Technical Report 2012-1

Migratory Behavior, Run Timing, and Distribution of Radio-tagged Adult Spring Chinook Salmon in the Willamette River - 2011

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University of Idaho
Moscow, ID 83844-3141

For

U. S. Army, Corps of Engineers
Portland District

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Executive Summary

The objectives of this study were to determine the basic behavior, distribution, and migration success of adult spring Chinook salmon through the main stem Willamette River and to evaluate their exposure to potentially high water temperatures that may contribute to prespawn mortality. From 2 May through 8 July 2011, we intragastrically radio-tagged 150 Chinook salmon at Willamette Falls Dam and released them back into the fishway upstream from the trap. Almost all (97%) radio-tagged salmon also received an archival temperature logger. An additional 100 salmon were tagged with archival temperature loggers only. Run timing of the run-at-large and the radio-tagged sample was relatively late in 2011 compared to the ten year average and the late timing was associated with high flow and cool temperatures in 2011.

Approximately 25% (38/150) of the radio-tagged salmon had intact adipose fins (i.e., presumed wild origin) and ~75% (112/150) had clipped adipose fins (i.e., were of certain hatchery origin). Radio-tagged salmon received one of two handling treatments. Thirteen percent (19/150; unclipped only) received an experimental, eugenol-based anesthetic, AQUI-S®E. The remaining ~87% were tagged without anesthesia and with the use of a fish restraint device.

Of the 150 radio-tagged salmon, three (2%) regurgitated or lost their transmitters, 109 (73%) were last recorded or recaptured in spawning tributaries, and 38 (25%) were last detected at main stem sites. Twenty-one tagged salmon were last detected downstream from Willamette Falls (excluding adults last recorded in the Clackamas River) and all of them received the FRD treatment. Nineteen of these 21 fish were of hatchery origin. Of the 109 radio-tagged salmon last detected in tributaries, ten were last recorded in the Clackamas River, three were in the Molalla River, 50 were in the Santiam River, 29 were in the McKenzie River, and 17 were in the Middle Fork Willamette River at or near Dexter Dam.

Run composition varied seasonally for the 109 salmon last recorded in tributaries. Among salmon radio-tagged in May, 54% returned to the Santiam River and smaller percentages returned to the McKenzie River (20%), and the Middle Fork Willamette River (25%). Fish tagged in June and early July included salmon that returned to the Santiam (40%), McKenzie (25%), Clackamas (18%), Molalla (10%), and Middle Fork Willamette rivers (7%).

Migration rates through the main stem river for tagged salmon that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers averaged 22.3 km/day (s.d. = 10.5, n = 96). Main stem residence time was related to the distance from Willamette Falls to the tributary confluence with the main stem and varied from two to more than four weeks. Adults that were last recorded in the Santiam River spent 14 d in the main stem, on average, and those returning to the McKenzie and Middle Fork Willamette rivers spent an average of 25 and 32 days in the main stem, respectively. Few downstream movements were recorded for tagged salmon in the main stem or in tributaries. Evaluations of individual temperature histories from recovered archival
temperature tags suggest that few (~1%) tagged salmon experienced main stem or tributary temperatures > 20°C in 2011, which was consistent with the below average water temperatures.

Data from the system-wide migration study will be integrated with results from spring Chinook salmon studies in Fall Creek and the North Fork Middle Fork Willamette River to evaluate the potential contribution of main stem versus tributary factors to prespawn mortality. The data will also provide valuable baseline information on the relationship between upstream migration, Willamette Valley Project operations, and environmental conditions as they pertain to the implementation of the WVP Biological Opinion.

Acknowledgments

Many people assisted with the field work and data compilation for this report and its successful completion was made possible through their efforts. U. Idaho personnel included: Chuck Boggs, Travis Dick, Dan Joosten, Steve Lee, and George Naughton for performing the radiotagging of adult salmon, and Matt Knoff and Mark Morasch for downloading receivers. Oregon Department of Fish and Wildlife personnel that contributed to the success of the project included: Wayne Vandernaald, Cameron Sharpe, Todd Alsbury, Jeff Ziller, Tony Amandi, Muhammad Latif, Kelly Reis, Joy Vaughan, Shivonne Nesbit, Tom Friesen, Kirk Schroeder, and Craig Tinus. We thank Stephanie Burchfield and Kim Hatfield, NOAA, for their assistance with securing federal permits for the study. We are grateful to Bonnie Johnson, USFWS, for coordinating the use of AQUI-S®E under the Investigational New Animal Drug program. We also appreciate the contributions made by Tim Shibahara of the Portland Gas and Electric Company and Doug Drake of the Oregon Department of Environmental Quality. We thank the University of Idaho’s Institutional Animal Care and Use Committee for reviewing the animal procedures used in this study. This study was funded by the U.S. Army, Corps of Engineers (USACE), Portland District, with assistance provided by Rich Piaskowski and David Griffith.
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Introduction

Dams without upstream fish passage facilities, habitat loss, and a variety of other factors contributed to the decline and and ESA-listing of spring Chinook salmon (*Oncorhynchus tshawytscha*) in the upper Willamett River (NMFS 1999). In the last several decades, naturally-produced Chinook salmon and hatchery salmon spawning in the wild have experienced high prespawn mortality (PSM) in many Willamette River tributaries (Schroeder et al. 2007; Kenaston et al. 2009), and this mortality may be negatively affecting population recovery efforts (NMFS 2008). Recent research has indicated associations between water temperature in the Willamette River and its tributaries, Chinook salmon disease, and PSM rates (Keefer et al. 2010; Mann et al. 2011). However, the mechanisms responsible for these patterns remain unclear. More specifically, there are important information gaps regarding adult Chinook salmon behavior, disease exposure, temperature exposure, and survival in the main stem Willamette River migration corridor (Keefer and Caudill 2010; Mann et al. 2011).

The primary goal of this study was to gain information on the relationships between fish condition, upstream migration history, river environment, and spawning success/PSM of Chinook salmon from the Upper Willamette River. There were two study components. The first, which began in 2008, included collecting, evaluating, and tagging adult salmon in the Middle Fork Willamette River, outplanting them in tributaries to spawn naturally, and monitoring their spawning success (Mann et al. 2011; Naughton et al. 2012). The second study component, which was initiated in 2011 and is addressed in this report, included capture, assessment, and radio-tagging of adult Chinook salmon at Willamette Falls and then monitoring salmon during their upstream migration to spawning areas. This work builds upon main stem migration data collected in the early 1990s by Schreck et al. (1994).

Specific 2011 study objectives addressed in this report include: (1) data collection on energetic condition, disease status, and other adult Chinook salmon traits at Willamette Falls Dam; (2) monitoring radio-tagged salmon passage success at Willamette Falls Dam; (3) characterizing salmon migration rates and behaviors; (4) estimating population-specific run-timing metrics for salmon returning to spawning tributaries; (5) reconstruction of individual salmon thermal histories in the main stem Willamette River and in tributaries; and (6) assessing potential relationships among salmon condition, main stem behavior, thermal history, river environment, and prespawn mortality. Separate reports include summaries of research on adult Chinook salmon outplanted in the Middle Fork Willamette River basin (Naughton et al. 2012) and on adult Chinook salmon disease status at Willamette Falls (Scheck et al. 2012).

