Technical Report 2014-4

MIGRATORY BEHAVIOR, RUN TIMING, AND DISTRIBUTION OF RADIO-TAGGED ADULT WINTER STEELHEAD, SUMMER STEELHEAD, AND SPRING CHINOOK SALMON IN THE WILLAMETTE RIVER – 2013

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For

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Summary

In this study, we collected information on run composition, run timing, and migration behaviors of adult winter and summer steelhead and spring Chinook salmon in the Willamette River basin. Adults were collected and radio-tagged at Willamette Falls Dam, and their upstream movements and final distribution were monitored using an array of fixed-site receiver stations, mobile tracking, and returns to collection facilities. 2013 was the third study year for Chinook salmon and the second year for steelhead. It was also the second study year when summer steelhead were collected and radio-tagged at Foster and Dexter dams to estimate behavior and final distribution of recycled steelhead.

We used an anesthetic (AQUI-S 20E) when tagging all salmonids in 2013 based on previous results that indicated anesthetized salmon were less likely to exit the Willamette Falls Dam fishway to the tailrace and were more likely to escape to tributaries than were fish tagged using a restraint device. River conditions in 2013 were characterized by warm temperatures and low flows, in contrast to 2011 and 2012.

We radio-tagged 184 winter steelhead in 2012 and 170 in 2013. The timing of the winter steelhead run as a whole was early in 2012 compared to the 10-year average whereas the 2013 run was one of the latest. In both years, we found that early-run winter steelhead were a well-mixed combination from lower basin populations (i.e., Clackamas, Tualatin, Molalla, and Yamhill rivers). Mid-basin populations (i.e., Santiam and Calapooia rivers) were intermediately-timed and upper basin populations (i.e., McKenzie, Coast Fork and Middle Fork Willamette rivers, and Fall Creek) tended to be relatively late-timed at Willamette Falls Dam. We found that winter steelhead migrated at rates up to ~50 rkm/d, with a mean of ~30 rkm/d, and that winter steelhead moved more slowly as they migrated through successive upstream river reaches.

We inferred spawning distribution from the maximum upstream records for each adult. After adjusting for known transmitter loss, 81% (2012) and 84% (2013) of the radio-tagged winter steelhead escaped to Willamette River tributaries. The remaining fish were last detected downstream from Willamette Falls Dam (5-12%), at the dam (1-3%), or in the lower (3-7%) or upper (0-1%) main stem. If we assumed that all tagged steelhead not detected in a tributary died before spawning, then the maximum *en route* main stem mortality estimate for this study was ~19% in 2012 and ~16% in 2013. Using logistic regression models, we found that neither tag date, weight nor fork length was a significant predictor of tagged winter steelhead escaping to a tributary in 2012 or 2013.

Almost two-thirds of the winter steelhead tagged in 2013 were last detected downstream from Willamette Falls Dam or in the lower main stem, reflecting post-spawn kelt movements downstream. Smaller percentages of tagged steelhead were last recorded in the Santiam (12%), Molalla (8%), and the Middle Fork (3%) rivers. Two percent were last recorded in the upper main stem. The distributions of last detections of tagged winter steelhead were similar in both years. Slightly less than 60 percent of the tagged winter steelhead considered to have escaped to tributaries in both study years exhibited kelt behavior. The ODFW Fish Life History Analysis Project provided scale interpretations

for tagged adults and results indicated that 8% in 2012 and 13% in 2013 of winter steelhead collected and tagged during upstream migration had spawned previously.

Overall, 71-72% of radio-tagged summer steelhead were last detected in Willamette River tributaries in both years. The remaining fish were last detected downstream from the Willamette Falls Dam (4-8%), at the dam (1-2%), in the lower main stem (8-9%), or in the upper main stem (11% both years). Summer steelhead behaviors in the main stem were generally similar to those reported for winter steelhead. Summer-run fish migrated more slowly through upstream reaches than downstream reaches, had median migration rates from ~15 to ~40 rkm/d, and exhibited considerable variability among fish. The run timing and run composition data collected in both years indicated that there is high potential for summer steelhead to overlap spatially and temporally with winter steelhead. Generally, the three most abundant summer-run groups (i.e., Santiam, McKenzie, and Middle Fork) were present throughout the nominal summer-run period at Willamette Falls Dam.

In a separate evaluation of summer steelhead recycling below Foster and Dexter dams, 4-5% of the Foster-tagged fish and 4-17% of the Dexter-tagged fish were reported as harvested during 2012-2013. The lack of a reward program likely resulted in under-reporting of harvest in 2012 but recovery rates were also low in 2013 when a reward program was in place. The low recovery rates may indicate that the recycling programs increase the likelihood that summer steelhead interact with winter steelhead.

The collection of Chinook salmon in 2013 was the first year when samples of clipped and unclipped salmon were tagged in proportion to the run using the same collection and handling protocol that included anesthesia with AQUI-SE 20. The 2012 sample of radio-tagged Chinook salmon was larger and included a higher proportion of unclipped salmon because of our effort to radio-tag McKenzie River wild fish in collaboration with the Eugene Water and Electric Board (EWEB) that year.

Of the 297 Chinook salmon tagged in 2013 that had no evidence of transmitter loss, 229 (77%) were last recorded or recaptured in Willamette River tributaries and 68 (23%) were last detected at main stem sites either upstream or downstream from Willamette Falls Dam. The overall escapement percentage in 2013 was higher than in 2011 (74%) and 2012 (61%). In 2012, salmon restrained during tagging were less likely to escape than anesthetized salmon. In all years, small percentages of radio-tagged salmon last recorded or recaptured in tributaries were reported as recaptured by anglers (*range* = 1.6 to 3.7%).

In statistical models examining Chinook salmon fate in relation to fish traits, behavior and environmental factors, no covariates (tag date, fork length, weight, and lipid content) were statistically significant in the escapement models for clipped or unclipped Chinook salmon tagged in 2013. The absence of a relationship between estimated initial lipid content and fate of adult fish suggested that energetic reserves at river entry were sufficient to fuel upstream migration to tributaries during 2013.

Chinook salmon migrated through the main stem faster as water temperature and date increased, with the highest migration rates observed in the lower main stem. The median main stem migration rate for spring Chinook salmon in 2013 was 27.3 rkm/day. Few (5-10%) of tagged salmon exhibited downstream movements in the main stem during migration in all three years. Similarly, we detected little temporary straying into non-natal tributaries by tagged salmon (it was not possible to assess permanent straying).

The early timing of the 2013 spring Chinook salmon run was consistent with expectations given relatively warm river temperatures and low discharge. Chinook salmon populations in the 2013 run past Willamette Falls Dam were well-mixed and the composition differences between clipped and unclipped samples were modest. Run composition for the 176 fin-clipped Chinook salmon last recorded in tributaries in 2013 showed that the three most abundant return groups (i.e., Santiam, McKenzie, and Middle Fork) were represented in all of the 10-day tagging intervals. Run composition for the 53 unclipped salmon last recorded in tributaries was characterized by the two largest return groups (i.e., South Santiam and McKenzie rivers) making up 33-100% of all the returns in each 10-day tagging interval.

Reconstructed temperature exposure histories for 68 hatchery Chinook salmon tagged with temperature loggers in 2011-2013 indicated that the highest temperatures most fish experienced were in lower main stem reaches. Logger-tagged salmon accumulated up to ~1,500 degree days from release to recapture in tributaries, thermal loadings that have been associated with heightened risk from parasites, fungal infections and other diseases. A majority of degree days for most fish accumulated during the pre-collection holding period inside tributaries. Evidence for behavioral thermoregulation by Chinook salmon along the main stem migration corridor was limited, although a few fish temporarily entered the much cooler Clackamas River downstream from Willamette Falls Dam.

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: Timothy Blubaugh, Steve Lee, and Theresa Tillson tagged adult salmon and steelhead; Matt Knoff and Mark Morasch maintained and downloaded receivers; and Luis Martinez-Rocha, Charles Erdman, and Joseph Renner interpreted and coded the telemetry data. Oregon Department of Fish and Wildlife personnel that contributed to the success of the project included: Wayne Vandernaald, Todd Alsbury, Jeff Ziller, Kelly Reis, Michele Weaver, Shivonne Nesbit, Tom Friesen, Kirk Schroeder, and Craig Tinus. Justin Huff and Brian Franklin performed mobile-tracking surveys for steelhead. We thank Stephanie Gunckel, Ben Clemens, Lisa Borgerson, and Kanani Bowden, ODFW Scale Project and Fish Life History Analysis Lab, for conducting the scale analyses. We thank Stephanie Burchfield and Kim Hatfield, NOAA, Michele Weaver and Shivonne Nisbit, ODFW for their assistance with securing federal permits for the study. We are grateful to Bonnie Johnson, USFWS, for coordinating the use of AQUI-S 20E under the Investigational New Animal Drug program and George Naughton, U. Idaho, for serving as INAD monitor. We also appreciate the contributions made by Tim Shibahara of the Portland General Electric 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 conducted under Cooperative Ecosystems Study Unit (CESU) agreement CESU W912HZ-12-2-0004 funded by the U.S. Army, Corps of Engineers (USACE), Portland District, with the assistance of Robert Wertheimer, Rich Piaskowski, David Griffith Sean Tackley, Glen Rhett, and Deberay Carmichael.

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Table of Contents

Introduction

Our goal for this study was to gather information on the run timing, stock composition, migration behavior, distribution among spawning areas, and survival of radio-tagged adult winter and summer steelhead (*Oncorhynchus mykiss*) and Chinook salmon (*O. tshawytscha*) in the Willamette River basin. We assessed potential effects of the river environment on these salmonids.

Upper Willamette River (UWR) winter steelhead are a distinct population segment that was listed as threatened under the Endangered Species Act (ESA) in 1999 (NMFS 1999). Long-term trends in returns of UWR steelhead have been in decline for the aggregate run upstream from Willamette Falls Dam and for most individual sub-basin populations (Kostow 1995; Chilcote 1998, 2001). However, there have been very few adult winter steelhead tagging studies in the Willamette River basin so little is known about migration behavior, mortality in the main stem and spawning tributaries, or some basic life history traits (i.e., kelting and iteroparity rates). Similarly, few quantitative data have been collected on run composition, migration timing of the native sub-basin populations, or the potential spatial or temporal overlap of native winter steelhead with introduced winter-run steelhead from the Big Creek hatchery stock and introduced summer-run steelhead from the Skamania stock (Keefer and Caudill 2010).

Habitat loss and dams without upstream and downstream fish passage facilities have contributed to the decline of ESA-listed UWR Chinook salmon (NMFS 1999). Moreover, naturally-produced and hatchery UWR Chinook spawning in the wild have experienced high prespawn mortality in many Willamette River tributaries (Schroeder et al. 2007; Kenaston et al. 2009) in the last several decades. This mortality may be negatively affecting population recovery efforts (NMFS 2008). High temperatures can affect the reproductive success of salmonids well before spawning (McCullough et al. 2001) and they have been implicated in the mortality of adult Chinook salmon in the Willamette River main stem and tributaries (Schreck et al. 1994; Mann et al. 2009; Keefer et al. 2010; Naughton et al. 2013) and in other species such as sockeye salmon (*O. nerka*, Naughton et al. 2005; Rand et al. 2006). Upstream dams affect water temperature in the Willamette River main stem and in tailrace holding areas (e.g., below Dexter Dam) as a result of augmented flows and effects of reservoirs on thermal regime over the course of summer and fall (Rounds 2007; 2010). Understanding the relationships among temperature exposure, migration behavior, and prespawn mortality is an important current research objective for Chinook salmon in the Willamette River basin. We note that adult reproduction requires succesful migration, summer holding in tributaries, and spawning. Here we focus on migration success and assess the potential for indirect or carry-over effects during upstream migration to affect holding and spawning success.

In 2013, we continued a radiotelemetry study to monitor adult steelhead (winter- and summer-run) and spring Chinook salmon in the main stem Willamette River and its major tributaries. Collection and tagging occurred at the Willamette Falls Dam trap near Oregon City. Radio-tagged fish were monitored during their upstream migration, on spawning grounds, and during any post-spawn kelt migrations (for steelhead), using a fixed-site radio receiver array and mobile tracking. Based on our previous experience collecting and radio-tagging adult Chinook salmon (e.g., Keefer et al. 2005; Jepson et al. 2010) and summer steelhead (e.g., Keefer et al. 2009) we think that radiotelemetry is an effective adult monitoring method and that most of the tagged fish in the 2013 Willamette River study behaved similarly to untagged fish.

The general research questions addressed by our research program were: 1) what is the behavior, migration success, and final distribution of returning adult salmonids?; 2) how do environmental factors affect adult salmon and steelhead migration behavior and survival?; 3) are there differences in adult life history, behavior, or survival among tributary populations?; and 4) to what degree might winter and summer steelhead interact during migration and spawning? There were two primary study components for Chinook salmon. The first is reported elsewhere and has focused in tributaries during the holding and spawning periods starting in 2008, and included radio- and PIT-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. 2013; Naughton et al. *in review*). The second study component is reported here, began in 2011, and included radio-tagging adult Chinook salmon at Willamette Falls Dam and monitoring their behaviors and survival as they migrated to natal streams (Jepson et al. 2012, 2013). This is the third year of the main stem study component, which builds upon migration data collected by Schreck et al. (1994). The main stem steelhead study started in 2012 and 2013 was the second study year. 2013 was the second study year when summer steelhead were collected and radio-tagged at Foster and Dexter dams to estimate behavior and final distribution of recycled steelhead.

Specific 2013 objectives addressed in this report include:

1) assessing energetic condition and physical traits of adult Chinook salmon and steelhead at Willamette Falls Dam;
2) characterizing Chinook salmon and steelhead migration rates and behaviors;
3) estimating population-specific run-timing metrics for Chinook salmon and steelhead returning to spawning tributaries;
4) reconstruction of individual Chinook salmon thermal histories in the main stem Willamette River and in tributaries;
5) assessing potential relationships among fish condition, their main stem behavior, thermal history, river environment, and prespawn mortality; and
6) evaluating fates of summer steelhead collected at Foster and Dexter dams and released downstream from the dams to increase angler opportunity.

Separate companion reports include summaries of 2013 research on adult Chinook salmon outplanted in the Middle Fork Willamette River basin (Naughton et al. *in review*) and on adult Chinook salmon disease status at Willamette Falls Dam (Schreck et al. *in prep.*).

Methods

Tagging site, procedures, and fish measurements

Adult steelhead and Chinook salmon were collected and tagged at the adult fish trap at Willamette Falls Dam (Figures 1 and 2). Salmonids 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 head of the cage so that trapped fish could volitionally ascend the Denil and enter a chute from which they were diverted into a holding tank with anesthetic. Samples were not truly random with respect to the entire run 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.

In 2013, all collected fish were anesthetized with AQUI-S 20E prior to tagging. The anesthetic was used under the Investigational New Animal Drug (INAD) program, sponsored by the U.S. Fish and Wildlife Service. The active ingredient of AQUI-S20E is eugenol, an essential oil derived from cloves and used as an antiseptic and anesthetic (INAD 2011).

When the fish was properly sedated, length, weight, marks and injuries, signs of disease, and an estimate of sex were 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 if placed in a fish with a clipped adipose fin (i.e., a fish susceptible to harvest). A PIT tag was inserted into the pelvic girdle of all adults lacking a PIT tag as a secondary mark. A sub-sample of 66 Chinook salmon was additionally tagged with an archival temperature pod (models DS1921G, DS1921Z, or DS1922L Thermochron iButton, Embedded Data Systems, Lawrenceburg, KY). The loggers recorded fish body temperature every 30 min.

Telemetry sites and mobile tracking efforts

A total of 47 fixed-site radio receivers were distributed throughout the study area (Figure 3 and Table 1). Monitoring efforts also included mobile tracking via truck and boat. Truck mobile tracking by Oregon Department of Fish and Wildlife (ODFW) personnel occurred on 75 unique days from 21 February to 25 June, with the highest number of surveys conducted in the Santiam River basin. Mobile telemetry was conducted along fixed routes so that the probability of tag detection was relatively constant from survey to survey. No mobile tracking surveys were conducted in Rickreall Creek or in the Coast Fork, Luckiamute, Mary’s, or Clackamas rivers.

Figure 1. Overhead view of the Denil (left), trap, and ladder return (right) used to collect adult steelhead and Chinook salmon at Willamette Falls Dam in 2011-2013.

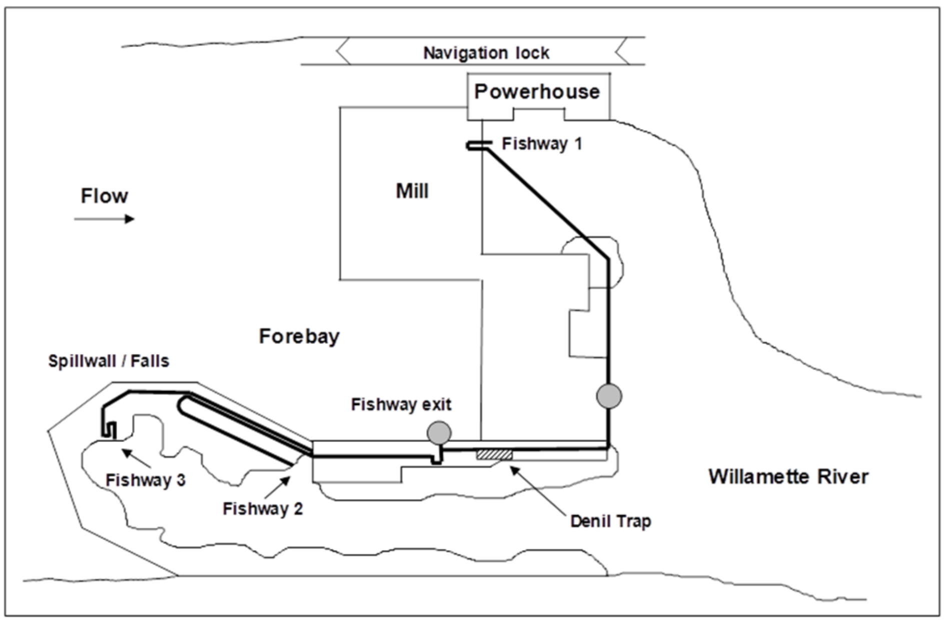

Figure 2. Schematic drawing of Willamette Falls Dam, Oregon, showing the location of three fishways, and the two fixed-location radio receiver sites (●) deployed at the dam in 2013. Additional antennas were located in the dam tailrace (0.5 km downstream).

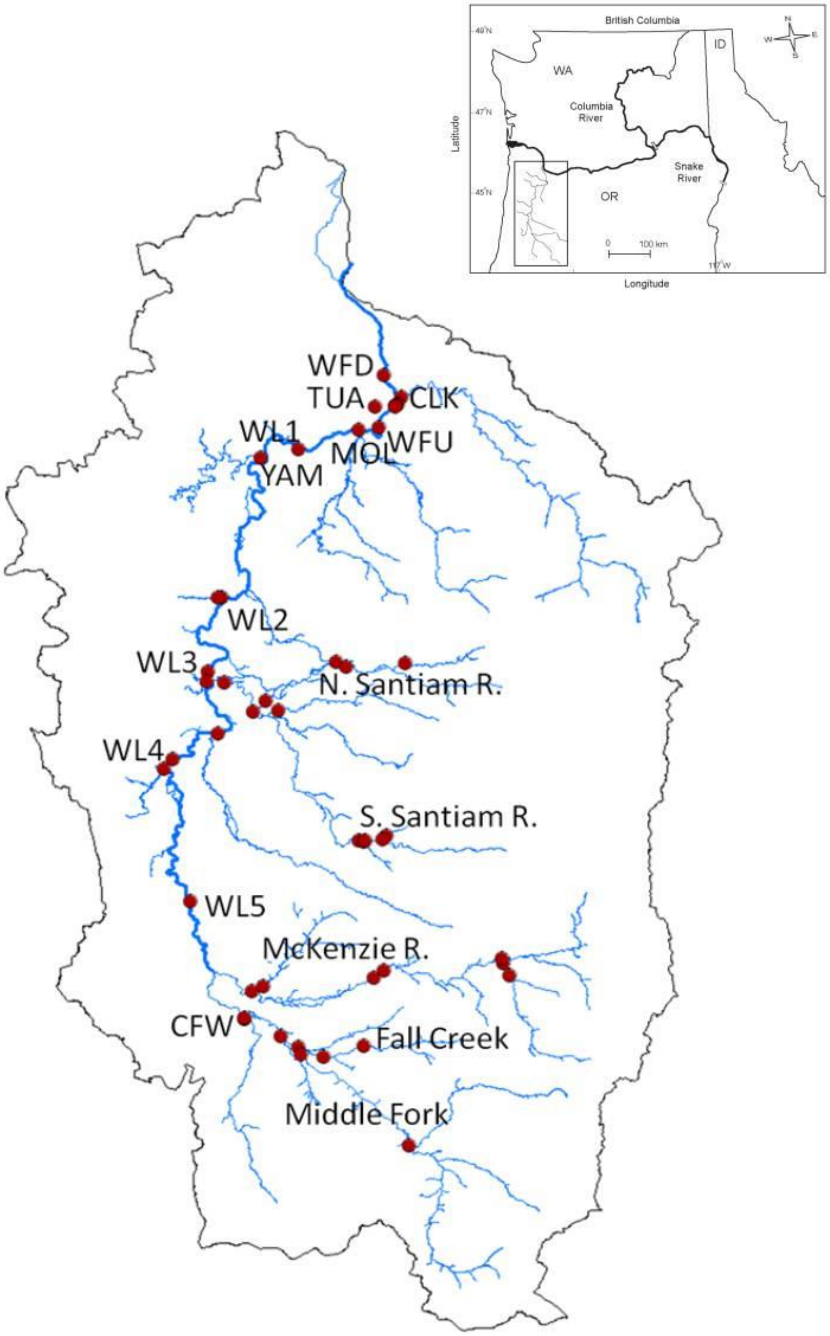

Figure 3. Map of the Willamette River basin and locations where fixed-site radio receivers (red dots) were deployed by the University of Idaho in 2013.

Table 1. List of radio receivers deployed in the Willamette River basin in 2013, their site name abbreviations, and the river kilometer (rkm, from the Columbia River mouth) where they were deployed.

Monitoring site	Site code	rkm
Willamette Falls Dam (downstream)	WFD	195.9
Clackamas River	CLK	203.8
Willamette Falls Dam tailrace	1WF	205.6
Willamette Falls Dam (downstream from trap)	WLL	206.1
Willamette Falls Dam (upstream from trap)	WFF	206.1
Tualatin River	TUA	211.5
Molalla River	MOL	220.9
Willamette Falls Dam (upstream)	WFU	212.9
Willamette main stem 1 (Champoeg)	WL1	237.1
Yamhill River	YAM	252.9
Willamette main stem 2 (Eola)	WL2	304.9
Rickreall Creek	RIC	306.0
Willamette main stem 3 (Buena Vista)	WL3	334.8
Luckiamute River	LUK	336.5
Santiam River Mouth	STM	343.9
Santiam River (South Fork)	SST	357.9
Middle Santiam Reservoir	MSR	423.5
South Fork Santiam Reservoir	SFR	422.0
Thomas Creek	THC	365.9
Foster Dam tailrace	SSF	416.6
Wiley Creek	WLY	417.9
Foster Dam trap	FST	418.0
Santiam River (North Fork)	STN	362.0
Little North Santiam River	LNO	406.0
Lower Bennett Dam	NS1	385.2
Upper Bennett Dam	NS2	389.3
Upstream from Upper Bennett Dam	UUB	389.5
Downstream from Minto Fish Facility	1MT	423.0
Minto Collection Facility	MCF	424.3
Calapooia River	CAL	356.2
Willamette main stem 4 (Corvallis)	WL4	374.4
Mary’s River	MRR	376.4
Willamette main stem 5 (Harrisburg)	WL5	417.9
McKenzie River	MCK	453.9
Mohawk River	MOH	464.5
McKenzie River Hatchery Trap	MHT	489.7
McKenzie River (Leaburg Dam)	MKL	492.9
McKenzie River (South Fork)	MKS	527.5
McKenzie River (Cougar Dam)	COG	531.1
McKenzie River (upstream from S. F confluence)	MSU	527.2
Coast Fork Willamette R.	CFW	465.2
Middle Fork (near Coast Fork Confluence)	MFC	465.2
Willamette Middle Fork	WMF	478.4
Fall Creek Mouth	FCR	484.0
Fall Creek Dam tailrace	FCT	493.3
Dexter Dam tailrace	1DX	486.7
North Fork Middle Fork	NFM	523.7

Results

Environmental data

In 2013, water temperatures were generally warmer and Willamette River discharge was generally lower than in both 2011 and 2012 (Figure 4). Water temperature measured in 2013 at the USGS gauge near Albany, OR increased from April through August, reached a maximum of 21.9 °C on 3 July (with a secondary peak of 21.8 °C on 26 July), and then decreased through September and October. Albany data are presented in Figure 4 to illustrate the relative differences among years. In 2013 (and previous years), main stem temperatures were warmer at the Portland and Newburg USGS gauges than at Albany and were cooler at Harrisburg (Figure 5). Tributary temperatures in the Middle Fork, McKenzie, South Santiam and North Santiam were consistently cooler than the main stem, while the lower Santiam at the Jefferson gauge was similar to the middle main stem Willamette.

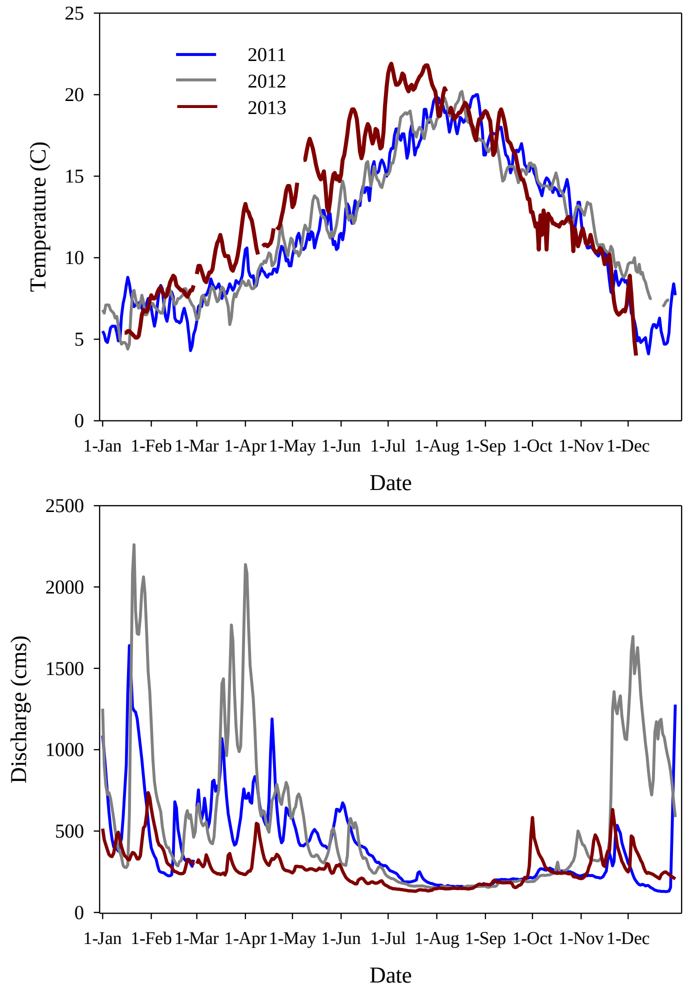

Figure 4. Mean daily Willamette River water temperature (°C, top panel) and mean daily Willamette River discharge (cms) recorded at the USGS gauge at Albany, OR, in 2011-2013 (bottom panel). Data were collected from http://ida.water.usgs.gov/.

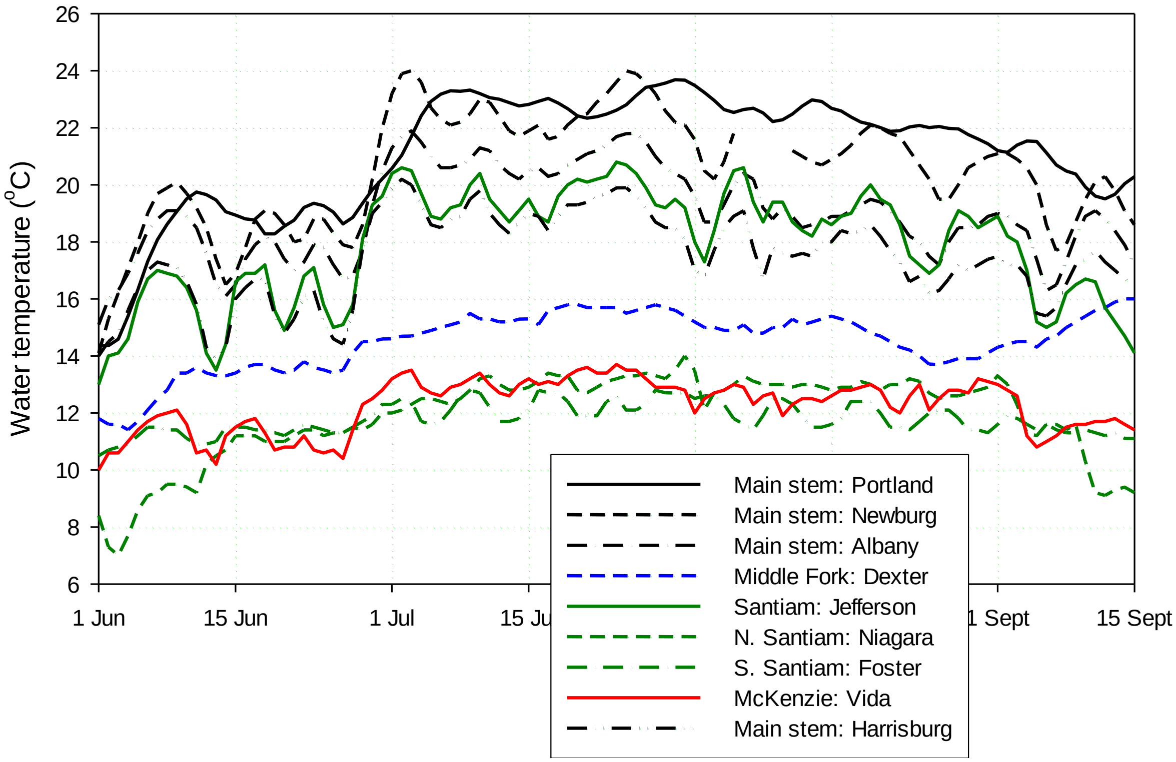

Figure 5. Mean daily water temperatures (°C) recorded at USGS gauge sites in the main stem Willamette, Middle Fork Willamette, Santiam, and McKenzie rivers during the spring Chinook salmon migration in 2013.

Steelhead collection and tagging

Willamette Falls Dam – A total of 31,629 adult steelhead were counted passing Willamette Falls Dam from 15 November 2011 to 31 August 2012, which was 115% of the ten year average (Figure 6). Adult steelhead returns in the same 2013 interval (17,604 counted) were 68% of the 10 year average (25,858 steelhead).

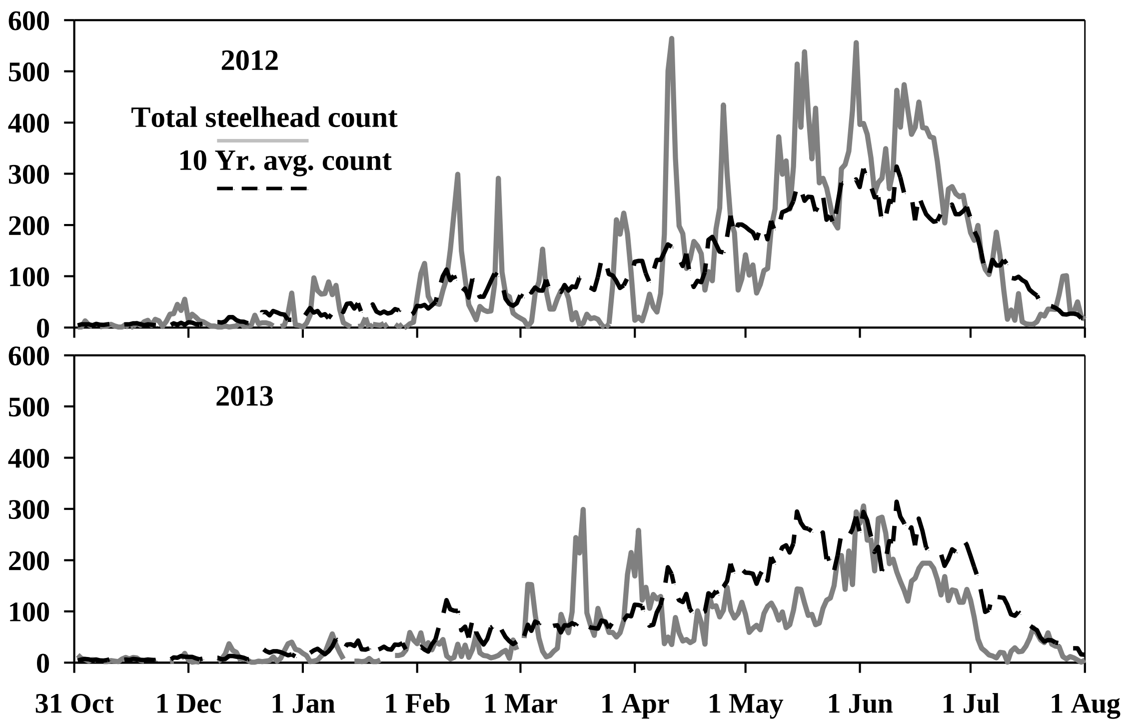

Figure 6. The number of adult steelhead (clipped and unclipped combined) counted at Willamette Falls Dam in 2012 (upper panel) and 2013 (lower panel) and the ten-year average count. Count data from http://www.cbr.washington.edu/dart/adult.html and http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

We defined any adult steelhead with an intact adipose fin as a winter steelhead and any steelhead with a clipped adipose fin as a summer steelhead for this report, which differs from Jepson et al. (2013). In 2012, 13 steelhead with intact adipose fins were classified as summer steelhead by the taggers (based on coloration). Their tag dates ranged from 19 May to 1 July 2012. In 2013, seven steelhead with intact adipose fins (tag date range = 11-28 May) were classified as summer steelhead based on phenotype. One ad-clipped steelhead tagged on 2 February 2013 was classified as a winter steelhead by the taggers but is included with the summer steelhead in this report.

We radio-tagged 184 steelhead with intact adipose fins in 2012, which was 2.4% of the 7,616 winter steelhead counted from 1 November 2011 through 31 May 2012 (Table 2 and Figure 7). Of the 184 winter steelhead tagged, 94 (51%) received the anesthetic treatment and 90 were restrained. Tag dates ranged from 2 March – 1 July, 2012. We radio-tagged 195 summer steelhead from 28 March to 1 July, which was 0.8% of the 24,103 summer steelhead counted through 31 July (Table 2 and Figure 8).

In 2013, we radio-tagged 170 adult winter steelhead, which was 3.4% of the 4,944 winter steelhead counted from 1 November 2012 through 31 May 2013 (Figure 7). The 31 May cutoff date was the end of the winter run, as defined by ODFW. We note that one unclipped steelhead was tagged on 5 June. We radio-tagged 250 summer steelhead from 22 January to 26 June, which was 2.0% of the 12,661 summer steelhead counted from 1 March through 31 July (Figure 8). Overall, we radio-tagged 2.4% of all steelhead (winter and summer) counted (419/17,605) at Willamette Falls Dam from 1 November 2012 through 31 July 2013. All steelhead were radio-tagged using anesthetic in 2013. No mortality events occurred during tagging or handling and all steelhead were released in good condition.

Table 2. Annual numbers of adult steelhead radio-tagged at Willamette Falls Dam, their adipose fin clip status and the number restrained and anesthetized in 2012-2013.

Year	Adipose fin status	Number of steelhead Tagged	Restrained	Anesthetized
2012	intact	184	90	94
	clipped	195	194	1
2013	intact	170	-	170
	clipped	250	-	250

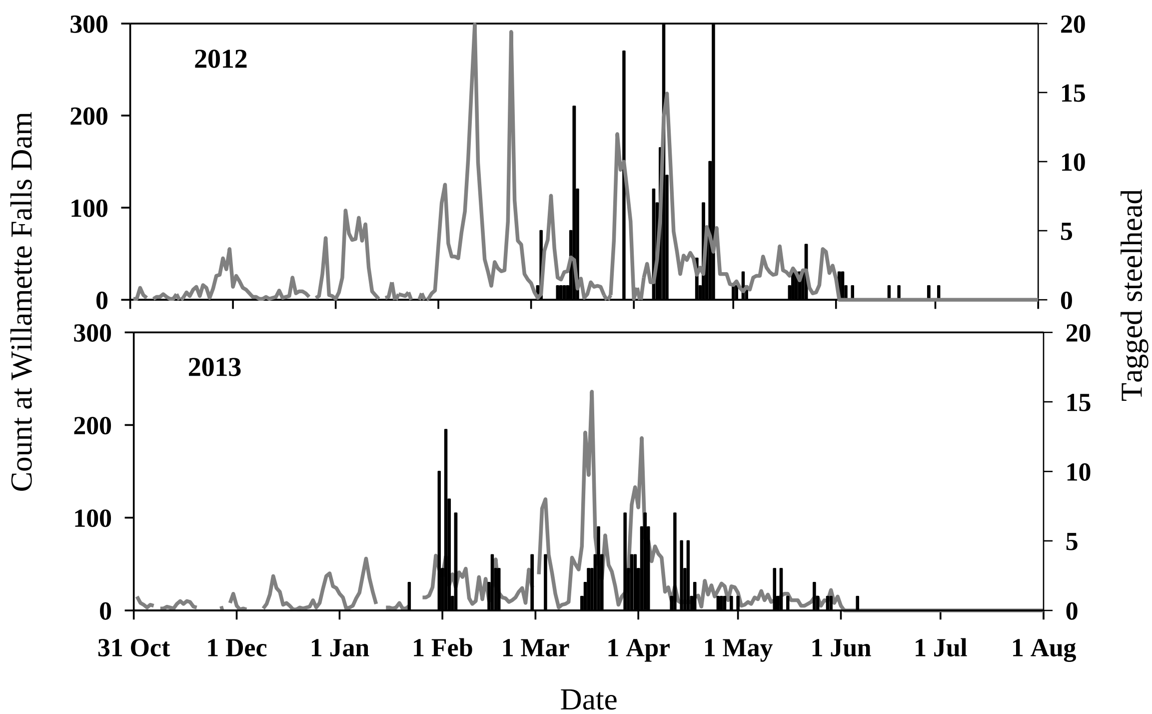

Figure 7. The number of winter steelhead counted (line) and radio-tagged (bar) at Willamette Falls Dam in 2012 (upper panel) and 2013 (lower panel). Count data from http://www.cbr.washington.edu/dart/adult.html and http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

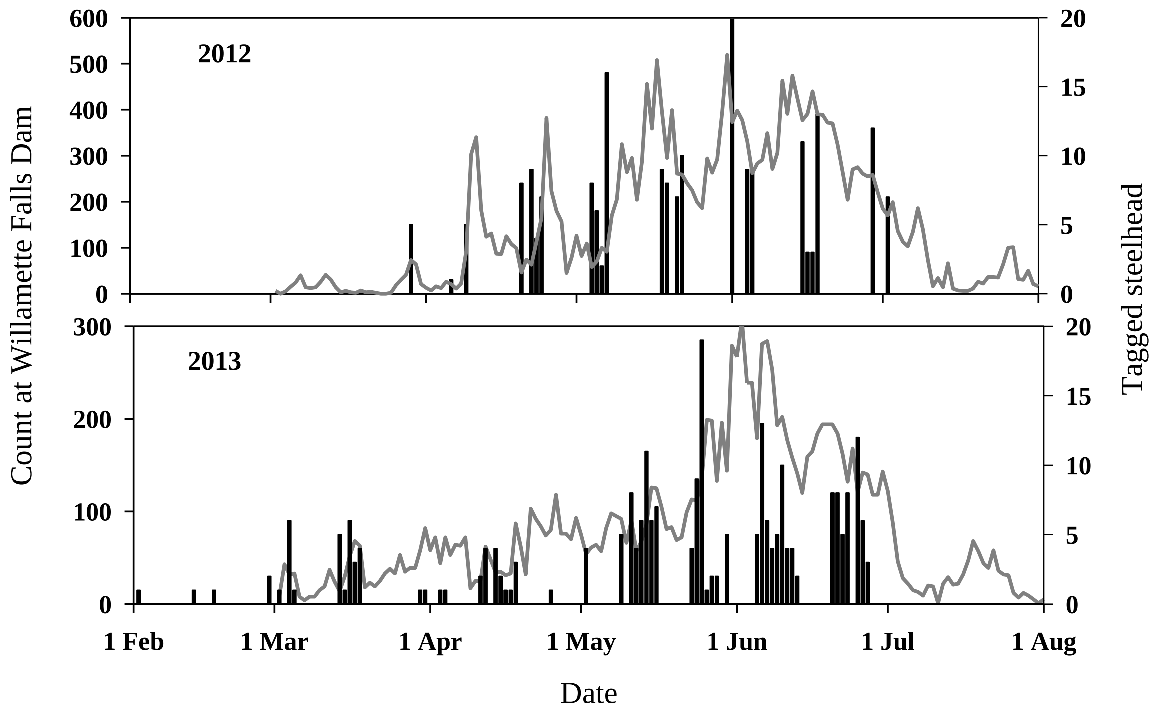

Figure 8. The number of summer steelhead counted (line) and radio-tagged (bar) at Willamette Falls Dam in 2012 (upper panel) and 2013 (lower panel). Count data from http://www.cbr.washington.edu/dart/adult.html and http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Two of the 184 (1.2%) transmitters placed in winter steelhead in 2012 were recovered in Fishway 1 during an August dewatering event. We concluded that these two steelhead regurgitated their transmitters some time after release and they were excluded from analyses (modified n = 182). No transmitters placed in either winter or summer steelhead in 2013 were recovered in Fishway 1. There were five tags placed in winter steelhead and one placed in a summer steelhead that produced detections only at Willamette Falls Dam receivers in 2013. Some or all of these may have been regurgitated transmitters but all six fish were included in all analyses.

Recycled steelhead at Foster and Dexter dams - A total of 100 summer steelhead were collected at Foster Dam on five days from 14 June through 16 August 2013. These fish were radio-tagged, transported by truck by ODFW, and released downstream from the dam at one of three release locations: either ~49 rkm downstream from Foster Dam (near Waterloo, OR), 6.4 rkm downstream from the dam (near Pleasant Valley, OR), or near the mouth of Wiley Creek (< 1 km downstream from Foster Dam). A total of 50 summer steelhead were collected at Dexter Dam on four days from17 July through 13 August, radio-tagged, trucked, and released 4.6 kilometers downstream from the dam. Movements were monitored using the fixed-site array of receivers, mobile tracking, and returns to the Foster and Dexter dam traps.

Chinook salmon collection and tagging

At Willamette Falls Dam, we radio-tagged a total of 949 Chinook salmon from 2011 through 2013 (Table 3 and Figure 9). A total of 310 ad-clipped salmon were outfitted with temperature loggers in the three study years, which included 210 with radio transmitters and 100 with temperature loggers only).

In 2011, 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 in 2011. Thirteen percent (19/150; unclipped only) received an experimental, eugenol-based anesthetic, AQUI-S 20E. The remaining ~87% were tagged without anesthesia using a fish restraint device modeled after Larson (1995).

The 2012 sample of radio-tagged Chinook salmon included a disproportionate number of unclipped salmon (62% of sample) because of our effort to radio-tag McKenzie River wild fish in collaboration with the Eugene Water and Electric Board (EWEB). About half of the unclipped salmon were anesthetized in 2012 as part of a second year of experimental tests of AQUI-S 20E (see Jepson et al. 2013 and Caudill et al. *in press* for details).

