT tags prior to examination. A higher proportion of double-tagged adults were recovered (15.5%). Eight of 72 adults released after holding at Willamette Hatchery were recovered (11.1%).

A total of five tagged adults of the 26 recovered tagged adults were scored as prespawn mortalities, with none, two and two, from the PIT-only, double-tag, and hatchery held groups, respectively. Prespawn mortality of radio-tagged fish in the NFMF was estimated to be 27.6% while none of the seven PIT-tagged carcasses was considered a prespawn mortality (Table 11). The overall prespawn mortality rate for both immediate outplant samples was 11.1%. The estimate for the hatchery-held group was 25.0%. While sample sizes of recovered adults were low in 2011, the rates for all groups were among the lowest from the three study years on the NFMF.

In the NFMF, spawning activity was concentrated in a 10 km reach just upstream of the release site (Figure 22) a pattern similar to spawning distributions observed in previous years (Mann et al. 2011). We recovered a single carcass at 23 km upstream from the release site at ~rkm 580. A total of 115 redds were counted in 2011 (11.9 fish:red), and all were upstream from the release site.

Table 8. Final fates of PIT- and radio-tagged subsets of the Chinook salmon outplanted in the NFMF Willamette River. Double-tagged fish were only included in the PIT tagged numbers if the whole carcass was recovered, and not just the radio tag in 2008-2010. Double-tagged and radio-tagged fish were separated in 2011. Hatchery-held and immediate-outplanted fish are combined in 2008-2010 but separated in 2011 (DEX for immediate outplant and HH for hatchery-held fish, respectively) in this table.

<table>
<thead>
<tr>
<th>Year</th>
<th>Group</th>
<th># released</th>
<th># recovered</th>
<th>% recovered</th>
<th>%PSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>PIT</td>
<td>209</td>
<td>10</td>
<td>4.8</td>
<td>40.0</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>12</td>
<td>11</td>
<td>91.7</td>
<td>27.3</td>
</tr>
<tr>
<td>2010</td>
<td>PIT</td>
<td>272</td>
<td>53</td>
<td>19.5</td>
<td>45.3</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>61</td>
<td>41</td>
<td>67.2</td>
<td>61.0</td>
</tr>
<tr>
<td>2011 (DEX)</td>
<td>PIT</td>
<td>109</td>
<td>7</td>
<td>6.4</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>71</td>
<td>11</td>
<td>15.5</td>
<td>27.3</td>
</tr>
<tr>
<td></td>
<td>Unmarked</td>
<td>1366</td>
<td>186</td>
<td>13.6</td>
<td>22.6</td>
</tr>
<tr>
<td>2011 (HH)</td>
<td>PIT</td>
<td>72</td>
<td>8</td>
<td>11.1</td>
<td>25.0</td>
</tr>
</tbody>
</table>
Figure 22. Distribution of PIT-tagged (including radio tagged) Chinook salmon carcasses that were recovered in the NFMF Willamette River spawning ground surveys in 2011, including their spawning status.

**Fall Creek Reservoir Releases**

Nineteen salmon (18 radio- and 1 PIT-tagged) were released into Fall Creek Reservoir on three dates (13 June, \( n = 12 \); 25 July, \( n = 3 \); 11 August, \( n = 4 \)). Releases times were 10:15 AM on 13 June, 9:30 AM on 25 July and 9:15 AM on 11 August. Seventeen of the 18 (94%) radio-tagged fish were recorded upstream from the receiver above the reservoir. However, only one of the radio-tagged fish was recovered on the spawning grounds (it was considered a prespawn mortality). The one PIT-tagged fish was not recovered.

Median reservoir residence time was less than a day for the June and combined July-August groups. Residence time was five hours longer (8.4 h) for the June release group compared to the July-August release groups (3.4 h; Figure 23).
Figure 23. Reservoir residence times of radio-tagged adult Chinook salmon released into Fall Creek reservoir in 2011. Fish were released on 13 June, 25 July, and 11 August. One radio-tagged salmon passed the Fall Creek receiver without being recorded and one fish was never detected after release. Box plots represent median (solid line), 25th and 75th percentiles (ends of boxes), and 10th and 90th percentiles (whiskers).