Methods

From 2 May through 8 July 2011, we collected and intragastrically radio-tagged 150 Chinook salmon at the Willamette Falls Dam adult trap and released them back into the fishway upstream from the trap (Figure 1). One hundred and forty-five radio-tagged salmon were tagged with archival temperature tags (models DS1921G, DS1921Z, and
DS1922L Thermochron iButton, Embedded Data Systems, Lawrenceburg, KY) and five salmon received radio tags only. An additional 100 salmon were tagged with archival temperature tags only. A total of 38,320 adult Chinook salmon were counted passing the dam from 2 May through 8 July 2011. The radio-tagged and temperature-tag-only samples represented ~0.4% and 0.3% of the salmon counted at the dam during the tagging period, respectively.

*Tagging site, handling procedures, and fish traits*

Adult salmon were collected and tagged at Willamette Falls Dam adult fish trap (Figures 2 and 3). Salmon were diverted from the fishway into an underwater cage using a fishway viewing window and pneumatically-controlled gates. A Denil fishway was installed into the top of the cage so that trapped salmon could volitionally ascend the Denil and enter a chute from which they were diverted in a holding tank with or without anesthetic. Samples were not truly random because only fish passing via fishway 1 (Ackerman and Shibahara 2009) at Willamette Falls Dam were sampled, proportions sampled each day varied, and no fish were sampled at night.

Figure 1. The number of Chinook salmon that were tagged with radio-transmitters and temperature loggers (top panel) or temperature loggers only (bottom panel) that were released at Willamette Falls Dam trap and the count of adult Chinook salmon passing the dam from 30 April through 14 July 2011.
Figure 2. Overhead view of the Denil and trap used to collect adult Chinook salmon at Willamette Falls Dam in 2011.

Figure 3. Schematic drawing of Willamette Falls Dam, Oregon, showing the location of its fishways and the two fixed-location radio receiver sites (WLL and WFF) deployed at the dam in 2011.

The mean fork lengths of the salmon radio-tagged or tagged with temperature loggers only at Willamette Falls Dam were 75.3 cm ($SD = 6.9$ cm, $range = 58.5 – 96.5$ cm) and 75.2 cm ($SD = 6.9$ cm, $range = 58.5 – 96.5$ cm), respectively (Figure 4). The mean weights of the salmon radio-tagged or tagged with temperature loggers only at Willamette Falls Dam were 5.71 kg ($SD = 1.51$ kg, $range = 2.57 – 11.03$ kg) and 5.61 Kg ($SD = 1.38$ kg, $range = 3.04 – 10.31$ kg), respectively (Figure 5).
Figure 4. Histograms of spring Chinook salmon fork lengths (cm) for the samples that were radio-tagged (top panel) or tagged with temperature loggers only (bottom panel) at Willamette Falls Dam in 2011.

Figure 5. Histograms showing weights (kg) of spring Chinook salmon radio-tagged (upper panel) or tagged with temperature loggers only (lower panel) at Willamette Falls Dam in 2011.
Approximately 25% (38/150) of the radio-tagged salmon had intact adipose fins (i.e., were not marked at a hatchery and were of presumed wild origin) and ~75% (112/150) had clipped adipose fins (i.e., were of certain hatchery origin) (Table 1). Salmon that were tagged with radio transmitters received one of two handling treatments. Thirteen percent (19/150) of radio-tagged salmon received an experimental anesthetic, AQUI-S®E, under the Investigational New Animal Drug program, sponsored by the U.S. Fish and Wildlife Service. The active ingredient of AQUI-S®E is eugenol, which is an essential oil derived from cloves and used as an antiseptic and anesthetic (INAD 2011). Only unclipped salmon received the anesthetic treatment because these fish were not susceptible to legal harvest and therefore the mandatory 72 hour drug withdrawal period did not apply (INAD 2011 and ODFW 2011 Fishing Regulations). The remaining 87% of radio-tagged salmon were tagged without anesthesia and with the use of a fish restraint device (FRD, Figure 6) modeled after Larson (1995). Radio-tagged salmon that received the anesthetic treatment had a mean tag date of 29 May, a mean fork length of 79.7 cm, and weighed 6.7 kg on average. Those that received the FRD treatment had a mean tag date of 31 May, a mean fork length of 79.6 cm, and weighed 5.6 kg on average.

Table 1. Numbers of Chinook salmon that were radio-tagged and released at Willamette Falls Dam trap that had clipped or unclipped adipose fins and received an experimental anesthetic (AQUI-S®E) or no anesthetic (FRD) during tagging.

<table>
<thead>
<tr>
<th>Handling treatment</th>
<th>Adipose fin</th>
<th># AQUI-S®E</th>
<th># FRD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clipped</td>
<td>0</td>
<td>112</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>Unclipped</td>
<td>19</td>
<td>19</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>131</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

When the fish was properly restrained or sedated, length, weight, marks or injuries, signs of disease, and an estimate of sex was recorded. Lipid content was also estimated using a Distell Fatmeter (Distell Industries Ltd., West Lothian, Scotland) and each fish was scanned for the presence of a PIT-tag. Adults to be radio-tagged received an appropriately-sized transmitter (e.g., model MCFT-3A or -7A; Lotek Wireless Inc., Newmarket, Ontario) that included a reward label to increase recovery of final fate information and temperature loggers. A secondary visual tag, a Floy tag (Floy Tag & Mfg., Inc., Seattle, WA), was used to help identify all study fish (i.e., also fish with temperature loggers only) at tributary collection facilities or during angler recapture events.
Telemetry sites and mobile tracking efforts

A total of 32 fixed-site radio receivers were distributed throughout the study area (Figure 7 and Table 2). Monitoring efforts also included mobile tracking via truck, boat, and airplane. Truck mobile tracking efforts occurred on 13 unique days from 26 July to 30 September 2011, with the highest number of surveys conducted in the McKenzie \((n = 5)\) and Santiam rivers \((n = 4)\). Two mobile tracking surveys were conducted via raft by U. Idaho and ODFW personnel. The first was on the North Fork Santiam River on 20 September (Upper Bennett Dam [rkm 389] to Shelburn Landing [rkm ~375]) and the second was on the South Fork Santiam River on 21 September (Pleasant Valley Bridge [Sweet Home, OR [rkm 412] to Waterloo, OR [rkm 396]). One airplane survey was conducted over the main stem Willamette River from the Coast Fork to the river mouth on 22 July. The survey used a fixed-wing aircraft (Cessna 185) owned by Wilderness Air (Salem, OR) with H-antennas mounted on the struts.
Figure 7. Map of the Willamette River basin and locations where radio receivers (red dots) were deployed in 2011.
Table 2. List of radio receivers deployed in the Willamette River basin in 2011, their site name abbreviations, and the river kilometer (rkm, from the Columbia River mouth) where they were deployed.