Table 3. Annual numbers of adult Chinook salmon radio-tagged (RT) at Willamette Falls Dam, the number of adipose-clipped and adipose-intact, the number restrained and anesthetized, and the number outfitted with temperature loggers, 2011-2013.

	Number of radio-tagged Chinook salmon					
Year	Tagged	Adipose clipped	Adipose intact	Restrained	Anesthetized	Temperature pods
2011	150	112	38	131	19	145 RT + 100 non-RT
2012	500	189	311	346	154	99 RT (ad-clipped)
2013	299	229	70	-	299	66 RT (ad-clipped)

In 2013, we radio-tagged 299 Chinook salmon from 16 April through 12 June, which was 1.1% (299/27,500) of the adult Chinook salmon counted at the dam from 1 April through 31 July (Figure 9). We estimated that 6,875 of the 27,500 salmon counted had unclipped adipose fins based on a 25.0% wild composition estimate provided by ODFW counts at the Willamette Falls Dam count station. The 70 radio-tagged salmon with intact adipose fins were 1.0% (70/6,875) of the estimated unclipped run. The 229 adipose-clipped salmon were 1.1% (229/20,625) of the estimated clipped run. All Chinook salmon were radio-tagged using anesthesia. The subset of 66 with temperature loggers were released from 26 May through 12 June 2013 (i.e., in the second half of the run) in an effort to collect temperature histories during the warmer period of the migration. No mortality events occurred during tagging or handling and all salmon were released in good condition.

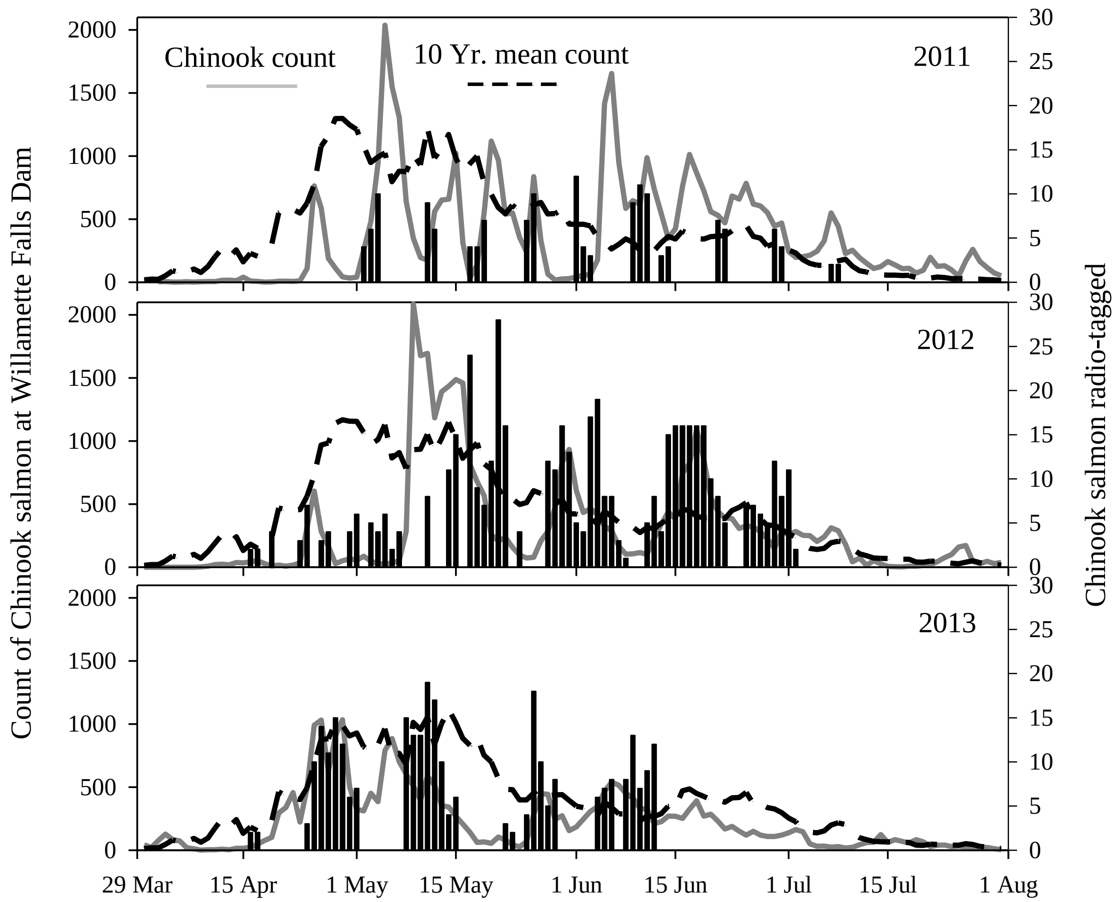

Figure 9. The number of adult Chinook salmon counted at Willamette Falls Dam (solid line), the ten-year average count (dashed line), and the number of Chinook salmon radio-tagged (bar) in 2011-2013. Count data from http://www.cbr.washington.edu/dart/adult.html and http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Two of the 299 (0.7%) transmitters placed in radio-tagged Chinook salmon in 2013 were recovered in Fishway 1 at Willamette Falls Dam during ladder dewatering events.; Both were from unclipped salmon and these fish were excluded from all analyses (modified n = 297). There were four tags placed in salmon that produced detections only at Willamette Falls Dam, but all tags had credible radio detections, suggesting that no tags failed. The salmon with detections only at the dam may have regurgitated their transmitters but we included these four fish in all analyses.

In 2013, the mean fork lengths of winter steelhead, summer steelhead, and spring Chinook salmon radio-tagged at Willamette Falls Dam were 69.5, 69.5, and 74.3 cm, respectively (Figure 10). The mean weights were 4.0, 3.4, and 5.4 kg, respectively. Distributions for all groups were slightly right-skewed.

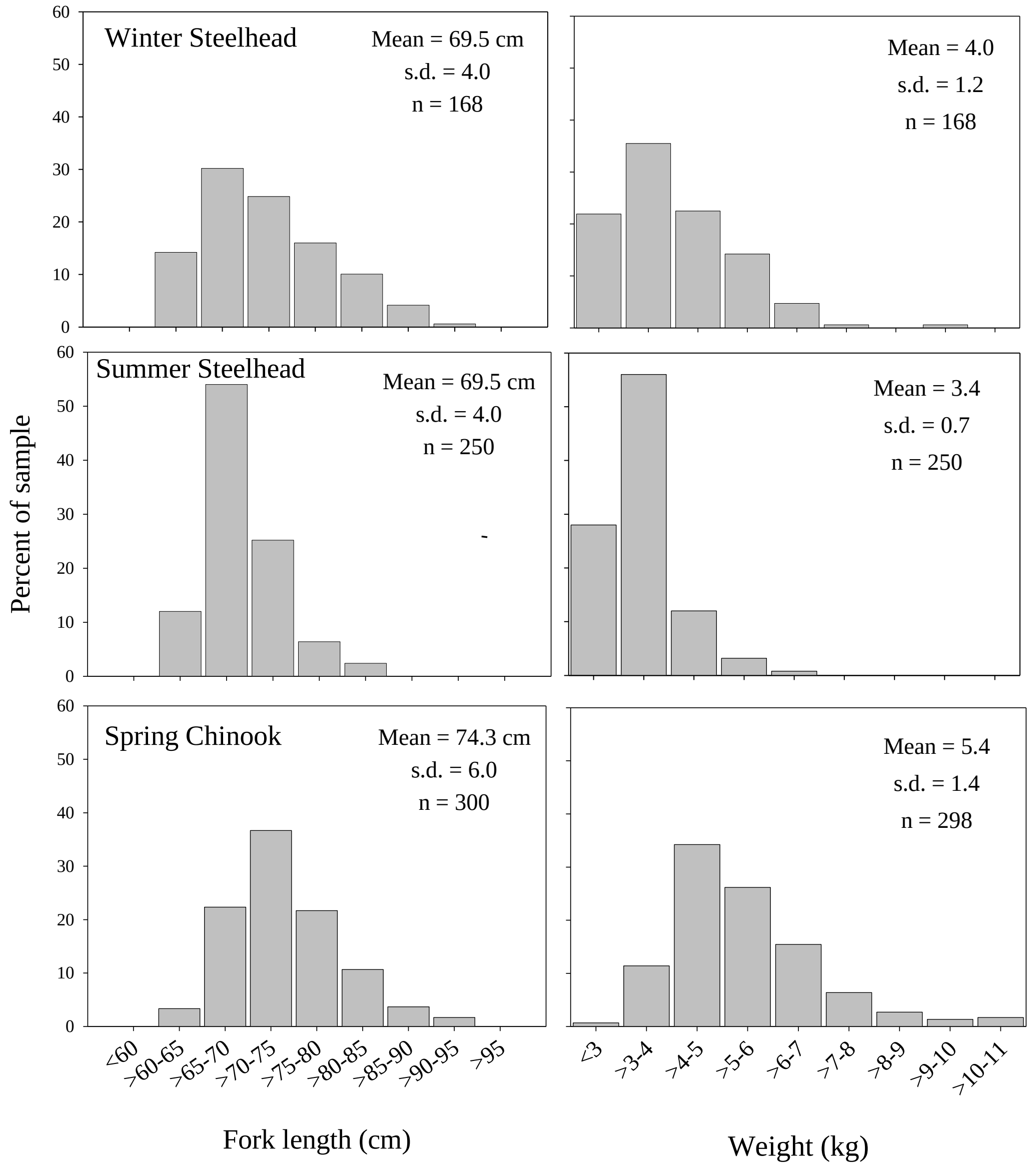

Figure 10. Histograms of winter steelhead, summer steelhead, and spring Chinook salmon fork lengths (cm) and weights (kg) for samples that were radio-tagged at Willamette Falls Dam in 2013.

Fatmeter readings collected at the time of tagging decreased with increasing tag date for Chinook salmon in 2013 ($r^2 = 0.37$, $P < 0.01$, Figure 11). Chinook salmon also exhibited the highest absolute fatmeter values and the highest among-fish variation. There was no evidence for seasonal effects on fatmeter readings for either winter or summer steelhead.

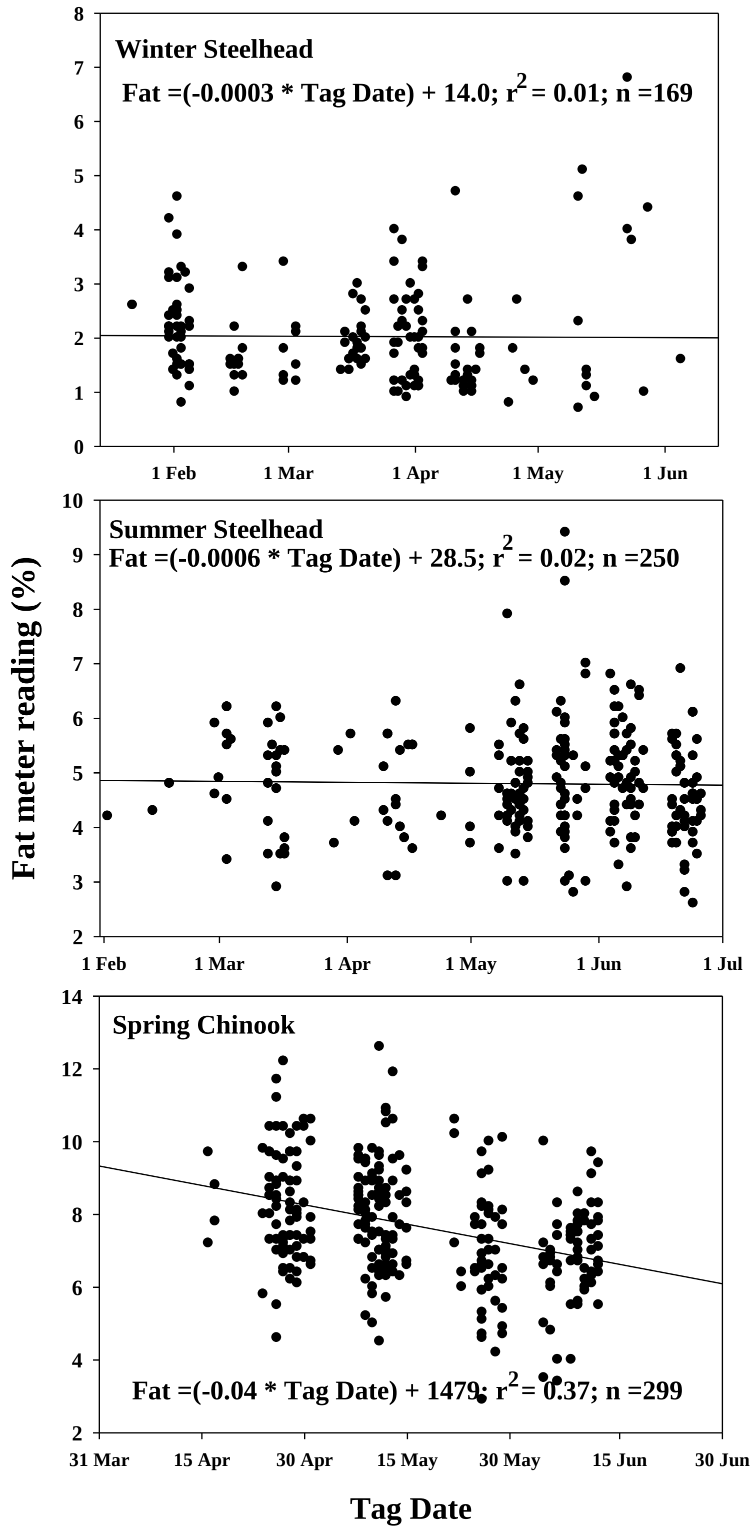

Figure 11. Scatterplots of Distell fatmeter readings versus tag date for winter steelhead, summer steelhead, and spring Chinook salmon radio-tagged at Willamette Falls Dam in 2013. Note different ranges along the x- and y-axes.

Results: Winter steelhead

Historic count data and run timing

The number of adult winter steelhead counted passing Willamette Falls Dam from 1 November 2012 to 30 May 2013 was 4,944 (Figure 12). This was at the low end of the range of counts since 1971 but was approximately 3,100 more fish than the lowest count of 1,801 in 1996. The 2013 winter steelhead run was one of the three latest-timed runs in the last twelve years (Figure 13). The 2013 median passage date was 15 March, compared to medians that ranged from 19 February to 16 March in 2002-2012.

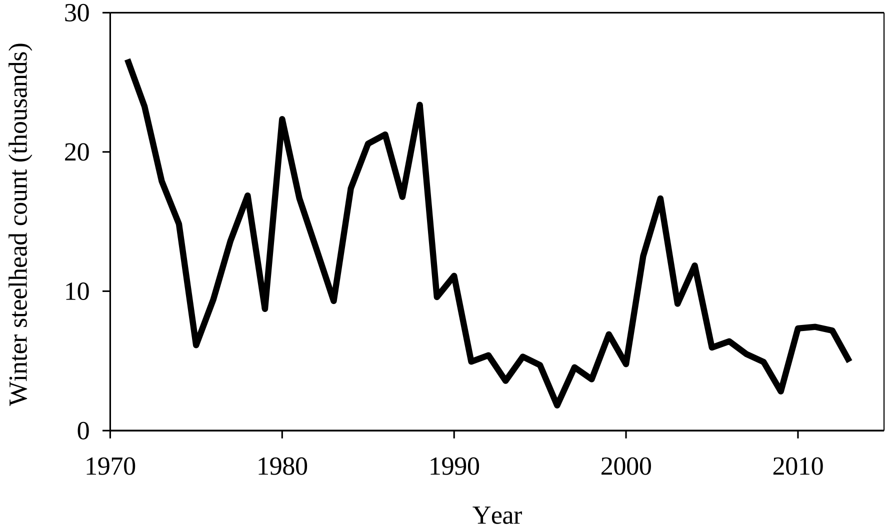

Figure 12. Total annual numbers of adult winter steelhead counted passing Willamette Falls Dam, 1971-2013. Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

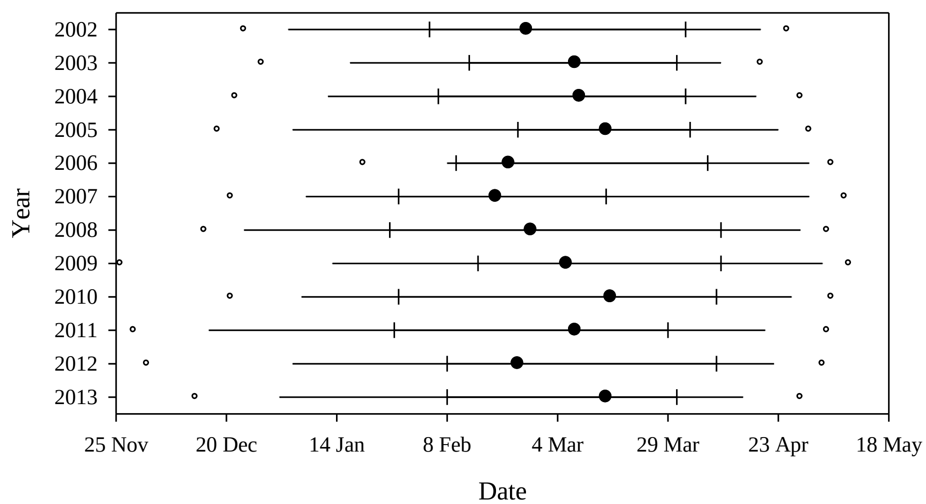

Figure 13. Annual migration timing distributions for winter steelhead counted at Willamette Falls Dam, 2002-2013. Symbols show median (●), quartile (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (○). Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Main stem residence times and migration rates

Tagged winter steelhead typically resided in each of the monitored main stem sections for approximately 1-3 days in both study years (Figure 14). On median, winter steelhead took 7.0 d (*range* = 4.6-12.8 d) to migrate through the main stem from above Willamette Falls Dam (WFU) to near Harrisburg (WL5) in 2013. This was very similar to the 7.2 d median for the same reach in 2012. Section lengths were 24.2 rkm from Willamette Falls Dam 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). Migration rates indicated that steelhead moved more slowly as they migrated through successive upstream sections (Figure 14).

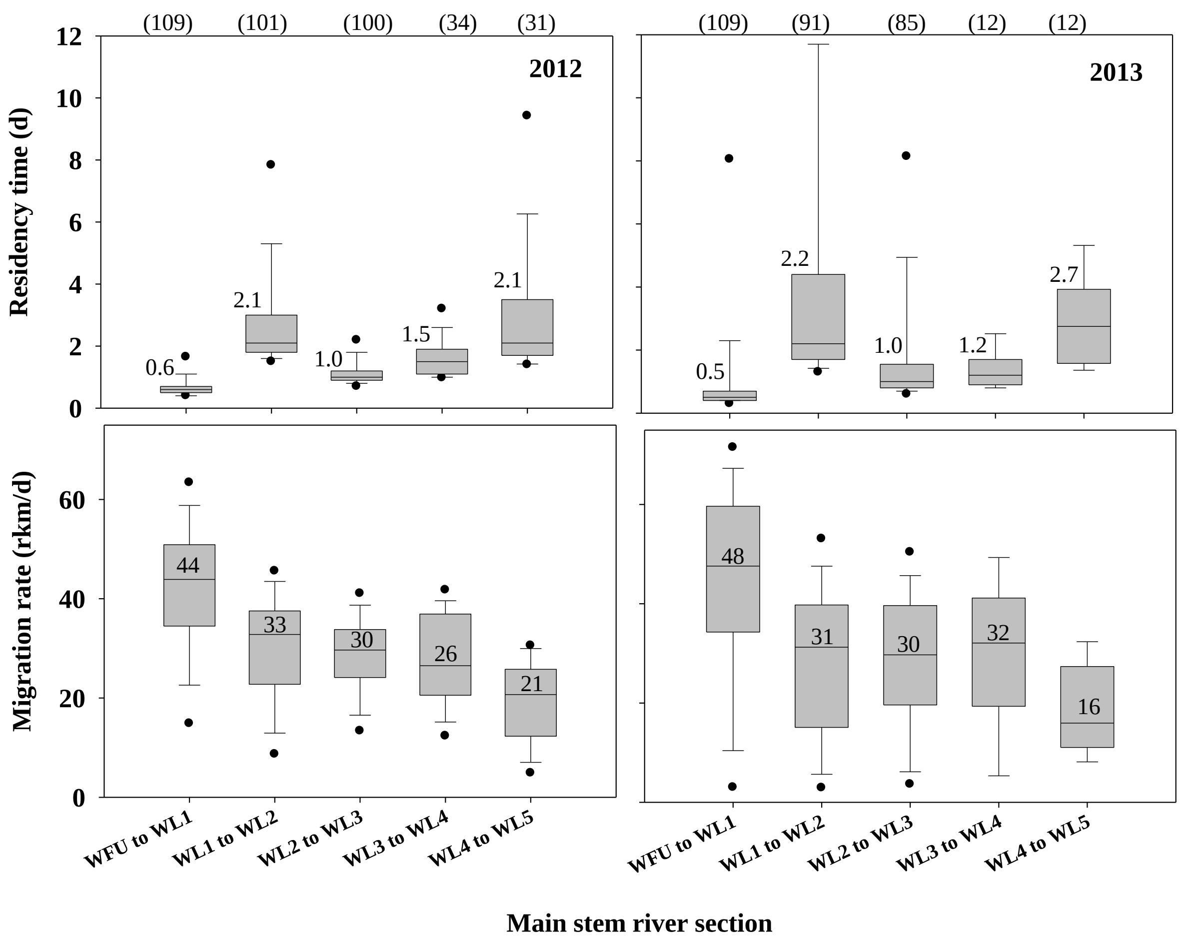

Figure14. Box plots of residence times (days, upper panels) and migration rates (rkm/d, lower panels) of radio-tagged winter steelhead in reaches of the main stem Willamette River in 2012 (left panels) and 2013 (right panels). Box plots show: median (line, and number above line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles (filled circles). Sample sizes are listed in parentheses above panels.

Last radio detections

Almost two-thirds of tagged winter steelhead in 2013 were last detected downstream from Willamette Falls Dam or in the lower main stem, and many of these detections reflected post-spawn kelt movements downstream (Figures 15 and 16). Smaller percentages were last recorded in the Santiam (12%), Molalla (8%) and Middle Fork (3%) rivers. Two percent were last recorded in the upper main stem. These distributions of last detections of tagged winter steelhead were similar in 2012 and 2013.

We also estimated distribution by the maximum river kilometer where steelhead were detected to better approximate spawning distribution among tributaries. In 2013, the highest percentage (40%) of tagged winter steelhead was in the Santiam River (N. Santiam 17%; S. Santiam 23%; Figures 17 and 18). Eighteen percent had their most upstream records in the Molalla River. Smaller percentages were in the Tualatin (8%),Yamhill (5%), Calapooia (4%), Middle Fork (4%) and McKenzie (2%) rivers. Three radio-tagged winter steelhead returned to the Clackamas River and all of them had their final detections there (i.e., none exhibited kelt behavior – see kelting section below). It was not known whether these fish originated from the Clackamas or from a site upstream from Willamette Falls Dam. The three Clackamas winter steelhead were exceptions to the maximum river kilometer criterion because the Clackamas receiver site had a lower river kilometer than any site upstream from Willamette Falls Dam.

Sample sizes were small for many winter steelhead fate groups, but there were some phenotypic differences among groups (Table 4). Mean fork lengths ranged from 67.0 cm to 82.0 cm. Steelhead assigned to the Fall Creek, North Santiam, Middle Fork and Rickreall Creek groups were larger, on average, than those assigned to the McKenzie, Clackamas, Tualatin, and Yamhill groups. Steelhead from the North Santiam group (n = 29) averaged almost five centimeters longer than those that returned to the South Santiam River (n = 39). Mean fatmeter readings among fate groups ranged from 1.6 to 4.6%, with the highest estimates for McKenzie, Middle Fork, Rickreall Creek, and upper main stem groups. There were also among-group differences in tagging date. The earliest mean dates were for Rickreall Creek, Yamhill, and Tualatin groups (late January to late February). The latest mean dates were for Middle Fork, Clackamas, lower main stem, and McKenzie groups (late March to early May). The 2013 distribution of mean tag dates among groups was similar to the distribution from 2012, except when the lower main stem group had an earlier mean tag date and the upper main stem group had a later mean tag date in 2012.

One hundred forty-two (84%) of the 170 winter steelhead tagged in 2013 were considered to have escaped to a tributary (please note: escapement to a tributary can not be considered equivalent to spawning success). This was slightly higher than the 81% tributary escapement rate observed in 2012 (80.7%; 147 escaped/182 tagged; two lost/regurgitated tags excluded). Using the logistic regression model [Escape to tributary (y/n) = tag date + weight + fork length] neither tag date, weight, nor fork length was a significant predictor of tagged winter steelhead escaping to a tributary in 2013 (tag date P = 0.48, weight P = 0.79, fork length P = 0.58, n =170). Removing the fork length or weight term from the 2013 model produced no significant predictors. The overall model had similar results in 2012: there were no significant associations with escapement (tag date P = 0.24, weight P = 0.37, fork length P = 0.34, n =182).

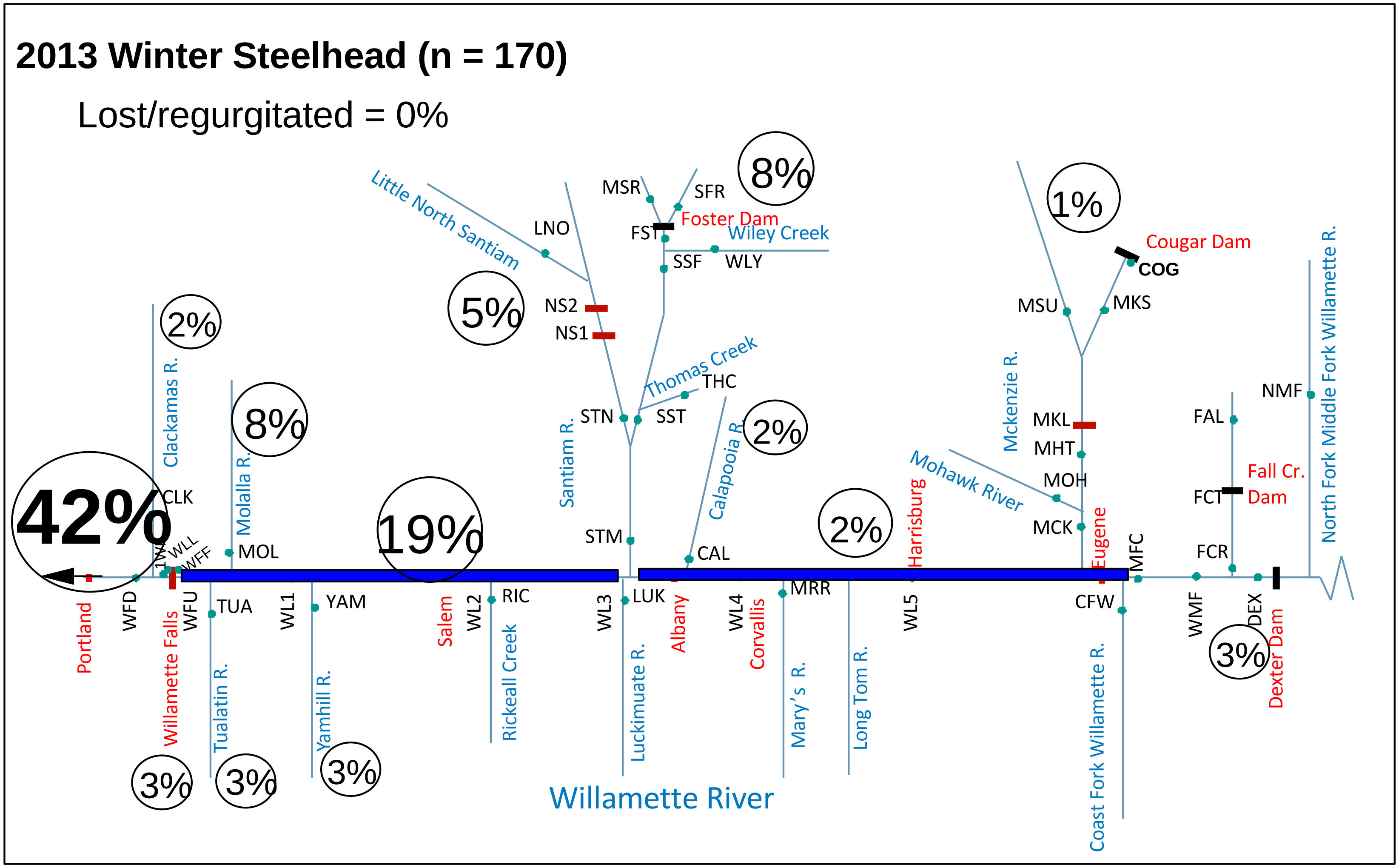

Figure 15. Sites and river basins where radio-tagged adult winter steelhead were last detected in 2013 (i.e., includes post-spawn kelt movements). Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference. The blue rectangles represent the upper and lower main stem.

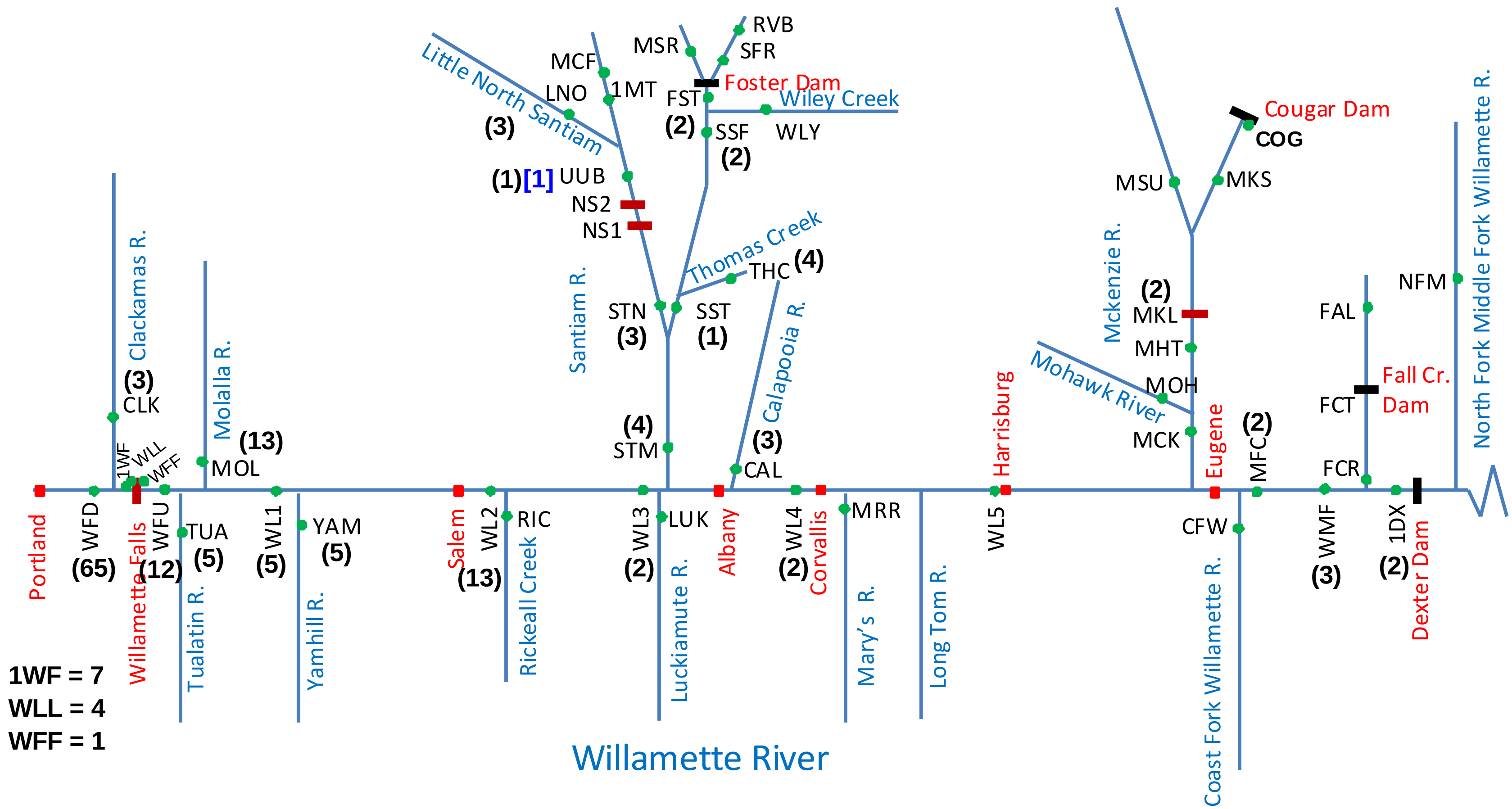

Figure 16. Sites and river basins where radio-tagged adult winter steelhead were last detected in 2013 (i.e., includes post-spawn kelt movements). Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference.

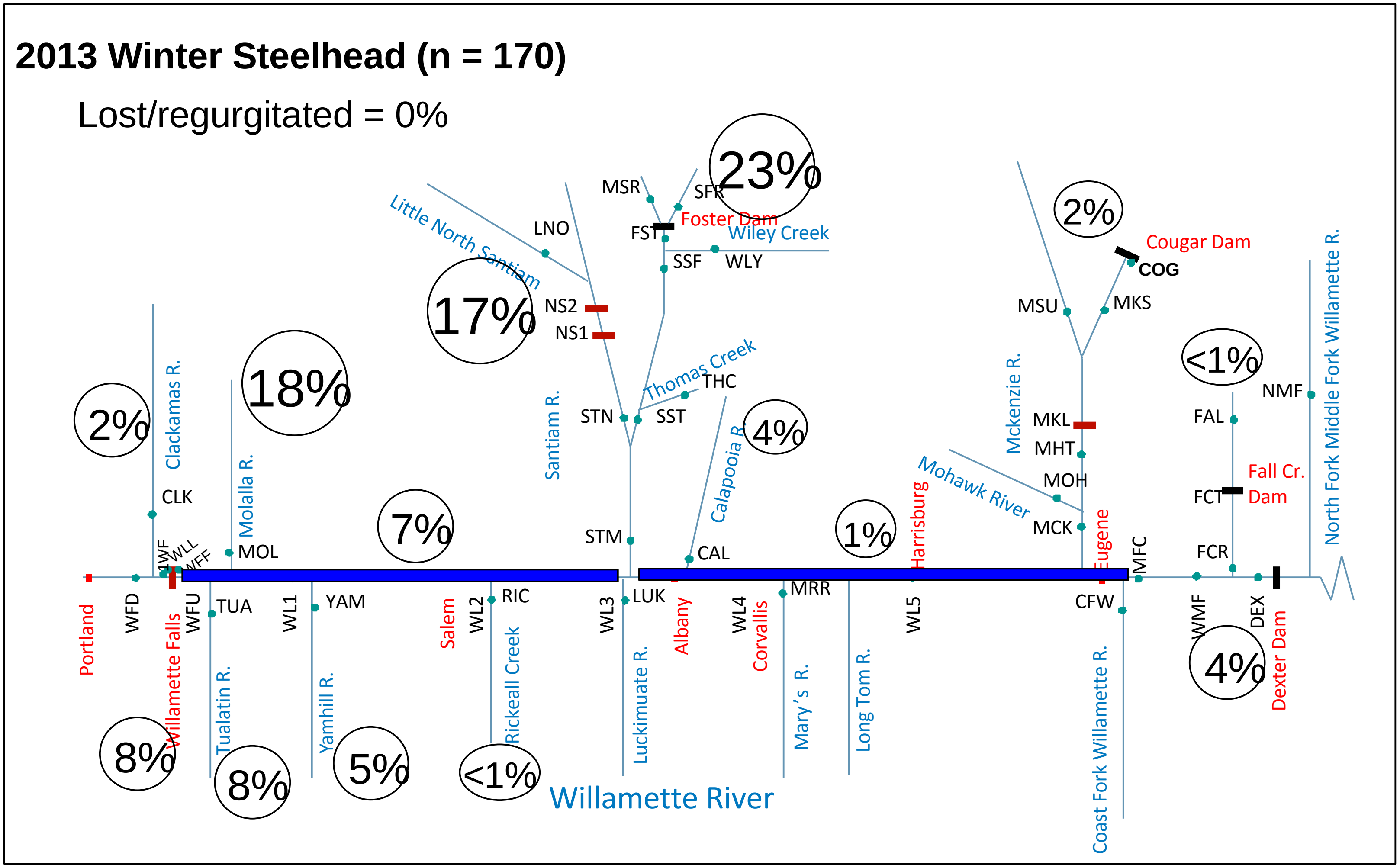

Figure 17. Sites and drainages where adult winter steelhead radio-tagged and released at Willamette Falls Dam in 2013 migrated for potential spawning based on their maximum river kilometer.

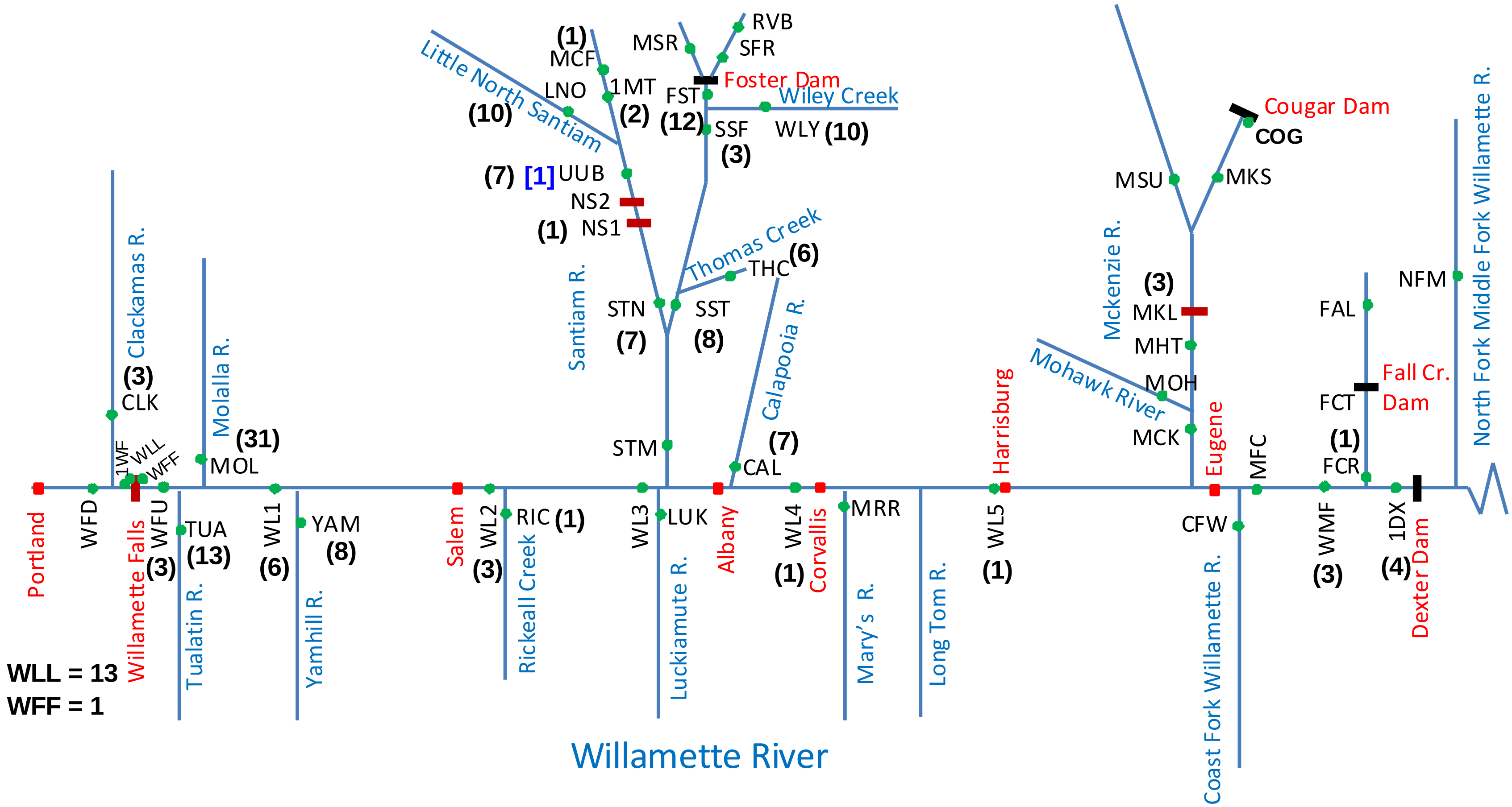

Figure 18. Sites and drainages where adult winter steelhead radio-tagged and released at Willamette Falls Dam in 2013 migrated for potential spawning based on their maximum river kilometer.

Table 4. Sample sizes and mean tag date, fork length, weight, and fatmeter readings for radio-tagged adult winter steelhead that migrated to different sites within the Willamette River in 2013.

Fate	*n*	Mean tag date	Mean fork length (cm)	Mean weight (kg)	Mean fatmeter (%)
Clackamas River	3	27 Mar.	67.7	3.28	1.9
At Dam	14	21 Mar.	68.9	3.46	1.8
Lower main stem[1]	12	26 Mar.	73.3	3.90	1.6
Tualatin River	13	27 Feb.	68.4	3.49	1.8
Molalla River	31	9 Mar.	73.2	4.18	1.9
Yamhill River	8	27 Feb.	69.6	3.58	1.7
Rickreall Creek	1	22 Jan.	74.0	4.33	2.6
S. Santiam River	39	19 Mar.	71.5	3.78	2.0
N. Santiam River	29	13 Mar.	76.2	4.63	2.0
Calapooia	7	13 Mar.	72.8	3.70	1.9
Upper main stem[2]	2	7 Mar.	73.0	4.17	2.9
McKenzie River	3	5 May	67.0	3.01	4.6
Fall Creek	1	18 Mar.	82.0	5.58	1.9
Middle Fork	7	9 Mar.	73.2	4.18	1.9

[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.

Estimated returns by sub-basin

We used the 2013 distribution of radio-tagged fish and winter steelhead counts at Willamette Falls Dam to estimate total escapement (Table 5). We expanded the escapement proportions of the tagged fish (n = 170) using three ODFW count scenarios: 1) the count of winter steelhead during the radio-tagging interval, 2) the count beginning 15 February 2013 (the nominal start of the 'native' run), or 3) the count from 1 November 2012 (start of the winter run according to ODFW). Given the small total sample size, we did not weight the estimates by sampling date. The estimates assume the counts at the Falls were without error and are uncorrected for fallback. We calculated 95% confidence intervals for proportions derived from the radio-tagged sample using the Wilson score for binomial proportions.

The highest number of adults returned to the South Santiam River, with point estimates ranging from 833 to 1,134 individuals across the three scenarios (Table 5). The next highest estimates were to the Molalla (662-902) and North Santiam rivers (620-843). Fewer than 100 winter-run steelhead were estimated to have returned to the McKenzie River under any scenario.

Table 5. Point estimates and 95% confidence intervals of adult winter steelhead escapement to Willamette River tributaries based on return numbers and percentages of radio-tagged fish (*n* = 170) and three scenarios of ODFW count data from Willamette Falls Dam in 2013.