Discussion

Summary

The primary study objectives were to estimate prespawning mortality rates in the two populations, determine relationships between prespawn mortality and potential causative agents, to evaluate the efficacy of hatchery-holding prior to outplanting and to 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 2011, though low sample size of recovered adults hindered some analyses. Nonetheless, several important results were obtained and the data will be valuable for future multi-year analyses.
Sampling at Fall Creek was more representative of the timing of the run than sampling at Dexter. This was due to the operations of ODFW-operated trap as part of the broodstock collections for Willamette Hatchery. With the assistance of ODFW the collection of adults at Dexter Dam were the most representative to date because the trap began operating on 26 May, approximately three weeks earlier than in previous years with collections occurring about every two to three weeks thereafter until the third week in August. Despite the earlier operation of the trap, data from a concurrent study revealed that radio-tagged adults spent approximately three to seven weeks in the Dexter Dam tailrace prior to collection (Jepson et al. 2012). Future operations that allowed adults to enter the trap throughout the run season could reduce tailrace residence time and densities in the trap during collection of broodstock and adults for outplanting to the NFMF.

Sampling at Fall Creek Dam better matched run timing. At Fall Creek Dam, run timing displayed a typical pattern with one distinct peak in early June followed by a smaller peak in the fall. In 2010 three distinct peaks were observed including peaks on 17 May, 21 June, and 19 August. The lack of fish in late May and early June in 2010 was related to cold water temperature and high volume discharge from Fall Creek Dam, which deterred fish movement upstream. Similar temperature and discharge patterns occurred in 2011 but did not appear to change the typical run timing.

Recovery rates for PIT tagged fish in 2011 were lower than in previous years. Although the overall effort was less than in 2010 (due to personnel shortages) it was comparable to the 2009 and 2008 study 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 to increase the stream area covered. Use of radio-tags increased recovery rate in both drainages in 2011, particularly the larger NFMF. Increased personnel and/or increased survey frequency will be necessary in order to substantially increase tag recovery rates and increased effort is planned for 2012.

Prespawn mortality rates in Fall Creek observed in 2011 were substantially lower than in 2009 and 2010. Prespawning mortality estimates were about 15-18% for PIT- and radio-tagged fish compared to 40-90% in 2009 and 2010. Overall, the NFMF prespawn mortality was similar or lower in 2011 than in 2009 and 2010. Prespawn mortality rates for radio-tagged fish in 2011 was the same as in 2009 (27%) but substantially lower than observed in 2010 (61%). No PIT-tagged fish were classified as prespawn mortalities in 2011 compared to 85% in 2009 and 42% in 2010. Moreover, the rates for 2011 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 2011 and other years suggest that prespawn mortality rates were slightly higher in tagged versus untagged and double-tagged versus PIT-tagged in Fall Creek, potentially 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. No consistent pattern was observed in the NFMF among years. The trade-offs between the potential for negative tagging effects and benefits of telemetry-based movement data should be carefully considered in the design of future studies.
As in 2010, prespawn mortality in 2011 were observed 1 to 2 days following a release event at the NFMF (22 fish dead before first redd, 8 on same day as transport). These were 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. 2012) rather than 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 CO₂ for anesthetization. While CO₂ 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.

Similar to 2010, our qualitative observations suggested that poaching may have affected the survival of salmon outplanted above Fall Creek Dam in 2011. While we do not have direct evidence of poaching in 2011, 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 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.

**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 Distel 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 2011 was 3.2% and 4.0% 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 2011 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 fish collected at Willamette Falls were about 2-5% higher than those averaged across adults collected at Fall Creek or the Dexter Dam trap. This is not surprising because significant energy is required to migrate the more than 250 km from Willamette Falls to these upstream sites.
In contrast to 2010, there was no association between lipid levels and spawning success in 2011. The lack of relationship in 2011 may have been due to low sample size or a true lack of relationship. We did not observe a consistent relationship between lipid level and prespawn mortality at Fall Creek when accounting for arrival date (Figure 21), perhaps because water temperatures were cool and were generally below levels shown to have sub-lethal effects on migrating salmon (Richter and Kolmes 2005).

We did not observe a significant association between physical condition and spawning success in 2011, in contrast to earlier observations (e.g., Keefer et al. 2010). Because salmon were in generally good condition in 2011 (mean condition score = 2.2), there may not have been enough variability in the data to detect a condition effect. The mean condition in 2011 was lower than in 2010 (mean = 2.5) and the same as in 2009 (mean = 2.2). However, because this index is somewhat subjective, 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 four study years, there was an association between annual prespawn mortality rate and annual summer temperatures, particularly in Fall Creek. In 2009, we observed prespawn mortality that directly coincided with increases in temperatures. The 2010 river conditions were cooler, although daily maximums exceeded 22°C, which are still within the range that are considered deleterious to adult Chinook salmon (Richter and Kolmes 2005; Mann 2007). We observed lower mortality rates for fish migrating in May in 2010. In 2011, 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 exposed to lower overall temperatures because of the rapid movement upstream after release to relatively cool reaches and low temperatures 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 comparable levels of prespawn mortality in 2010 and 2011 between NFMF and Fall Creek, which averaged 4.5-5.0°C higher in July and August. 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, 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.