<table>
<thead>
<tr>
<th>Monitoring site</th>
<th>Receiver code</th>
<th>rkm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willamette Falls (downstream)</td>
<td>WFD</td>
<td>195.9</td>
</tr>
<tr>
<td>Clackamas River</td>
<td>CLK</td>
<td>203.8</td>
</tr>
<tr>
<td>Willamette Falls Dam (fish ladder 1)</td>
<td>WLL</td>
<td>206.1</td>
</tr>
<tr>
<td>Willamette Falls Dam (ladder top)</td>
<td>WFF</td>
<td>206.1</td>
</tr>
<tr>
<td>Willamette Falls (upstream)</td>
<td>WFU</td>
<td>212.9</td>
</tr>
<tr>
<td>Willamette main stem 1 (Champoeg, OR)</td>
<td>WL1</td>
<td>237.1</td>
</tr>
<tr>
<td>Willamette main stem 2 (Eola, OR)</td>
<td>WL2</td>
<td>304.9</td>
</tr>
<tr>
<td>Willamette main stem 3 (Buena Vista, OR)</td>
<td>WL3</td>
<td>334.8</td>
</tr>
<tr>
<td>Santiam River Mouth</td>
<td>STM</td>
<td>343.9</td>
</tr>
<tr>
<td>Santiam River (South Fork)</td>
<td>STS</td>
<td>361.6</td>
</tr>
<tr>
<td>Foster Dam tailrace</td>
<td>SSF</td>
<td>416.6</td>
</tr>
<tr>
<td>Foster Dam trap</td>
<td>FST</td>
<td>418.0</td>
</tr>
<tr>
<td>Santiam River (North Fork)</td>
<td>STN</td>
<td>362.0</td>
</tr>
<tr>
<td>Lower Bennett Dam</td>
<td>NS1</td>
<td>385.0</td>
</tr>
<tr>
<td>Upper Bennett Dam</td>
<td>NS2</td>
<td>389.1</td>
</tr>
<tr>
<td>Calapooia River</td>
<td>CAL</td>
<td>356.2</td>
</tr>
<tr>
<td>Willamette main stem 4 (Corvallis, OR)</td>
<td>WL4</td>
<td>374.4</td>
</tr>
<tr>
<td>Willamette main stem 5 (Harrisburg, OR)</td>
<td>WL5</td>
<td>417.9</td>
</tr>
<tr>
<td>McKenzie River</td>
<td>MCK</td>
<td>453.9</td>
</tr>
<tr>
<td>McKenzie River Hatchery Trap</td>
<td>MHT</td>
<td>489.7</td>
</tr>
<tr>
<td>McKenzie River (Leaburg Dam)</td>
<td>MKL</td>
<td>492.9</td>
</tr>
<tr>
<td>McKenzie River (South Fork)</td>
<td>MKS</td>
<td>527.5</td>
</tr>
<tr>
<td>McKenzie River (Cougar Dam)</td>
<td>COG</td>
<td>531.3</td>
</tr>
<tr>
<td>McKenzie River (upstream from S. Fork confluence)</td>
<td>MSU</td>
<td>527.2</td>
</tr>
<tr>
<td>Coast Fork Willamette R.</td>
<td>CFW</td>
<td>465.2</td>
</tr>
<tr>
<td>Middle Fork (near Coast Fork Confluence)</td>
<td>MFC</td>
<td>465.2</td>
</tr>
<tr>
<td>Middle Fork Willamette River</td>
<td>WMF</td>
<td>478.4</td>
</tr>
<tr>
<td>Middle Fork downstream from Fall Creek Mouth</td>
<td>MF2</td>
<td>482.6</td>
</tr>
<tr>
<td>Fall Creek Dam tailrace</td>
<td>FCT</td>
<td>492.9</td>
</tr>
<tr>
<td>Fall Creek Reservoir</td>
<td>FAL</td>
<td>502.6</td>
</tr>
<tr>
<td>Dexter Dam tailrace</td>
<td>DXT</td>
<td>487.0</td>
</tr>
<tr>
<td>North Fork of the Middle Fork</td>
<td>NFM</td>
<td>526.8</td>
</tr>
</tbody>
</table>
Results

Environmental Data

In 2011, Willamette River water temperatures were generally cooler and discharge was generally higher than the ten-year means (Figures 8). Water temperature measured at the USGS gauge near Newberg, OR increased from April through August, reached a maximum of 22.5 °C on 26 August, and then decreased through September and October. For the interval between 1 April and 1 September 2011, the mean daily temperature at the Newburg gauge was 1.7°C cooler than the ten-year mean and 2.8°C cooler than the mean in 2004, the year with the maximum mean difference from 2011 in the last ten years.

Figure 8. Mean daily Willamette River temperature (°C, black line) and ten-year mean temperature (grey line) recorded at USGS gauge at Newberg, OR (top panel) and mean daily Willamette River discharge (cms) solid line) and ten-year mean discharge (grey line) recorded at USGS gauge at Salem, OR (bottom panel). Data were collected from http://ida.water.usgs.gov/.
Receiver outages

Fixed site receivers were deployed for a maximum of ~4,250 hours from the beginning of the study (2 May 2011) to its end (26 October 2011). Fifteen of the 32 (47%) receivers experienced no outages and cumulative outage times for receivers that did experience outages ranged from 138 h (3% - WMF site) to 830 h (20% - FCT site) (Figure 9).

Salmon behavior at Willamette Falls Dam

Detailed evaluation of Chinook salmon passage at Willamette Falls Dam was not a primary study objective, although two receivers (WLL and WFF – see Figure 3) were installed at the project during the tagging season. Thirty-five salmon were tagged and released before both receivers were installed. This reduced our sample size to 115 radio-tagged salmon for evaluating whether some fish passed the dam and subsequently fell back downstream after ascending fishways or whether they swam downstream and exited the fishway after release. Of these 115 tagged salmon, 14 received the anesthetic treatment and 101 received the FRD treatment. One of the 14 tagged salmon that received the anesthetic treatment had its transmitter caught on a trap door during release and one regurgitated its tag before release (i.e., $n_{\text{anesthetic}} = 12$). One of the 101 tagged salmon that received the FRD treatment, one regurgitated its tag in the fishway downstream from the trap after release (i.e., $n_{\text{frd}} = 100$).
Of the 12 anesthetic treatment salmon, four (33%) exited the fishway into the tailrace. Two of the four subsequently passed the dam and two did not. Of the 100 tagged salmon that received the FRD treatment, 42 (42%) exited the fishway into the tailrace. Of these 42, 20 subsequently ascended a fishway and passed the dam, 20 were last detected downstream, and two (2%) exited to the tailrace, re-entered a fishway and passed the dam, then fell back over the dam and did not re-ascend. The proportion of tagged salmon that exited the fishway after release did not differ between handling treatments ($P = 0.70$, Chi-square test). Similarly, the proportion that did not re-ascend after exiting to the tailrace did not differ between treatments ($P = 0.74$, Chi-square test).

*Residence times and migration rates in the main stem Willamette River*

The time tagged salmon spent in the main stem Willamette River was directly related to the distance between Willamette Falls Dam and the tributary which they ultimately entered (Figure 11). Tagged salmon that returned to the Santiam River spent 14 d in the main stem, on average, and those returning to the McKenzie and Middle Fork Willamette rivers spent an average of 25 and 32 days in the main stem, respectively.

Figure 11. Distributions of radio-tagged spring Chinook salmon passage times (d) from their release at Willamette Falls Dam to first detection in the Santiam, McKenzie, or Middle Fork Willamette rivers in 2011. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles. Sample sizes are in parentheses above boxes.