			Winter steelhead counted		
			Tag intrvl. *n* = 4,096	From 15 Feb. *n* = 3,632	From 1 Nov. *n* = 4,944
Tributary	*n*	% (95% ci)	Estimate	Estimate	Estimate
None	28	16.5 (11.6-22.8)	675 (477-933)	598 (423-827)	814 (839-1,642)
Clackamas	3	1.8 (0.6–5.0)	72 (25-207)	64 (22-183)	87 (30-250)
Tualatin	13	7.6 (4.5-12.6)	313 (186-518)	278 (165-459)	378 (224-625)
Molalla	31	18.2 (13.1-24.7)	747 (539-1,013)	662 (478-898)	902 (651-1,223)
Yamhill	8	4.7 (2.4-9.0)	193 (99-369)	171 (88-328)	233 (119-446)
Rickreall Cr.	1	0.6 (0.1-3.3)	24 (4-134)	21 (4-118)	29 (5-161)
N. Santiam	29	17.1 (12.1-23.4)	699 (498-960)	620 (441-851)	843 (601-1,158)
S. Santiam	39	22.9 (17.3-29.8)	940 (707-1,221)	833 (627-1,083)	1,134 (853-1,474)
Calapooia	7	4.1 (2.0-8.3)	169 (82-338)	150 (73-300)	204 (99-408)
McKenzie	3	1.8 (0.6-5.1)	72 (25-207)	64 (22-183)	87 (30-250)
Fall Creek	1	0.6 (0.1-3.3)	24 (4-134)	21 (4-118)	29 (5-161)
Middle Fork	7	4.1 (2.0-8.3)	169 (82-338)	150 (73-300)	204 (99-408)

The ODFW winter steelhead counts (http://www.dfw.state.or.us/fish/fish_counts/) were 655 at Upper Bennett Dam and 33 at Lower Bennett Dam on the N. Santiam River. The combined ODFW count total (n =688) was within the 95% confidence intervals of all three estimates based on radio-tagged fish (Table 5). Two hundred eighty-six winter steelhead were counted at Foster Dam on the S. Santiam River from February through September 2013, which was considerably lower than the 95% confidence interval minima for all three telemetry-based estimates (*range* = 627-853), presumably due to detection of radio-tagged individuals in the S. Santiam that were not later collected at Foster Dam. Two steelhead without adipose clips (i.e., nominal winter run) were counted at Leaburg Dam on the McKenzie River in July 2013 but they may have been naturally-produced summer run steelhead based on the count timing. Escapement estimates based on the three radio-tagged winter steelhead that returned to the McKenzie River in 2013 and the Leaburg counts all suggested that winter steelhead escapement there was relatively low.

Importantly, the telemetry-based estimates included all winter steelhead in these three tributaries, including fish that potentially spawned downstream from the Bennett complex, Foster Dam, or Leaburg Dam. Other potential causes for differences in estimates include steelhead run mis-identification at tributary count sites, the inflation of counts from fallbacks (where possible), and inter-annual differences in the timing of trap operations.

Run Composition

Run composition varied seasonally for the 147 radio-tagged winter steelhead considered to have escaped to tributaries in 2012 (Figure 19), with lower basin populations typically passing Willamette Falls Dam earlier in the run. Among winter steelhead radio-tagged from late-March to mid-April (*n* = 62), 31% entered the North Santiam River and 27% entered the South Santiam River. Smaller percentages returned to the Molalla (16%), Clackamas (8%), Middle Fork (8%), Calapooia (5%), and Yamhill rivers (2%). The highest percentages of winter steelhead tagged after mid-April (*n* =61) returned to the Middle Fork (41%), and the North (21%) and South (18%) Santiam rivers.

In 2013, lower basin populations also typically passed Willamette Falls Dam relatively early in the run (Figure 19). Among those radio-tagged from mid-March to mid-April (*n* = 55), 60% returned to the Santiam River (South Santiam – 38%, North Santiam – 22%) and smaller percentages returned to the Molalla (16%), Tualatin (7%), Middle Fork (5%), and Calapooia (5%) rivers. The 34 winter steelhead tagged after mid-April included a relatively high percentage that returned to the Santiam (South Santiam – 26%, North Santiam - 18%) and Molalla rivers (21%).

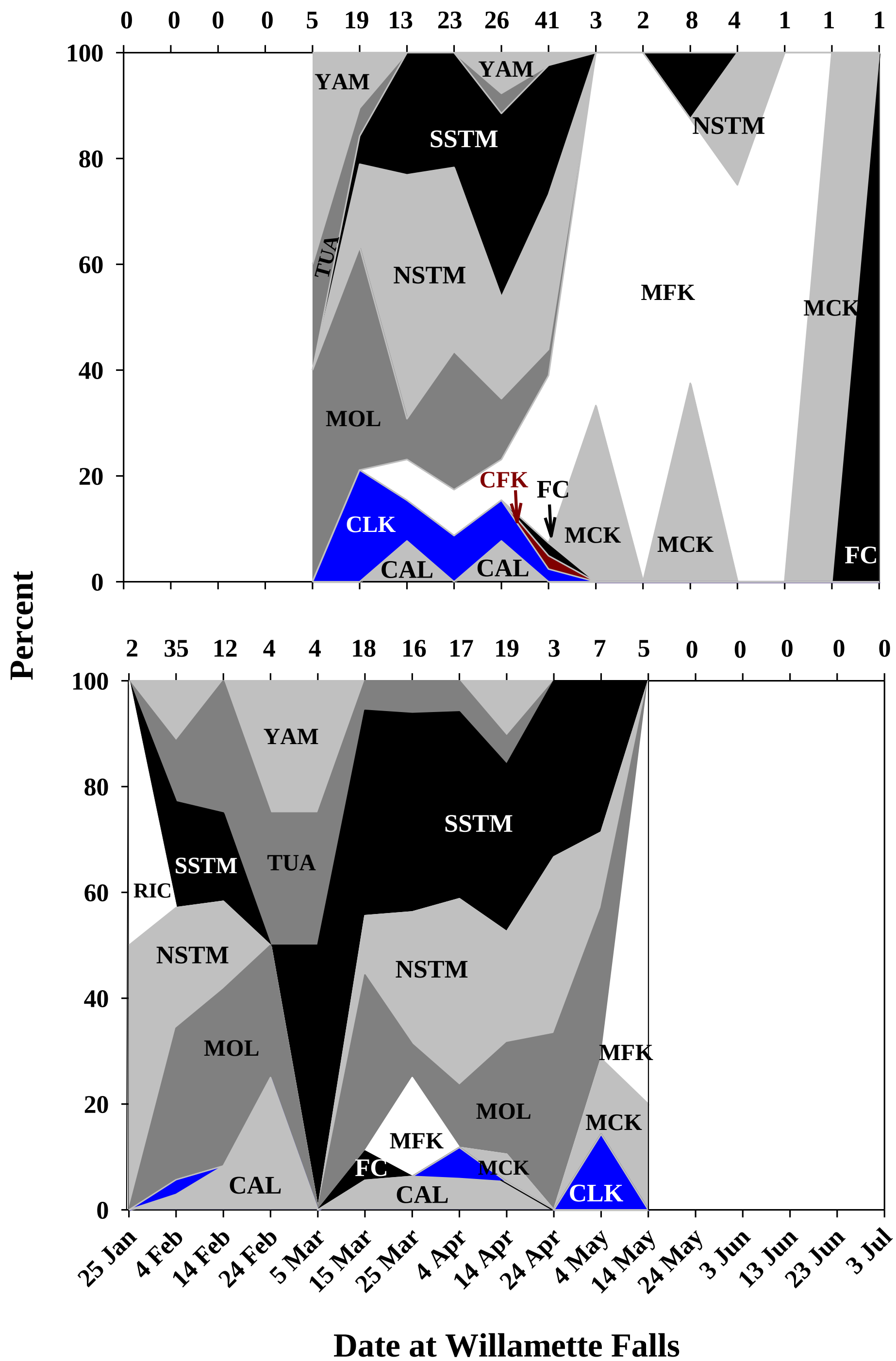

Figure 19. Composition of 'escaped' winter steelhead radio-tagged at Willamette Falls Dam in 2012 (upper panel; *n* = 147) and 2013 (lower panel; *n* = 142). Data were binned using 10-d release date intervals. Sample sizes for each bin are listed at the top of each panel. YAM = Yamhill River; TUA = Tualatin River; SSTM = South Santiam River; NSTM = North Santiam River; RIC = Rickreall Creek MOL = Molalla River; MFK = Middle Fork Willamette River; FC = Fall Creek; MCK = McKenzie River; CLK = Clackamas River; CAL = Calapooia River; CFK = Coast Fork Willamette River.

Kelting frequencies, distributions, and tributary residency times

Of the tagged winter steelhead considered to have escaped to tributaries, 59% (2012) and 57% (2013) exhibited kelt behavior (Table 6). Tributary-specific kelting percentages for sites that produced kelts ranged from 33 to 77% in 2012 and from 33 to 100% in 2013 (please note small samples sizes).

Mean tributary entry dates for kelts ranged from 17 March to 14 May and mean residency times ranged from 13 to 38 days (Table 7). Kelts from the Tualatin River had the earliest mean tributary entry date and the longest mean residency time. There was no clear pattern of sex-related differences in tributary residency times or entry dates within tributary group (Table 7).

Table 6. Frequencies of radio-tagged winter steelhead that entered Willamette River tributaries in 2012-2013 and the frequencies and percentages that exhibited kelt behavior.

	2012			2013		
Tributary	Entered *n*	Kelt *n*	Kelt %	Entered *n*	Kelt *n*	Kelt %
Clackamas	10	7	70	3	0	0
Yamhill	7	5	71	8	3	38
Molalla	22	16	73	31	17	55
Tualatin	3	2	67	13	7	54
Rickreall Cr.	0	0	0	1	1	100
N. Santiam	35	27	77	29	20	69
S. Santiam	29	17	59	39	28	72
Calapooia	3	1	33	7	3	43
McKenzie	5	1	20	3	1	33
Coast Fork	1	0	0	0	0	0
Fall Creek	2	0	0	1	1	100
Middle Fork	30	11	37	7	0	0
Total	147	87	59	142	81	57

Table 7. Mean entry dates, exit dates, and residency times (+ s.d.) of radio-tagged female and male steelhead that exhibited kelting behavior in Willamette River tributaries in 2013. Note: sex was estimated at time of tagging.

Tributary	Estimated Sex	Mean entry date	Mean exit date	Residence time (d) mean	s.d.	*n*
Tualatin R.	F	2 March	8 April	36.7	22.5	5
	M	3 Feb.	13 April	68.5	29.9	2
	All	22 Feb.	9 April	45.8	27.0	7
Molalla R.	F	10 March	22 April	42.9	21.7	14
	M	12 March	13 April	32.2	5.1	3
	All	10 March	20 April	41.1	20.1	17
Yamhill R.	F	17 Feb.	19 March	30.9	13.3	2
	M	5 Feb.	1 April	55.4	-	1
	All	13 Feb.	23 March	39.1	17.0	3
N. Santiam R.	F	28 March	23 April	26.1	11.2	15
	M	26 March	6 May	39.9	24.3	7
	All	28 March	27 April	30.5	17.2	22
S. Santiam R.	F	29 March	26 April	28.3	15.2	18
	M	24 March	26 April	33.1	19.4	8
	All	27 March	26 April	29.8	16.4	26
Calapooia R.	F	28 March	21 April	23.5	17.6	3
McKenzie R.	M	31 May	22 June	21.1	-	1
Fall Creek	F	5 April	16 April	10.9	-	1

Iteroparity rates based on scale analysis

We collected 182 scale samples from 184 radio-tagged winter steelhead in 2012 and 168 samples from 170 tagged in 2013. Two samples were unreadable in 2012 (n = 180) and one was not readable in 2013 (n = 167). Fourteen steelhead in 2012 (7.8%) and 21 in 2013 (13%) were scored as having entered freshwater as an adult at least once before the sampling year. In 2012, 13 of the 14 appeared to have entered freshwater once before and one was scored as entering twice before. In 2013, 17 of the 21 appeared to have entered freshwater once before and four were scored as entering twice before.

Eleven of the 14 (79% - 2012) and 18 of 21 (86% - 2013) steelhead with iteroparous scale patterns returned to tributaries, including the Clackamas, Tualatin, Molalla, Yamhill, Santiam, McKenzie, and Middle Fork Willamette rivers (Figure 20). In 2012, three of the 14 were last detected in the main stem: one exited the dam to the tailrace after release and did not reascend, one had detections at Willamette Falls Dam only, and the third was last detected in the lower main stem near Salem, OR. In 2013, two of the 21 were last detected in the lower main stem and one was last detected in the upper main stem. Within the tributaries, the percentage of tagged steelhead that were likely repeat spawners ranged from 3-30% in 2012 and 8-21% in 2013.

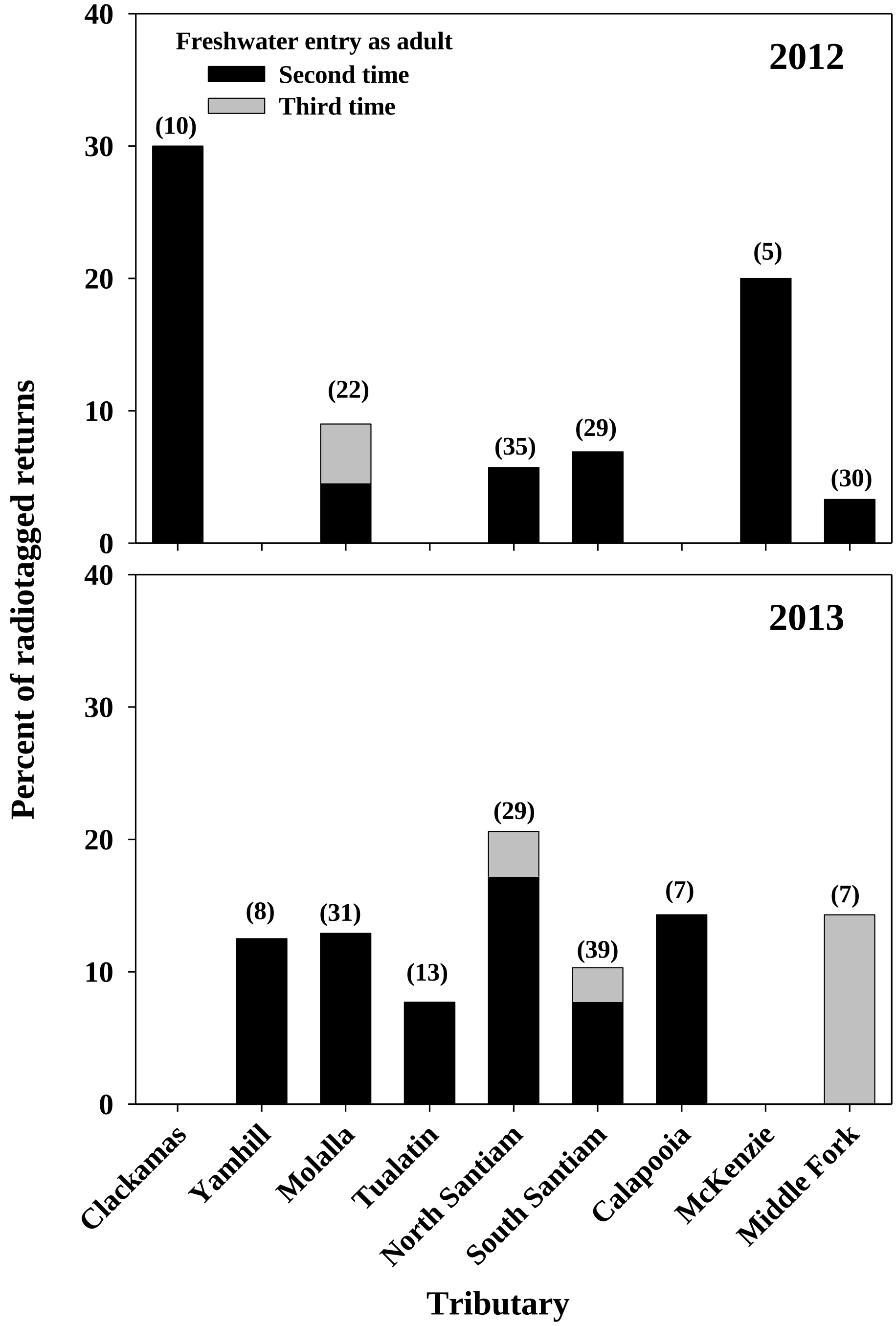

Figure 20. Percentage of radio-tagged winter steelhead that were estimated to be on their second or third migration into freshwater based on scale analyses, by tributary in 2012-2013. Total tributary sample sizes in parentheses are above each bar.

Results: Summer steelhead

Historic count data and run timing

The annual count of adult summer steelhead passing Willamette Falls Dam in 2013 was 13,549 (Figure 21). This was approximately 2,000 fewer fish than the average count since 1971 (15,331) and approximately 27,000 fewer fish than the maximum count of 40,719 in 1986. The timing of the 2012 and 2013 summer steelhead runs past Willamette Falls Dam were in the middle of the range since 2001, with 2013 being slightly more protracted than 2012 (Figure 22). The median passage dates were 1 April (2012) and 2 April (2013); medians ranged from 17 March to 11 April in 2001-2011.

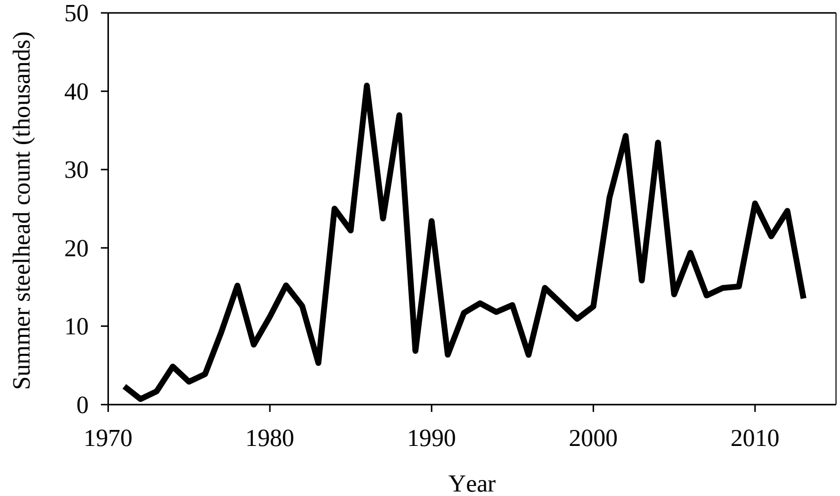

Figure 21. Total annual numbers of adult summer steelhead counted passing Willamette Falls Dam, 1971-2013. Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

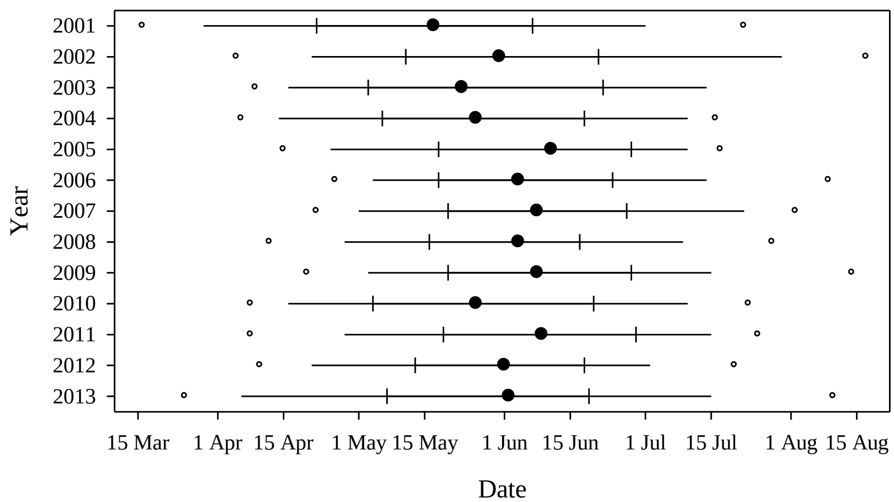

Figure 22. Annual migration timing distributions for summer steelhead counted at Willamette Falls Dam, 2001-2013. Symbols show median (●), quartile (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (○). Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Main stem residence times and migration rates

Tagged summer steelhead that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers in 2012 and 2013 were in each of the monitored main stem sections for ~1-3 days, on median (Figure 23). As with winter steelhead, summer-run fish migrated more slowly through successive upstream reaches, though there was considerable variability in migration rates among fish in both years (Figure 24).

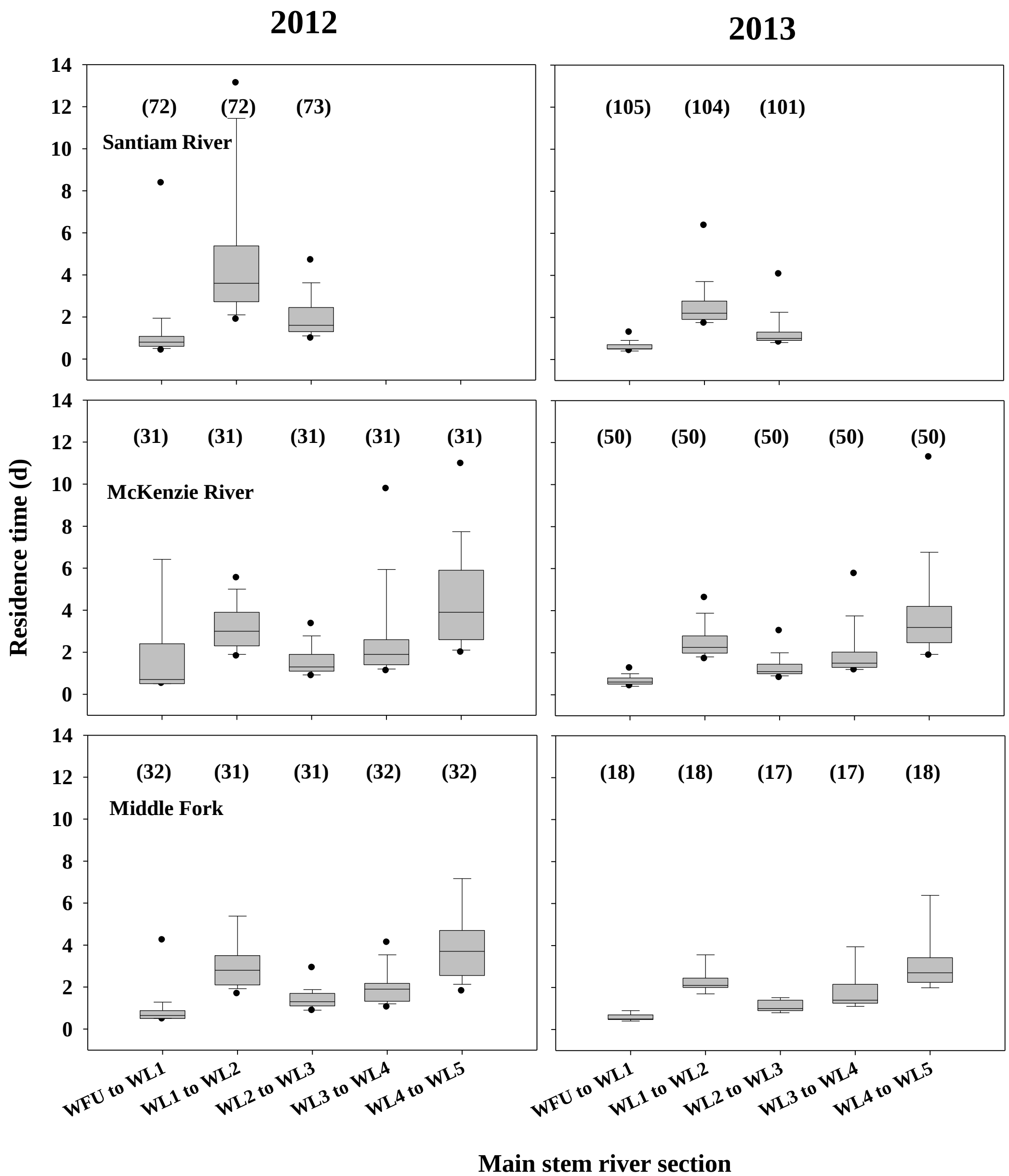

Figure 23. Box plots of residence times (days) of radio-tagged summer steelhead in reaches of the main stem Willamette River in 2012 (left panels) and 2013 (right panels). The three panels are for steelhead that returned to the Santiam, McKenzie, and the Middle Fork Willamette rivers. Box plots show: median (line), quartile (box), 10^{th} and 90^{th} (whisker), and 5^{th} and 95^{th} percentiles. Sample sizes are listed in parentheses above boxes.

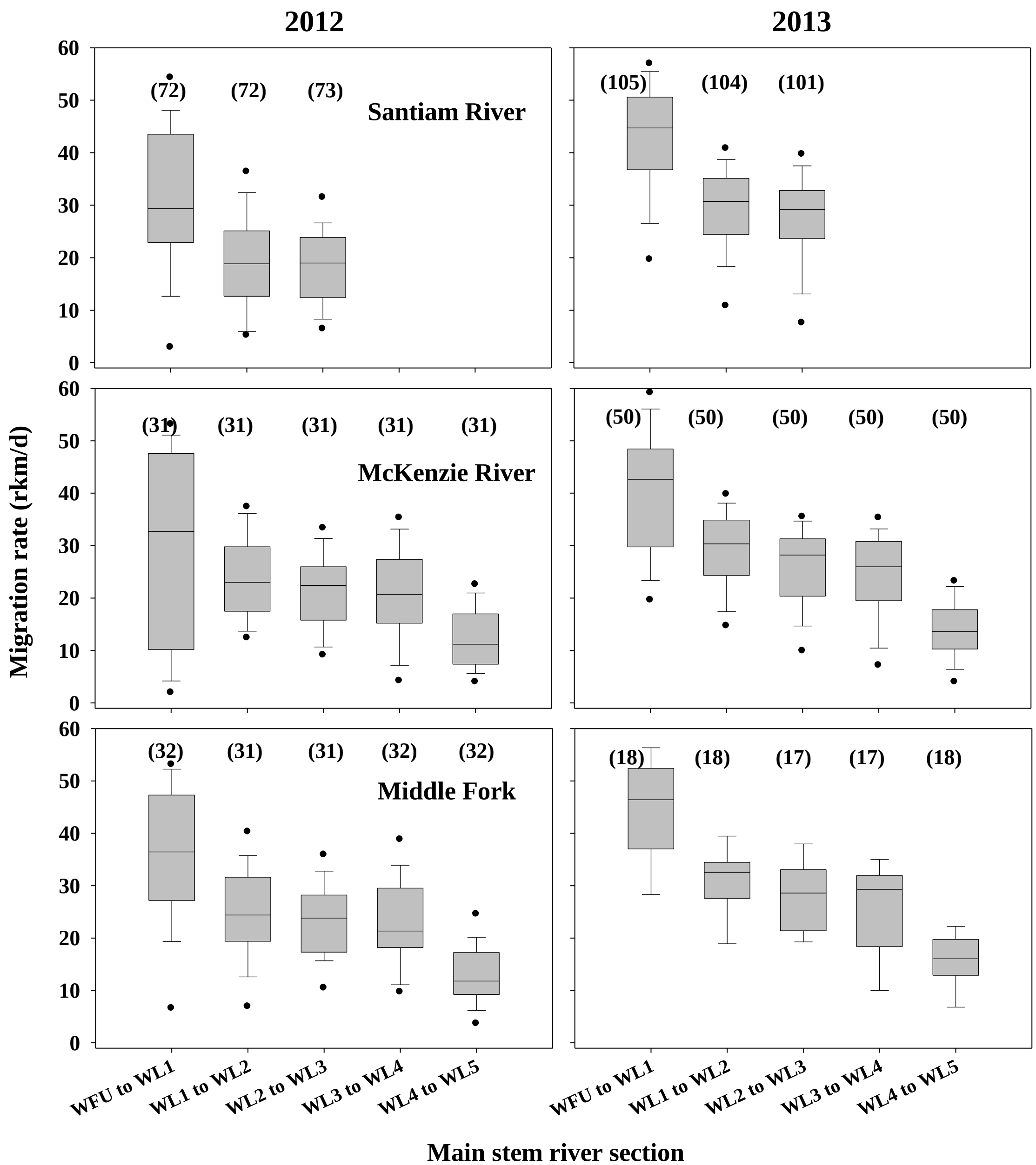

Figure 24. Box plots of migration rates (river kilometers/day) of radio-tagged summer steelhead in reaches of the main stem Willamette River in 2012 (left panels) and 2013 (right panels). Three panels are for steelhead that returned to the Santiam, McKenzie, and the Middle Fork Willamette rivers. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles. Sample sizes are listed in parentheses above boxes.

Last radio detections (through Fall, 2013)

Overall, 71-72% of radio-tagged summer steelhead were last detected in Willamette River tributaries in both study years. In 2013, the highest percentage of tagged summer steelhead (38%) was last recorded in the South Santiam River (Figures 25 and 26). Smaller percentages were last recorded in the McKenzie (20%) and Middle Fork Willamette (7%) rivers. Twenty-four percent were last recorded in the main stem upstream from Willamette Falls Dam. Eleven of the 61 steelhead last detected in the main stem above the dam were reported as harvested by anglers near the confluence of the Coast Fork and Middle Fork Willamette rivers.

In 2012, the distribution of last detections of summer steelhead included in the South Santiam River (26%), the McKenzie River (14%), the Middle Fork (14%), the North Santiam River (11%, the upper main stem (11%), the lower main stem (9%), downstream from the dam (8%), and the Clackamas River (4%). Approximately 1% or less were last detected at Willamette Falls Dam, in Fall Creek, or in the Coast Fork.

Mean fork length for the different groups ranged from 64.0 cm to 70.3 cm, with minor differences among the major categories (Table 8). Steelhead assigned to the groups below Willamette Falls Dam and to the lower main stem were larger, on average, than those assigned to the tributaries. Mean fatmeter readings among fate groups varied little (*range* = 3.9 to 4.4%). There were among-group differences in tagging date. The earliest mean dates were for the Coast Fork, lower main stem, and Santiam groups. The latest mean dates were for Fall Creek and upper main stem groups (early June).

Summer steelhead that escaped to a tributary were tagged approximately ten days earlier, on average, than those that did not escape. *P* values in the logistic regression model [Escape to tributary (y/n) = tag date + weight + fork length] that included all 250 fish were 0.01 (tag date), 0.26 (weight), and 0.48 (length).

Estimated returns by sub-basin

We used the distribution of the radio-tagged sample and summer steelhead counts at Willamette Falls Dam to estimate total 2013 escapement (Table 9). We expanded the escapement proportions of the tagged fish (n = 208) using two ODFW count scenarios: 1) summer steelhead counted during the radio-tagging interval, and 2) the total summer count 1 March – 31 October 2013.

The highest estimated number (7,660-8,679) of summer steelhead returned to the Santiam River using the two scenarios (Table 9). The next highest estimates were to the Middle Fork (3,358-3,804) and McKenzie (3,253-3,686) basins. All point estimates were < 1,000 fish for the Clackamas, Coast Fork, and Fall Creek. As with the winter steelhead expansions, these values assume no error in the total counts at Willamette Falls Dam and that the sampled adults were representative of the run at large.

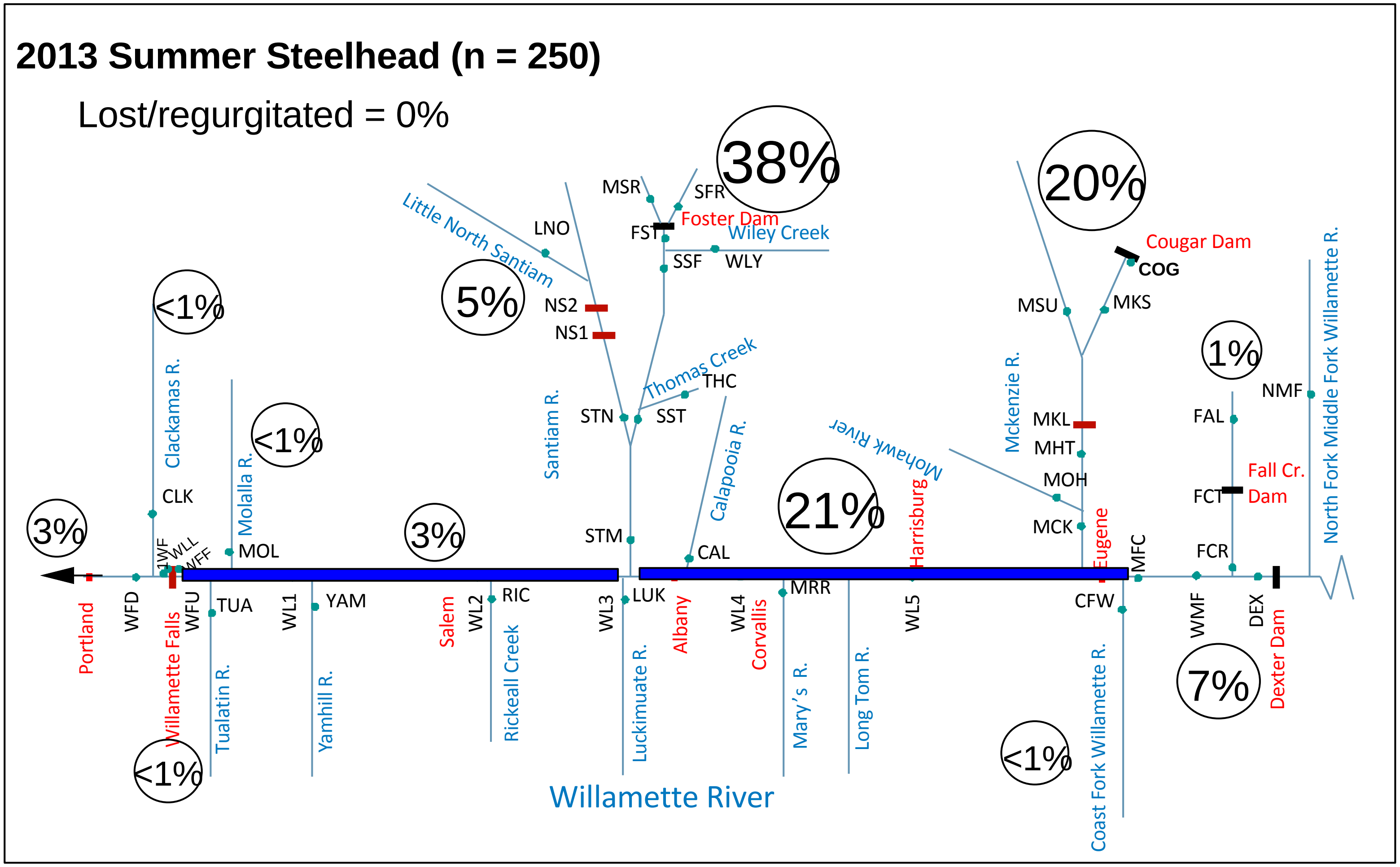

Figure 25. Sites and drainages where adult summer steelhead radio-tagged and released at Willamette Fall Dam in 2013 migrated based on their last radio detections.

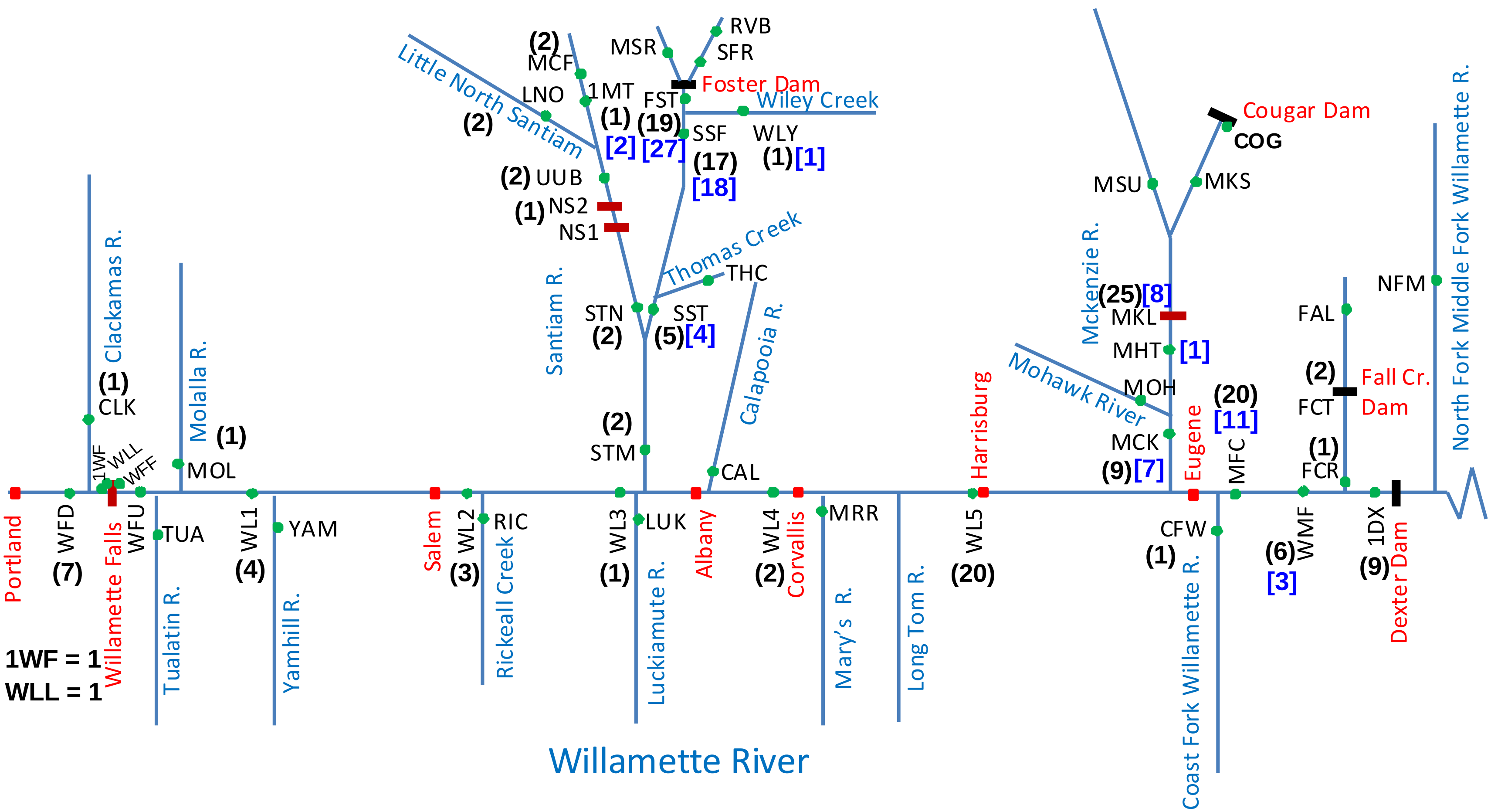

Figure 26. Sites where adult summer steelhead radio-tagged and released at Willamette Fall Dam in 2013 were last detected (black font and parentheses) or where they were recaptured (blue font and brackets). Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference.

Table 8. Sample sizes, and mean tag date, fork length, weight, and fatmeter readings for radio-tagged adult summer steelhead that experienced different fates within the Willamette River in 2013.

Fate	*n*	Mean Tag date	Mean length (cm)	Mean weight (kg)	Mean fatmeter (%)
Clackamas R.	1	13 Mar.	69.5	3.69	5.9
Downstream from Dam	8	25 Apr.	69.8	3.49	4.1
At Dam	1	12 May	76.0	4.22	4.8
Lower main stem[1]	8	20 May	68.1	3.26	4.5
Molalla R.	1	1 May	63.0	2.31	4.0
S. Santiam R.	94	16 May	69.5	3.42	4.8
N. Santiam R.	12	22 May	68.6	3.28	4.2
Upper main stem[2]	53	29 May	69.8	3.48	4.8
McKenzie R.	50	4 May	69.0	3.34	5.1
Coast Fork	1	16 Mar.	66.0	2.68	3.5
Fall Creek	3	7 Jun.	68.7	3.09	4.8
Middle Fork	18	25 May	71.4	3.60	4.7

[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.

Table 9. Estimated returns of adult summer steelhead to Willamette River tributaries based on return numbers and percentages of radio-tagged summer steelhead (n = 250) and two scenarios of ODFW count data from Willamette Falls Dam in 2013.

			Summer steelhead counted	
			Tag interval	1 Mar-31 Oct
			n = 11,310	*n* = 13,549
Tributary	n	% (95% ci)	Estimate	Estimate
None	70	28.0 (22.8-33.9)	3,167 (2,579-3,831)	3,794 (3,089-4,589)
Clackamas	1	0.4 (0.1-2.2)	45 (8-252)	54 (9-302)
Molalla	1	0.4 (0.1-2.2)	45 (8-252)	54 (9-302)
N. Santiam	12	4.8 (2.8-8.2)	543 (313-927)	650 (375-1,111)
S. Santiam	94	37.6 (31.8-43.8)	4,253 (3,600-4,948)	5,094 (4,313-5,928)
McKenzie	50	20.0 (15.5-25.4)	2,262 (1,754-2,873)	2,710 (2,101-3,441)
Coast Fork	1	0.4 (0.1-2.2)	45 (8-252)	54 (9-302)
Fall Creek	3	1.2 (0.4-3.5)	136 (46-392)	163 (56-470)
Middle Fork	18	7.2 (4.6-11.1)	814 (520-1,254)	976 (623-1,503)

The ODFW summer steelhead counts were 717 at Upper Bennett Dam and 229 at Lower Bennett Dam on the N. Santiam River in 2013. The combined ODFW count total (n =946) was within the 95% confidence interval of one of the two estimates based on radio-tagged fish and slightly higher than the other (Table 9). The summer steelhead count at Foster Dam on the S. Santiam River was 4,155, which was within the 95% confidence interval of one of the two estimates based on radio-tagged fish and slightly lower than the other. In contrast, the 2013 count from Leaburg Dam on the McKenzie River (n = 716) was only 26-31% of telemetry-based point estimates.

Run Composition

Run composition for the 138 summer steelhead last recorded in tributaries in 2012 varied less across sampling dates than it did for winter steelhead (Figure 27). The four largest return groups (i.e., South Santiam, North Santiam, McKenzie, and Middle Fork) typically were represented in all of the 10-day tagging intervals. The few tagged steelhead that returned to the Coast Fork in 2012 passed Willamette Falls Dam in mid-run. In 2013, summer steelhead from the South Santiam and McKenzie rivers comprised the largest return groups and they were present in most 10-d tagging bins (Figure__). Tagged steelhead that returned to the Molalla River in 2013 passed Willamette Falls Dam in mid-run and those that returned to Fall Creek passed Willamette Falls Dam in the late run in both years. Summer steelhead that returned to the Clackamas River were at Willamette Falls Dam late in the 2012 run but early in the 2013 run. When the two years were combined (Figure 28), the four largest return groups were well-mixed through most of the run.

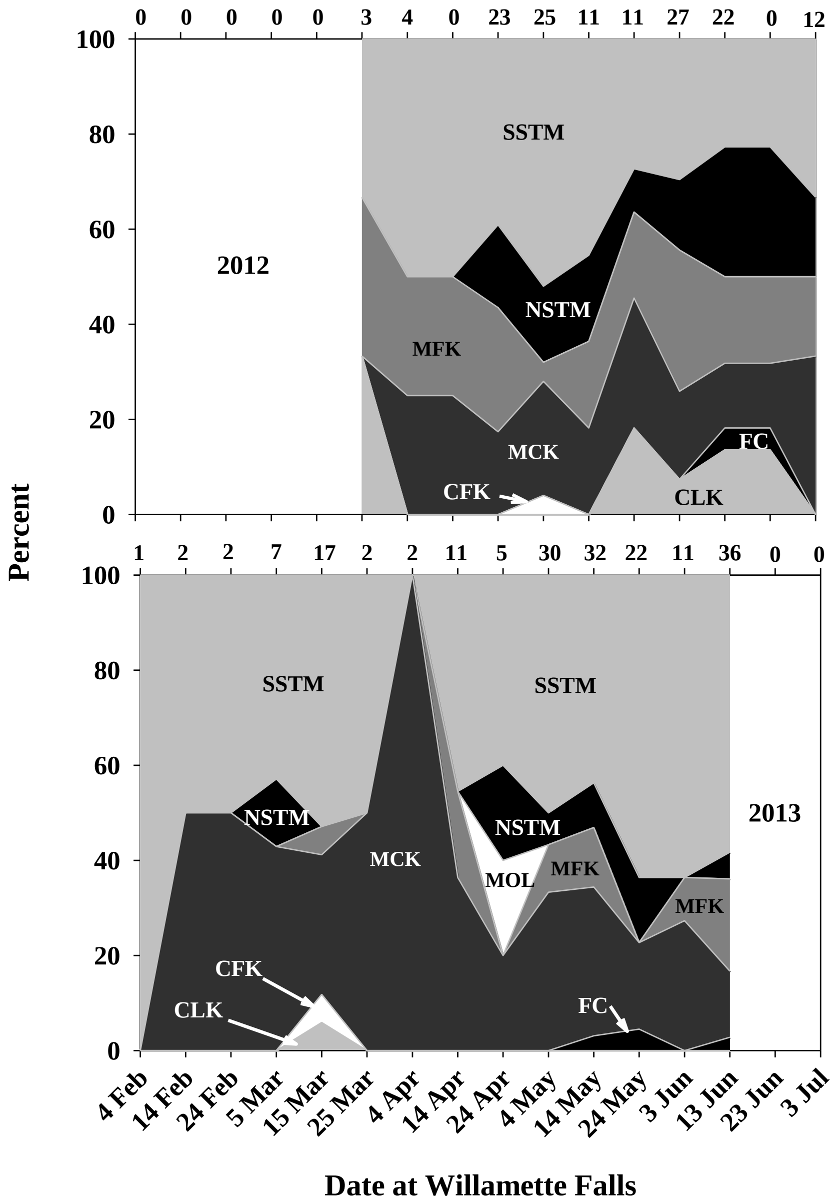

Figure 27. Composition of ‘escaped’ summer steelhead radio-tagged at Willamette Falls Dam in 2012 (upper panel; *n* = 138) and 2013 (lower panel; *n* = 180). Data were binned using 10-d intervals based on release dates. Sample sizes for each 10-d interval are listed at top. SSTM = South Santiam River; NSTM = North Santiam River; MOL = Molalla River; MFK = Middle Fork Willamette River; FC = Fall Creek; MCK = McKenzie River; CLK = Clackamas River; CFK = Coast Fork Willamette River.