**Holding and Spawning Success**

We recovered enough PIT-tagged salmon in 2011 from the NFMF to make a comparison between the two treatment groups at Dexter. In contrast to previous years, fish held at Willamette Hatchery in 2011 were collected concurrently with fish that were immediately outplanted. Our best estimate of prespawn mortality in the hatchery-held group was 7.2% with a worst case scenario of 25% based on unrecovered fish in the pond. While the conservative
measure was lower, the worst case scenario estimate was similar to the prespawn mortality rates for immediately outplanted radio-tagged and unmarked fish (22% and 27%, respectively). Thus, the available data suggest that this strategy was neutral or beneficial in 2011. Importantly, the cool conditions and relatively low prespawn mortality rate observed in the NFMF suggest the potential benefit of hatchery holding in 2011 was low relative to other years with higher temperatures. There are a few additional caveats to consider when evaluating the costs and benefits of holding fish in 2011. First, mortality during holding was nearly 9% (7 out of 79 fish), similar to our best case prespawn mortality estimates for fish recovered on the spawning grounds. Mortalities during holding at the hatchery may be partially attributed to injuries or stress incurred during the additional handling required for tagging at the hatchery (operational constraints in 2011 required recapture of adults at the hatchery the day after collection and transport from Dexter Dam), and fish in holding pens often hit their heads against holding pen grates while attempting to avoid capture during tagging. Whether the observed mortality resulted from handling effects or was prespawn mortality unrelated to handling is unknown. A more appropriate approach would be to tag the fish to be held in the hatchery concurrently with the immediate outplant fish at the Dexter Dam trap, a protocol we plan to implement in 2012.

**Fall Creek Reservoir Releases**

Radio- and PIT-tagged fish were released in Fall Creek reservoir for the first time in 2011. 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, adult Chinook salmon in the three release groups moved into Fall Creek on the same day of release. This is not surprising because temperatures in Fall Creek were less than 20 degrees throughout the migration season and thus the reservoir probably was not a thermal refuge in 2011. However, the pilot was valuable because the releases demonstrated adults released to reservoir environments were able to return to Fall Creek and spawn (though we note that the reservoir release site was near the head of reservoir). An additional potential application of reservoir releases is for reservoirs with multiple tributary spawning populations. Release to the reservoir would allow unmarked (natural-origin) adults collected below dams to select and home to their natal tributary. In 2012, we propose to conduct paired reservoir and in-stream releases at Fall Creek and Foster Dam to more rigorously evaluate the use of reservoir release for thermal and homing benefits.

**Management Implications**

Prespawn mortality is a concern for management of listed WVP stocks because high prespawn mortality levels have been observed frequently in a number of populations (Beidler and Knapp 2005; Kenaston et al 2009; Keefer and Caudill 2010). Further, demographic modeling suggests that observed levels of prespawn mortality (e.g. > 50-70%) may strongly negatively affect population growth rates and hinder salmon recovery, even if juvenile survival is improved (Keefer et al. 2010). The importance of prespawn mortality to the dynamics and viability of tributary populations may increase if future climate change increases the rate of temperature-related mortality. An improved understanding of the relationship between adult mortality, population growth rate, and temperature is important given current climate predictions and uncertainty about the underlying mechanisms of prespawn mortality.
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 or summer climate 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.). 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.

Although there was indirect evidence of poaching or harassment in 2011, it is unknown to what degree these events affected salmon. Our 2009 and 2010 observations suggest that it may be significant in the study area, and particularly in Fall Creek. The lower impact on the NFMF was likely due to both the increased distance from major metropolitan areas and current fishing regulations, which limit anglers in the NFMF to flies only with barbless hooks. Balancing spawner protection with the negative effects of open access and multi-use recreation management goals will be challenging.

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 and is an on-going goal of this collaborative project (see Schreck et al. 2012a, b and companion 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. 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. Given the variable effect of each on prespawn mortality from year to year and the interactions between each of these factors, it is particularly important to continue to monitor all in the face of changing ocean conditions and
warming regional climate (e.g., Eaton and Scheller 1996; Mote et al. 2003). 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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