The time radio-tagged salmon spent in different sections of the main stem Willamette River varied with reach length (Figure 12). Section lengths were 24.2 rkm from Willamette Falls to Champoeg (WFU-WL1), 67.8 rkm from Champoeg to Eola (WL1-WL2), 29.9 rkm from Eola to Buena Vista (WL2-WL3), 39.6 rkm from Buena Vista to Corvallis (WL3-WL4), and 43.5 rkm from Corvallis to Harrisburg (WL4-WL5). Tagged
salmon that returned to the Santiam River had the highest mean main stem residency time in the WL1-WL2 reach at 3.6 days. Tagged salmon that returned to the McKenzie or Middle Fork Willamette rivers spent an average of 2.8 days in the WL1-WL2 reach. Tagged salmon that returned to the McKenzie or Middle Fork Willamette rivers spent the most of their main stem residency time in the WL4-WL5 reach, averaging 4.6 and 4.7 days there, respectively.

Figure 12. Distribution of times (days) radio-tagged spring Chinook salmon used in reaches of the main stem Willamette River for salmon that returned to the Santiam, McKenzie, and the Middle Fork Willamette rivers. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles. Sample sizes are listed in parentheses above boxes.
The distribution of migration rates (rkm/d) through the main stem Willamette River for radio-tagged salmon that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers was modestly right-skewed, with an overall mean migration rate of 22.3 rkm/d ($s.d. = 10.5$, $n = 96$; Figure 13). Means for groups of tagged salmon that returned to specific tributaries ranged from 20.3 rkm/d (McKenzie River) to 24.0 rkm/d (Santiam River). The highest variation within a tributary grouping was for salmon returning to the Santiam River, with rates ranging from 5.9 to 49.6 rkm/d.

Migration rate in main stem Willamette River (rkm/day)

![Histogram](Image)

Figure 13. Histogram of radio-tagged Chinook salmon migration rates (rkm/d) within the main stem Willamette River for salmon that escaped to the Santiam, McKenzie, and Middle Fork Willamette rivers in 2011.

Migration rate increased later in the season (linear regression; $r^2 = 0.16$, $P < 0.0001$; Figure 14), though the relationship differed among tributary populations. Migration rate was significantly and weakly positively associated with tag date for the adults returning to the Santiam River (linear regression $r^2 = 0.34$, $P < 0.0001$; Figure 14). However, migration rate and tag date were not significantly related for adults returning to the McKenzie ($r^2 = 0.02$, $P = 0.49$) or Middle Fork Willamette rivers ($r^2 = 0.10$, $P = 0.22$). The significant relationship for the Santiam population presumably resulted from higher river temperatures and lower discharge later in the migration, while the lack of relationship for the upstream populations may have been related to lower sample size or river conditions in the upper reaches that reduced overall migration rate later in the season.
Figure 14. Relationships between radio-tagged Chinook salmon migration rates in the main stem Willamette River and tag date at Willamette Falls Dam in 2011. Lines show separate linear regressions for Middle Fork Willamette, McKenzie, and Santiam River salmon.

**Downstream movements in the main stem, overshoot behavior, and tributary dip-ins**

Approximately five percent (7/150) of radio-tagged salmon moved downstream in the main stem Willamette River after moving upstream from Willamette Falls Dam. Four of the seven had intact adipose fins and three had fin clips. The fish that moved downstream were last recorded in the Santiam River (two hatchery fish) or in the main stem (one hatchery fish and four unclipped fish).

Downstream-moving fish in the main stem included one radio-tagged salmon that swam from Corvallis (WL4) ~70 rkm downstream to Eola (WL2). Two salmon migrated to the Dexter Dam tailrace before moving downstream 69-182 rkm to Harrisburg (WL5), or Eola. One tagged salmon entered the McKenzie River before returning to the main stem and swimming downstream to Harrisburg. The remaining three salmon entered the Santiam River before returning to Buena Vista (WL3). Two of these three tagged fish, both of hatchery origin, subsequently re-entered the Santiam River and the other was last detected in the main stem at Eola.
We differentiated downstream movements of fish that stayed within the main stem from those that moved downstream within the main stem and subsequently entered a tributary (i.e., overshoot behavior). Four tagged salmon were detected upstream from the tributary to which they eventually escaped and three of them were of hatchery origin. One hatchery salmon entered the Santiam River before moving downstream to the Molalla River. The other three tagged salmon that exhibited overshoot behavior moved upstream to Corvallis or Harrisburg before they escaped downstream to the Santiam River.

With the exception of one radio-tagged salmon that exited the Willamette Falls fishway after tagging and briefly entered the Clackamas River before ascending the dam, no salmon was detected temporarily entering a tributary downstream from a tributary to which it ultimately escaped. Moreover, no radio-tagged salmon were detected on the Coast Fork Willamette River or the Calapooia River receiver sites throughout the study.

Behavior in tributaries downstream from WVP projects

The time radio-tagged salmon spent within different reaches of their migratory routes varied among groups that migrated to tributary dams that have no adult passage facilities. These include Foster Dam on the South Santiam River, Dexter Dam on the Middle Fork Willamette River, and Cougar Dam on the McKenzie River (Figure 15). Based on data from tagged salmon with complete detection histories, salmon recaptured at Foster Dam spent an average of 48 days in the Santiam River downstream from the tailrace. Those recaptured at Dexter Dam spent an average of two days in the Middle Fork downstream from the Dexter tailrace. Tailrace residency times varied considerably within both groups, with times in the Foster tailrace ranging from <1 to 56 days (mean = 10 d) and those in the Dexter tailrace ranging from <1 to 108 days (mean = 48 d). One tagged salmon was detected in the Cougar Dam tailrace for six days (1-7 August) before it was subsequently detected downstream from Leaburg Dam in the McKenzie River.

Figure 15. Distribution of times (days) that radio-tagged spring Chinook salmon spent in the main stem Willamette River, a tributary, and in dam tailraces for salmon recaptured at Foster (left panel) and Dexter (right panel) dams in 2011. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles. Sample sizes are listed in the top, right corner of each panel.
The two tagged salmon with unclipped adipose fins that had complete detection histories and were recaptured at Dexter Dam spent 56 days in the Dexter Dam tailrace on average, whereas those with clipped adipose fins spent 46 days there on average (Figure 16).

Figure 16. Distribution of times (days) radio-tagged spring Chinook salmon spent in the main stem Willamette River, the Middle Fork Willamette River, and the Dexter Dam tailrace for unclipped (left panel) and clipped (right panel) salmon recaptured at Dexter Dam in 2011. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles. Sample sizes are listed in the top, right corner of each panel.

Run timing and composition

The 2011 spring Chinook salmon run at Willamette Falls Dam was the second latest-timed run in the last eleven years (median = 6 June; Figure 17). This was likely due to the cold April-June water temperatures and high river discharge compared to ten-year averages (see Figures 8 and 9). Run composition varied seasonally for the 109 salmon last recorded in tributaries (Figure 18), with lower basin populations typically passing Willamette Falls Dam later in the run. Among salmon radio-tagged in May, 54% returned to the Santiam River and smaller percentages returned to the McKenzie River (20%), and Middle Fork Willamette River (25%). For salmon tagged in June and early July, run composition again included a relatively high percentage that returned to the Santiam River (40%), followed by the McKenzie (25%), Clackamas (18%), Molalla (10%), and Middle Fork Willamette rivers (7%). The mean tag date for each population was: 23 May (Middle Fork Willamette R.), 29 May (Santiam R.), 3 June (McKenzie R.), 16 June (Clackamas R.), and 27 June (Molalla R.).
Figure 17. Annual migration timing distributions for spring Chinook salmon counted at Willamette Falls Dam. Symbols show median (●), quartile (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (○). Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Figure 18. Composition of 109 ‘escaped’ Chinook salmon at Willamette Falls Dam in 2011 using 10-d intervals based on release dates of radio-tagged fish.
Last radio detections and transmitter recoveries

Three of the 150 radio-tagged salmon were known to have lost transmitters: one was caught on a trap door during release, one was regurgitated before release, and another was regurgitated in the fishway downstream from the trap (Figure 19 and 20). Of the 147 tagged salmon that had no evidence of transmitter loss, 109 (74%) were last recorded or recaptured in Willamette River tributaries and 38 (26%) were last detected at main stem sites either upstream or downstream from Willamette Falls Dam. The only reported harvest of radio-tagged salmon among the 109 salmon last recorded or recaptured in tributaries were four salmon (4%) captured by anglers in the McKenzie River.