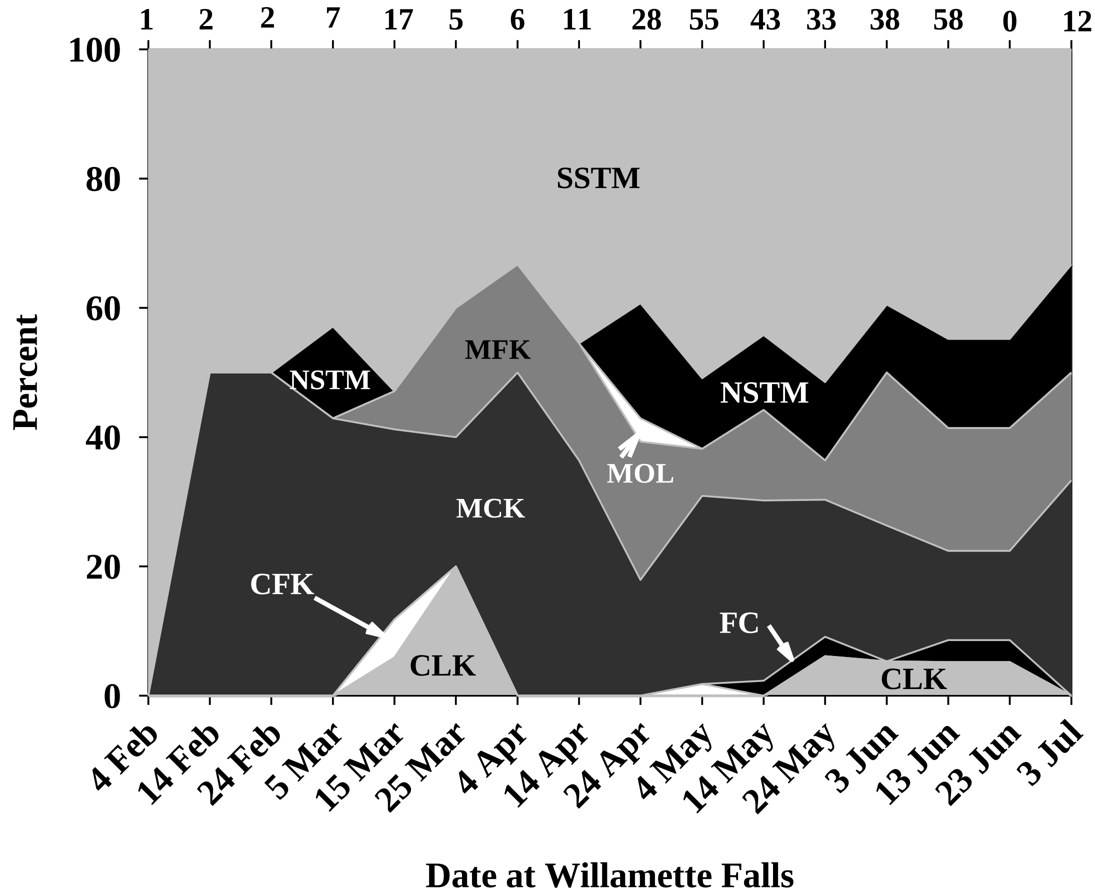

Figure 28. Composition of 318 'escaped' summer steelhead radio-tagged at Willamette Falls Dam in 2012-2013. Data were binned using 10-d intervals based on release dates. Sample sizes for each 10-d interval are listed at top. SSTM = South Santiam River; NSTM = North Santiam River; MOL = Molalla River; MFK = Middle Fork Willamette River; FC = Fall Creek; MCK = McKenzie River; CLK = Clackamas River; CFK = Coast Fork Willamette River.

Kelting frequencies and distributions

A maximum of 9 of the 195 (4.6%) summer steelhead tagged in 2012 exhibited kelt behavior based on the following criteria: 1) Willamette tributary entry in summer/fall 2012, 2) substantial downstream movements in spring 2013 after tributary entry, and 3) the downstream movements occurred after 1 March (Table 10). We were less confident about some summer steelhead kelt assignments than others because some fish did not meet all criteria. Five summer steelhead met all three criteria which produced a minimum estimated summer steelhead kelting rate of 2.6%. The highest estimated kelting frequencies were produced by summer steelhead that migrated to the North Santiam River. Estimates of kelting rates for 2013 summer steelhead will be available in 2014.

Table 10. Estimated minimum and maximum kelting frequencies and percentages of radio-tagged summer steelhead that entered Willamette River tributaries or the upper main stem in 2012.

Tributary	Entered *n*	Kelt *n (min.)*	Kelt *n (max.)*	Kelt %
N. Santiam	22	3	3	14%
S. Santiam	51	1	2	2-4%
McKenzie	28	0	1	0-4%
U. Main stem	22	0	2	0-9%
Middle Fork	27	1	1	4%
Total	150	5	9	3-6%

Fates of tagged summer steelhead and overlap with winter steelhead

We compared the final detections of summer steelhead radio-tagged in 2012 (that may have spawned in 2013) to the maximum rkms for winter steelhead radio-tagged in 2013 to evaluate the degree to which summer and winter runs may be sharing spawning habitat. We excluded all fish with last detections or maximum rkms in the main stem Willamette River associated with recapture events. Similarly, we excluded steelhead that were captured at Foster Dam and released upstream from it because only unclipped steelhead were released there.

There was evidence for spawning habitat overlap in the South and North Santiam River and in the Middle Fork Willamette River (Table 11). We found overlap within the upper and lower reaches of the North Santiam River but none in the Little North Santiam River (Figure 29). The most overlap we noted in the South Santiam River was near Foster Dam (Figure 30). In the Middle Fork, overlap extended from the mouth to Dexter Dam and into Fall Creek (Figure 31). We found no spatial overlap among winter- and summer-run fish in the Tualatin, Molalla, Yamhill, or Calapooia rivers (Table 11). Steelhead from both runs were recorded entering the Clackamas River on the fixed site receiver but their distributions within the tributary were not monitored by mobile tracking.

Table 11. Frequencies of last detections of summer steelhead radio-tagged in 2012 and the maximum river kilometer reached by winter steelhead radio-tagged in 2013.

Tributary	Number of steelhead		Total
	2012 Summer	2013 Winter	
Clackamas	7	3	10
Tualatin	0	13	13
Molalla	0	31	31
Yamhill	0	8	8
Rickreall Cr.	0	1	1
South Santiam (SS)	32	13	45
SS – Crabtree Cr.	0	4	4
SS –Thomas Cr.	0	6	6
SS – Wiley Cr.	2	10	12
North Santiam	21	20	41
Little North Santiam	0	8	8
Calapooia	0	7	7
McKenzie	19	3	22
Coast Fork	1	0	1
Fall Creek	1	1	2
Middle Fork	17	7	24
Total	100	135	235

Figure 29. Distribution of maximum river kilometer detections in the North Santiam River for winter steelhead radio-tagged in 2013 (red circles) and last detections for summer steelhead radio-tagged in 2012 (yellow circles). Numbers indicate number of tagged fish at each site. This figure demonstrates the spatial overlap of the two runs; only a sub-sample of these detections also overlapped temporally.

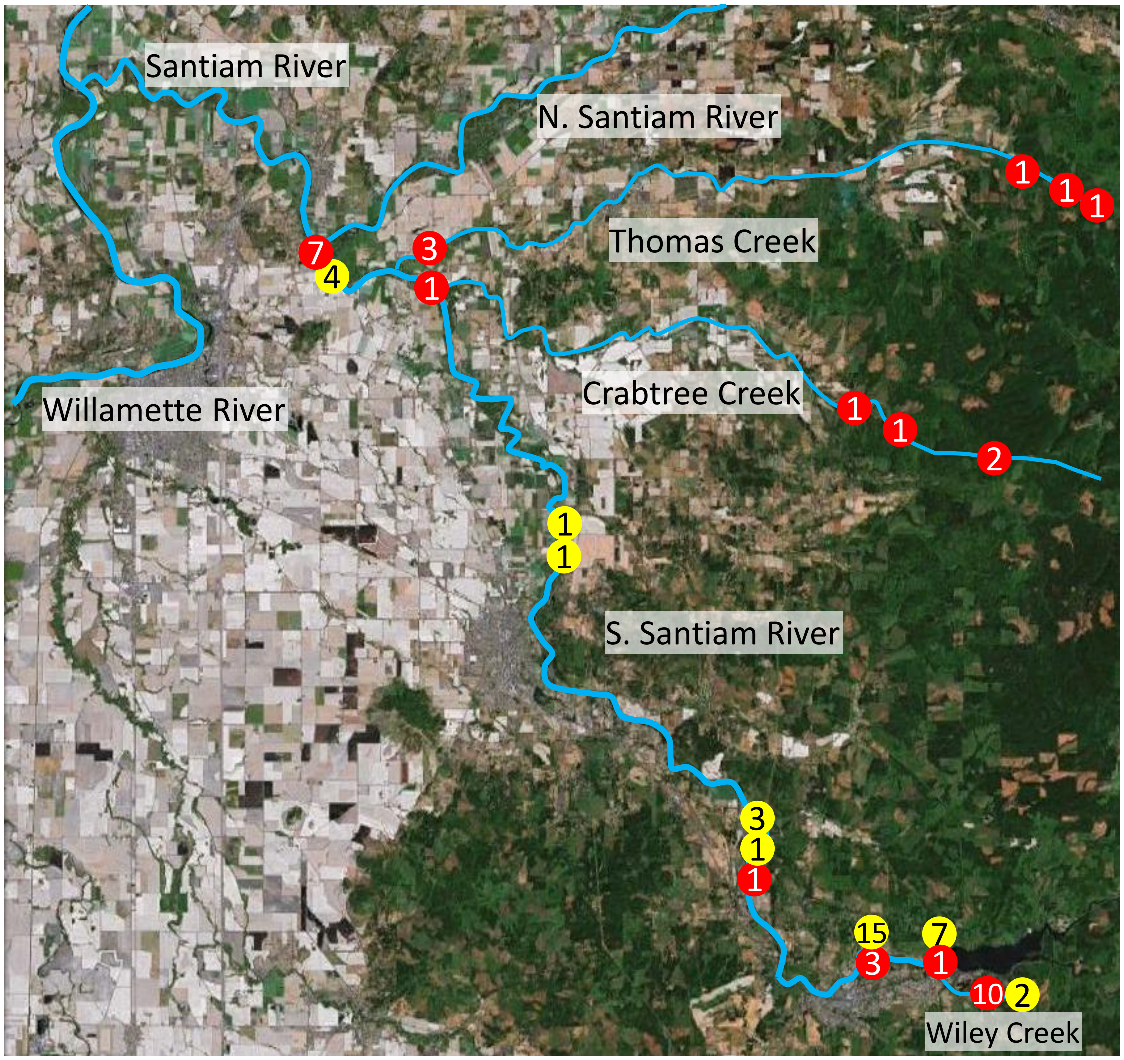

Figure 30. Distribution of maximum river kilometer detections in the South Santiam River for winter steelhead radio-tagged in 2013 (red circles) and last detections for summer steelhead radio-tagged in 2012 (yellow circles). Numbers indicate number of tagged fish at each site. This figure demonstrates the spatial overlap of the two runs; only a sub-sample of these detections also overlapped temporally.

We compared the range of dates that 2013 winter steelhead kelts were in tributaries to the maximum dates the 2012 summer steelhead kelts were in tributaries to evaluate the extent to which summer and winter runs may have temporally shared spawning habitat. Based on the tributary exit dates of summer steelhead estimated to be kelts in 2012, temporal overlap appears most likely to have occurred between mid-February and late March, assuming that the timing of kelt outmigration corresponded to the end of spawning by the entire summer steelhead population (Figure 32). Alternatively, we note that several summer steelhead tagged in 2012 were detected in the North (n = 8) and South (n = 11) Santiam rivers after 1 April 2013 but were designated as kelts. Whether these detections represeted an extended period of spawning in adults which did not outmigrate or whether the detections were of spawned-out carcasses remains unknown.

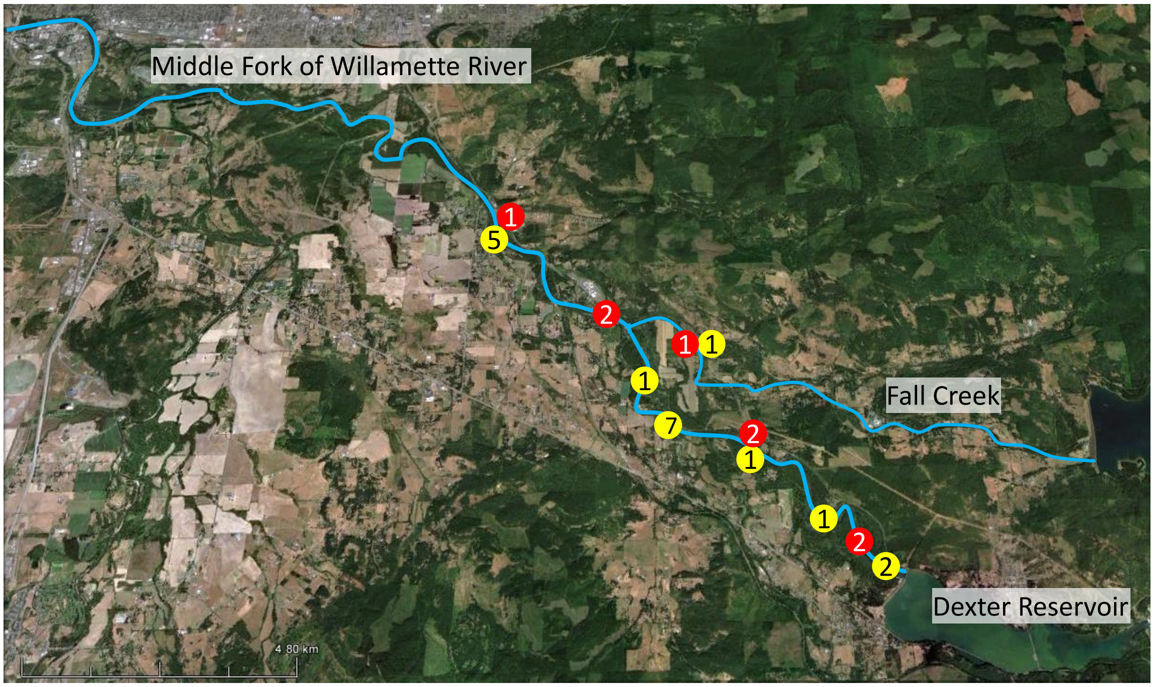

Figure 31. Distribution of maximum river kilometer detections in the Middle Fork Willamette River for winter steelhead radio-tagged in 2013 (red circles) and last detections for summer steelhead radio-tagged in 2012 (yellow circles). Numbers indicate number of tagged fish at each site. This figure demonstrates the spatial overlap of the two runs; only a sub-sample of these detections also overlapped temporally.

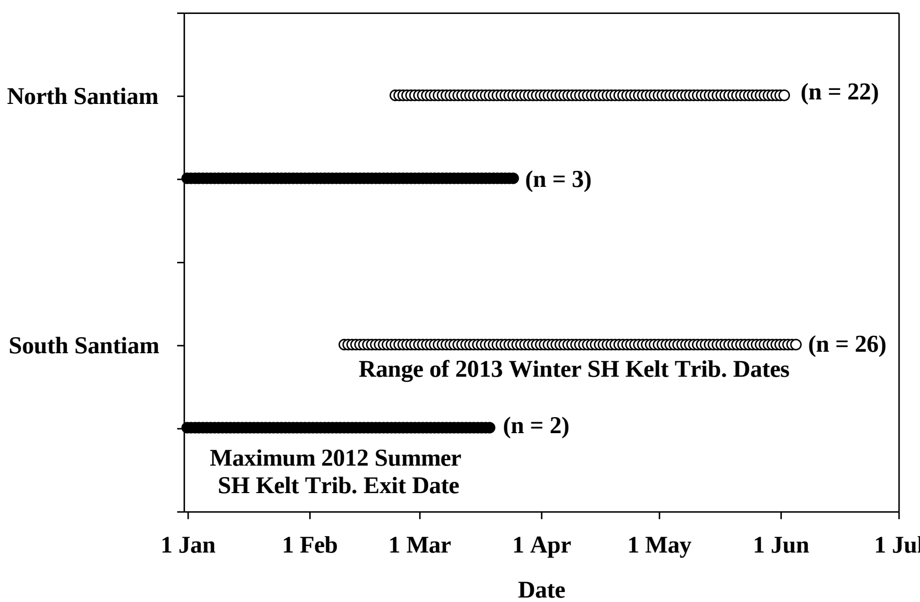

Figure 32. Range of dates winter steelhead kelts radio-tagged in 2013 (light bars) and the range of maximum dates summer steelhead kelts radio-tagged in 2012 (black bars)

were in the North and South Santiam rivers. The overlapping date ranges are times when fish from the two runs potentially comingled on the spawning grounds.

Iteroparity rates based on scale analysis

We collected scale samples from all 195 summer steelhead radio-tagged at Willamette Falls Dam in 2012 and of these, 192 were readable for iteroparity analysis. Four of the 195 scale samples (2%) were scored as having entered freshwater as an adult at least once before 2012. Two of the four steelhead with repeat spawner scale patterns returned to a tributary (Middle Fork) and two did not (the upper main stem). In 2013, we collected scale samples from all 250 summer steelhead radio-tagged at Willamette Falls Dam and 249 were readable. Two of the 249 scale samples (<1%) were scored as having entered freshwater as an adult at least once before 2013. Last detections for the two fish were in the South Santiam and the upper main stem.

Behavior and distribution of recycled steelhead

Foster releases - Of the 100 radio-tagged steelhead that were recycled downstream from Foster Dam in 2013, 45 (45%) were last detected on a fixed-site receiver or mobile tracked in the South Santiam River (Table 12). Five (5%) were reported recaptured by anglers and no tags were recovered in or near carcasses during spawning ground surveys. Forty (40%) steelhead returned to Foster Dam, where they were ponded for broodstock or surplused. Two (2%) were last detected in the lower main stem Willamette River and 8 (8%) had no radio detections after release. In both study years, small percentages (2-7%) of steelhead recycled from Foster Dam were detected leaving the South Santiam River or were reported as recaptured by anglers (4-5%) (Figure 33).

Table 12. Distribution of last detections for summer steelhead captured and radio-tagged at Foster Dam and released at Waterloo, Pleasant Valley, or Wiley Creek release sites in 2013. MBT = mobile-tracked.

Fate	Waterloo release n	Pleasant Valley release n	Wiley Creek release n	Total
Tag record only	6	1	1	8
Lower main stem Williamette R.	0	1	1	2
S. Santiam fixed receiver or MBT	18	17	10	45
Spawning grounds recapture	0	0	0	0
Angler recapture	0	2	3	5
Foster Dam return/recapture	16	19	5	40
Total	40	40	20	100

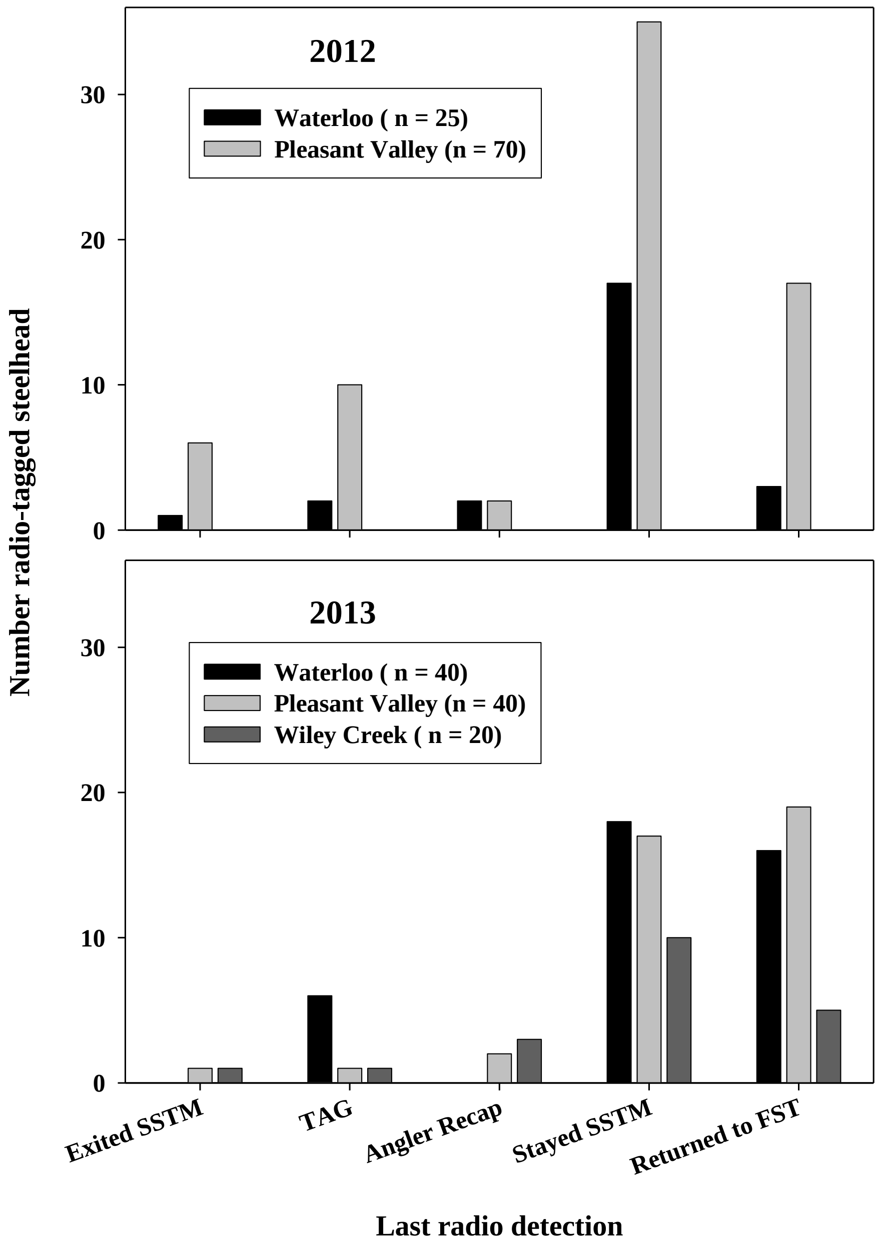

Figure 33. Fate frequencies for radio-tagged summer steelhead recycled from Foster (FST) Dam on the South Santiam River (SSTM) in 2012 and 2013.

Dexter releases – Of the 50 radio-tagged summer steelhead released downstream from Dexter Dam in 2013, 24 (48%) were last detected in the Middle Fork Willamette River (Figure 34). Two (2%) were reported as recaptured by anglers, including one from the upper main stem and the other from the Middle Fork. One tag was reported as found near the confluence of the Coast Fork and Middle Fork. Eighteen (36%) were last detected in the upper main stem and two (4%) were in the lower main stem. There were no radio detections for three (6%) of the 50 recycled summer steelhead.

Of the 49 radio-tagged summer steelhead released downstream from Dexter Dam in 2012, 22 (44%) were last detected in the Middle Fork Willamette River, including three that were recaptured by hatchery personnel at Dexter Dam (Figure 34). Eight (16%) were recaptured by anglers. Fifteen (31%) steelhead were last detected downstream from the Middle Fork Willamette River: six (12%) at the confluence of the Coast Fork and Middle Fork, six (12%) in the upper main stem, one (2%) in the lower main stem, and two (4%) downstream from Willamette Falls Dam. There were no radio detections for four (8%) of the 49 summer steelhead recycled in 2012.

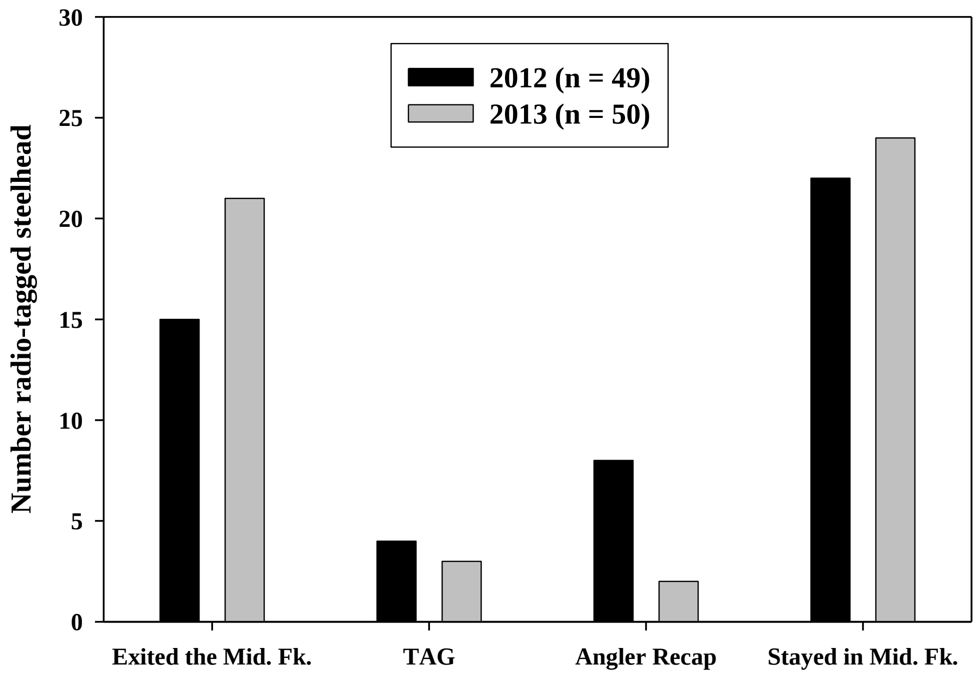

Figure 34. Fate frequencies for radio-tagged summer steelhead recycled from Dexter Dam on the Middle Fork Willamette River in 2012 and 2013.

Results: Spring Chinook salmon

Historic counts and run timing

The annual count of adult spring Chinook salmon passing Willamette Falls Dam in 2013 was 27,897 (Figure 35). This was almost 11,000 fewer fish than the average count of 38,646 since 1953. The 2013 spring Chinook salmon run at Willamette Falls Dam tied for the third earliest-timed run in the last thirteen years (Figure 36). This was likely associated with the warm April-June water temperatures and low river discharge compared to ten-year averages. The date of median passage in 2013 was 12 May, compared to medians that ranged from 8 May – 13 June in 2001-2012.

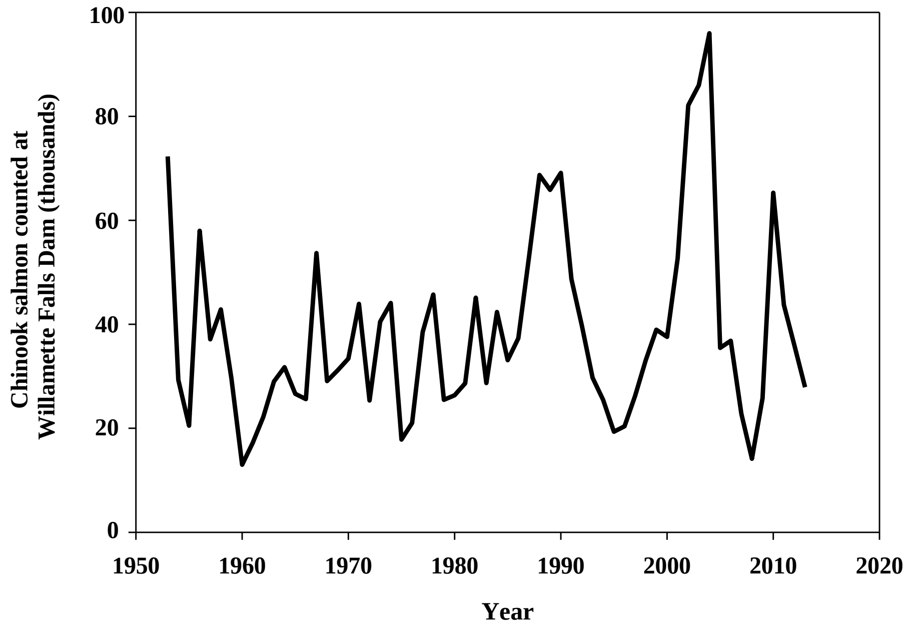

Figure 35. Total annual numbers of adult spring Chinook salmon counted passing Willamette Falls Dam,1953-2013. Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

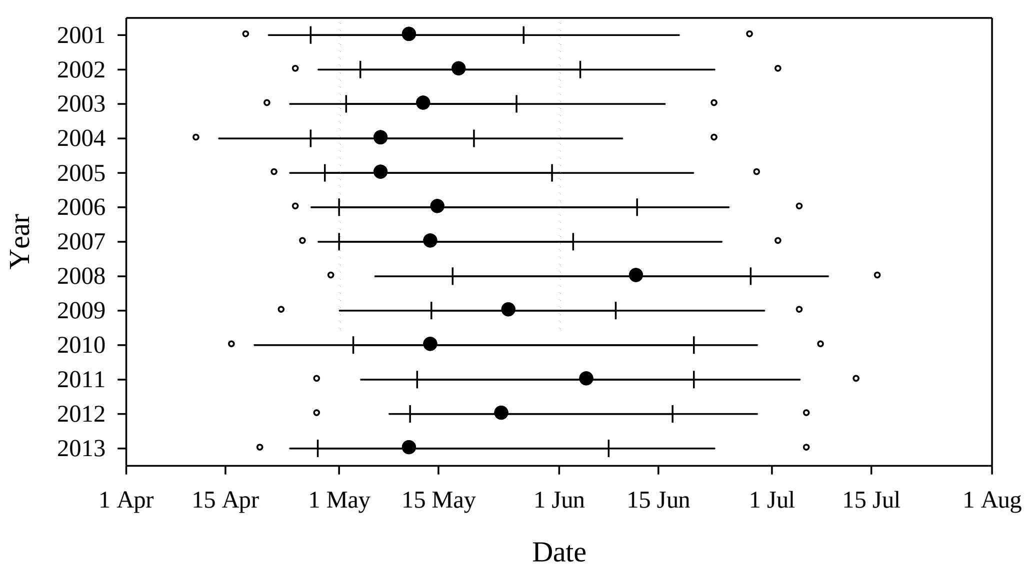

Figure 36. Annual migration timing distributions for spring Chinook salmon counted at Willamette Falls Dam, 2001-2013. Symbols show median (●), quartile (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (○). Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Main stem residence times and migration rates

Median times tagged salmon spent in the main stem were lower in 2013 than in the 2011-2012 for those that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers (Figure 37). Tagged salmon that returned to the Santiam River spent 12 d in the main stem in 2011 on median, approximately a day more than in 2012 (*median* = 10.8 d) and six days more than in 2013 (*median* = 5.9 d). Those that returned to the McKenzie River in 2011 spent a median of 24.0 d in the main stem, four days more than in 2012, and almost eight more days than in 2013. Tagged salmon that returned to the Middle Fork in 2011 spent 32 d in the main stem on median, ten days more than those in 2012, and over two weeks more than in 2013. Faster main stem migration times were likely due to lower flows and warmer temperatures in 2013.

The time tagged salmon spent in different sections of the main stem Willamette River varied with reach length (Figure 38). In all years, tagged salmon that returned to the Santiam River had the highest median main stem residency time in the WL1-WL2 reach. The distributions of times tagged salmon that returned to the McKenzie and Middle Fork resided in different sections of the main stem were generally similar in all years, with the exception of 2013 when salmon migrated faster through the lowest main stem section than in 2011 or 2012.

The distribution of migration rates (rkm/d) through the main stem Willamette River for radio-tagged Chinook salmon that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers varied with river section (Figure 39). As with both winter and summer steelhead, the speed that Chinook salmon migrated through successive sections generally decreased as fish moved upstream. This pattern was evident in all three years.

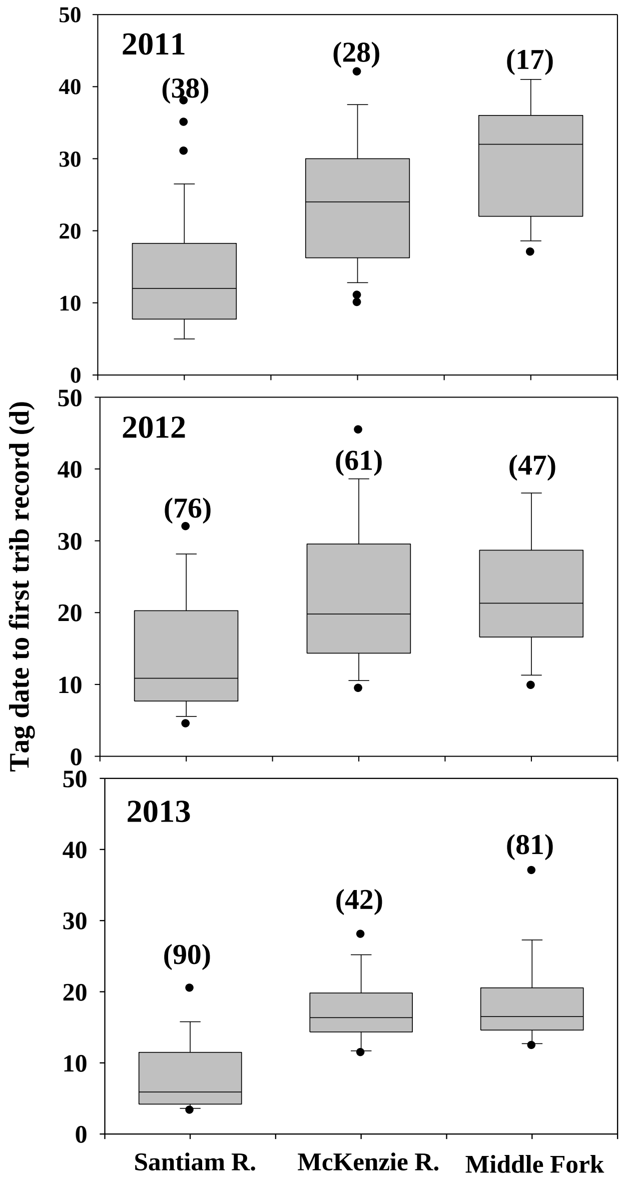

Figure 37. Box plots of radio-tagged spring Chinook salmon passage times (d) from their release at Willamette Falls Dam to first detection in the Santiam, McKenzie, or Middle Fork Willamette rivers in 2011 (upper panel), 2012 (middle panel), and 2013 (lower panel). Box plots show: median (line), quartile (box), 10^{th} and 90^{th} (whisker), and 5^{th} and 95^{th} percentiles. Sample sizes are in parentheses above boxes.

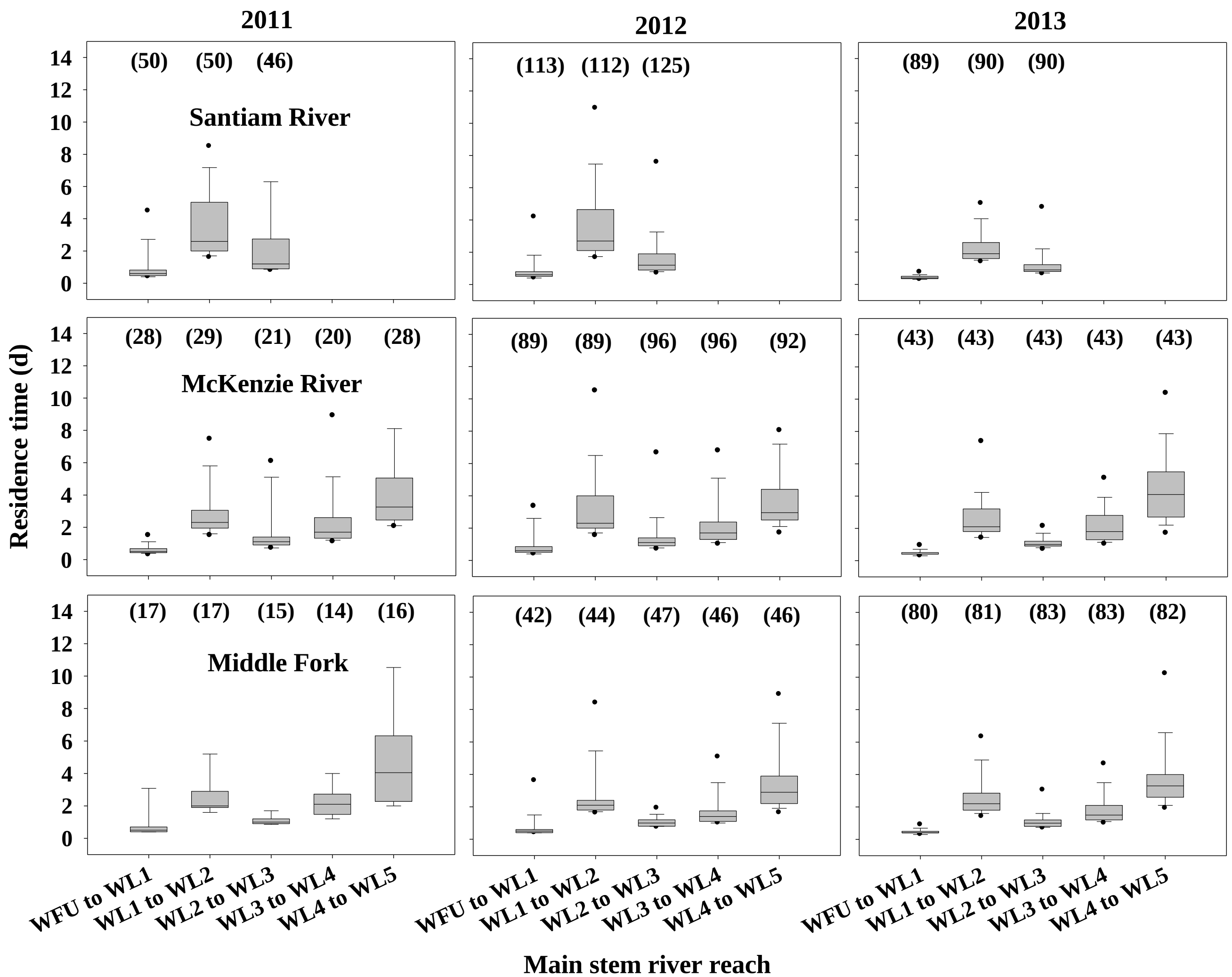

Figure 38. Box plots of times (days) radio-tagged spring Chinook salmon spent in reaches of the main stem Willamette River for salmon that returned to the Santiam, McKenzie, and the Middle Fork Willamette rivers in 2011-2013. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles. Sample sizes are listed in parentheses above boxes.

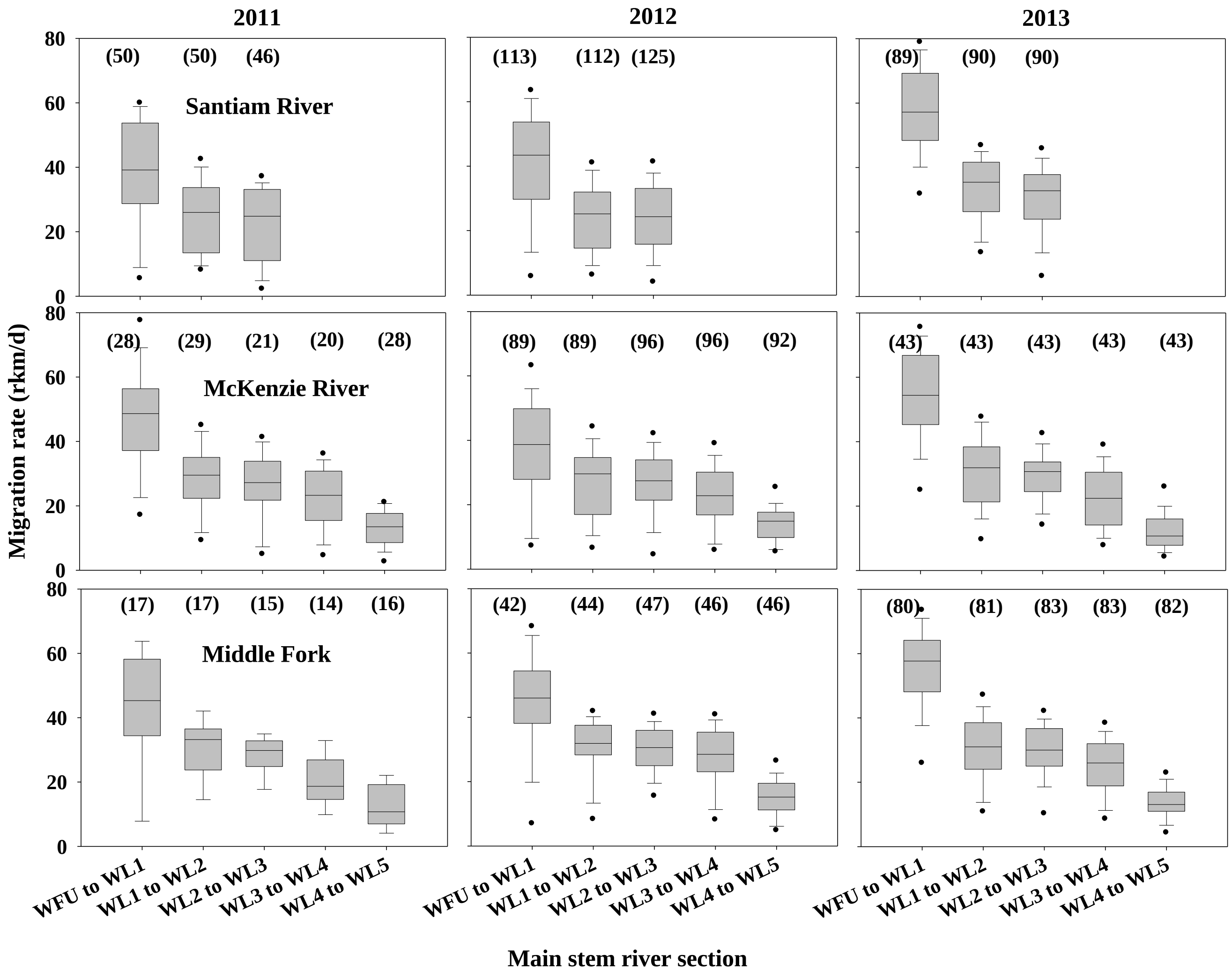

Figure 39. Box plots of rates (rkm/d) radio-tagged spring Chinook salmon used in reaches of the main stem Willamette River for salmon that returned to the Santiam, McKenzie, and the Middle Fork Willamette rivers in 2011-2013. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles. Sample sizes are listed in parentheses above boxes.