Twenty-one (14%) tagged salmon were last recorded or mobile-tracked downstream from the dam at or near the WFD receiver site. All 21 of these salmon received the FRD treatment and 19 of the 21 were of hatchery origin. Ten tagged salmon (7%) were last recorded in the Clackamas River. Two tagged salmon (1%) had their last detections on the WLL receiver site at the dam and three transmitters (2%) were recovered in the Molalla River. Fifteen tagged salmon (10%) were last detected on receivers in the main stem, nine in the lower portion (from Willamette Falls Dam to the Santiam River mouth) and six in the upper portion. Fifty radio-tagged salmon (34%) were last detected in the Santiam River, 29 (20%) were in the McKenzie River, and 17 (12%) were in the Middle Fork Willamette River.

![Histogram showing the locations where radio-tagged Chinook salmon were last recorded in the Willamette River basin in 2011. Regurg./Lost = tags that were caught on a trap door during release or regurgitated before/after release.](image)

Among the 50 salmon with fates in the Santiam River, 19 were recaptured at Foster
Dam and one each was recaptured at Lower and Upper Bennett dams (Figure 19). The
distribution of recovered transmitters from the McKenzie River included seven from
McKenzie Hatchery trap, five from Leaburg Dam, four angler recaptures, and one from
ODFW spawning ground surveys. Twelve tagged salmon were recaptured at Dexter
Dam and five were last detected in the Middle Fork Willamette River (i.e., seventeen fish
total).

Tagged salmon with clipped adipose fins comprised the majority or half of all fate
groups (Table 3). Clackamas River salmon had the latest mean tag date among groups
and the two salmon last detected at Willamette Falls Dam had the earliest. Molalla River
salmon and those salmon last detected in the upper main stem were the longest and
heaviest on average. Mean fatmeter readings among fate groups ranged from 5.6 to
7.6%.

Table 3. Sample sizes, adipose fin clip status, mean tag date, mean fork length, mean
weight, and mean fatmeter readings for radio-tagged adult Chinook salmon that
experienced different fates within the Willamette River in 2011.

<table>
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<th># Ad-clipped (y/n)</th>
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<th>Mean fork length (cm)</th>
<th>Mean weight (kg)</th>
<th>Mean fatmeter (%)</th>
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<td>5.5</td>
<td>5.6</td>
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<td>16 Jun</td>
<td>75.0</td>
<td>5.5</td>
<td>6.2</td>
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<tr>
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<td>3 May</td>
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<tr>
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<td>2/1</td>
<td>27 Jun</td>
<td>79.8</td>
<td>6.1</td>
<td>6.7</td>
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<tr>
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<td>5.9</td>
<td>7.6</td>
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<td>7.0</td>
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<td>79.2</td>
<td>6.4</td>
<td>7.7</td>
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<td>19/10</td>
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<td>74.7</td>
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<td>6.7</td>
</tr>
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<td>23 May</td>
<td>74.4</td>
<td>5.4</td>
<td>6.7</td>
</tr>
</tbody>
</table>

\(^1\) – between Willamette Falls Dam and the WL3 receiver site (Buena Vista).
\(^2\) – between the WL3 receiver site and the confluence of the Coast Fork and Middle Fork
Willamette rivers.

Among salmon with adipose fins exclusively (n = 35 after excluding 3 salmon that
regurgitated or lost their transmitters), we found a significant difference in the proportion
of salmon that received the anesthetic treatment and escaped to a tributary (15/17 = 88%)
compared to the proportion that received the FRD treatment and escaped (10/18 = 55%)
(P = 0.04, Chi-square Test). Using the logistic regression model [Escape to tributary
(y/n) = tag date + fin clip (hatchery vs. wild)] on all 147 salmon without known tag loss,
we found that neither tag date nor fin clip status were significant predictors of tagged
salmon successfully escaping to a tributary (tag date P = 0.25; fin clip P = 0.68).
Figure 20. Sites where adult Chinook salmon radio-tagged and released at Willamette Falls Dam were last detected (black font and parentheses) or where they were recaptured (blue font and brackets). Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference.
Fates of tagged salmon with unclipped adipose fins

Of the 38 tagged salmon with an intact adipose fin, 10 were last detected in the McKenzie River, 8 were in the Santiam River, and 5 were in the lower main stem Willamette River (Figure 21). The upstream distribution of unclipped salmon in the anesthetized and FRD tagging treatments differed and may have been a partially explained by the mean tag dates differing between the two groups (anesthetized = 25 May; FRD = 2 June). Among the 19 unclipped salmon that received the anesthetic treatment, seven returned to the McKenzie River. The highest frequency of unclipped salmon that received the FRD treatment returned to the Santiam River (5). Two anesthetized, unclipped salmon regurgitated or lost their transmitter compared to one unclipped salmon that had received the FRD treatment.

Temperature histories of individual salmon

There were 57 radio-transmitter recoveries which included the recovery of 53 temperature loggers (i.e., two salmon had radio-tags only and two temperature loggers were not returned with their transmitters). Of the 53 temperature loggers recovered from radio-tagged salmon 37 (74%) had retrievable data, 3 (6%) were from regurgitated transmitters (data was not used), and 13 had unrecoverable data (i.e., data could not be downloaded or water had seeped into archival tags). Loggers with retrievable data came from the Santiam River \((n = 13)\), the McKenzie River \((n = 12)\), the Middle Fork Willamette River \((n = 10)\), and the Molalla River \((n = 2)\). The maximum temperature recorded on any temperature logger recovered from a radio-tagged salmon was 22.0 °C (Figure 22).

Twenty-eight salmon outfitted with temperature loggers only (no radio transmitters) were recovered. Temperature data were retrieved from 15 of the 28 (54%), including 6 collected at McKenzie Hatchery, 5 at Dexter Dam, 2 at Foster Dam, and 2 from unknown locations. The maximum temperature recorded on any temperature logger recovered from a non-radio-tagged salmon was 17.0°C.
Figure 21. Histograms showing the locations where all unclipped, radio-tagged spring Chinook salmon were last recorded (lower panel) and where those that received the anesthetic (upper panel) or fish restraint device handling treatment (middle panel) were last recorded.
The thermograph for the South Fork Santiam River near Foster Dam was characterized by steadily increasing temperatures from April through mid-July, reached a daily maximum temperature of 13.1°C on 29 July, and steadily decreased from August through October (Figure 23). The thermograph from the McKenzie River generally followed a similar pattern, with a higher maximum temperature (15.2°C on 6 August) and higher diel variations. In contrast, the thermograph from the Middle Fork Willamette River near Dexter, was characterized by increasing temperatures from April through the end of June, a modest decrease of approximately 1°C in early July, and a rapid rise in mean temperature from 12°C on 12 July to 17.2°C on 17-20 July. Dexter Dam and reservoir serve as the reregulating project for Lookout Point Dam and reservoir, which is located about three miles upstream from Dexter. The discharge water from Lookout Point pool dumps directly into the Dexter pool and often passes with little mixing before it passes Dexter Dam. Warm water (17-19 °C) occupied the upper 20 feet of Lookout Point Dam forebay in mid-July 2011 when there was sustained spillway discharge at Lookout Point from 11 to 22 July 2011 (D. Garletts, USACE, pers. comm.). Mean daily water temperatures returned to less than 14.0°C by 26 July where they remained through August. Mean daily temperatures ranged from 13.5 to 15.6 °C in September and October.
Figure 23. Minimum (blue line), mean (black line), and maximum (red line) daily water temperatures recorded at USGS gauge stations near Foster, Vida, and Dexter, OR in 2011. Data were collected from http://ida.water.usgs.gov/

Temperature loggers recovered from salmon recaptured in the Santiam River had thermal histories consistent with the relatively cool temperatures recorded in the Santiam River thermograph. The mean arrival date for all tagged salmon with complete detection histories of entry into the Santiam River was 8 June 2011 \( (n = 38) \) and the mean arrival date for the temperature logger sample was 9 June 2011 \( (n = 13, \text{ a subset of the } 38 \text{ above}) \). Generally, the highest temperatures encountered by tagged salmon that escaped to the Santiam River were experienced while they were in the main stem Willamette River (e.g., Figure 24 – see Appendix A for a complete set of thermal history graphs).
Tagged salmon that returned to the McKenzie River generally experienced their maximum temperatures in the main stem Willamette River (e.g., Figure 25). Higher diel variations in temperature were evident in the McKenzie River temperature logger data compared to the South Fork Santiam River and consistent with the McKenzie River thermograph.

While tagged salmon that returned to the Santiam and McKenzie rivers generally experienced their highest temperatures in the main stem Willamette River, this was not the case for most of the tagged salmon recaptured in the Middle Fork Willamette River (e.g., Figure 26). Eight of ten temperature loggers from the Middle Fork (with retrievable data) recorded maximum temperatures after tagged salmon had entered the tributary during the period of relatively warm water associated with spill from Lookout Point Reservoir.
Figure 25. Locations (points), migration rate (slope of solid line), and temperature experienced (dashed line) by a spring Chinook salmon (Channel 3, Code 503) radio-tagged at Willamette Falls Dam and recovered at McKenzie Hatchery in 2011 (See Table 2 for radio receiver site abbreviations).
Figure 26. Locations (points), migration rate (slope of solid line), and temperature experienced (dashed line) by a spring Chinook salmon (Channel 3, Code 1048) radio-tagged at Willamette Falls Dam and recovered at Dexter Dam in 2011 (See Table 2 for radio receiver site abbreviations).

Both temperature loggers recovered in the Molalla River recorded the highest temperatures among all recovered temperature loggers (i.e., 22.0°C; Figure 27). It is not clear when the tagged salmon entered the Molalla River because there was no fixed-site receiver deployed there in 2011.
Figure 27. Locations (points), migration rate (slope of solid line), and temperature experienced (dashed line) by a spring Chinook salmon (Channel 3, Code 506) radio-tagged at Willamette Falls Dam and recovered in the Molalla River in 2011 (See Table 2 for radio receiver site abbreviations).

Overall, the temperature logger data suggested that salmon migrating in the lower main stem late in the season and those holding downstream from Dexter Dam were most prone to high temperature exposures in 2011.

Energetic status at Willamette Falls Dam and fates

The estimated energetic content of tagged salmon decreased with increasing tag date (Figure 28) and the mean fat meter reading recorded at Willamette Falls Dam for tagged salmon that escaped to a tributary (7%) was equal to the mean fat meter reading for tagged salmon that did not escape to a tributary (Figure 29).
Fat = (-0.05 \times \text{Tag Date}) + 8.6, r^2 = 0.20, n = 232.

Figure 28. Relationship between Fatmeter readings (%) recorded for adult spring Chinook salmon at Willamette Falls Dam and salmon collection date. Plot includes radio-tagged salmon and those tagged with temperature loggers only.

Figure 29. Distributions of fat meter readings (%) from radio-tagged spring Chinook salmon that escaped and did not escape to a Willamette River tributary in 2011. Box plots show: median (line), quartile (box), 10\textsuperscript{th} and 90\textsuperscript{th} (whisker), and 5\textsuperscript{th} and 95\textsuperscript{th} percentiles. Sample sizes are in parentheses above boxes.
Discussion

In this study, we collected information on run composition, run timing, migration behaviors, and thermal conditions encountered by adult Chinook salmon during migration in the Willamette River basin. No mortality events occurred during tagging and all salmon were released in good condition. Based on our previous experience collecting and radio-tagging adult salmon (e.g., Keefer et al. 2005) and reports from other studies (Burger et al. 1985; Thorstad et al. 2000; Jokikokko 2002), we think it is likely that tagged salmon in the 2011 Willamette River study behaved similarly to untagged fish. However, there were no independent data to corroborate or refute this assumption. Unlike in the Columbia River adult salmon studies, there were no upstream main stem dams above Willamette Falls or previously PIT-tagged samples by which to gauge behavior or relative salmon passage success between tagged and untagged populations (e.g., Matter and Sandford 2003). We did find some evidence that handling treatment (AQUI-SE vs. FRD) affected escapement to tributaries although this was based on a relatively small sample size. In 2012, we are expanding this experiment to more rigorously test for any effects of handling treatment on behavior or fate.

After adjusting for known transmitter loss, 74% of radio-tagged salmon (109/147) escaped to Willamette River tributaries. The remaining fish were either last detected downstream from the dam (15%), at the dam (1%), or in the lower (6%) or upper (4%) main stem. The only previous Willamette River radiotelemetry study of adult salmon (Schreck et al. 1994) reported non-harvest mortality of 20-40%. If we assumed that all tagged salmon last detected outside a tributary died before spawning, the maximum prespawn mortality estimate for our study would be 26%, which is in the lower end of the range provided by Schreck et al. (1994).