In 2013, the mean migration rate in the main stem (i.e., from the WFU site to the WL3 site for salmon that returned to the Santiam River and from the WFU site to the WL5 site for salmon that returned to the McKenzie River or the Middle Fork) was 27.3 rkm/d (*s.d.* = 10.9, *n* = 213), which was approximately 4-5 rkm/d faster than the 2011 and 2012 means (Figure 40). Means for groups of tagged salmon that returned to specific tributaries in 2013 ranged from 18.9 rkm/d (McKenzie River) to 34.6 rkm/d (Santiam River). The highest variation within a tributary grouping in 2013 was for salmon last detected in the Santiam River, with individual rates ranging from 8.3 to 56.9 rkm/d. The distributions of migration rates were generally similar in all three years.

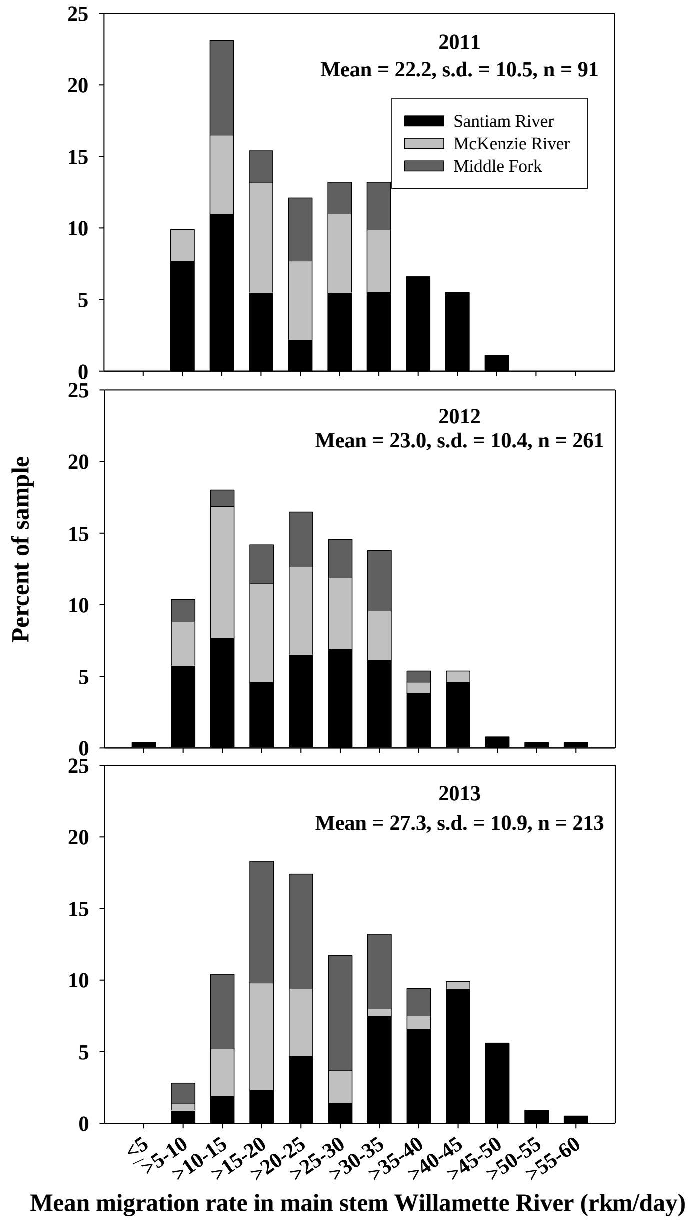

Figure 40. Histogram of radio-tagged Chinook salmon migration rates (rkm/d) in the main stem Willamette River for salmon that escaped to the Santiam, McKenzie, and Middle Fork Willamette rivers in 2011-2013.

Main stem migration rates for tagged salmon that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers were weakly positively associated with tag date in all years (Table 13 and Figure 41). Linear regression models for adults returning to the three tributaries each indicated faster movement later in the run. The higher slopes associated with salmon returning to the Santiam River were likely a result of these fish migrating through the lower sections of the main stem only (see Figure 39 above).

Table 13. Linear regression parameters for Willamette River main stem migration rate versus release date of adult, radio-tagged Chinook salmon that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers in 2011-2013.

Year	Tributary	Slope	Intercept	*n*	r^2	*P*
2011	Santiam	0.38	-36.4	46	0.37	<0.0001
	McKenzie	0.08	6.6	28	0.04	0.33
	Middle Fork	0.15	-1.4	17	0.10	0.22
2012	Santiam	0.27	-16.7	125	0.16	<0.0001
	McKenzie	0.18	-7.5	92	0.19	<0.0001
	Middle Fork	0.17	-2.2	44	0.15	0.008
2013	Santiam	0.34	-12.8	89	0.31	<0.0001
	McKenzie	0.11	5.4	43	0.06	0.10
	Middle Fork	0.05	16.1	81	0.01	0.37

Behavior at Willamette Falls Dam, downstream movements, overshoot behavior, and temporary straying

Behavior at Willamette Falls Dam - Fifty-six of the 299 tagged salmon (19%) were detected downstream from the dam after release in 2013 and of these, 27 ascended the dam, five were detected entering the Clackamas River, and 24 did not ascend the dam.

Downstream movements – Approximately ten percent (31/299) of radio-tagged salmon moved downstream in the main stem Willamette River after moving upstream from Willamette Falls Dam (Table 14). Six of the 31 salmon had intact adipose fins and 25 had adipose fin clips. There were a total of 13 likely fallback events at Willamette Falls Dam by 10 unique salmon (3.8% of the 264 tagged salmon that passed the dam at least once); all 10 were ad-clipped salmon. One salmon fell back three times, one fell back twice, and seven of the 13 fallback events did not result in dam re-ascensions. Two of the fallback salmon that did not re-ascend were last detected entering the Clackamas River. Two salmon migrated as far as the WL5 site near Harrisburg, OR, before initiating downstream movements and half (5/10) migrated no farther upstream than the WL1 site near Champoeg, OR, before swimming downstream.

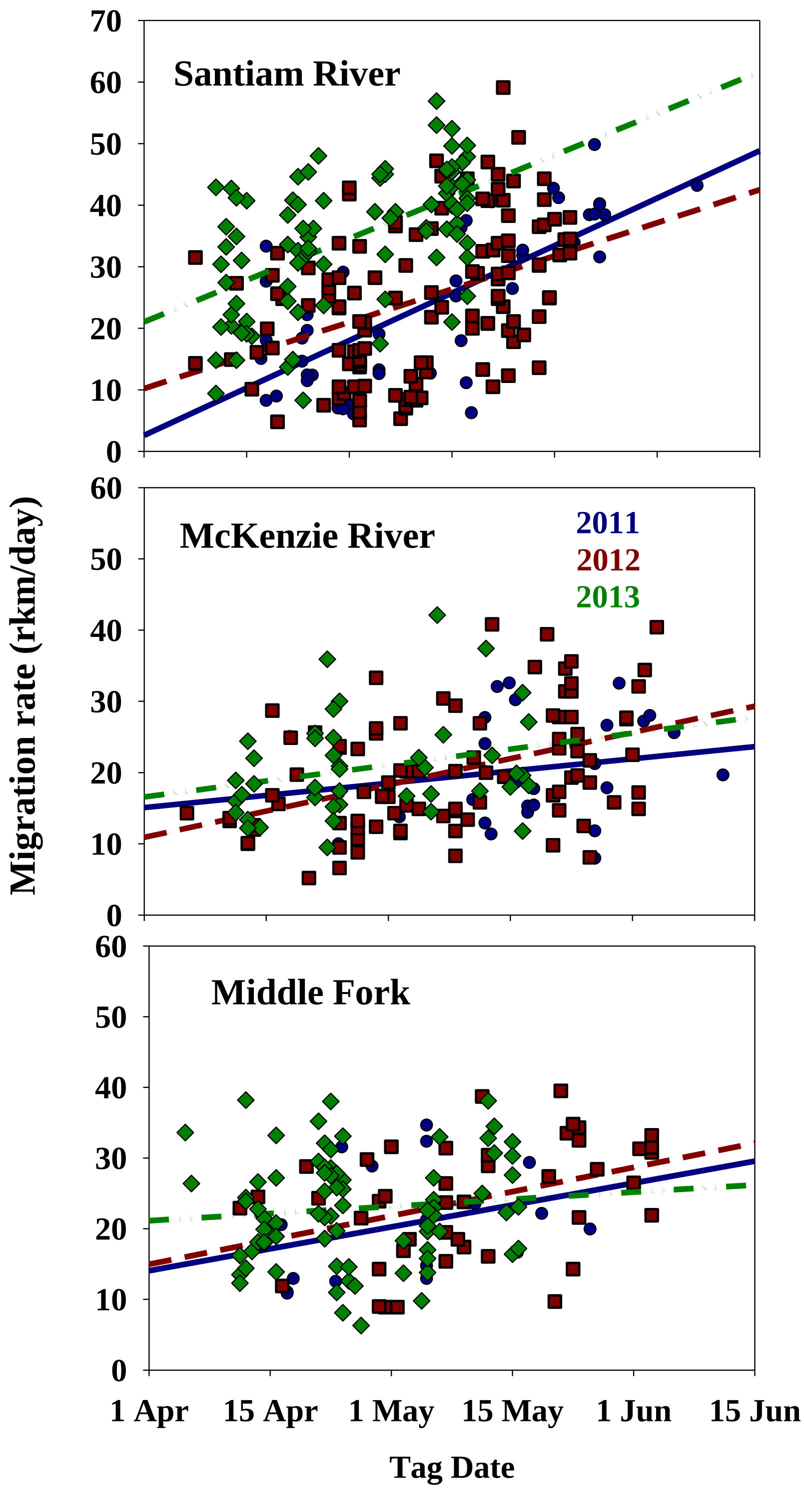

Figure 41. Relationships between radio-tagged Chinook salmon migration rates in the main stem Willamette River and tag date at Willamette Falls Dam in 2011-2013. Lines show separate linear regressions for different years. Note different y-axis scales.

Table 14. Numbers of adipose-clipped and unclipped radio-tagged Chinook salmon that moved downstream in the main stem Willamette River in 2013.

Downstream Behavior	**Ad-clipped Chinook**	**Unclipped Chinook**	**Row sum**	**Group total**
Fallback over WillametteFalls (no re-ascension)				
WL5 to fallback	2		2	7
WL2 to fallback then Clackamas R.	1		1	
WL2 to fallback	1		1	
WL1 to fallback	2		2	
WFU to fallback then Clackamas R.	1		1	
Tributary to main stem				
1DX to MFC	3		3	9
1DX to MFC (to 1DX)	1		1	
1DX to WL5 (to 1DX)	1		1	
FCR to MFC	1		1	
MOL to WFU	1		1	
STM to WL2	1		1	
Yamhill R. to WL1		1	1	
Main stem				
WL1 to MOL (to WL1 to Yam to WL1)		1	1	9
WL1 to WFU	1	1	2	
WL3 to WL2	1		1	
WL4 to WL3		1	1	
WL5 to WL4	2	1	3	
WL5 to WL4 (to 1DX)	1		1	
Overshoot				
WL1 to Molalla R.	1		1	6
WL4 to N. Santiam R.	1		1	
WL4 to S. Santiam R.	1	1	2	
WL5 to N. Santiam R.	1		1	
WMF to McKenzie R.	1		1	
Column Sum	25	6	31	31

Nine tagged salmon were detected in tributaries before they returned to the main stem and migrated downstream. Two re-entered to the Middle Fork Willamette River after leaving it for the main stem; all others were last detected in the main stem or at the confluence of the Middle Fork and Coast Fork after leaving the tributary where they were initially detected. Nine tagged salmon initiated downstream movements in the main stem and were not detected falling back at Willamette Falls Dam. One of these salmon swam downstream, resumed upstream movements, and subsequently entered a tributary upstream from where they started to move downstream.

Overshoot behavior - 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 downstream from where they started swimming downstream (i.e., tributary overshoot behavior). Six tagged salmon overshot the tributary to which they eventually escaped (five adipose-clipped and one unclipped). Two unclipped salmon and one clipped salmon entered the Santiam River after being detected near Corvallis, OR (WL4) and one clipped salmon entered the Santiam River after being detected near Harrisburg, OR (WL5). One unclipped salmon was detected near Champoeg, OR (WL1) before entering the Molalla River and one unclipped salmon entered the Middle Fork before migrating downstream to the McKenzie River.

Temporary straying - One tagged salmon was detected temporarily entering a tributary other than the tributary to which it ultimately escaped. It was detected in the Molalla River before migrating upstream to the Middle Fork. Nine of the 56 tagged salmon that exited the Willamette Falls Dam fishway after tagging briefly entered the Clackamas River before ascending the dam. No radio-tagged salmon were detected on the Tualatin River, Rickreall Creek, Mary's River, the Coast Fork Willamette River, or the Calapooia River receiver sites in 2013.

Behavior in tributaries downstream from Willamette Valley projects

The time radio-tagged salmon spent within different reaches of their migratory routes varied among groups that migrated to tributary dams that had no adult passage facilities. These included Foster Dam on the South Santiam River, Dexter Dam on the Middle Fork Willamette River, and Cougar Dam on the McKenzie River. We used a combination of recapture records and detections on the Foster fishway receiver (FST) to estimate times tagged salmon were in the Foster tailrace because all recapture events did not appear to have been recorded. We estimated Foster tailrace times using the last detection on the FST receiver in cases where salmon may have been recycled downstream as indicated by the presence of detections on a downstream receiver one or more days after being detected on the FST receiver. This method may have underestimated tailrace residency times for some fish. We relied solely on recapture records at Dexter Dam to estimate tailrace residency times there because there was no receiver deployed in the Dexter Dam fishway in any year.

A range of 15 to 29 salmon detected/recaptured at Foster Dam had complete radio detection histories across years. Of the nine tagged salmon recaptured at Dexter Dam in 2012, three had complete radio detection histories (i.e., six were not detected on the Dexter tailrace receiver site). We estimated the time salmon with incomplete histories arrived at the DEX site using the mean time salmon with complete histories used migrating the short distance between the WMF and DEX sites (*mean* = 0.9 d, *range* = 0.4 – 1.3 d, $n = 3$). There were no credible recapture data collected at Dexter Dam Trap in 2013. Specifically, no recapture dates were provided and two of the eight transmitters recovered there (based on telemetry data) were incorrectly reported as recaptured at Foster Dam.

Among years, salmon recaptured at Foster Dam spent a median of less than 12 d each in the main stem and in the Santiam River downstream from the tailrace (Figure 42). Median tailrace times ranged from 25 to 40 days among years. Tagged salmon that returned to Foster Dam spent over half of their migrations in the dam tailrace, on median, when expressed as a percentage of Willamette Falls Dam release to recapture times. Median tailrace residency times for tagged salmon with intact adipose fins were modestly lower than for tagged salmon of known hatchery origin but samples sizes of unclipped 'wild' fish were small (Figure 43). We note that Foster trap operations ended on 25 September 2013 to prepare for construction of a new trap facility and that some radio-tagged salmon and steelhead were mobile tracked downstream from Foster Dam or detected on the SSF site (i.e., the Foster tailrace receiver) into late October 2013.

Tagged salmon recaptured at Dexter Dam were estimated to have spent one to two days in the Middle Fork downstream from the Dexter tailrace, on median (Figure 44). Tailrace residency times varied between years for those in the Dexter tailrace, with medians ranging from 19 days in 2012 to 57 days in 2011, or from 36% in 2012 to 57% in 2011, when expressed as a percentage of release to recapture times. Median tailrace residency times for tagged salmon with intact and clipped adipose fins were similar but samples sizes of 'wild' fish at Dexter Dam were small (Figure 45).

One tagged salmon with an intact adipose fin was detected on the Cougar Dam fishway receiver for (COG) seven days in 2011 and it was last detected via mobile tracking in the main stem McKenzie River, downstream from its confluence with the South Fork. Thirteen tagged salmon with unclipped adipose fins were detected there in 2012 for an average of seven days. Among these 13 salmon, three were last detected downstream from Cougar Dam on the South Fork receiver site (MKS), nine were last detected on the COG site, and one was last detected via mobile tracking approximately seven river kilometers upstream from Cougar Dam. In 2013, one tagged salmon with a clipped adipose fin was detected there for one day and its transmitter was last detected via mobile tracking approximately eight river kilometers upstream from the dam in early November.

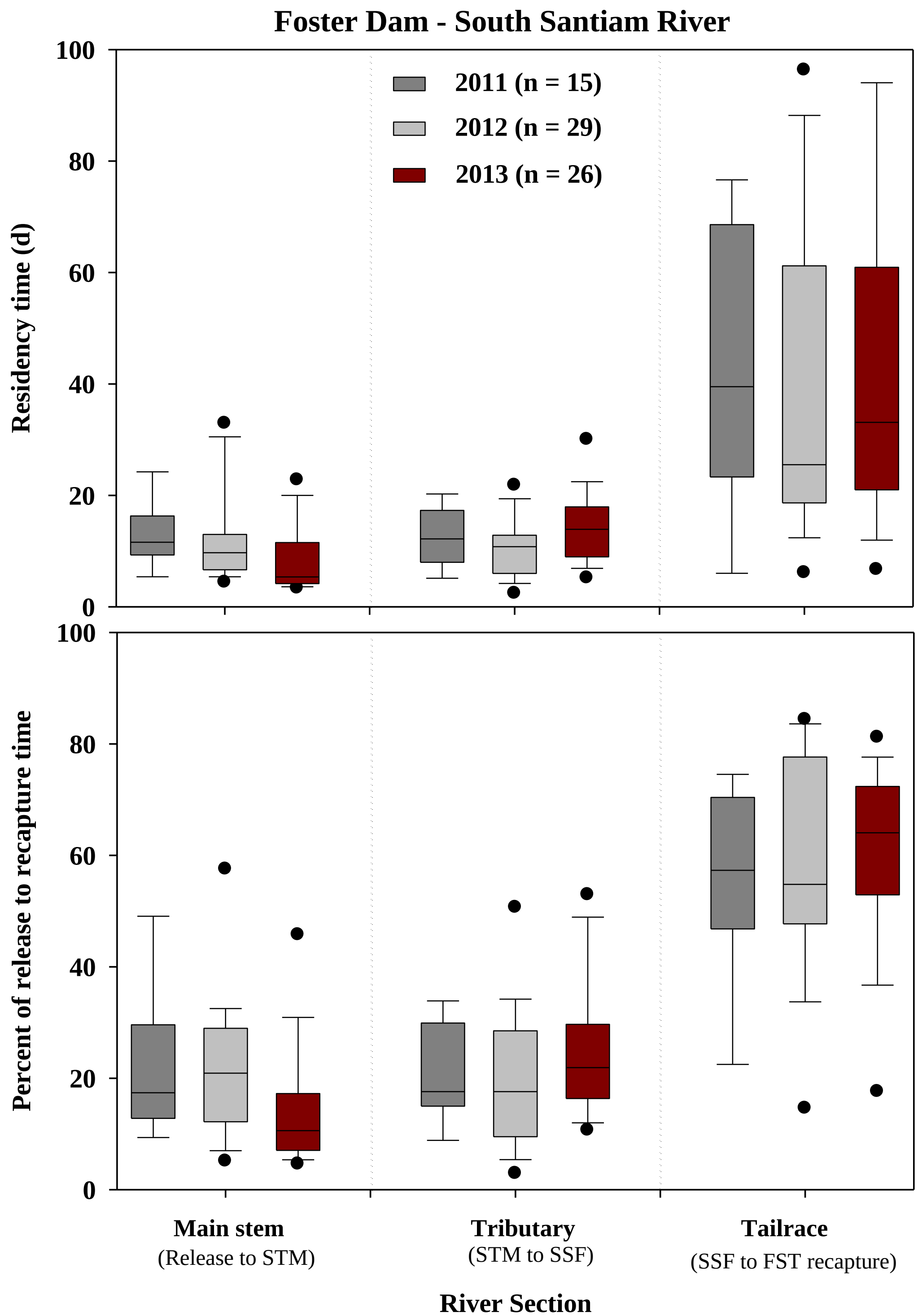

Figure 42. Box plots of times (days – upper panel) and percentages of release to recapture time (lower panel) that radio-tagged spring Chinook salmon spent in the main stem Willamette River (distance = 137.8 rkm), the Santiam River (distance = 72.7 rkm), and in the tailrace (distance = 1.4 rkm) for salmon detected / recaptured at Foster Dam in 2011-2013. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles (points). Sample sizes are listed in parentheses in the legend.

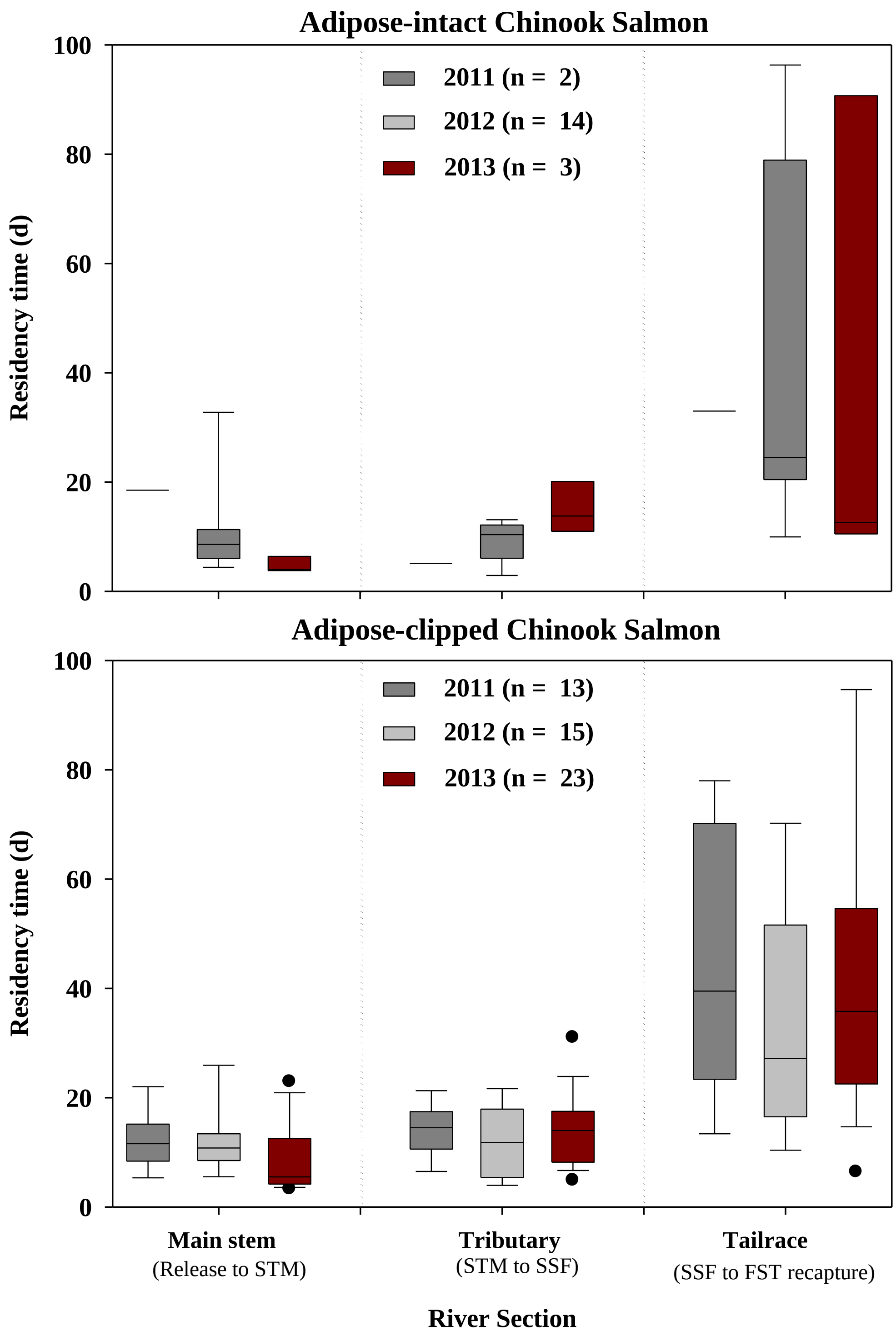

Figure 43. Box plots of times (days) that adipose-intact (upper panel) and adipose-clipped (lower panel), radio-tagged spring Chinook salmon spent in the main stem Willamette River (distance = 137.8 rkm), the Santiam River (distance = 72.7 rkm), and in the tailrace (distance = 1.4 rkm) for salmon detected / recaptured at Foster Dam in 2011-2013. Box plots show: median (line), quartile (box), 10^{th} and 90^{th} (whisker), and 5^{th} and 95^{th} percentiles (points). Sample sizes are listed in parentheses in the legend.

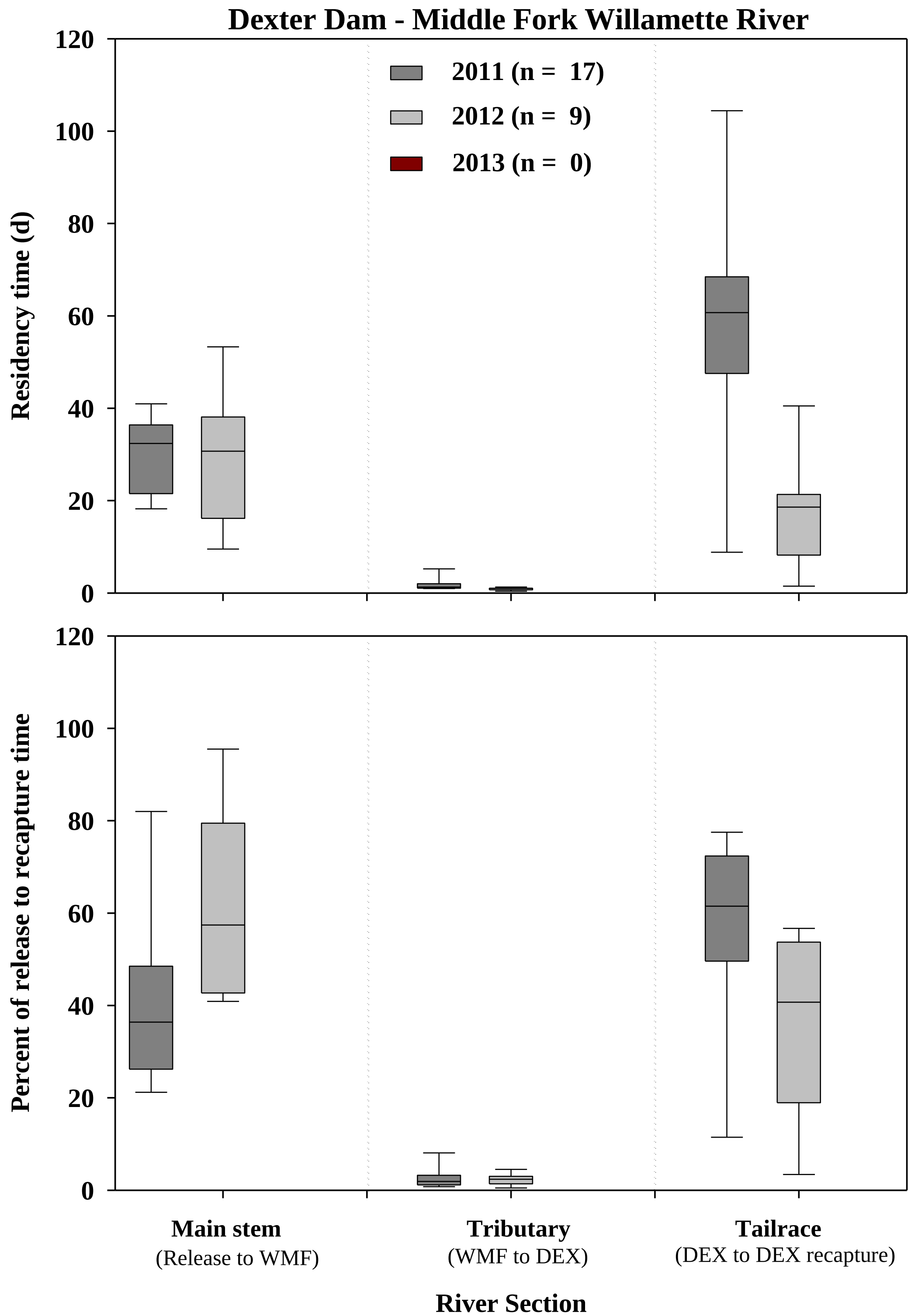

Figure 44. Box plots of times (days – upper panel) and percentages of release to recapture time (lower panel) that radio-tagged spring Chinook salmon spent in the main stem Willamette River (distance = 272.3 rkm), the Middle Fork Willamette River (distance = 8.3 rkm), and the Dexter Dam tailrace (distance = 4.5 rkm) for salmon recaptured at Dexter Dam in 2011-2013. Box plots show: medians (line) and quartiles (box). Sample sizes are listed in parentheses in the legend.

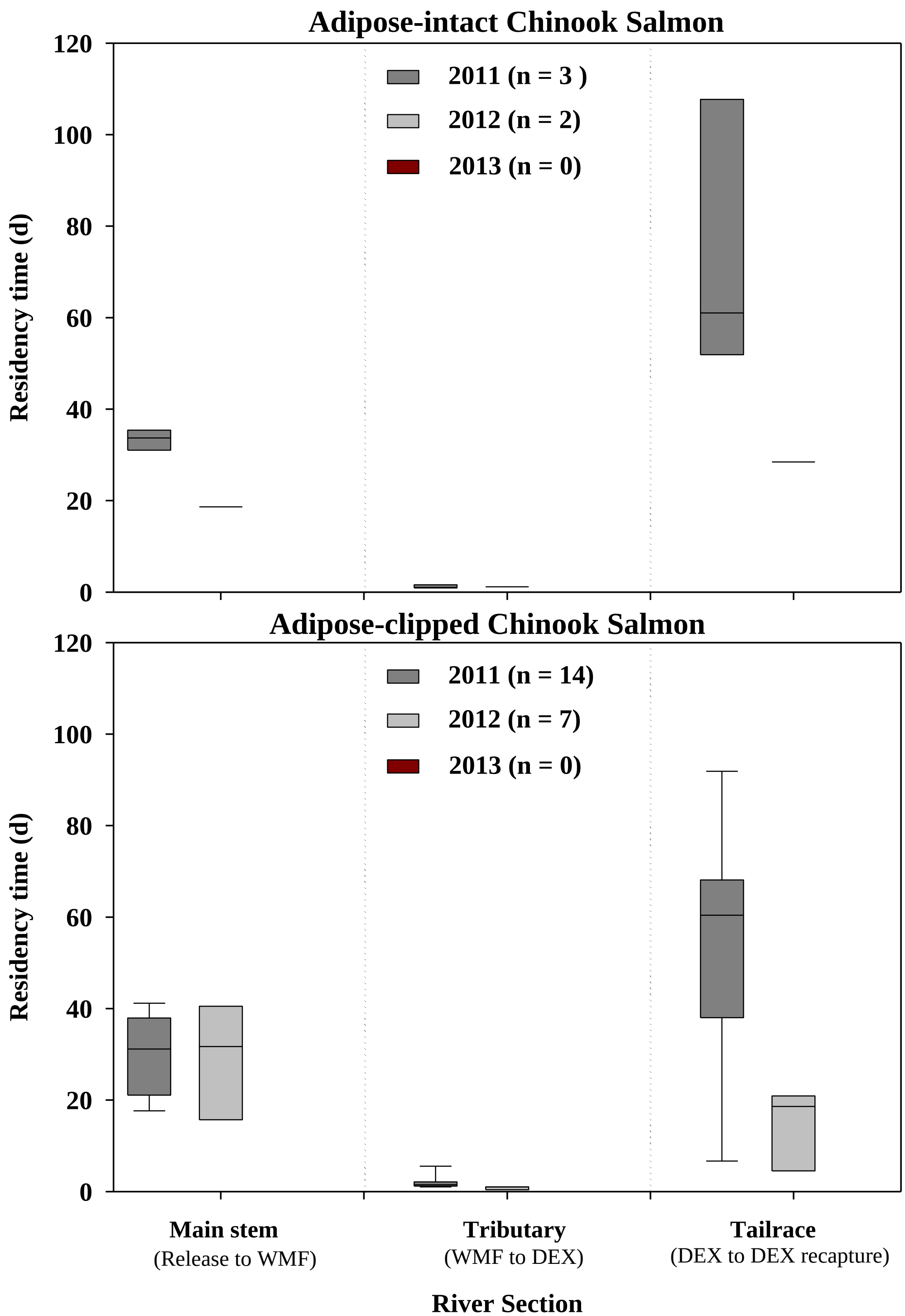

Figure 45. Box plots of times (days) that adipose-intact (upper panel) and adipose-clipped (lower panel), radio-tagged spring Chinook salmon spent in the main stem Willamette River (272.3 rkm), the Middle Fork Willamette River (distance = 8.3 rkm), and in the tailrace (distance = 4.5 rkm) for salmon recaptured at Dexer Dam in 2011-2013. Box plots show: median (line), quartile (box), 10^{th} and 90^{th} (whisker), and 5^{th} and 95^{th} percentiles (points). Sample sizes are listed in parentheses in the legend.

Last radio detections and transmitter recoveries

Of the 297 salmon tagged in 2013 that had no evidence of transmitter loss, 229 (77%) were last recorded or recaptured in Willamette River tributaries and 68 (23%) were last detected at main stem sites either upstream or downstream from Willamette Falls Dam (Table 15 and Figures 46 and 47). The overall escapement percentage in 2013 was higher than in 2011 and 2012, when salmon that were restrained during tagging were less likely to escape than anesthetized salmon (see Caudill et al. *in press*). The escapement percentage among anesthetized salmon was highest in 2011, the year with the smallest sample size, and percentages in 2012 and 2013 ranged from 77-83%.

Table 15. Percentages of radio-tagged salmon that escaped to Willamette River tributaries based on adipose fin status and handling treatment, 2011-2013. Sample sizes are listed in parentheses.

Year	All	Adipose-clipped	Adipose-intact	Restrained	Anesthetized
2011	74 (147)	75 (112)	71 (35)	72 (130)	88 (17)
2012	61 (496)	56 (188)	64 (308)	52 (344)	83 (152)
2013	77 (297)	78 (227)	76 (70)	n/a	77 (297)

In all years, small percentages of radio-tagged salmon last recorded or recaptured in tributaries were reported as recaptured by anglers (*range* = 1.7 to 3.7%). Four tagged salmon were captured and kept in the McKenzie River in 2011 (*n* = 4/109 reported captured, 3.7%). In 2012, five radio-tagged salmon last recorded or recaptured in tributaries were reported as recaptured by anglers: two were captured and released in the McKenzie River, two were captured and kept in the Santiam basin, and one was captured and kept downstream from Willamette Falls Dam (*n* = 5/303, 1.7%). In 2013, three were reported captured (one was kept and two had unknown dispositions) in the McKenzie River, two were captured and kept in the Santiam basin, and one was captured and kept in the Middle Fork Willamette River (*n* = 6/229, 2.6%).

In 2013, twenty-nine (10%) tagged salmon were last recorded downstream from Willamette Falls Dam (Table 16 and Figures 46 and 47). Six (4%) additional fish were last recorded in the Clackamas River and five (3%) had their last detections at the WLL receiver site at the dam. A total of 257 were last recorded upstream from Willamette Falls Dam. Three fish (2%) were last detected in the Molalla River. Thirty- four tagged salmon (11%) were last detected on receivers in the main stem, including 24 in the lower portion (from Willamette Falls Dam to the Santiam River mouth) and ten in the upper portion (from the Santiam River mouth to the confluence of the Coast and Middle Forks). Another 90 (30%) were last detected in the Santiam River, with 56 and 24 in the South and North Santiam rivers, respectively. Forty-three (14%) were in the McKenzie River, two (<1%) were in Fall Creek, and 83 (28%) were in the Middle Fork Willamette River.

Among the 56 transmitters recovered in the South Santiam River, ten from salmon with unclipped adipose fins were last detected upstream from Foster Dam (two were recovered in spawning ground surveys, five were mobile-tracked, and three were detected on the SFR or RVB sites), 18 were associated with Foster Dam (13 recaptures and five with final telemetry detections), one was captured by an angler, seven were recovered during spawning ground surveys (downstream from Foster Dam), and one was found by the public. In the North Santiam River, 19 transmitters were recaptured at the Minto Fish Collection Facility and one was recaptured by an angler downstream from the facility. The distribution of recovered transmitters from the McKenzie River included 20 hatchery returns, three angler recaptures, and one tag recovered during spawning ground surveys. Information associated with 25 recapture events in the Middle Fork was often absent or incomplete and some of it contradicted telemetry data from fixed sites. Nevertheless, we are confident that three tags were recovered in the North Fork of the Middle Fork during spawning ground surveys and one tag was last mobile-tracked there. Two tags were found near Hills Creek Reservoir, near Oakridge, OR.

The lone salmon last detected in the Luckiamute River had the latest mean tag date among groups and the 24 salmon last detected in the lower main stem had the earliest (Table 16). The two salmon last detected at Fall Creek were the longest and heaviest on average. Mean fatmeter readings among fate groups ranged from 6.2 to 8.2%.

Table 16. Sample sizes, adipose fin clip status, mean tag date, mean fork length, mean weight, and mean fatmeter readings for radio-tagged adult Chinook salmon by final detection site within the Willamette River in 2013.

Fate	*n*	# Ad-clipped (y/n)	Mean tag date	Mean fork length (cm)	Mean weight (kg)	Mean fatmeter (%)
Clackamas River	6	5/1	22 May	72.1	4.52	6.2
Lost/regurge.	2	2/0	29 Apr	71.8	4.86	7.8
Downstream from Dam	29	24/5	15 May	75.1	5.68	7.6
Willamette Falls Dam	5	5/0	15 May	73.6	4.87	8.2
Molalla River	3	2/1	21 May	70.7	4.61	6.3
Yamhill River	1	1/0	25 May	71.5	4.44	7.9
Lower main stem[1]	24	14/10	14 May	74.9	5.50	7.8
Luckiamute River	1	1/0	6 Jun	71.5	3.97	3.4
S. Santiam River	56	40/16	16 May	75.0	5.69	7.8
N. Santiam River	34	26/8	24 May	74.6	5.65	7.6
Upper main stem[2]	10	8/2	12 May	73.8	5.05	7.8
McKenzie River	43	29/14	16 May	75.5	5.76	7.7
Fall Creek	2	0/2	23 May	78.0	6.33	7.9
Middle Fork Willamette River	83	72/11	13 May	73.1	5.08	7.7

[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.

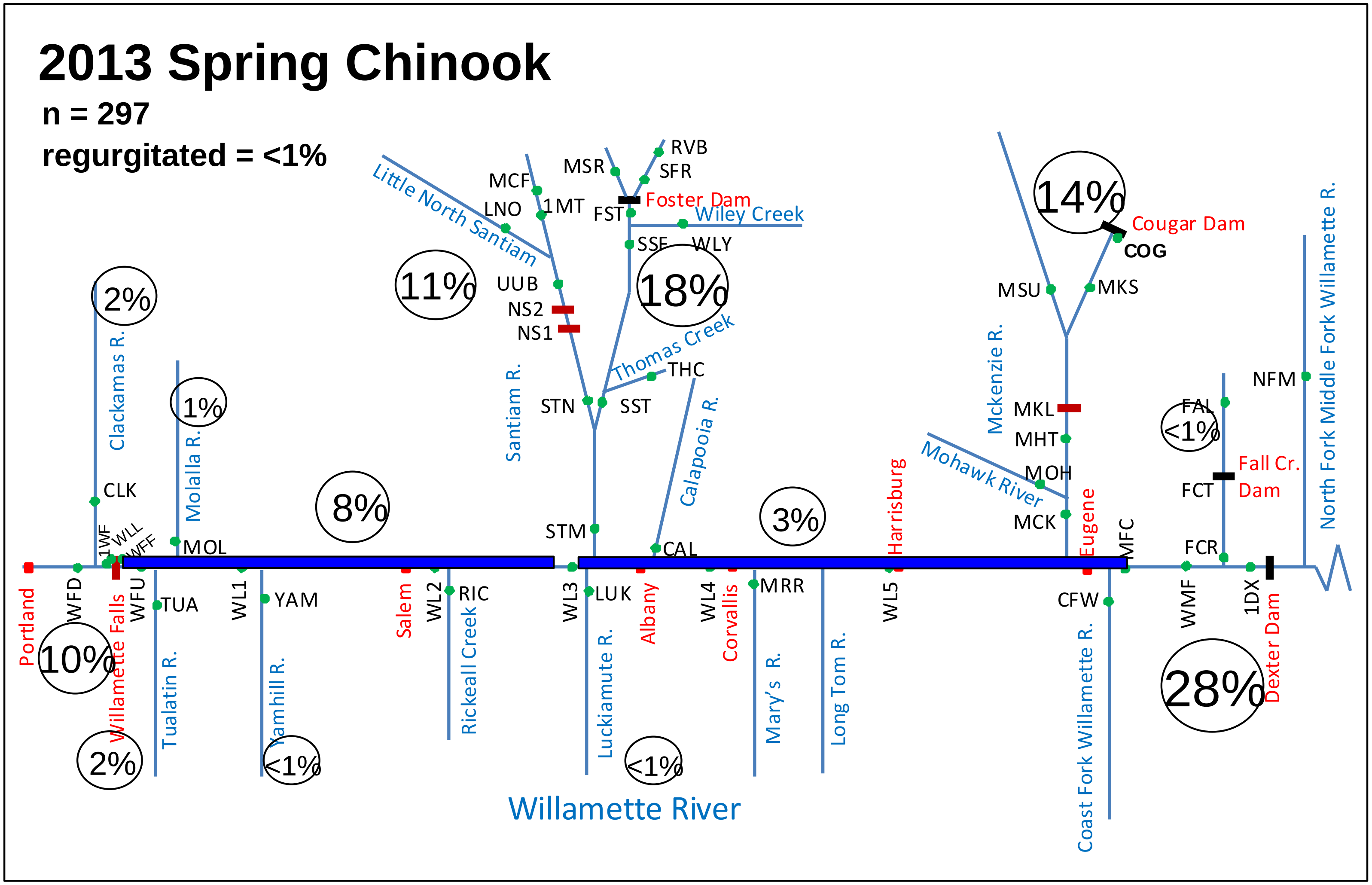

Figure 46. Sites and drainages where adult spring Chinook salmon radio-tagged and released at Willamette Fall Dam in 2013 migrated based on their last radio detections. Adipose-clipped and adipose-unclipped salmon are combined.

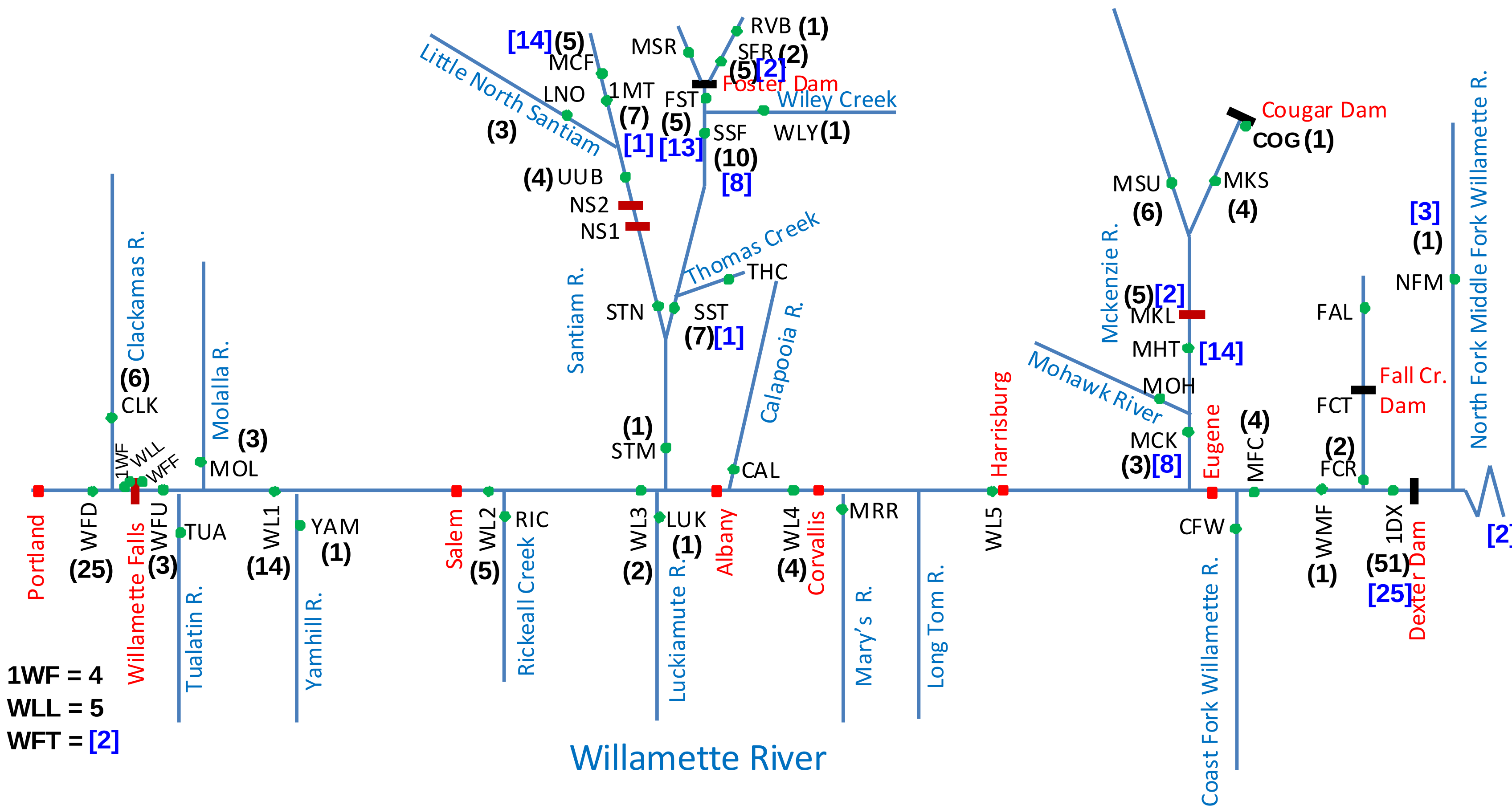

Figure 47. Sites where adult Chinook salmon radio-tagged and released at Willamette Falls Dam in 2013 were last detected (black font and parentheses) or where they were recaptured (blue font and brackets). Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference. Adipose-clipped and adipose-unclipped salmon are combined.

Escapement was 77% for the 227 clipped salmon and 76% for the 70 unclipped salmon in 2013. No tested covariates were statistically significant ($P > 0.05$) in the escapement models for clipped and unclipped Chinook salmon (Table 17). The models included tag date, fork length, weight, and fatmeter value. Removing the fork length or weight term from the model produced no significant predictors.

Table 17. Results of separate logistic regression models of escapement to tributaries by unclipped (left) and fin-clipped Chinook salmon (right) radio-tagged at Willamette Falls Dam in 2013.

	Fin-clipped salmon (*n* = 227)		Unclipped salmon (*n* = 70)	
	χ^2	*P*	χ^2	*P*
Tag date	<0.01	0.94	2.77	0.10
Fork length	2.02	0.16	0.08	0.78
Weight	2.00	0.16	0.23	0.63
Fatmeter	0.41	0.52	0.05	0.82

Fates of tagged salmon with intact adipose fins

The collection of Chinook salmon in 2013 was the first year when a proportionate sample of clipped and unclipped salmon was tagged and no handling treatment experiment was conducted. Of the 70 adipose-intact salmon in 2013, 23% were last detected in the South Santiam River, 20% were in the McKenzie River, and 16% were in the Middle Fork (Figure 48). The percentage of unclipped salmon last detected downstream from Willamette Falls Dam in 2013 (7%) was the lowest percentage among years for all clip × handling groups.

The high percentage of unclipped, radio-tagged Chinook salmon last detected downstream from Willamette Falls Dam in 2012 was associated with the fish restraint device (FRD) handling treatment. Thirty-eight percent of unclipped salmon that received the FRD treatment were last detected downstream from the dam versus 12% of anesthetized unclipped salmon. Consequently, 8-14% more anesthetized salmon were last detected in the Santiam, McKenzie, and Middle Fork drainages than salmon that received the FRD treatment.

With handling treatments combined, the highest percentages of unclipped salmon radio-tagged in 2011 returned to the McKenzie and Santiam Rivers. We note the small sample size of unclipped salmon in 2011 ($n = 38$) and the difference in percentages of tagged salmon that returned to tributaries among handling treatments. Specifically, 10 of 18 (55%) restrained salmon returned to a tributary (with one fish excluded) whereas 15 of 17 (88%) anesthetized salmon returned to a tributary (with two fish excluded).

Fates of tagged salmon with clipped adipose fins

All 229 of the adipose-clipped salmon in 2013 received the anesthetic treatment. Of these, 31% were last detected in the Middle Fork, 18% were in the South Santiam River, 13% were in the McKenzie River, and 11% were in the North Santiam River (Figure 48). The percentage of clipped salmon last detected downstream from the dam in 2013 (10.5%) was the lowest percentage among years (2011 = 17%, 2012 = 30%); all clipped fish received the FRD treatment in both 2011 and 2012.

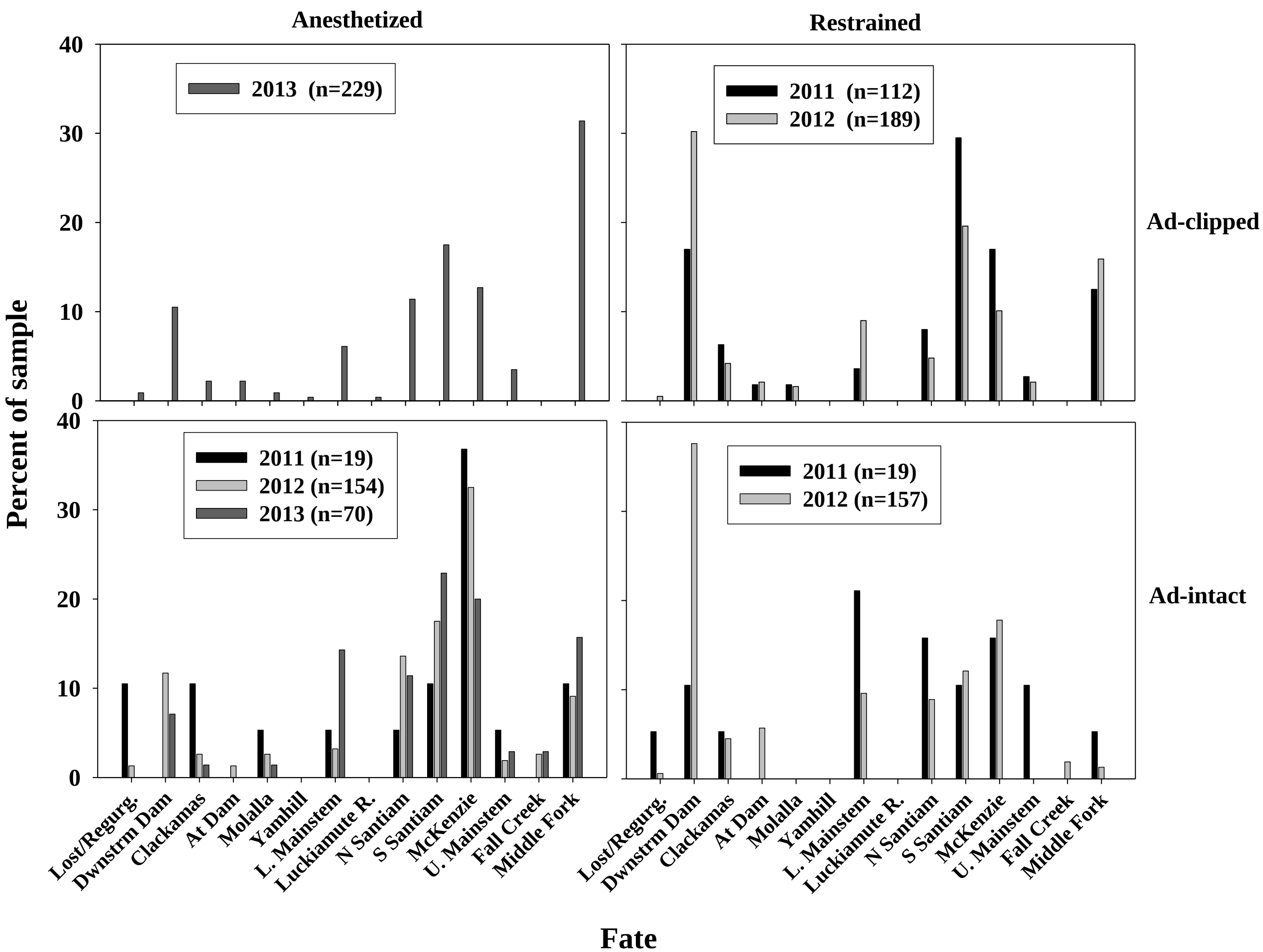

Figure 48. Histograms showing where all adipose-clipped (upper panels) and unclipped (lower panels), radio-tagged spring Chinook salmon that received the anesthetic (panels on left) or fish restraint device handling (panels on right) treatment were last recorded in 2011-2013.

Estimated returns by sub-basin

We estimated the number of Chinook salmon returning to tributaries using: 1) the percentage of the count past Willamette Falls Dam that was fin-clipped (75.0%) and unclipped (25.0%), 2) the percentage of each radio-tagged fate group that was clipped (*n* = 227) and unclipped (*n* = 70), and 3) two count scenarios: a) Chinook salmon counted during the radio-tagging interval (16 April – 12 June), and b) the total annual count (21 February – 15 August) (Table 18).

Table 18. Estimated returns of adult Chinook salmon to Willamette River tributaries based on return numbers and percentages of 297 radio-tagged salmon (*n* = 227 adipose-clipped and 70 unclipped) and two scenarios of ODFW count data from Willamette Falls Dam in 2013. Percentages were weighted by the ODFW-reported proportions of fin-clipped (75.0%) and unclipped (25.0%) salmon passing Willamette Falls Dam.

			Fin-clipped Chinook count	
			Tag interval	Annual
			n = 16,206	*n* = 20,923
Tributary	*n*	% (95% ci)	Estimate	Estimate
None	51	22.5 (17.5-28.3)	3,641 (2,836-4,586)	4,701 (3,662-5,921)
Clackamas	5	2.2 (0.9-5.0)	357 (146-810)	461 (188-1,046)
Yamhill	1	0.4 (0.1-2.4)	71 (16-389)	92 (21-502)
Molalla	2	0.9 (0.2-3.1)	143 (32-502)	184 (42-649)
Luckiamute	1	0.4 (0.1-2.4)	71 (16-389)	92 (21-502)
N. Santiam	26	11.5 (7.9-16.2)	1,856 (1,280-2,625)	2,396 (1,653-3,390)
S. Santiam	40	17.6 (13.2-23.1)	2,856 (2,139-3,744)	3,687 (2,762-4,833)
McKenzie	29	12.8 (9.0-17.8)	2,070 (1,459-2,885)	2,673 (1,883-3,724)
Fall Creek	-	-	-	-
Middle Fork	72	31.7 (26.0-38.0)	5,140 (4,214-6,158)	6,636 (5,440-7,951)

			Unclipped Chinook count	
			Tag interval	Annual
			n = 5,402	*n* = 6,974
Tributary	*n*	% (95% ci)	Estimate	Estimate
None	17	24.3 (15.8-35.5)	1,312 (854-1,918)	1,694 (1,102-2,476)
Clackamas	1	1.4 (0.2-7.7)	77 (11-416)	100 (14-537)
Yamhill	-	-	-	-
Molalla	1	1.4 (0.2-7.7)	77 (11-416)	100 (14-537)
Luckiamute	-	-	-	-
N. Santiam	8	11.4 (5.9-21.0)	617 (319-1,134)	797 (411-1,465)
S. Santiam	16	22.9 (14.6-34.0)	1,265 (789-1,837)	1,594 (1,018-2,371)
McKenzie	14	20.0 (12.3-30.8)	1,080 (664-1,664)	1,395 (858-2,148)
Fall Creek	2	2.9 (0.8-9.8)	154 (43-529)	199 (56-683)
Middle Fork	11	15.7 (9.0-26.0)	849 (486-1,405)	1,096 (1,102-2,476)

The tributary to which the highest estimated return of clipped Chinook salmon was the Middle Fork, based on the return percentages of 227 clipped, radio-tagged salmon (Table 18). Point estimates of adult returns to the Middle Fork ranged from 5,140 to 6,636 adipose-clipped individuals. The tributary to which the highest estimated return of unclipped Chinook salmon was the South Santiam River, based on return percentages of 70 unclipped, radio-tagged salmon (Table 18). Point estimates for the South Santiam ranged from 1,265-1,594 unclipped fish. Estimates for the McKenzie River were 2,070-2,673 fin-clipped fish and 1,080-1,395 unclipped fish.

The summed counts of adipose-clipped Chinook salmon passing Lower and Upper Bennett dams on the North Santiam River in 2013 was 3,100, which was 29-67% higher than our telemetry-based point estimates (Table 18). The discrepancy may have resulted from fallback and double-counting at the Bennett dams and/or under-sampling of the N. Santiam group at Willamette Falls. The 2013 count of adipose-clipped Chinook salmon from Foster Dam on the South Santiam River (n = 2,499) was within the 95% confidence interval of one telemetry-based estimate and slightly lower than the 95% confidence interval for the other. No Chinook salmon count data from Leaburg Dam are currently available for 2013.

The summed counts of unclipped Chinook salmon passing Lower and Upper Bennett dams in 2013 (n = 1,181) was within the 95% confidence intervals of both telemetry-based estimates. Similarly, the count of unclipped Chinook salmon at Foster Dam in 2013 (n = 913) was within the 95% confidence interval of both telemetry-based estimates.

Run Composition

Chinook salmon populations in the 2013 run at Willamette Falls Dam were well-mixed and the differences between clipped and unclipped samples were modest (Figures 49 and 50). Run composition for the 176 adipose-clipped Chinook salmon last recorded in tributaries in 2013 showed that the three largest return groups (i.e., Santiam, McKenzie, and Middle Fork) were represented in all of the 10-day tagging intervals (Figure 49). The small percentage of clipped salmon that returned to the Molalla River passed Willamette Falls Dam in the middle of the run whereas those that returned to the Luckiamute and Yamhill rivers did so later in the run. The mean tag date for each group was: 14 May (Middle Fork and South Santiam), 16 May (McKenzie), 18 May (Molalla), 22 May (Clackamas), 25 May (North Santiam and Yamhill), and 6 June (Luckiamute).

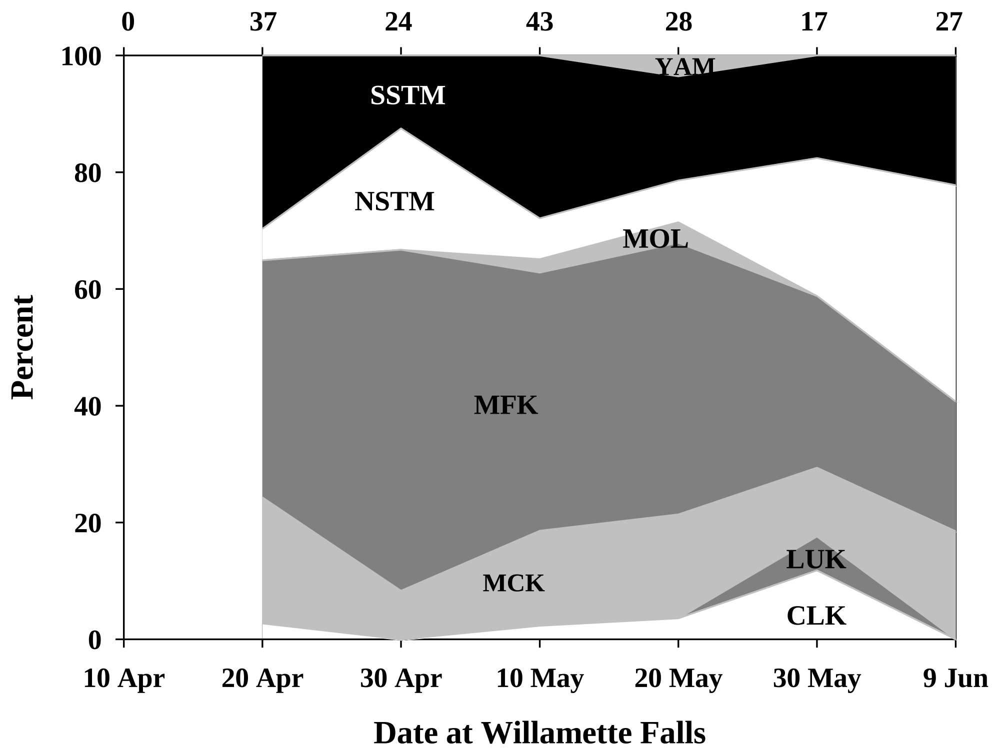

Figure 49. Composition of 176 'escaped', fin-clipped Chinook salmon at Willamette Falls Dam in 2013 using 10-d bins based on release dates of radio-tagged fish. Sample sizes for each 10-d bin are listed at top. SSTM = South Santiam River; NSTM = North Santiam River; MOL = Molalla River; MFK = Middle Fork Willamette River; MCK = McKenzie River; CLK = Clackamas River; LUK = Luckiamute River; YAM = Yamhill River.

Run composition for the 53 unclipped salmon last recorded in tributaries in 2013 was characterized by the two largest return groups (i.e., South Santiam and McKenzie rivers) making up 33-100% of the sample in each 10-day tagging interval (Figure 50). Unclipped salmon that returned to Fall Creek passed Willamette Falls Dam in the third and sixth 10-day blocks only and those that returned to the Middle Fork were present, typically in small percentages, in six of the seven 10-day blocks. Unclipped salmon that returned to the Molalla and Clackamas rivers were absent from the early run but small percentages passed Willamette Falls Dam after early May. The mean tag date for each population was: 8 May (Middle Fork), 16 May (McKenzie), 19 May (South Santiam), 22 May (North Santiam), 23 May (Fall Creek), and 26 May (Clackamas and Molalla).

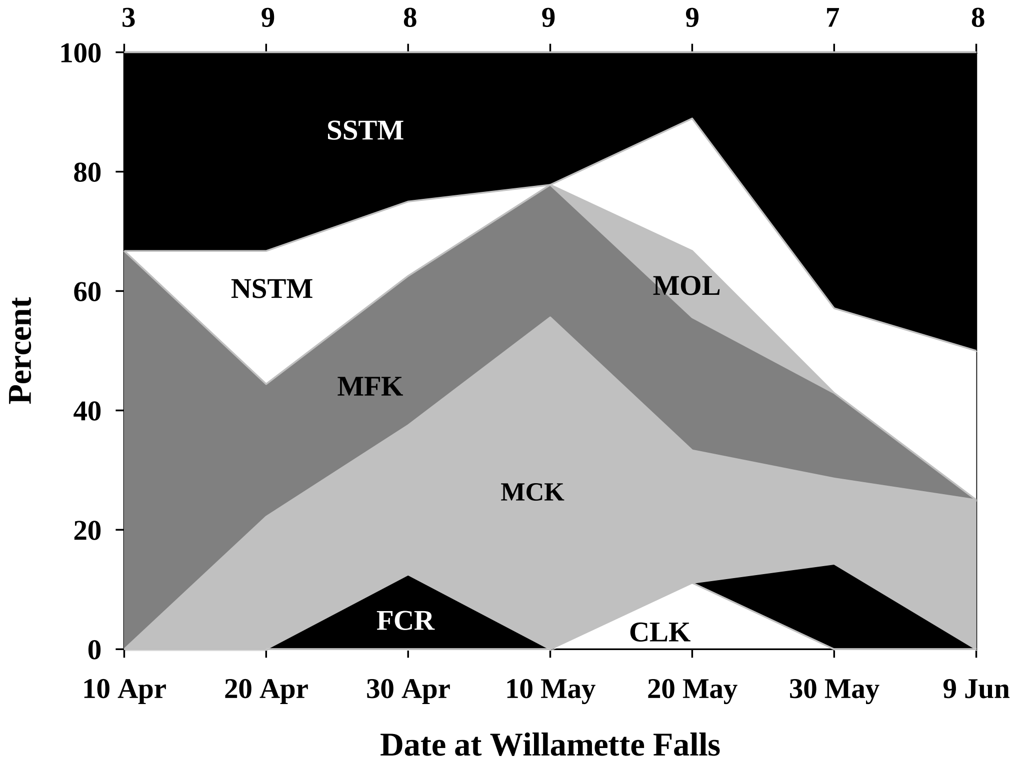

Figure 50. Composition of 53 'escaped', unclipped Chinook salmon at Willamette Falls Dam in 2013 using 10-d bins based on release dates of radio-tagged fish. SSTM = South Santiam River; NSTM = North Santiam River; MOL = Molalla River; MFK = Middle Fork Willamette River; MCK = McKenzie River; CLK = Clackamas River; FCR = Fall Creek.

Temperature histories of individual salmon

There were 20 temperature loggers recovered from the 66 adipose-clipped (hatchery) Chinook salmon outfitted with radio transmitters and loggers in 2013. All 20 had retrievable data, including from fish recovered in the McKenzie River (*n* = 8), the North Santiam (*n* = 5), South Santiam (*n* = 4), and Middle Fork Willamette (*n* = 3) rivers (Figure 51). Two Middle Fork fish were collected at Dexter trap, transported, and then recovered in either the North Fork Middle Fork or in the upper reaches of Hills Creek Reservoir, near Oakridge, OR. Only temperature data prior to the outplant dates were included in the summaries below.

In 2011-2013, 68 loggers with usable data were collected from hatchery Chinook salmon in the North Santiam (*n* = 6), South Santiam (27), McKenzie (19), and Middle Fork (16) basins (Table 19). Almost all were trapped at Minto, Foster, Dexter, or McKenzie collection facilities. The elapsed time between salmon release at Willamette Falls Dam and recapture in a tributary was 61 d on average (*median* = 58 d, *range* = 15-112 d). In all years, the elapsed time was shortest for fish recaptured in the McKenzie River (*annual medians* = 27-37 d) and was longer for those in the North Santiam (48-100 d), South Santiam (53-76 d), and Middle Fork (46-77 d) rivers.

In all years, temperature logger histories showed that most individual salmon experienced a wide range of water temperatures ranging from minima of ~8-10 °C to maxima ranging from 13 to >21 °C. The highest annual temperature recorded for any fish was 22.0 °C (2011), 22.1 °C (2012), and 21.7 (2013), all in the main stem Willamette River. The maximum encountered temperatures for individual salmon were higher in 2012 (*mean* = 19.4 °C) and 2013 (*mean* = 20.4) than in 2011 (*mean* = 16.2) (Figure 52). Among-year differences were due, in part, to tagging salmon with loggers earlier in the run in 2011 (first logger deployed on 2 May) than in 2012 (31 May) and 2013 (26 May). Main stem temperatures were also higher, on average, in 2013 (see Figure 4).

Individual salmon predominantly encountered maximum water temperatures in the Willamette River (Figure 53). Across years, 72% of the maximum values were in the main stem, and these were concentrated in the lower three reaches, from release at Willamette Falls Dam to antenna WL2. The remaining fish encountered maxima in confluence reaches (10%) and in tributaries (15%). In contrast, 94% of the minimum encountered temperatures were in tributary reaches (Figure 53).

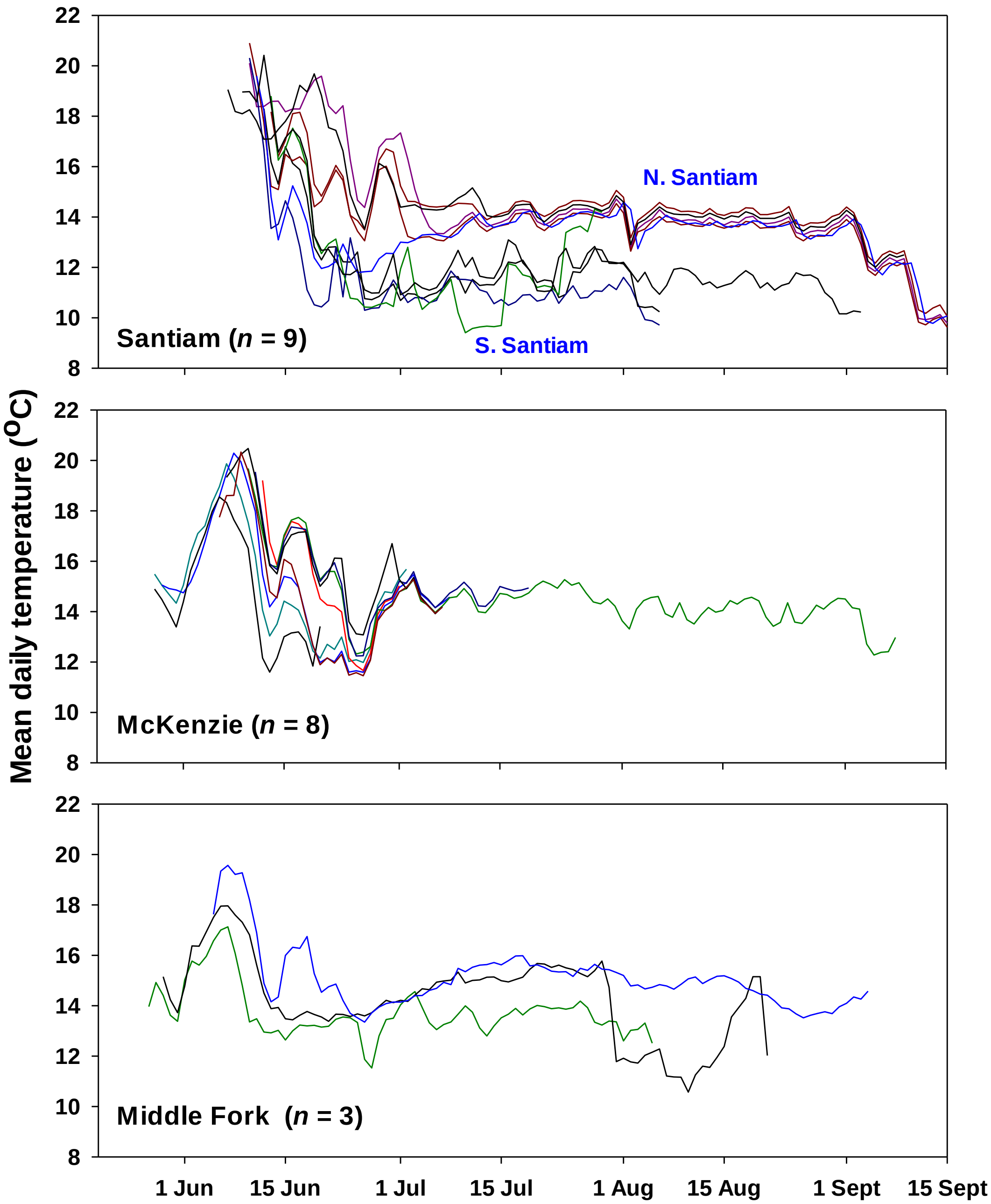

Figure 51. Mean daily temperatures (°C) of 20 radio-tagged hatchery Chinook salmon that had archival temperature loggers recovered in 2013. The three panels are for fish recaptured in the Santiam, McKenzie, and Middle Fork Willamette rivers. Each line represents an individual fish. (Appendix A includes all individual thermal histories, matched to radiotelemetry detections).

Table 19. Numbers of hatchery Chinook salmon for which temperature loggers were recovered in 2011-2013, with the median numbers of days between release at Willamette Falls Dam and recapture in tributaries. Note that data collected after outplanting upstream from dams were excluded from time calculations and subsequent analyses.

	Recovered loggers (*n*)			Median release to recapture time (d)		
Population	2011	2012	2013	2011	2012	2013
N. Santiam	-	1	5	-	48.4	99.8
S. Santiam	11	12	4	53.0	75.8	59.4
McKenzie	5	6	8	26.9	36.9	34.4
Middle Fork	9	4	3	76.9	46.4	63.4
All groups	25	23	20	53.0	65.1	59.4

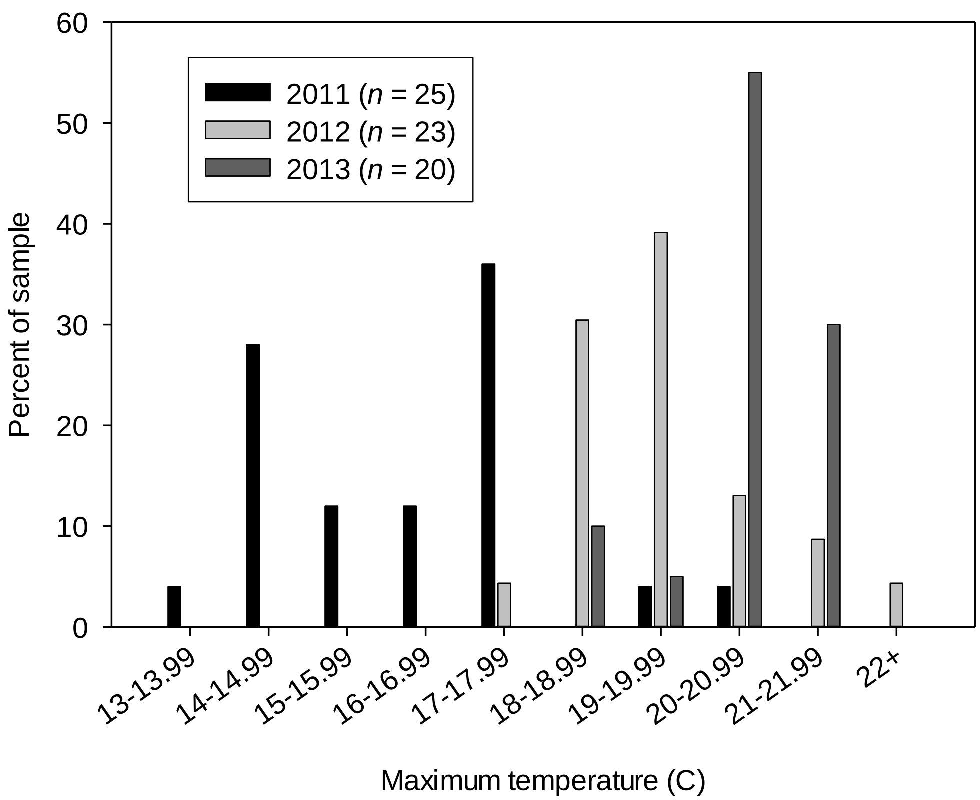

Figure 52. Histograms showing the maximum temperatures recorded on temperature loggers recovered from radio-tagged hatchery Chinook salmon released at Willamette Falls Dam in 2011-2013. Note that salmon were tagged with temperature loggers only later in the run in 2012 and 2013.

We calculated the accumulated degree days (DD) for each fish for their full migration from release at Willamette Falls Dam to recapture in a tributary and in each reach separately using the telemetry detections to bracket the temperature data blocks. DD were estimated by summing the 30 min temperature records for each fish and dividing the total by 48 (the number of temperature records per day). The same method was used for the full migration (release to recapture) and for individual river reaches (time between first detections at the radio antennas bracketing each reach).

DD accumulations from release to recapture ranged from 208 DD for a salmon recaptured at Foster trap in 2012 to 1,498 DD for one recaptured at Dexter trap in 2012. Annual mean estimates of release-recapture DD, with all populations combined, were 741 (2011), 826 (2012), and 879 (2013). Population-specific estimates, with all years combined, were 1,308 (North Santiam), 826 (South Santiam), 545 (McKenzie), and 912 (Middle Fork).

A majority of the release-to-recapture DD were accumulated in the tributaries (Figure 54). On average, with all years and populations combined, 28% of the accumulated DD were in the Willamette main stem and 72% were in tributaries. The main stem contribution ranged from 4-79% among individuals. There were also differences among populations, with higher main stem accumulation for the McKenzie (*mean* = 41%) and Middle Fork (30%) groups than for the North Santiam (22%) and South Santiam (20%) groups. This reflected longer main stem transit times for the McKenzie and Middle Fork populations (see Figure 37) as well as shorter pre-collection holding periods in the McKenzie River (see Figure 51).

DD accumulations were positively correlated with total release-to-recapture migration time (Figure 55). DD accumulations >1,000 occurred for 23 salmon (34% of the 68 fish), and release-to-recapture times were >75 d for all fish in this group. DD accumulation rates fell between ~10 and ~18 DD/d across the full sample, with typical rates ~14 DD/d (Figure 56). Some Chinook salmon were above 1,000 DD in each year, including 28% of the 2011 sample, 35% of the 2012 sample, and 40% of the 2013 sample.

The composition of the group with DD >1,000 was ten South Santiam, five North Santiam, two McKenzie, and six Middle Fork fish (Figure 56). These fish were 37-38% of the South Santiam and Middle Fork samples versus 11% of the McKenzie sample and 83% of the North Santiam sample. We caution against strong inferences regarding differences among groups and years given the unbalanced population composition and differences in release timing among years.

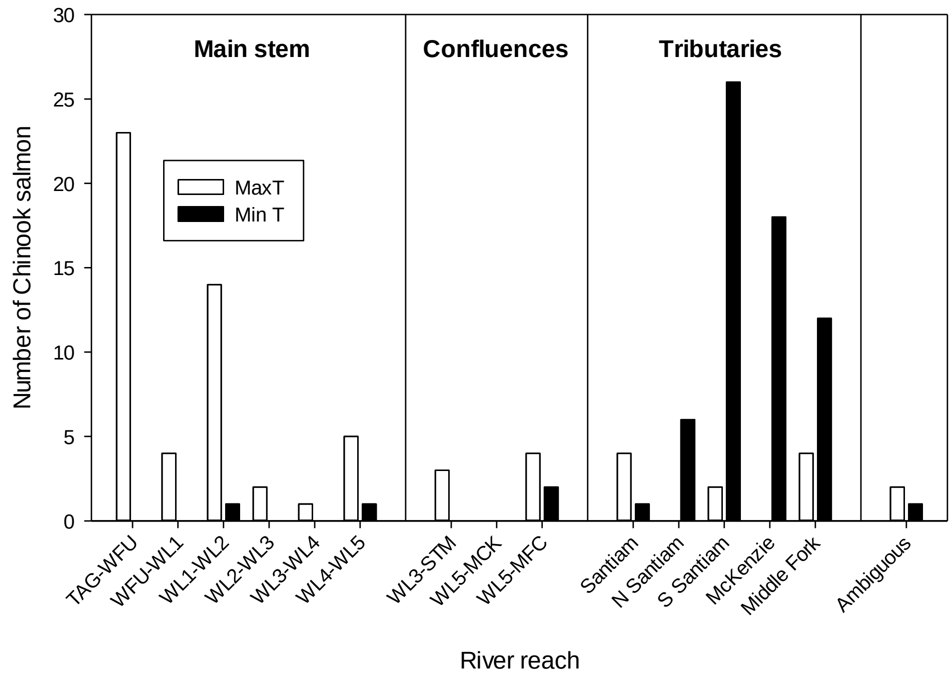

Figure 53. River reaches where hatchery Chinook salmon with temperature loggers encountered the highest (Max T) and lowest (Min T) water temperatures during their migrations in 2011-2013. Confluence reaches were those bracketed by a radio antenna in the main stem and the first antenna in a tributary upstream from the confluence. See Figure _ for antenna locations. 'Ambiguous' category refers to uncertainty in the telemetry data regarding the reach where fish were located.

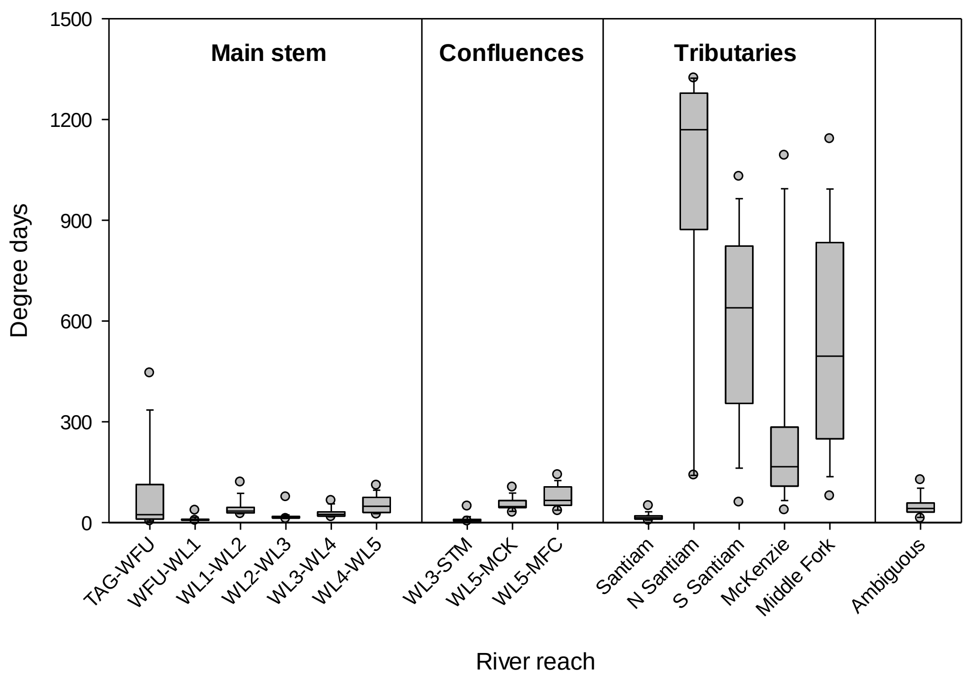

Figure 54. Box plots (median, quartile, 5th, 10th, 90th, 95th percentiles) of total accumulated degree days by river reach for hatchery Chinook salmon with temperature loggers in 2011-2013.

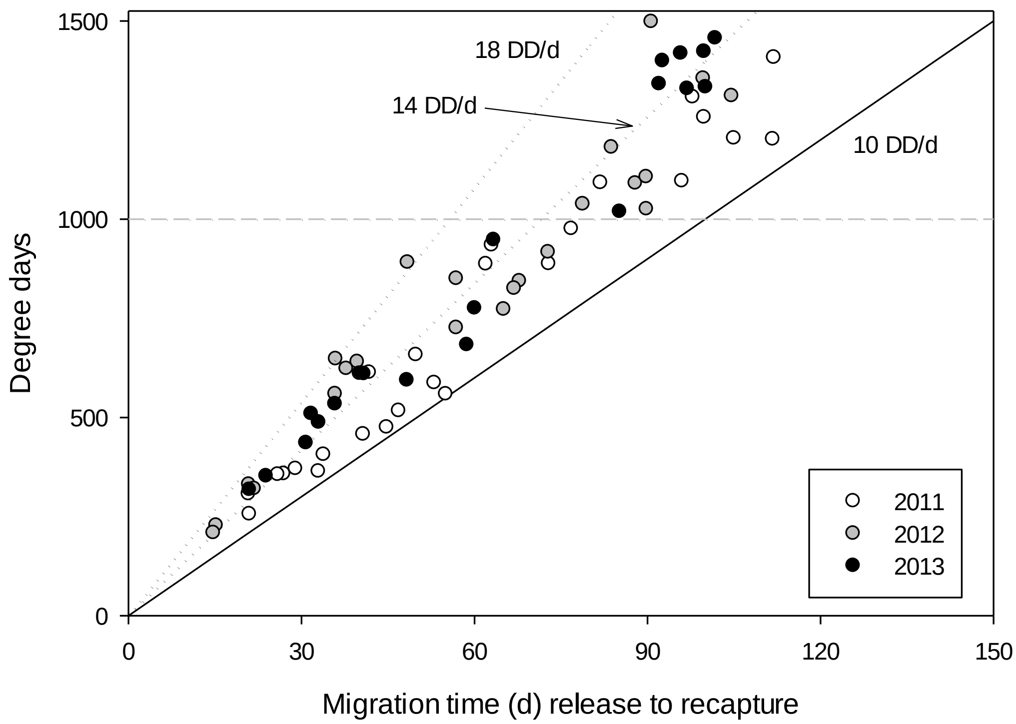

Figure 55. Relationship between hatchery Chinook salmon migration times (d) from release to recapture and total accumulated degree days in 2011-2013.

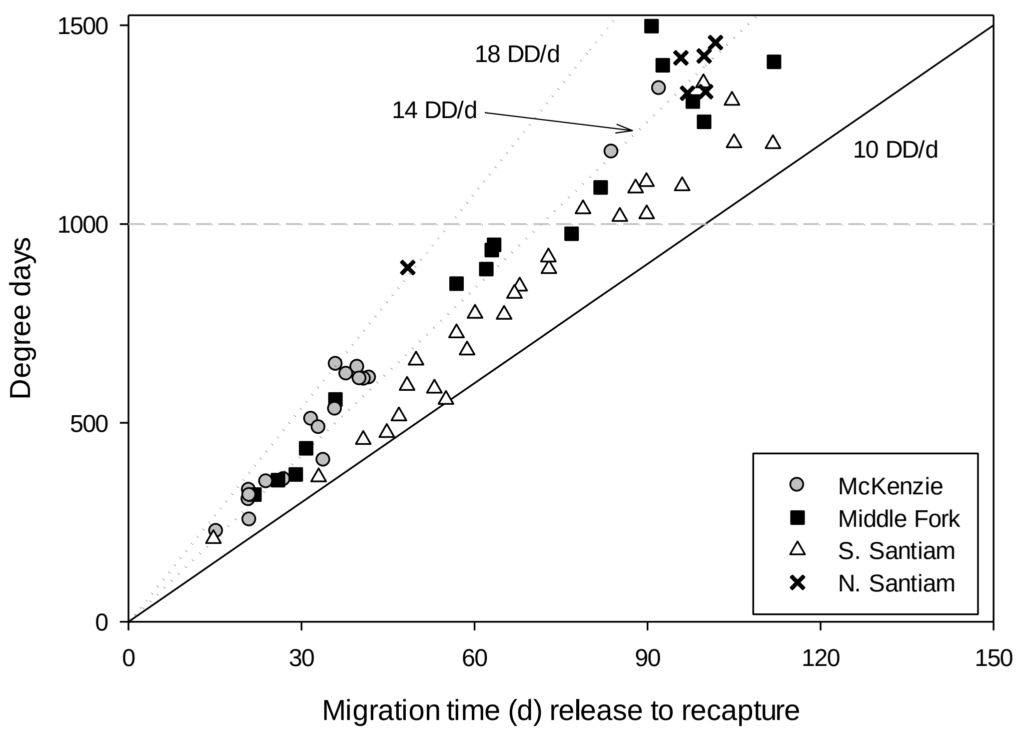

Figure 56. Relationship between hatchery Chinook salmon migration times (d) from release to recapture and total accumulated degree days in 2011-2013, by tributary population.

Thermoregulatory behavior in the main stem – To assess whether Chinook salmon used cool water sites during their migration through the main stem, we compared logger temperatures to daily minimum water temperatures at the nearest USGS gage site. Four USGS sites had daily mean, minimum and maximum water temperature data throughout the Chinook salmon migration in all three years: Portland (#14211720, rkm 184), Keizer (#14192015, rkm 244), Albany (#14174000, rkm 355), and Harrisburg (#14166000, rkm 422).