Twenty-one of the ‘unsuccessful’ tagged salmon in 2011 were last detected downstream from Willamette Falls. This may indicate that there was a negative handling or tagging effect, a high rate of unreported harvest in the fishery downstream from the dam, or perhaps overshoot behaviors by salmon whose natal sites were downstream from Willamette Falls (e.g., Keefer et al. 2008a). Some downstream fish movement following tagging is common (Bernard et al. 1999; Mäkinen et al. 2000), and that may be the most likely explanation. We also think it is possible that tagging treatment and perhaps salmon origin (hatchery, wild) affected whether salmon exited the Willamette Falls fishway after release and whether they resumed upstream migration. We found that fewer anesthetized salmon exited the fishway after release than restrained salmon (33% versus 42%), but all 21 salmon last detected downstream from the dam received the FRD treatment and 19 of the 21 (90%) were of hatchery origin. This may be a little misleading if taken alone because 75% of all tagged salmon were of hatchery origin and 87% of all tagged salmon received the FRD treatment. In any event, the fate of these fish was unknown as none were reported harvested and none entered the Clackamas River. These fish may have entered more distant downstream tributaries or migrated up the main stem Columbia River, as observed by Schreck et al. (1994) in an earlier study. However, we did not PIT-tag any of the salmon in our sample (i.e., they could not be detected at Lower Columbia River dam PIT-tag antennas) and we did not monitor any Columbia River sites with radiotelemetry in 2011.
Adult salmon migrating upriver can pass back downstream over dams via spillways, turbines, navigation locks, debris sluiceways, or juvenile fish collection devices after exiting a dam fishway and this event is referred to as fallback. Fallback can increase migration times to natal streams and may cause injury or death (Boggs et al. 2004). We recorded only two fallback events among 116 dam passage events by radio-tagged salmon at Willamette Falls Dam in 2011. Both salmon that fell back were last recorded in the Clackamas River, suggesting overshoot behavior.

Migration rates and main stem behaviors

Tagged salmon had higher main stem migration rates with increasing migration date. This was consistent with results reported in Schreck et al. (1994), who found that late-run Willamette River Chinook salmon tended to resume upstream migration at a relatively rapid pace in contrast to early run fish. Salinger and Anderson (2006) and Keefer et al. (2004) also found that spring–summer Chinook salmon migrated more rapidly as water temperature and date of migration increased in the Columbia River hydrosystem and they speculated that main stem migration rates might be expected to be higher in warmer years. Main stem migration rates for Willamette River spring Chinook salmon in 2011 (median = 20.6 rkm/day) were in the range of those observed for spring Chinook salmon in the Columbia River hydrosystem (median range = 14-33 rkm/day; Keefer et al. 2004) but considerably lower than the average of 52 rkm/day reported for Chinook salmon in the Yukon River by Eiler et al. (2006).

The few downstream movements recorded by tagged salmon in 2011 were in contrast to Schreck et al. (1994), who found that some late run fish ceased migrating or swam downstream after migrating 20-100 rkm up the Willamette River or its tributaries. They hypothesized that the downstream movements they observed were associated with the river warming in summer (estimated to be > 20°C), which was not pronounced in 2011. Similarly, we observed few tributary dip-ins by tagged salmon in 2011 (e.g. Goniea et al. 2006), likely because the cool conditions reduced the need for the use of thermal refuges. The only tributaries we monitored with fixed receiver sites were the Santiam, Calapooia, McKenzie, and the Coast Fork Willamette rivers, which were augmented by intermittent mobile tracking efforts of the Molalla River. It is possible that some tagged salmon entered unmonitored tributaries temporarily before moving to tributaries upstream or held in the tributary plume below the confluence.

Adult salmon spent two to more than six weeks in the main stem before reaching tributaries and duration in the mainstem was longer for upstream populations. The time spent in the main stem Willamette River may be an important factor affecting migration success and prespawn mortality. Main stem temperatures are higher than in tributaries, several reaches are heavily impacted by habitat alteration associated with urbanization, and there are many sources of point and non-point contaminants from agricultural, industrial and residential sources entering the main stem directly or from tributaries. Main stem reaches may also expose adults to bacterial, fungal, and eukaryotic pathogens and parasites during migration that affect prespawn mortality rates in tributaries. In a companion study (Schreck et al. 2012), we observed higher disease burdens in adults that died prior to spawning and in adults that migrated to tributary collection sites compared
to those held in cool disease-free water at the OSU Fish Performance and Genetics Laboratory. Collectively, the results suggest that some types of disease are acquired during upstream migration and/or upstream migration contributes to the expression of disease. Our preliminary results also suggest that the effects of disease manifest differently for pathogens that can reproduce in the salmon host (bacterial and fungal pathogens) than for non-proliferative parasites with intermediate hosts.

The interactions among river environmental conditions (especially temperature), exposure duration (migration rate and distance), disease status at river entry, exposure to disease during migration, and other impacts such as toxins exposure are likely to be complex and variable from year to year. Cool conditions during 2011 likely increased exposure time to potential impacts in the main stem, but this may have been offset by relatively low pathogen densities and reduced susceptibility of salmon during the cool conditions.

Adults returning to the North Fork Middle Fork Willamette River spent two to more than eight weeks holding in the tailrace of Dexter Dam prior to collection. Temperature conditions in the tailrace in 2011 were among some of the highest encountered by some individuals, though this was related to an unusual spill event. Nonetheless, fish densities are probably high, particularly near the trap entrance. Angler pressure is high, and whether conditions are more or less benign than holding conditions in the NFMF near outplant locations is unknown. Alternative operations at the Dexter Dam Trap that collected adults shortly after arrival could potentially reduce prespawn mortality observed in this population after outplanting if long tailrace holding negatively affects adults.

Run timing and composition

The late timing of the 2011 spring Chinook salmon run was consistent with cool river temperatures and high discharge. The latest-timed run in the last decade was in 2008 and it was associated with cold April-June water temperatures. Conversely, early-timed runs in 2001, 2004, and 2005 were associated with warm March water temperatures and/or low spring discharge. This pattern has been well documented for Columbia River spring Chinook salmon (Keefer et al. 2008c; Anderson and Beer 2009), and appears to be a result of both large-scale winter and spring weather patterns, ocean environment, and estuary and river conditions.

There has generally been little information on spring Chinook salmon run composition at Willamette Falls so the data collected in 2011 should represent a step forward in understanding relative population abundance through the migration season. Generally, we found that early-run fish were a well-mixed combination from upper basin populations (i.e., Santiam, McKenzie, and Middle Fork Willamette rivers), while lower basin populations (i.e., Molalla and Clackamas rivers) were relatively late-timed in 2011. This pattern may reflect differences in Chinook salmon spawn timing among tributary populations or selection for earlier timing in populations requiring greater time in the mainstem to reach upstream tributaries. It is also possible that past differences in hatchery selection, the distribution of wild versus hatchery-produced adults, or inter-basin straying rates affect the timing of migration through the migration corridor. Such
relationships have not been well described for the Willamette River populations (Keefer and Caudill 2010).

**Role of temperature in migration success**

High temperatures can affect the reproductive success of salmonids well before spawning (McCullogh et al. 2001) and they have been implicated in the mortality of adult Chinook salmon in the Willamette River (Schreck et al. 1994; Mann et al. 2009; Keefer et al. 2010) and in other species such as sockeye salmon (e.g., Naughton et al. 2005; Rand et al. 2006; Keefer et al. 2008b). Upstream dams have an important effect on water temperature in the Willamette River in the mainstem and in tailrace holding areas (e.g., below Dexter Dam) as a result of augmented flows as well as modified temperature releases over the course of summer and autumn (Rounds 2007; 2010). Excluding the radio-tagged salmon last detected downstream from or at Willamette Falls Dam, ~14% (15/111) of tagged salmon were last detected in the main stem. This circumstantially suggests that overall adult mortality in the main stem was low in 2011, whether it was from temperature-related causes or not. Naughton et al. (2012) found that prespawning mortality rates for Chinook salmon outplanted to Fall Creek and the North Fork Middle Fork Willamette River in 2011 were generally lower than rates observed in 2009-2010.