The first reach, from release to antenna WFU (Tag-WFU), had the highest percentage of logger temperatures (22%) that were lower than the minimum USGS daily temperatures (Figure 57). The coldest records relative to the main stem river in this reach were associated with five salmon temporarily detected in the Clackamas River. Logger histories for these fish showed clear spikes of cold water exposure associated with detections on the tributary telemetry antenna; these behaviors occurred when the main stem temperatures were ~15 to ~21 °C. Additional fish had telemetry records that suggested they likely entered the cool water plume from the Clackamas River. We think it is also likely that many logger records that were cooler than the Portland USGS minimum data simply reflected that the Willamette River was cooler (on average) near Willamette Falls Dam than near Portland (see Figure 5).

About 15% of the temperature logger records in the WL2-WL3 reach and 19% in the WL3-WL4 reach were lower than the closest USGS daily minimums (Figure 57). Examination of the individual logger histories for these fish did not show sharply lower temperature spikes. Rather, the coolest records tended to be at night or early in the morning and generally were < 1 °C cooler than the USGS minimum temperatures. It is likely that salmon encountered a wider range of temperature variation in the WL2-WL3 (29.9 rkm long) and WL3-WL4 (39.6 rkm) reaches than the temperature ranges recorded at the USGS Albany gage. There were almost no logger records (≤ 1%) that were lower than USGS minimums in the WFU-WL1, WL1-WL2 and WL4-WL5 reaches, suggesting limited use of cool or cold water refuges.

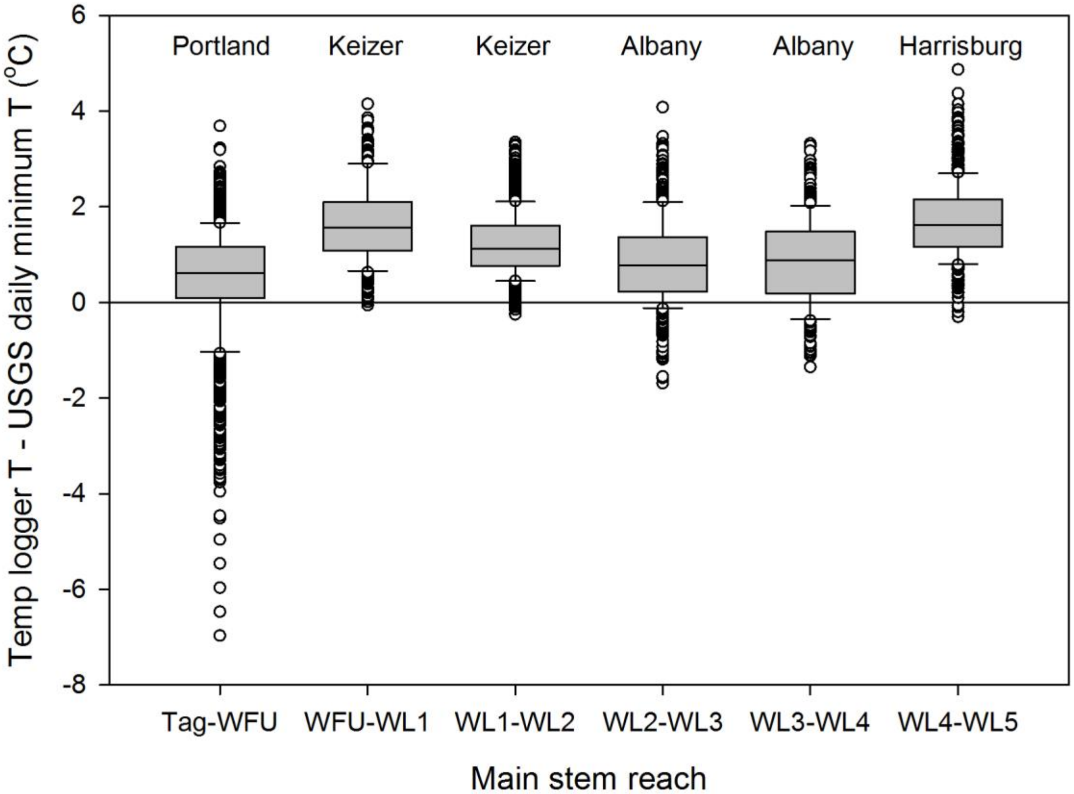

Figure 57. Box plots showing the difference between recorded internal temperature of hatchery Chinook salmon and minimum daily water temperatures recorded at the closest USGS monitoring station in main stem Willamette River reaches (closest sites above boxes). Negative values represent potential thermoregulatory behaviors. USGS Gage locations were at river kilometer (rkm): 184 (Portland), 244 (Keizer), 355 (Albany), and 422 (Harrisburg). Telemetry antennas bracketing reaches were at rkm: 206 (Tag site), 213 (WFU), 237 (WL1), 305 (WL2), 335 (WL3), 374 (WL4), and 418 (WL5). Box plots show median and quartile values (boxes), 10^{th} and 90^{th} percentiles (whiskers) and all outliers (○).

Discussion

Winter Steelhead

The 2012 and 2013 winter steelhead results provide important baseline information on this ESA-listed population. There are no previous system-wide migration studies of adult winter steelhead in the Willamette River basin (see review by Keefer and Caudill 2010). Therefore, these are some of the first data collected on relative distribution among tributaries, survival through the main stem migration corridor, migration timing differences among sub-populations, kelting rates, potential interactions with summer-run steelhead, and basic migration behaviors.

After adjusting for known transmitter loss, 81% (2012) and 84% (2013) of the radio-tagged winter steelhead escaped to Willamette River tributaries based on maximum upstream detection sites. The remaining fish were last detected downstream from Willamette Falls Dam (5-12%), at the dam (1-3%), or in lower (3-7%) or upper (0-1%) main stem reaches. If we assumed that all tagged steelhead not detected in a tributary died before spawning, then the maximum *en route* main stem mortality estimate for this study would be ~19% in 2012 and ~16% in 2013. It is more likely, however, that the 16-19% of tagged steelhead not detected in tributaries could be classified into several categories if more information were available. These include natural mortality (e.g., disease, predation, etc.), unreported harvest, main stem spawning, undetected entry into monitored tributaries, or entry into small unmonitored sites.

We did not attempt to estimate winter steelhead spawning success or prespawn mortality as this was beyond the study scope. Both spawning success and mortality are difficult to monitor in iteroparous species, particularly those that spawn during cold, high flow conditions. Our minimum estimate of successful spawners was 87 fish in 2012 (48% of the182 fish without known transmitter loss) and 81 fish in 2013 (48% of the 170 fish sample) that were recorded in tributaries during traditional spawning times and exhibited downstream movements consistent with post-spawn kelting. This was almost certainly an underestimate of success, however, as many steelhead die after spawning (i.e., do not kelt), even among winter-run populations (Chilcote 2001; English et al. 2006). We note that many of the steelhead that entered tributaries but did not kelt (n = 60 in 2012 and 61 in 2013) were mobile tracked near spawning areas. Considerable additional effort would be necessary to confirm spawning success or identify prespawn mortalities for this species.

In the logistic regression models of winter steelhead escapement to tributaries, we found no statistically significant predictors of migration success. Unlike spring Chinook salmon and summer steelhead in the Willamette River system, we found no evidence that winter steelhead were exposed to stressful water temperatures often associated with *en route* and prespawn mortality.

Twenty-two of the 35 (63%) ‘unsuccessful’ winter steelhead tagged in 2012 were last detected downstream from Willamette Falls Dam compared to eight of the 28 (29%) ‘unsuccessful’ fish in 2013. These percentages may indicate reduced handling effects in 2013, a higher rate of unreported harvest downstream from the dam in 2013, or differences in overshoot behaviors by steelhead whose natal sites were downstream from Willamette Falls Dam. The exclusive use of anesthesia to tag winter steelhead in 2013 (but not in 2012) may partially explain the difference between years. However, in the 2012 handling experiment we found that similar percentages of anesthetized and restrained winter steelhead exited the fishway after release (16% versus 18%, respectively). This suggested that handling treatment was not an important factor in 2012, but it did not rule out an overall handling effect. The harvest of winter-run adipose-intact steelhead was prohibited in most portions of the Willamette River basin in both study years (ODFW 2012 and 2013), which reduced the likelihood that winter steelhead last detected downstream from the dam were captured and killed. Based on queries of the PTAGIS database in December 2012 (for 2012 fish) and March 2014 (for

2013 fish), no radio-tagged (and PIT-tagged) winter steelhead were detected on any PIT antenna sites in the Columbia River basin other than those in the Willamette River basin, suggesting downstream movements were not associated with subsequent migration up the Columbia River past Bonneville Dam.

Winter steelhead migration rates have been estimated using fish counts at Willamette Falls Dam and at upstream dams and traps but no migration rate data based on individual fish have been reported prior to this study (Keefer and Caudill 2010). We found that winter steelhead migrated at rates up to ~50 rkm/d in some main stem sections, with a mean velocity of ~30 rkm/d. They also moved more slowly through successive sections of the main stem Willamette River in both study years, perhaps because the upstream reaches are higher gradient than downstream reaches. It is also possible that some other biological factors (e.g., searching behavior, prespawn holding or staging) or environmental effects (e.g., lower water temperature in upstream reaches) explain this behavior. Slower migration rates in upstream reaches was also observed in radio-tagged summer steelhead and spring Chinook salmon in this study, suggesting a common cause.

The run timing of the aggregate native winter steelhead population was thought to be later than that of the introduced Big Creek stock and they were once differentiated by ODFW using a fixed date in mid-February at Willamette Falls Dam. The arbitrary cutoff date used historically may not reflect the actual timing of these two groups because: 1) Johnson et al. (2013) found no empirical evidence of introgression of Big Creek stock into sampled native winter steelhead; 2) releases of the Big Creek stock hatchery steelhead into the upper Willamette River ceased after 1997; and 3) year-to-year variability in run timing driven by environmental cues likely make a fixed cutoff date unrealistic. The timing of the 2012 winter steelhead run was relatively early and 2013 run was relatively late, but we are not aware of any reported analyses of the factors that affect inter-annual variability in migration timing at Willamette Falls Dam. We hypothesize that timing is related to ocean distribution (e.g., Bracis and Anderson 2013), environmental conditions in the ocean, Columbia River estuary and lower Willamette River (e.g., Keefer et al. 2008a; Thomson and Hourston 2011), and genetically-mediated differences among Willamette spawning populations (e.g., Quinn et al. 2011; Beacham et al. 2012).

There is also little published information regarding winter steelhead run composition at Willamette Falls Dam. Generally, we found that early-run fish were a well-mixed combination from lower basin populations (i.e., Clackamas, Tualatin, Molalla, and Yamhill rivers). Mid-basin populations (i.e., Santiam and Calapooia rivers) were intermediately-timed and upper basin populations (i.e., McKenzie, Coast Fork and Middle Fork Willamette rivers, and Fall Creek) tended to be relatively late-timed in both years. This pattern may reflect underlying differences in native steelhead spawn timing among tributary populations as well as the legacy of non-native winter steelhead introductions into the upper sub-basins (i.e., McKenzie, Middle Fork). The modest separation among populations may provide some management opportunity, but we caution against drawing strong conclusions given sample sizes for some groups.

We observed extensive kelting behaviors in the radio-tagged samples. Nearly 60% of the winter steelhead that entered tributaries in both years moved downstream during the presumed post-spawn period. Many of the kelts were eventually detected downstream from Willamette Falls Dam. High kelting rates do not necessarily translate to high repeat spawning (iteroparity) rates, largely because many kelts do not survive to the next spawning period (e.g., Keefer et al. 2008b; Narum et al. 2008). Some kelt mortality may occur when emaciated fish with limited somatic reserves encounter warm water temperatures in the lower Willamette River. Mortality also likely occurs after kelts exit the Willamette River and enter the Columbia River estuary or ocean. Chilcote (2001) reported iteroparity rates for Willamette River winter steelhead in the 10-11% range for Clackamas, Molalla, Santiam, and Calapooia populations. Those estimates were consistent with our scale-based iteroparity estimate for the aggregate Willamette River sample of winter-run fish in this study (8% in 2012 and 13% in 2013). Both estimates imply high inter-spawn mortality rates (~87% mortality, 11 successful repeat spawners / 87 kelts in 2012; and ~78%, 18 successful repeat spawners / 81 kelts in 2013) in these populations, but this estimate requires several untested assumptions. Based on PIT tag data, none of the winter steelhead radio-tagged in 2012 were detected returning to spawn in the Willamette River basin in 2013.

Summer Steelhead

As with winter steelhead, the 2012-2013 summer steelhead study provided some of the first basin-wide information on the distribution, behavior, and fate of summer-run fish. Overall, 71% (2012) and 72% (2013) of radio-tagged summer steelhead were last detected in Willamette River tributaries. The remaining fish were last detected downstream from Willamette Falls Dam (3-8%), at the dam (~1%), or in the lower (3-9%) or upper (11-21%) main stem.

In contrast to the winter run fish, summer steelhead spawn in the spring after freshwater entry. It is therefore possible that some of the tagged steelhead last detected in the main stem overwintered there (e.g., Keefer et al. 2008b) and entered tributaries undetected the following spring, though there was no evidence of main stem overwintering observed in the sample tagged in 2012 (data are not yet available for the 2013-tagged summer steelhead). It is also likely that more summer than winter steelhead were harvested in the main stem given longer exposure to fisheries and legal harvest for fin-clipped steelhead. We were unable to implement a tag reward program in 2012 due to concerns of encouraging angling take but 3 (9%) of the 33 reported angler recapture events of summer steelhead occurred in the upper main stem (27 were recaptured in tributaries, one was recaptured in the lower main stem, and two were recaptured downstream from the dam). In comparison, 11 of 54 (20%) recaptures of adipose-clipped steelhead by anglers occurred in the upper main stem in 2013. If we assumed that all tagged steelhead not detected in a tributary were harvested or died before spawning, then the maximum *en route* main stem mortality was 29% in 2012 and 28% in 2013. However, we think that this portion of the sample had a variety of fates, including some likely successful migrants.

Summer steelhead behaviors in the main stem were generally similar to those reported for winter steelhead in both years. Summer-run fish migrated more slowly through upstream reaches than downstream reaches, had median migration rates from ~15 to ~40 rkm/d, and exhibited considerable variability among fish. We found little evidence in the telemetry data that summer steelhead used tributary confluence areas to behaviorally thermoregulate during their passage through the migration corridor.

The run timing and run composition data collected in both years indicated that there is high potential for summer steelhead to overlap spatially and temporally with winter steelhead below WVP dams. Generally, the three most abundant summer-run groups (i.e., Santiam, McKenzie, and Middle Fork) were present throughout the nominal summer-run period at Willamette Falls Dam. Final detections of many 2012 summer-run fish indicated direct spatial overlap with the maximum upstream detections of 2013 winter steelhead in the South and North Santiam River and in the Middle Fork Willamette River. We note that this may be partially explained by the release of hatchery summer steelhead near the base of Foster and Dexter dams, barriers where steelhead will congregate upon return. Although we had limited monitoring effort in the Clackamas River, tagged steelhead from both the summer- and winter-run entered the Clackamas River, and the two populations are known to inter-breed in this sub-basin (Kostow et al. 2003; Kostow and Zhou 2006). The recent genetic study by Johnson et al. (2013) also indicated winter-summer hybridization in the McKenzie and Santiam sub-basins. The observed three-fold difference between the winter steelhead count at Foster Dam and the radio-telemetry based escapement estimate in the S. Santiam suggests poor collection at Foster Dam of winter steelhead originating above and/or considerable production of winter steelhead below Foster Dam, including Wiley, Thomas and Crabtree creeks (~600 adults, Table 5). To what degree these adults represent summer-winter hybrids is unknown and will be examined using GSI assignments from radio-tagged adults when available during fall 2014.

Importantly, our assessment of summer-winter temporal overlap on spawning grounds was based on a comparison of the tributary residency dates of very few 2012 summer-run kelts and the tributary residency dates for the 2013 winter-run kelts. We note that the assignment of kelt status for spawn timing and distribution of summer steelhead is not well known in the Willamette River and its tributaries and the spawning status of radio-tagged fish was not assessed. Thus, inferences about the spawning timing of either run, particularly summer steelhead, should not be considered robust without additional data. Nevertheless, this comparison circumstantially indicated that the two runs use spawning habitat simultaneously. Moreover, it has been estimated that 10-30% of all summer steelhead passing Willamette Falls Dam spawn naturally (NMFS 2000; Johnson et al. 2013) and the radiotelemetry data suggest that fish from these populations interact with winter-run fish. Minimizing winter-summer interactions may be an important long-term conservation strategy for wild populations (Chilcote 2001). However, this management objective would need to be reconciled with the competing demands for harvestable summer-run fish (i.e., approximately 0.6 million hatchery steelhead smolts are produced annually in the Upper Willamette basin; Tinus and Friesen 2010).

In the summer steelhead recycling studies, 4-5% of the Foster-tagged fish and 4-17% of the Dexter-tagged fish were reported as harvested annually. The lack of a reward program in 2012 may have resulted in some under-reporting. However, these low recovery rates do suggest that the recycling programs increase the likelihood that summer steelhead interact with winter steelhead. One of the reasonable and prudent alternatives suggested in the 2008 Biological Opinion was to restrict or stop recycling adult summer steelhead by 1 September each year in the North and South Santiam rivers. This alternative is supported by our 2012 results and by a similar evaluation of recycled summer steelhead in the Clackamas River (Schemmel et al. 2011).

Chinook salmon

2013 was the third study year that spring Chinook salmon were radio-tagged at Willamette Falls Dam, but there were some important among-year differences in tagging protocols. First, the 2012 sample included a disproportionate number of adipose-intact salmon because of our effort to radio-tag McKenzie River wild fish in collaboration with EWEB. Second, about half of the unclipped fish were anesthetized in 2012 as part of the experimental test of anesthetic versus restraint (FRD) during tagging. Anesthetized salmon were less likely to exit the Willamette Falls Dam fishway to the tailrace and were substantially more likely to escape to upriver tributaries than were fish tagged using the FRD (Caudill et al. *in press*). The negative effect of the FRD should be kept in mind when interpreting study results from both 2011 and 2012.

After adjusting for known transmitter loss, 77% of 297 radio-tagged salmon escaped to Willamette River tributaries in 2013 compared to 74% in 2011 and 61% in 2012 (fin-clipped and unclipped samples combined and restrained and anesthetized sample combined). The remaining 2013 fish were last detected downstream from the dam (10%), at the dam (2%), or in the lower (8%) or upper (3%) main stem. Assuming that all tagged salmon last detected outside a tributary died before spawning, the maximum prespawn mortality estimates were 23% in 2013, 26% in 2011, and 39% in 2012. Estimates in all years were within the range in Schreck et al. (1994), who reported non-harvest mortality of 20-40% for spring Chinook salmon radio-tagged at Willamette Falls Dam in 1989-1992. We note that our tributary escapement estimates for unclipped, anesthetized salmon were 88% in 2011, 83% in 2012, and 76% in 2013, and these may be considered potential ‘best-case’ scenarios. Conversely, the ‘worst-case’ was 56% in 2012 for fin-clipped, restrained salmon.

The ten percent of tagged salmon last detected downstream from Willamette Falls Dam in 2013 was the lowest among study years (2011 =14% and 2012 = 27%). While some downstream fish movement following tagging is common (Bernard et al. 1999; Mäkinen et al. 2000), the rates we observed in 2012 were at the high end of the reported range and the apparent short-term effect of the FRD treatment (exit from the ladder to the tailrace) was also associated with last detection below the Falls. Potential mechanisms include long-term effects on behavior, additional exposure to unreported harvest in the fishery downstream from the dam and predation by the California sea lions (*Zalophus californianus*). Final detection below the dam could also have been associated with overshoot behaviors by fish whose natal sites were downstream from Willamette Falls Dam (e.g., Schreck et al. 1994; Keefer et al. 2008c). Seven of the 10 salmon that were recorded falling back at the dam in 2013 did not reascend, indicating that potential injury or mortality may have resulted from this behavior (e.g., Keefer et al. 2005). Regardless, the fate of the seven salmon last recorded downstream from the dam in 2013 was largely unknown: two entered the Clackamas River, none were reported as harvested, and none were detected at Columbia River PIT tag interrogation sites.

Migration rates and main stem behaviors

Chinook salmon migrated through the main stem faster as water temperature and date increased in all years. This was consistent with the steelhead results and the spring Chinook behaviors reported in Schreck et al. (1994). They found that late-run Willamette River Chinook salmon tended to migrate faster early run fish. Salinger and Anderson (2006) and Keefer et al. (2004a, 2004b) also found that spring–summer Chinook salmon migrated more rapidly as water temperature and date of migration increased in the Columbia and Snake rivers. Main stem migration rates for Willamette River spring Chinook salmon in 2013 (median = 27.3 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. 2004a) but considerably lower than the average of 52 rkm/day reported for Chinook salmon in the Yukon River by Eiler et al. (2006). Dams, reservoirs, and differences in river gradient, discharge, velocity and water temperature all likely contributed to the variability in migration rates among study sites.

The 5-10% of tagged salmon with downstream movements in the main stem in 2011-2013 was consistent with 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. We noted one adipose-clipped salmon that migrated to the Dexter Dam tailrace in 2012 before swimming downstream and falling back at Willamette Falls Dam, a one-way distance of ~281 rkm. Schreck et al. (1994) hypothesized that the downstream movements they observed were associated with the river warming in summer (estimated to be > 20°C). We observed little temporary straying into non-natal tributaries by tagged salmon in 2013. This suggests that salmon were not seeking thermal refuge sites, despite main stem temperatures > 20 °C on many dates. (See additional comments below in the ‘Temperature exposure histories’ section.)

Adult salmon spent two to more than six weeks in the main stem before reaching tributaries and time spent in the mainstem was longer for upstream populations. Longer transit times may be an important factor affecting migration success and prespawn mortality in Willamette River Chinook salmon, particularly in warm years. In all years, main stem water temperatures reported from USGS sites were higher than in the tributaries for most of the season. Additionally, several main stem reaches have been negatively 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. Each of these factors potentially affects prespawn mortality rates and may be exacerbated by high water temperatures.

No phenotypic covariates (i.e., tag date, fork length, weight, and fat meter reading) were significantly associated with spring Chinook salmon escapement to tributaries in our 2013 logistic regression models. This finding was somewhat surprising because of the higher water temperatures in the main stem in 2013 versus 2011-2012 (e.g., Naughton et al. 2005). 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. Warm conditions in 2013 may have resulted in higher than average *en route* and prespawn mortality but may have been ameliorated by the exclusive use of anesthesia as a handling treatment and/or by more rapid passage through the main stem reaches. Generally, we expect that mortality will be higher in warmer years, as has been observed in the Middle Fork adult outplanting studies (Keefer et al. 2010; Mann et al. 2011; Naughton et al. 2013).

We observed no relationship between estimated initial lipid content and fate of adult salmon, suggesting energetic reserves at river entry were sufficient to fuel upstream migration to tributaries in 2011-2013. 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). Several adults experienced temperatures above this threshold and exposure times for those that did were extended (1-3 weeks) in some cases. Alternately, estimation error associated with the fatmeter may have prevented detection of an effect. We note that values reported here are based on the manufacturer's algorithm and that concurrent evaluations in tributary populations suggest the analytical precision of the fatmeter can be useful for estimating relative, but not absolute, lipid levels for individual adults (Naughton et al. 2013). Regardless, the effects of energy limitation are expected to be highest in warm years (Hinch and Rand 2000; Mann et al. 2011) and we hypothesize that if there was an undetected effect of lipid reserves on migration success in 2013, the effect was small.

Tributary and tailrace behaviors

Chinook salmon that returned to the Middle Fork Willamette River spent one day to six weeks holding in the tailrace prior to collection. Data recovered from temperature loggers indicated that the fish held in water that was ~14-16°C in the Dexter tailrace in 2013, consistent with the temperatures recorded by the USGS sites at Jasper and Dexter. These temperatures were substantially lower than those encountered by some tagged Chinook salmon in 2011, when there was an extended period where warmer water was released from Dexter Dam (Jepson et al. 2012). We have hypothesized that the combination of long holding periods, high salmon density, and high angler pressure below Dexter Dam is stressful for salmon and contributes to the relatively high prespawn mortality in salmon outplanted from this location. Alternative operations at the Dexter Dam Trap that collected adults shortly after arrival could potentially reduce stress in this population. However, transport from the Dexter trap and conditions at outplant sites are also potentially stressful, and there are tradeoffs between the various trap-and-outplant scenarios being considered.

Run timing and composition

The early timing of the 2013 spring Chinook salmon run was consistent with relatively warm river temperatures and low discharge. The earliest-timed runs in the last decade were in 2004 and 2005 and they were associated with warm April-June water temperatures. Conversely, late-timed runs in 2008 and 2011 were associated with cool March water temperatures and/or high spring discharge. This pattern has been well documented for Columbia River spring Chinook salmon (Keefer et al. 2008a; Anderson and Beer 2009), and appears to be a result of large-scale winter and spring weather patterns, ocean environment, and estuary and river conditions.

There is limited information on spring Chinook salmon run composition at Willamette Falls Dam so the data collected in 2011-2013 represent steps forward in understanding relative population abundance through the migration season, for hatchery and naturally produced populations. Generally, we found that hatchery fish were a well-mixed combination from the Santiam, McKenzie, and Middle Fork Willamette rivers. The few salmon that returned to the Molalla River were relatively early-timed in 2012 but late-timed in 2013. Those that returned to the Clackamas River were late-timed in all years. Run composition of the 2013 adipose-intact sample was characterized by the two largest return groups (Santiam and McKenzie rivers) making up 33-100% of all the returns within each 10-day tagging interval, which was consistent with the 2011 and 2012 data. These patterns may reflect differences in Chinook salmon spawn timing among tributary populations or selection for earlier timing in populations requiring greater time in the main stem 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 may affect the timing of migration through the migration corridor. Such relationships have not been well described for the Willamette River populations.

Temperature exposure histories

Reconstructed temperature exposure histories for other salmon in the logger-tagged sample in 2011-2013 indicated that the highest temperatures most fish experienced were in lower main stem reaches. Some also encountered warm temperatures in confluence and tributary reaches. The maximum temperatures were > 18 °C for almost all fish in 2012 and 2013, the years when we selected later migrants for temperature loggers. Thermal histories for 2012 and 2013 should be representative of salmon in approximately the second half of the migrations in those years, which we consider those at the highest risk of exposure to high main stem water temperatures. The 2011 logger-tagged sample was sampled from throughout the run, and it is important to recognize that some early migrants potentially have longer main stem migration times and longer pre-collection holding periods in the tributaries relative to later migrants. We note, however, that the distributions of release-recapture times did not systematically differ among the three years. In fact, the 2011 South Santiam and McKenzie fish had shorter release-recapture times, on median, than the comparison groups in 2012-2013.

Despite exposure to main stem temperatures > 18 °C by many salmon, we found little evidence of thermoregulatory behavior during migration. Even those exposed to +20 °C water, a threshold associated with refuge seeking by adult ocean-type Chinook salmon (Goniea et al. 2006), did not appear to exploit sites with temperatures lower than the main river corridor. The only reach where there was clear evidence that salmon used cooler sites was below Willamette Falls Dam, where several fish temporarily entered the much cooler Clackamas River. In other main stem reaches, logger temperatures rarely fell below the minimum daily temperatures recorded at USGS gages, suggesting that fish did not spend extended time in cold water refuges. We note that this analysis does not rule out salmon selection of cooler water among the thermal habitats that were available along the migration corridor. For example, the mean daily exposure for salmon may have been lower than the mean river temperature if salmon make fine-scale thermal habitat selections (e.g., Donaldson et al. 2009). An evaluation of this type of thermoregulation would require that both river temperature and salmon location data be collected at smaller spatial scales.

In all three years, most logger-tagged salmon accumulated a majority of their degree days while holding in tributaries. This was true for all four populations, though the McKenzie group accumulated far fewer total degree days than the North and South Santiam and Middle Fork groups. This was because McKenzie fish were trapped soon after they entered the river relative to those trapped at the Dexter, Foster and Minto facilities. Total degree day accumulations varied among salmon by a factor of four or more in each year. Differences were primarily a function of the time between release at Willamette Falls Dam and recapture at a collection facility.

About a third of the logger-tagged salmon accumulated more than 1,000 degree days, and some salmon from all populations and all years were included in this group. The degree day accumulations were an important study result, because the exposure data can serve as a proxy for a variety of physiological metrics (e.g., energetic costs, disease expression, etc.). Willamette River Chinook salmon use energy reserves during migration and holding, and we have shown that more than half of the lipids that fish have available at Willamette Falls Dam has been used by the time fish are recaptured in tributaries (e.g., Naughton et al. 2013). The relationship between reserves and spawning success in Willamette River spring Chinook has been equivocal, with some evidence that fish with low lipid levels were more likely to be prespawn mortalities in some years, but not others. There is considerably more empirical support for the relationship between temperature exposure (including degree day accumulations) and the lethal and sub-lethal effects of a variety of pathogens, bacterial and fungal infections, and disease expression for adult salmonid species (e.g., Kocan et al. 2004; Bradford et al. 2010; also see *review* by Kent 2011). In some populations, degree day accumulations as low as 500 have been predictive of disease expression and prespawn mortality (e.g., Mathes et al. 2010).

In the sample of recovered loggers, degree day accumulation rates (DD/d) were higher – on average – for Middle Fork, North Santiam, and McKenzie River salmon than for those recovered at Foster Dam on the South Santiam River. This was largely an artifact of water temperature differences in the holding reaches downstream from collection facilities, but also reflective of overall holding times. The coldest holding area was downstream from Foster Dam, for example, and the shortest holding times were in the McKenzie River (i.e., McKenzie salmon spent proportionately more time in the main stem Willamette River, where water temperatures were higher).

We think it is likely that short-term exposure to stressful water temperatures – as occurred for many fish in the main stem – has different effects on adult Chinook salmon than the accumulation of degree days at cool to moderate temperatures. It is also likely that spatial and temporal components of exposure to high temperatures may be an important predictor of negative effects. For example, exposure early in migration may have a different impact than exposure closer to the spawning period. Unfortunately, to understand how these types of temperature histories relate to Chinook salmon survival to spawning and reproductive success requires information on the ultimate fate and productivity of the fish. This was not possible with the temperature logger-tagged group, which were not monitored after they entered hatchery facilities or after outplanting.

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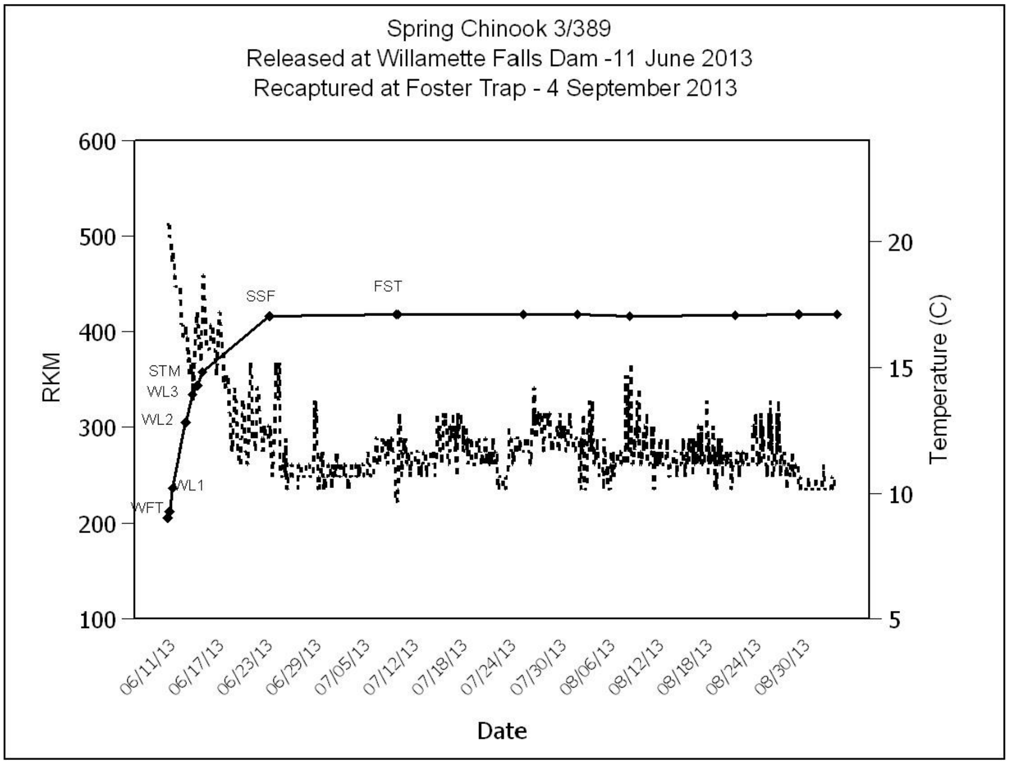
Appendix

Table of Contents for Appendix A. List of unique Chinook salmon recaptured with radio- and *archival temperature tags with downloadable data.


Spring Chinook 3/389
Released at Willamette Falls Dam -11 June 2013
Recaptured at Foster Trap - 4 September 2013
RKM
Temperature (C)
Date
SSF
FST
STM
WL3
WL2
WL1
WFT
600
500
400
300
200
100
20
15
10
5
06/11/13
06/17/13
06/23/13
06/29/13
07/05/13
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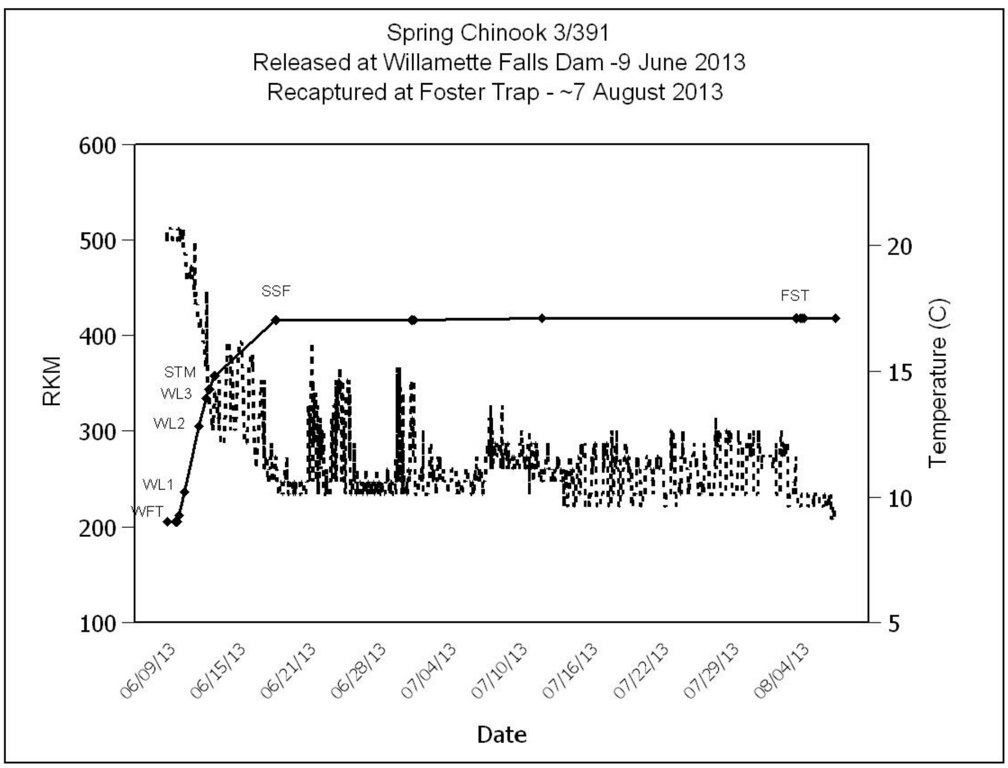
08/24/13
08/30/13


Spring Chinook 3/391
Released at Willamette Falls Dam -9 June 2013
Recaptured at Foster Trap - ~7 August 2013
RKM
Temperature (C)
Date
SSF
FST
STM
WL3
WL2
WL1
WFT
600
500
400
300
200
100
20
15
10
5
06/09/13
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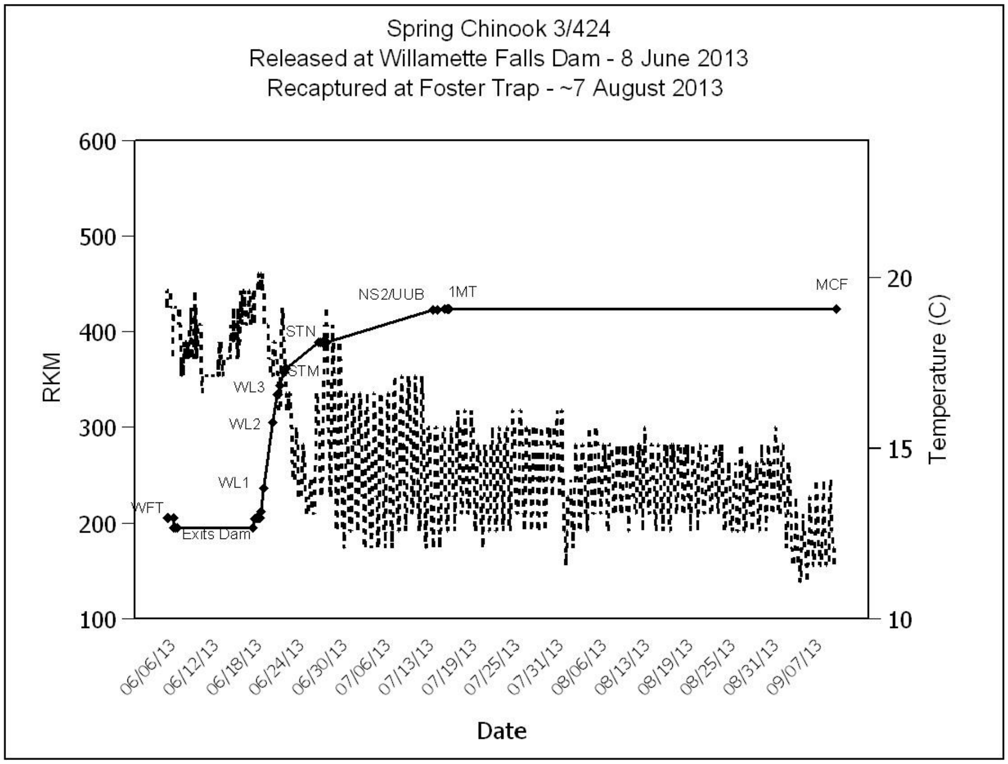
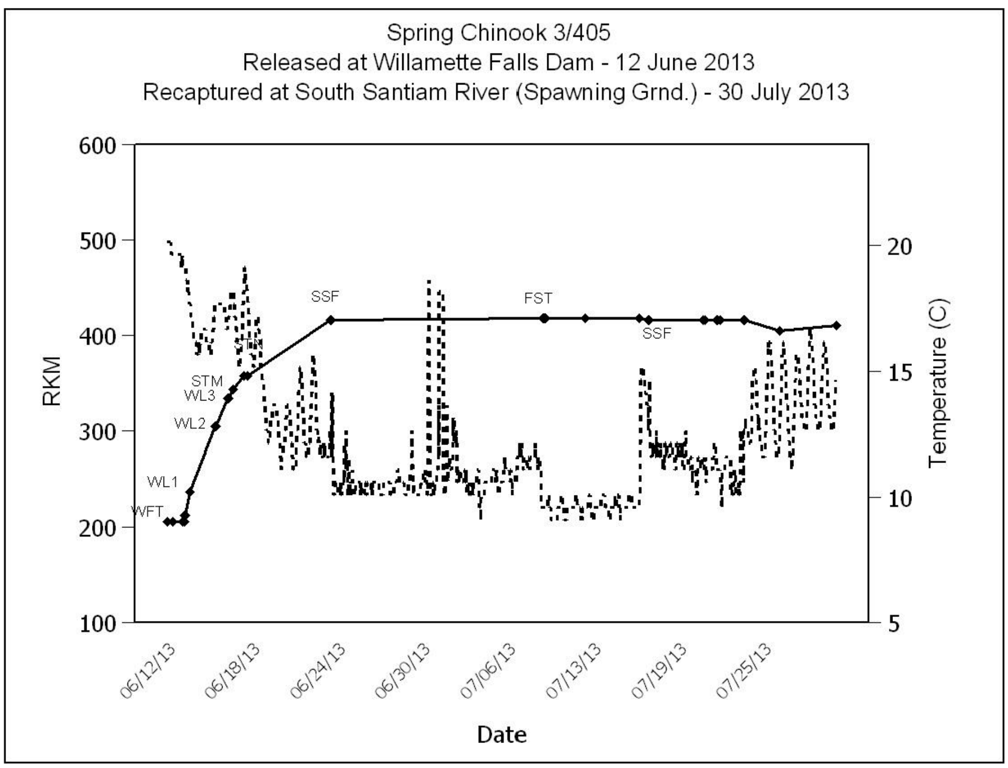
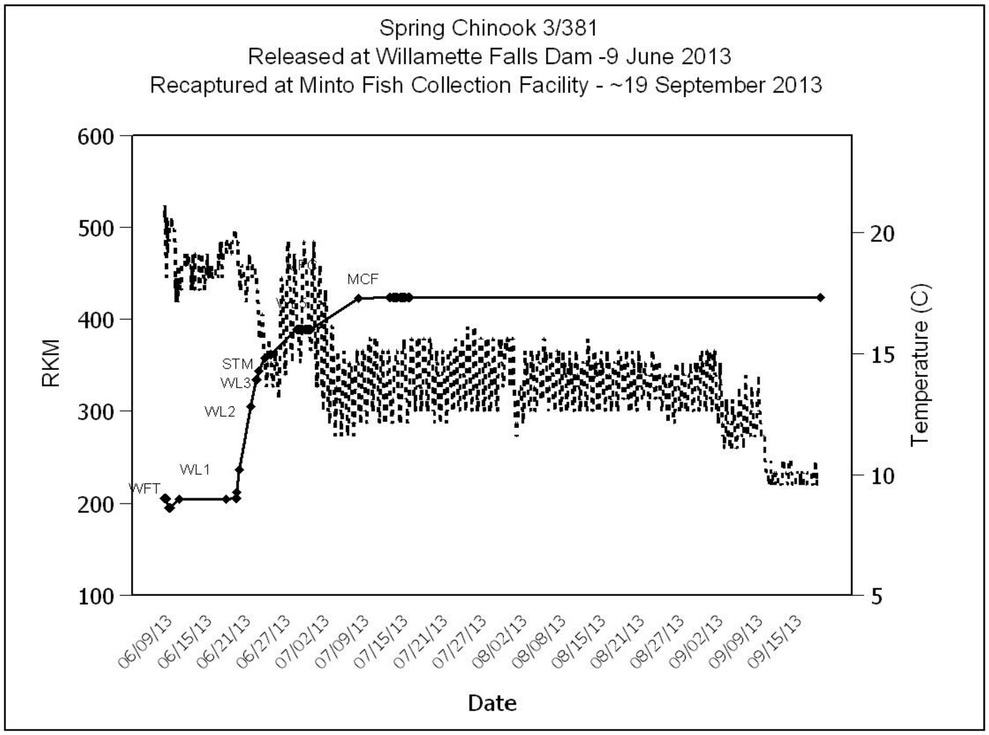
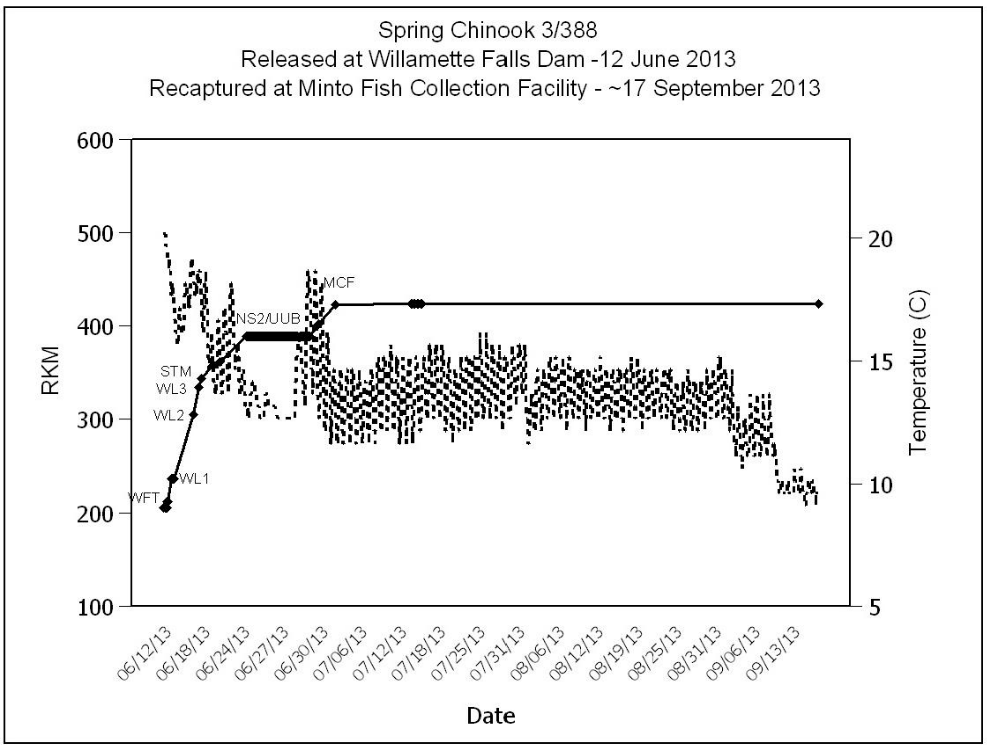
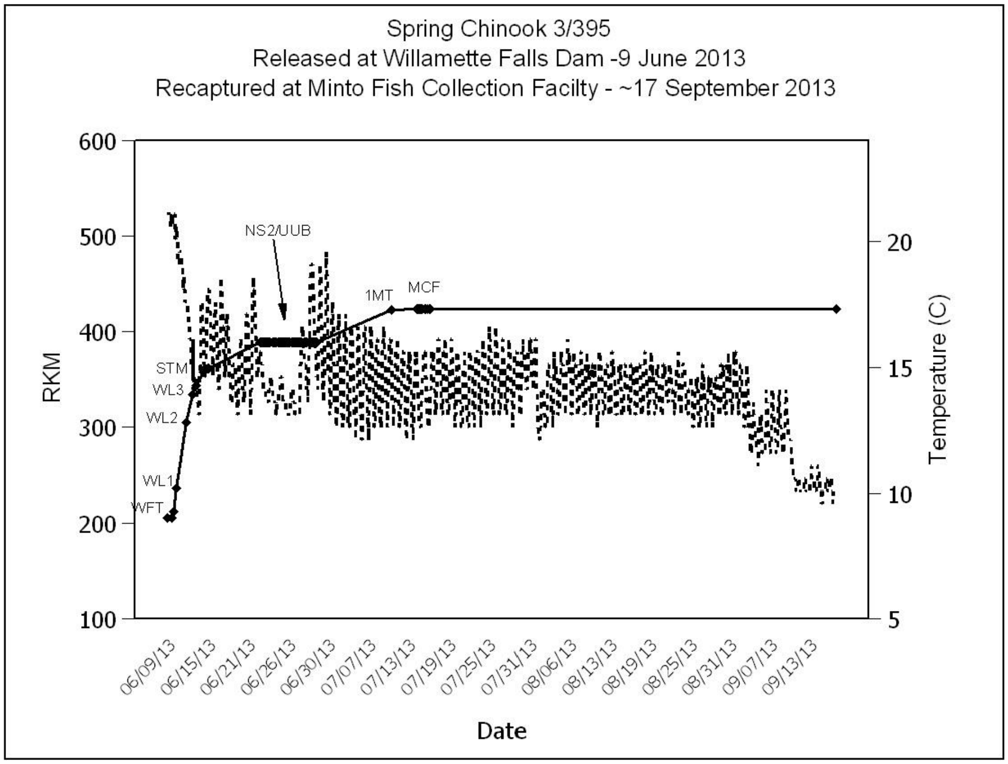
07/29/13
08/04/13