The below-average water temperatures in 2011 limited possible inferences about the relationship between main stem thermal experience and prespawning mortality in this study. The two tagged salmon with the highest temperature exposures in 2011 were fish that escaped to the Molalla River. Fourteen stream reaches of the Molalla-Pudding subbasin are listed as impaired by high stream temperatures, which affects rearing and spawning habitat for salmonids (Williams and Bloom 2008). No carcasses were found with the radio transmitters recovered in the Molalla River so the spawning success or failure of these fish was unknown. Similarly, the lone transmitter recovered in the upper main stem, near Harrisburg, had no carcass or temperature logger.

We observed no relationship between estimated initial lipid content and fate of adult fish, suggesting energetic reserves at river entry were sufficient to fuel upstream migration to tributaries in 2011. The metabolic costs of migration increase at higher temperatures, particularly at temperatures thought to be physiologically stressful to salmon (e.g. >18° C; Richter and Kolmes 2005). Few adults experienced temperatures above this threshold and exposure times for those that did were relatively short. Alternately, low sample size and estimation error associated with the fatmeter in 2011 (Naughton et al. 2011) may have prevented detection of an effect. Regardless, the effects of energy limitation are expected to be greatest in warm years (Mann et al. 2011) and we hypothesize that if there was an undetected effect of lipid on migration success in 2011, the effect was small.
Literature Cited


Willams, K. F., and J. Bloom. 2008. Molalla-Pudding Subbasin total maximum daily load (TMDL) and water quality management plan (WQMP). Oregon Department of Environmental Quality, Portland, OR.
http://www.deq.state.or.us/wq/TMDLs/willamette.htm#mp
Table of Contents for Appendix A. List of unique Chinook salmon recaptured with radio- and archival temperature tags with downloadable data.

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Spring Chinook 3/507
Released at Willamette Falls Dam - 13 June 2011
Recaptured in the Molalla River - 29 September 2011
Spring Chinook 3/506
Released at Willamette Falls Dam - 8 July 2011
Recaptured in the Molalla River - 20 September 2011
Spring Chinook 3/961
Released at Willamette Falls Dam - 02 May 2011
Recaptured at Foster Dam Trap - 16 June 2011
Spring Chinook 3/985
Released at Willamette Falls Dam - 04 May 2011
Recaptured at Foster Dam Trap - 28 June 2011
Spring Chinook 3/391
Released at Willamette Falls Dam - 12 May 2011
Recaptured at Foster Dam Trap - 30 August 2011
Spring Chinook 3/999
Released at Willamette Falls Dam - 18 May 2011
Recaptured at Foster Dam Trap - 22 August 2011
Spring Chinook 3/388
Released at Willamette Falls Dam - 19 May 2011
Recaptured at Foster Dam Trap - 30 August 2011
Spring Chinook 3/1034
Released at Willamette Falls Dam - 26 May 2011
Recaptured at Foster Dam Trap - 28 June 2011
Spring Chinook 3/1012
Released at Willamette Falls Dam - 26 May 2011
Recaptured at Foster Dam Trap - 12 July 2011
Spring Chinook 3/1021
Released at Willamette Falls Dam - 2 June 2011
Recaptured at Foster Dam Trap - 20 July 2011
Spring Chinook 3/1054
Released at Willamette Falls Dam - 02 June 2011
Recaptured at Foster Dam Trap - 12 July 2011
Spring Chinook 3/1079
Released at Willamette Falls Dam - 09 June 2011
Recaptured at Foster Dam Trap - 01 August 2011
Spring Chinook 3/1046
Released at Willamette Falls Dam - 10 June 2011
Recaptured at Foster Dam Trap - 22 August 2011
Spring Chinook 3/1075
Released at Willamette Falls Dam - 12 June 2011
Recaptured at Foster Dam Trap - 1 August 2011
Spring Chinook 3/392
Released at Willamette Falls Dam - 19 May 2011
Recaptured at Upper Bennett Dam - 27 September 2011
Spring Chinook 3/962
Released at Willamette Falls Dam - 03 May 2011
Recaptured at Dexter Dam Trap - 11 August 2011
Spring Chinook 3/381
Released at Willamette Falls Dam - 04 May 2011
Recaptured at Dexter Dam Trap - 24 August 2011
Spring Chinook 3/1003
Released at Willamette Falls Dam - 17 May 2011
Recaptured at Dexter Dam trap - 3 August 2011
Spring Chinook 3/1019
Released at Willamette Falls Dam - 26 May 2011
Recaptured at Dexter Dam Trap - 11 August 2011
Spring Chinook 3/1015
Released at Willamette Falls Dam - 26 May 2011
Recaptured at Dexter Dam Trap - 27 July 2011

Temperature (C)

Date

RKM

WL1

WL2

WL3

WL4

WL5

MFC

WMF

FCR

DXT

DXT
Spring Chinook 3/430
Released at Willamette Falls Dam - 26 May 2011
Recaptured at Dexter Dam Trap - 31 August 2011
Spring Chinook 3/1048
Released at Willamette Falls Dam - 3 June 2011
Recaptured at Dexter Dam Trap - 24 August 2011
Spring Chinook 3/1049
Released at Willamette Falls Dam - 10 June 2011
Recaptured at Dexter Dam Trap - 6 July 2011
Spring Chinook 3/1072
Released at Willamette Falls Dam - 14 June 2011
Recaptured at Dexter Dam Trap - 13 July 2011
Spring Chinook 3/1064
Released at Willamette Falls Dam - 22 June 2011
Recaptured at Dexter Dam Trap - 24 August 2011
Spring Chinook 3/967
Released at Willamette Falls Dam - 3 May 2011
Recaptured at McKenzie Hatchery - 5 July 2011
Spring Chinook 3/433
Released at Willamette Falls Dam - 1 June 2011
Recaptured in McKenzie R. - 30 September 2011
Spring Chinook 3/444
Released at Willamette Falls Dam - 1 June 2011
Recaptured at McKenzie Hatchery Trap - 10 September 2011
(Temperature data end on 28 August 2011)
Spring Chinook 3/451
Released at Willamette Falls Dam - 1 June 2011
Recaptured in McKenzie R. - 27 September 2011
Spring Chinook 3/1040
Released at Willamette Falls Dam - 1 June 2011
Recaptured at McKenzie Hatchery Trap - 5 July 2011
Spring Chinook 3/1081
Released at Willamette Falls Dam - 9 June 2011
Recaptured by Angler on McKenzie R. - 6 July 2011
Spring Chinook 3/437
Released at Willamette Falls Dam - 9 June 2011
Recaptured in McKenzie R. - 26 August 2011
Spring Chinook 3/1056
Released at Willamette Falls Dam - 10 June 2011
Recaptured by Angler on McKenzie R. (Springfield) - 1 July 2011
Spring Chinook 3/497
Released at Willamette Falls Dam - 12 June 2011
Recaptured in the McKenzie River - 26 August 2011
Spring Chinook 3/1061
Released at Willamette Falls Dam - 12 June 2011
Recaptured by Angler on McKenzie R. - 24 July 2011
Spring Chinook 3/1078
Released at Willamette Falls Dam - 21 June 2011
Recaptured at McKenzie Hatchery - 12 July 2011
Spring Chinook 3/503
Released at Willamette Falls Dam - 22 June 2011
Recaptured at McKenzie Hatchery - 3 October 2011