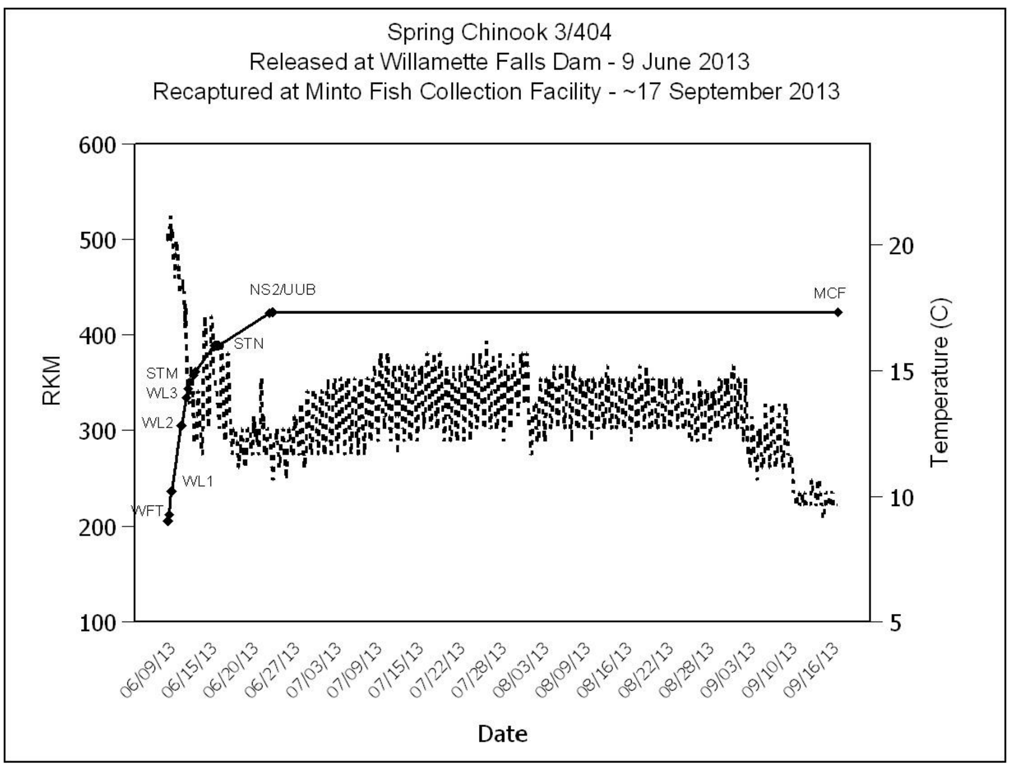

Spring Chinook 3/424
Released at Willamette Falls Dam - 8 June 2013
Recaptured at Foster Trap - ~7 August 2013
RKM
Temperature (C)
Date
600
500
400
300
200
100
20
15
10
WFT
Exits Dam
WL1
WL2
WL3
STM
STN
NS2/UUB
1MT
MCF
06/06/13
06/12/13
06/18/13
06/24/13
06/30/13
07/06/13
07/13/13
07/19/13
07/25/13
07/31/13
08/06/13
08/13/13
08/19/13
08/25/13
08/31/13
09/07/13

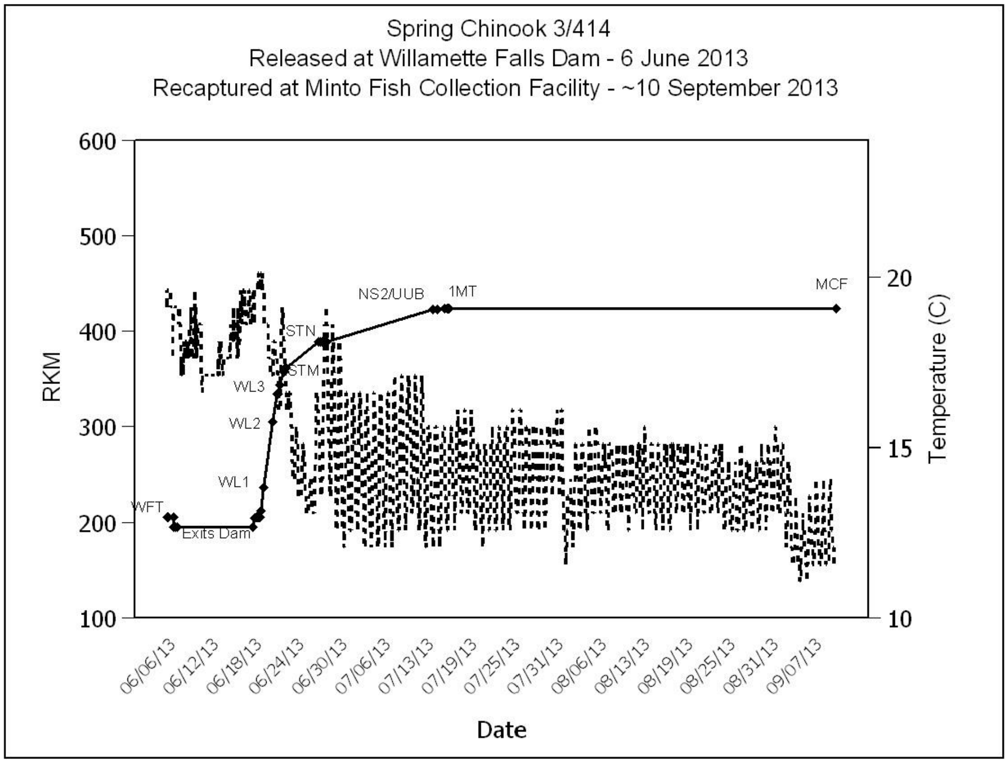

Spring Chinook 3/405
Released at Willamette Falls Dam - 12 June 2013
Recaptured at South Santiam River (Spawning Grnd.) - 30 July 2013
RKM
Temperature (C)
Date
600
500
400
300
200
100
20
15
10
5
WFT
WL1
WL2
WL3
STM
SSF
FST
SSF
06/12/13
06/18/13
06/24/13
06/30/13
07/06/13
07/13/13
07/19/13
07/25/13

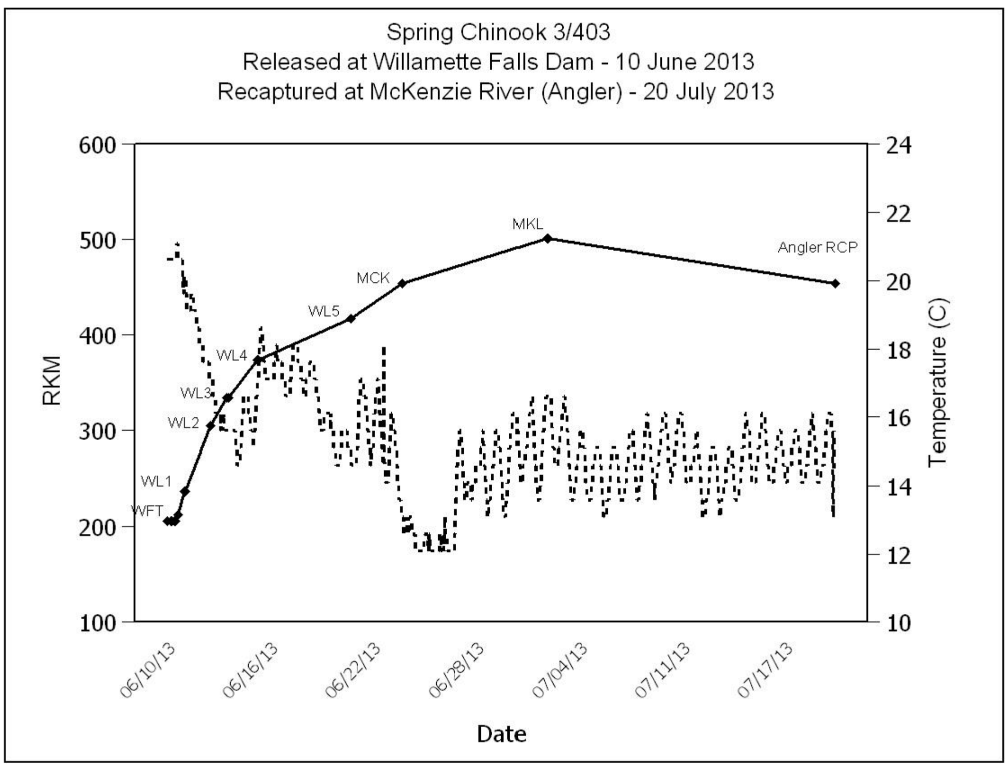

Spring Chinook 3/381
Released at Willamette Falls Dam -9 June 2013
Recaptured at Minto Fish Collection Facility - ~19 September 2013
RKM
Temperature (C)
Date
MCF
STM
WL3
WL2
WL1
WFT

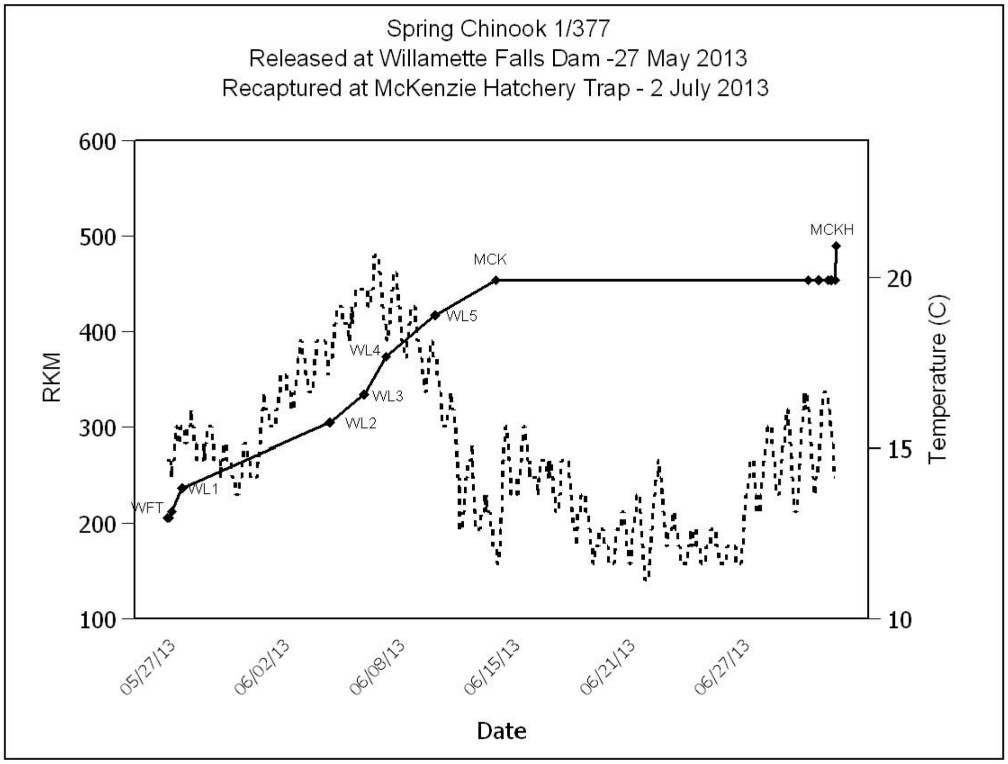

Spring Chinook 3/388
Released at Willamette Falls Dam -12 June 2013
Recaptured at Minto Fish Collection Facility - ~17 September 2013
RKM
Temperature (C)
Date
MCF
NS2/UUB
STM
WL3
WL2
WL1
WFT


Spring Chinook 3/395
Released at Willamette Falls Dam -9 June 2013
Recaptured at Minto Fish Collection Facilty - ~17 September 2013
RKM
Temperature (C)
Date
NS2/UUB
1MT
MCF
STM
WL3
WL2
WL1
WFT
600
500
400
300
200
100
20
15
10
5
06/09/13
06/15/13
06/21/13
06/26/13
06/30/13
07/07/13
07/13/13
07/19/13
07/25/13
07/31/13
08/06/13
08/13/13
08/19/13
08/25/13
08/31/13
09/07/13
09/13/13

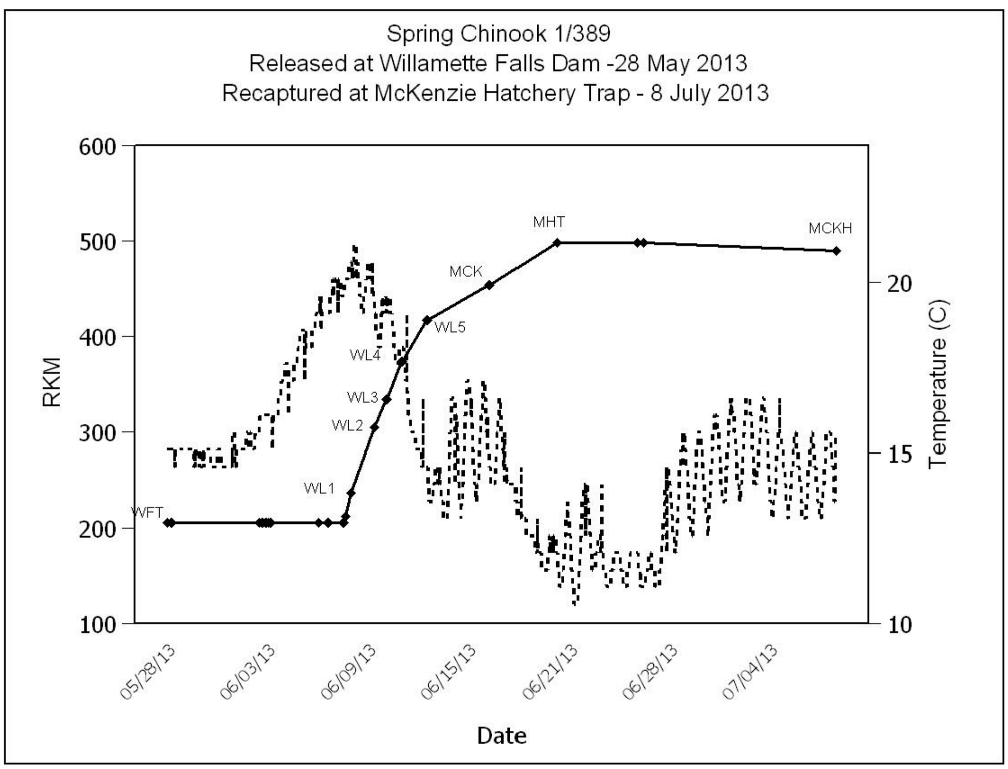

Spring Chinook 3/404
Released at Willamette Falls Dam - 9 June 2013
Recaptured at Minto Fish Collection Facility - ~17 September 2013
RKM
Temperature (C)
Date
NS2/UUB
MCF
STN
STM
WL3
WL2
WL1
WFT
600
500
400
300
200
100
20
15
10
5
06/09/13
06/15/13
06/20/13
06/27/13
07/03/13
07/09/13
07/15/13
07/22/13
07/28/13
08/03/13
08/09/13
08/16/13
08/22/13
08/28/13
09/03/13
09/10/13
09/16/13


Spring Chinook 3/414
Released at Willamette Falls Dam - 6 June 2013
Recaptured at Minto Fish Collection Facility - ~10 September 2013
RKM
Temperature (C)
Date
WFT
Exits Dam
WL1
WL2
WL3
STM
STN
NS2/UUB
1MT
MCF
600
500
400
300
200
100
20
15
10
06/06/13
06/12/13
06/18/13
06/24/13
06/30/13
07/06/13
07/13/13
07/19/13
07/25/13
07/31/13
08/06/13
08/13/13
08/19/13
08/25/13
08/31/13
09/07/13

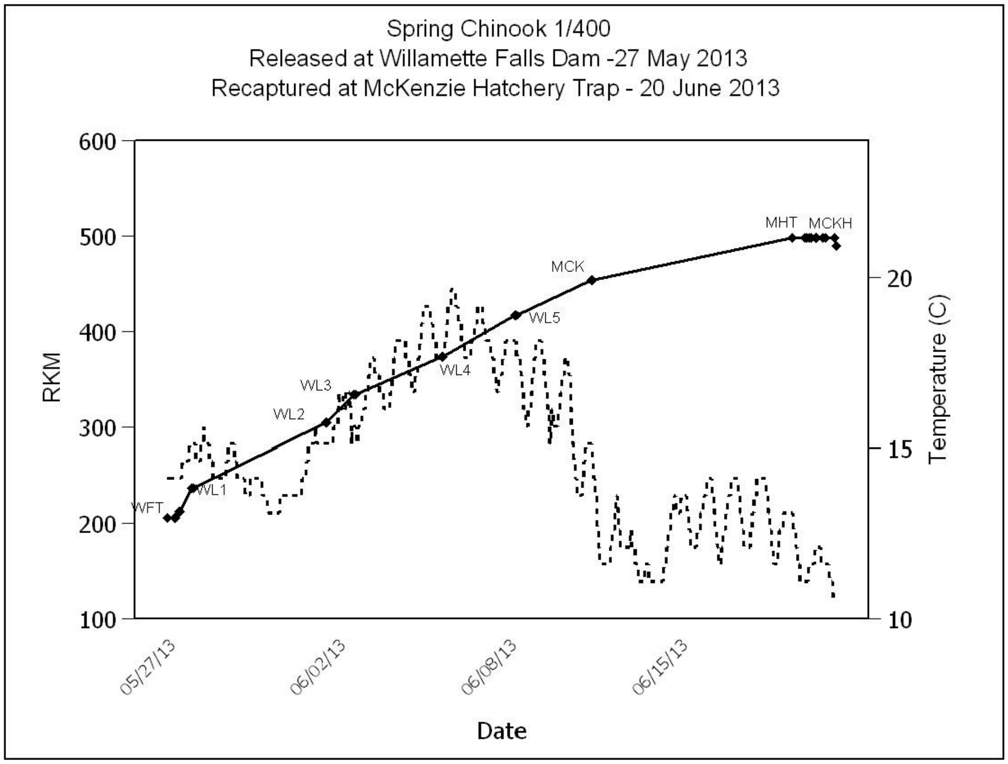

Spring Chinook 3/403
Released at Willamette Falls Dam - 10 June 2013
Recaptured at McKenzie River (Angler) - 20 July 2013
RKM
Temperature (C)
Date
WFT
WL1
WL2
WL3
WL4
WL5
MCK
MKL
Angler RCP
600
500
400
300
200
100
24
22
20
18
16
14
12
10
06/10/13
06/16/13
06/22/13
06/28/13
07/04/13
07/11/13
07/17/13

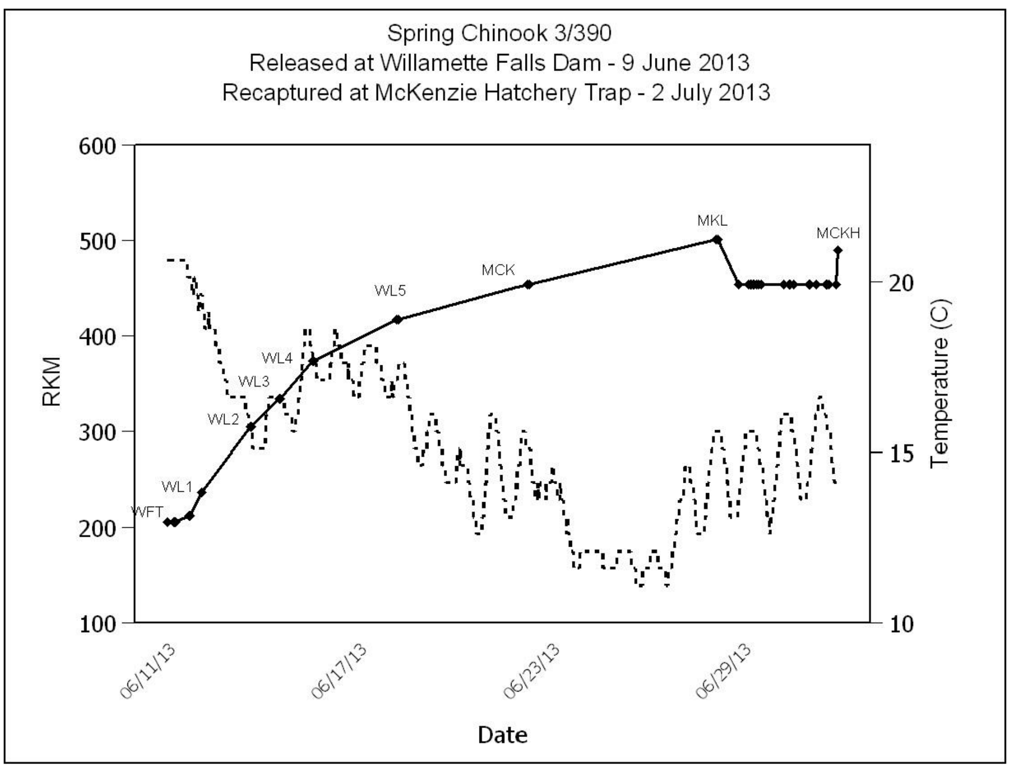


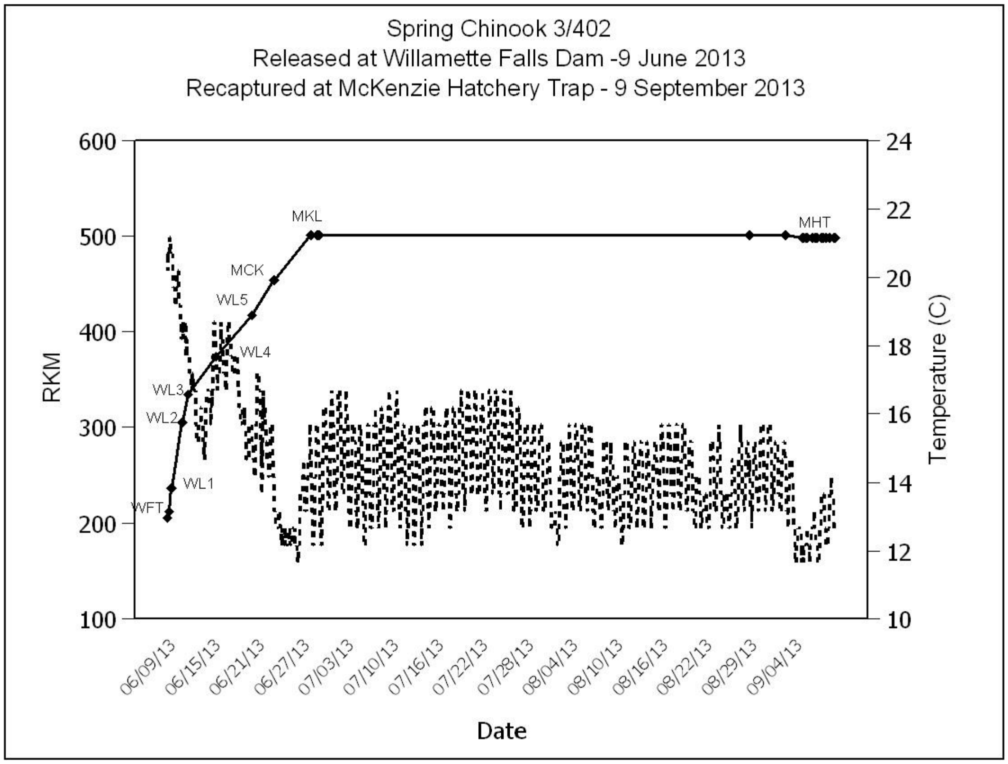
Spring Chinook 1/377
Released at Willamette Falls Dam -27 May 2013
Recaptured at McKenzie Hatchery Trap - 2 July 2013
RKM
Temperature (C)
Date
600
500
400
300
200
100
20
15
10
05/27/13
06/02/13
06/08/13
06/15/13
06/21/13
06/27/13
WFT
WL1
WL2
WL3
WL4
WL5
MCK
MCKH



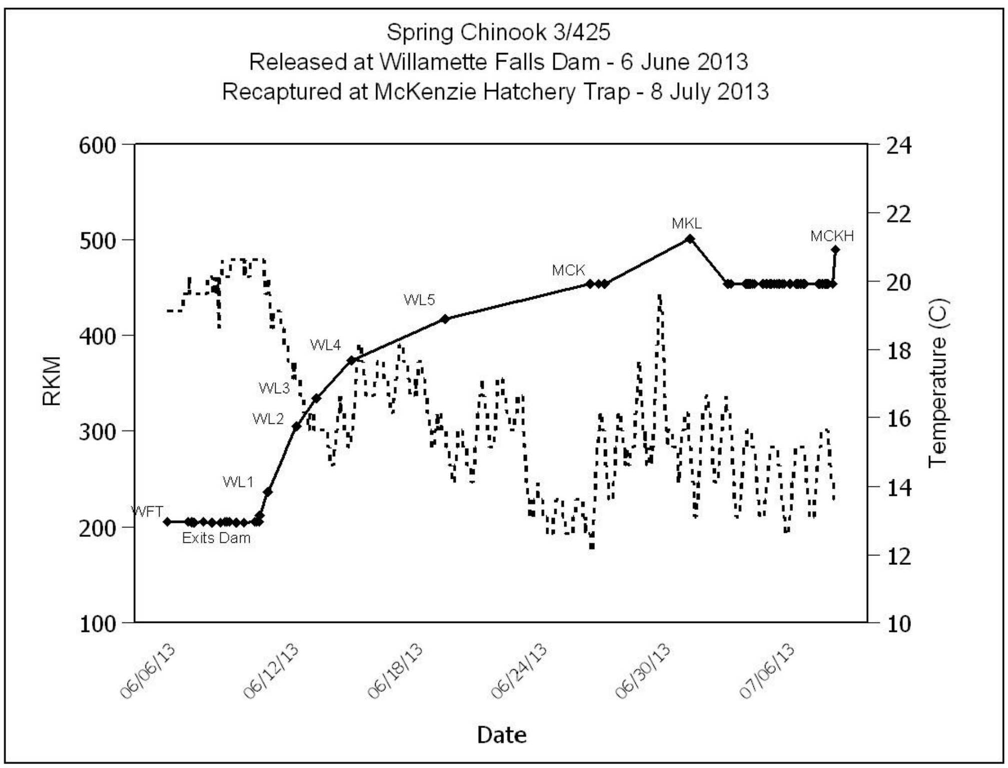
Spring Chinook 1/389
Released at Willamette Falls Dam -28 May 2013
Recaptured at McKenzie Hatchery Trap - 8 July 2013
RKM
Temperature (C)
Date
600
500
400
300
200
100
20
15
10
05/28/13
06/03/13
06/09/13
06/15/13
06/21/13
06/28/13
07/04/13
WFT
WL1
WL2
WL3
WL4
WL5
MCK
MHT
MCKH


Spring Chinook 1/400
Released at Willamette Falls Dam -27 May 2013
Recaptured at McKenzie Hatchery Trap - 20 June 2013
RKM
Temperature (C)
Date
600
500
400
300
200
100
20
15
10
05/27/13
06/02/13
06/08/13
06/15/13
WFT
WL1
WL2
WL3
WL4
WL5
MCK
MHT
MCKH

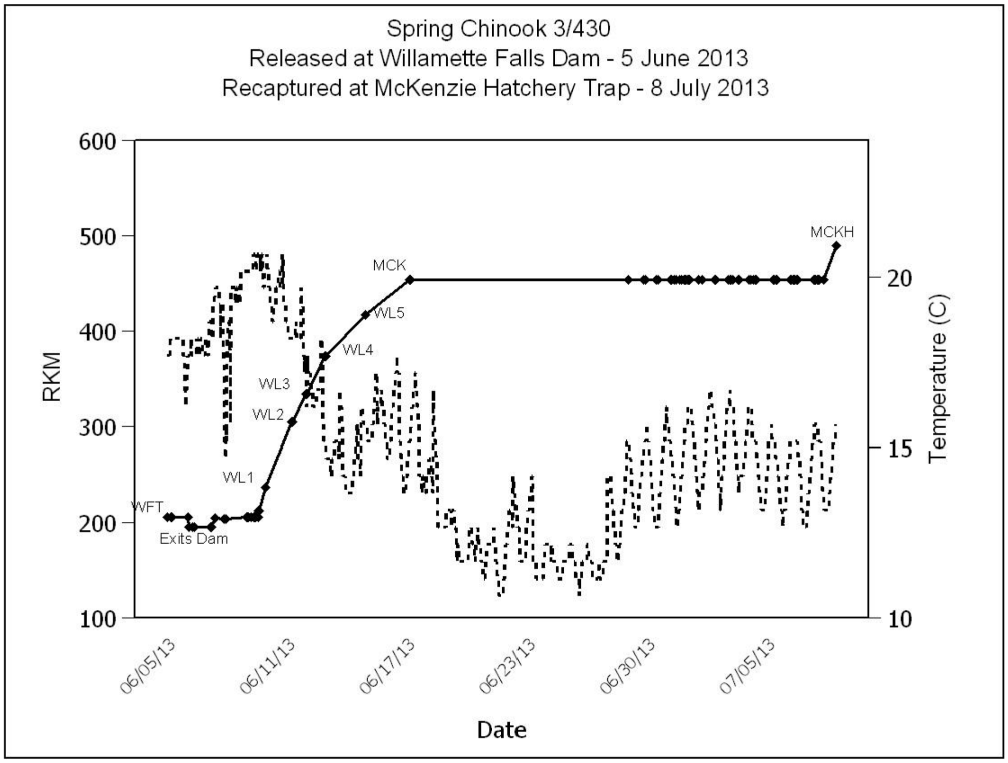

Spring Chinook 3/390
Released at Willamette Falls Dam - 9 June 2013
Recaptured at McKenzie Hatchery Trap - 2 July 2013
RKM
Temperature (C)
Date
600
500
400
300
200
100
20
15
10
06/11/13
06/17/13
06/23/13
06/29/13
WFT
WL1
WL2
WL3
WL4
WL5
MCK
MKL
MCKH



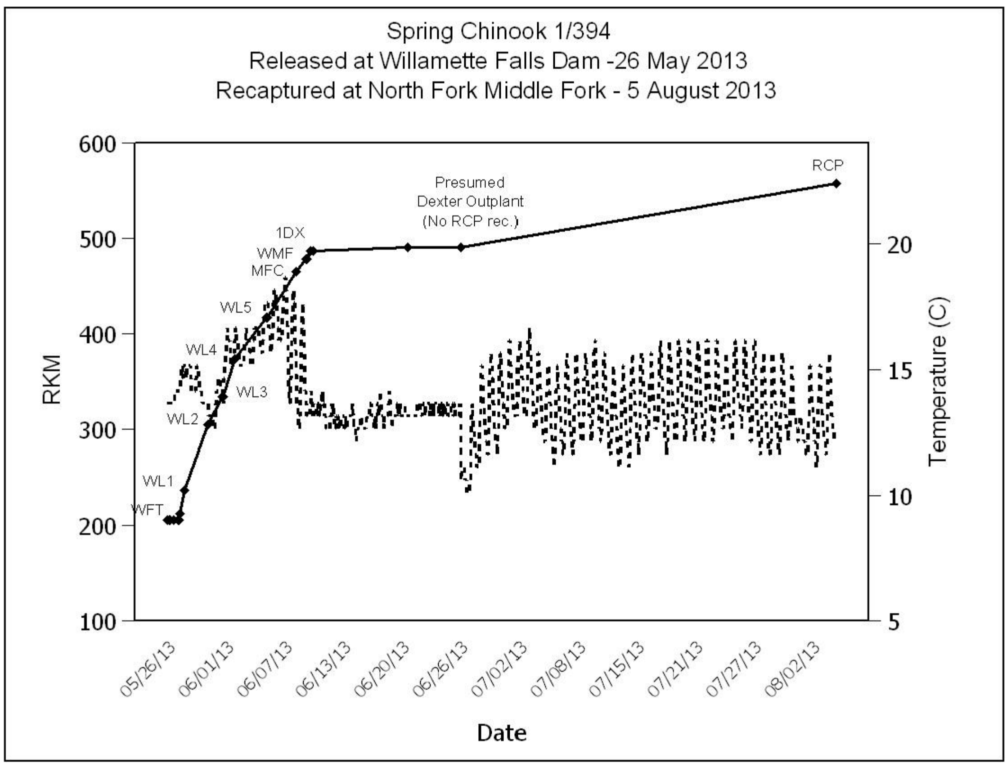
Spring Chinook 3/402
Released at Willamette Falls Dam -9 June 2013
Recaptured at McKenzie Hatchery Trap - 9 September 2013
RKM
Temperature (C)
Date
WFT
WL1
WL2
WL3
WL4
WL5
MCK
MKL
MHT
600
500
400
300
200
100
24
22
20
18
16
14
12
10
06/09/13
06/15/13
06/21/13
06/27/13
07/03/13
07/10/13
07/16/13
07/22/13
07/28/13
08/04/13
08/10/13
08/16/13
08/22/13
08/29/13
09/04/13



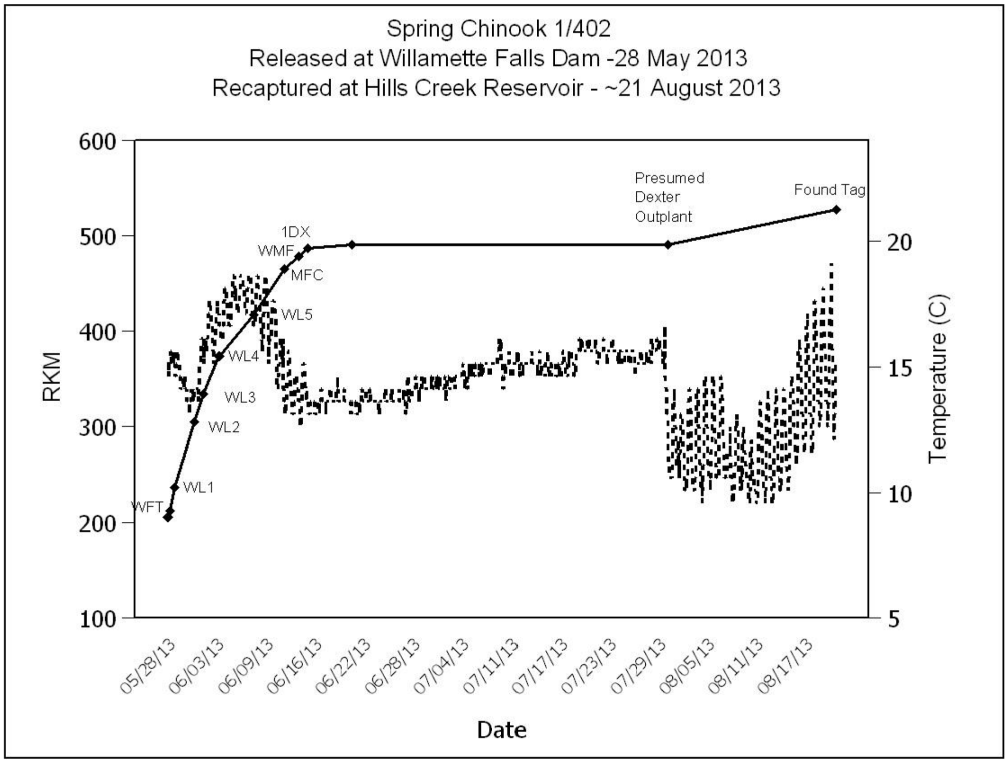
Spring Chinook 3/425
Released at Willamette Falls Dam - 6 June 2013
Recaptured at McKenzie Hatchery Trap - 8 July 2013
RKM
Temperature (C)
Date
WFT
Exits Dam
WL1
WL2
WL3
WL4
WL5
MCK
MKL
MCKH
600
500
400
300
200
100
24
22
20
18
16
14
12
10
06/06/13
06/12/13
06/18/13
06/24/13
06/30/13
07/06/13

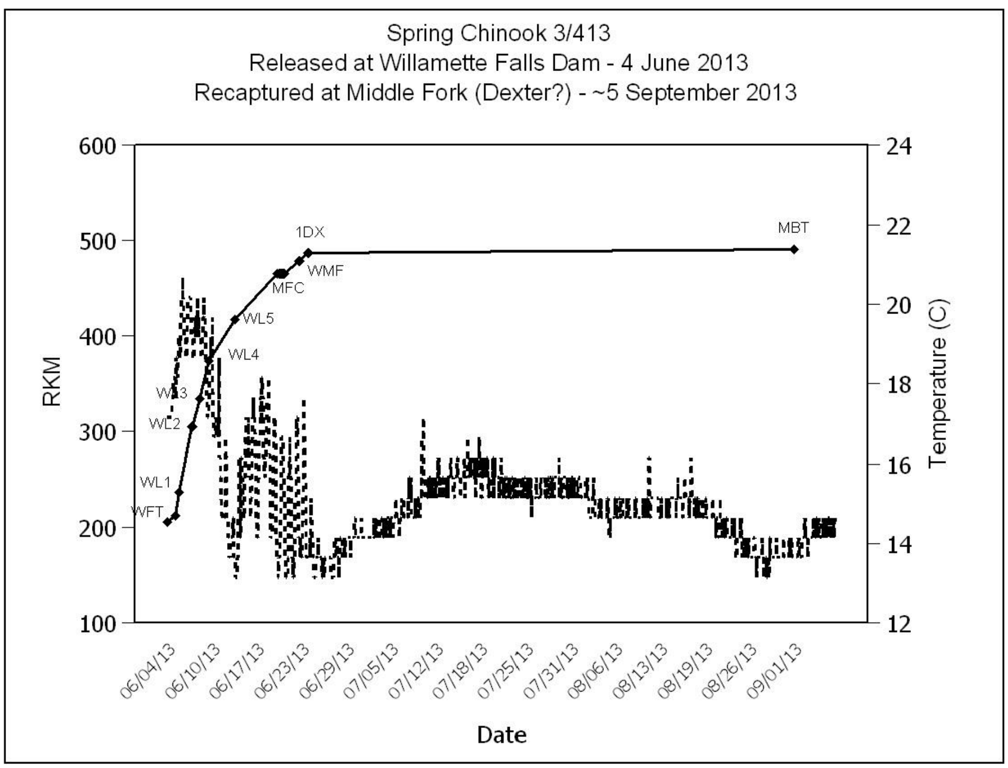


Spring Chinook 3/430
Released at Willamette Falls Dam - 5 June 2013
Recaptured at McKenzie Hatchery Trap - 8 July 2013
RKM
Temperature (C)
Date
600
500
400
300
200
100
20
15
10
06/05/13
06/11/13
06/17/13
06/23/13
06/30/13
07/05/13
WFT
Exits Dam
WL1
WL2
WL3
WL4
WL5
MCK
MCKH



Spring Chinook 1/394
Released at Willamette Falls Dam -26 May 2013
Recaptured at North Fork Middle Fork - 5 August 2013
RKM
Temperature (C)
Date
600
500
400
300
200
100
20
15
10
5
05/26/13
06/01/13
06/07/13
06/13/13
06/20/13
06/26/13
07/02/13
07/08/13
07/15/13
07/21/13
07/27/13
08/02/13
WFT
WL1
WL2
WL3
WL4
WL5
MFC
WMF
1DX
Presumed
Dexter Outplant
(No RCP rec.)
RCP


Spring Chinook 1/402
Released at Willamette Falls Dam -28 May 2013
Recaptured at Hills Creek Reservoir - ~21 August 2013
RKM
Temperature (C)
Date
Presumed
Dexter
Outplant
Found Tag
1DX
WMF
MFC
WL5
WL4
WL3
WL2
WL1
WFT
600
500
400
300
200
100
20
15
10
5
05/28/13
06/03/13
06/09/13
06/16/13
06/22/13
06/28/13
07/04/13
07/11/13
07/17/13
07/23/13
07/29/13
08/05/13
08/11/13
08/17/13


Spring Chinook 3/413
Released at Willamette Falls Dam - 4 June 2013
Recaptured at Middle Fork (Dexter?) - ~5 September 2013
RKM
Temperature (C)
Date
1DX
MBT
WMF
MFC
WL5
WL4
WL3
WL2
WL1
WFT
600
500
400
300
200
100
24
22
20
18
16
14
12
06/04/13
06/10/13
06/17/13
06/23/13
06/29/13
07/05/13
07/12/13
07/18/13
07/25/13
07/31/13
08/06/13
08/13/13
08/19/13
08/26/13
09/01/13