Technical Report 2015-1

MIGRATORY BEHAVIOR, RUN TIMING, AND DISTRIBUTION OF RADIO-TAGGED ADULT WINTER STEELHEAD, SUMMER STEELHEAD, SPRING CHINOOK SALMON, AND COHO SALMON IN THE WILLAMETTE RIVER: 2011-2014

by

M.A. Jepson, M.L. Keefer, C.C. Caudill, T.S. Clabough, C.S. Erdman, T. Blubaugh
Department of Fish and Wildlife Sciences
University of Idaho
Moscow, ID 83844-3141

and

C.S. Sharpe
ODFW Corvallis Research Lab
Corvallis, Oregon 97333

For

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

2015

Technical Report 2015-1

MIGRATORY BEHAVIOR, RUN TIMING, AND DISTRIBUTION OF RADIO-TAGGED ADULT WINTER STEELHEAD, SUMMER STEELHEAD, SPRING CHINOOK SALMON, AND COHO SALMON IN THE WILLAMETTE RIVER: 2011-2014

by

M.A. Jepson, M.L. Keefer, C.C. Caudill, T.S. Clabough, C.S. Erdman, T. Blubaugh
Department of Fish and Wildlife Sciences
University of Idaho
Moscow, ID 83844-3141

and

C.S. Sharpe
ODFW Corvallis Research Lab
Corvallis, Oregon 97333

For

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

2015

Summary

In this study, we collected information on run composition, run timing, and migration behaviors of adult winter and summer steelhead, spring Chinook salmon, and coho 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. 2014 was the fourth study year for Chinook salmon, the third year for steelhead, and the first year for coho salmon. It was also the third study year when summer steelhead were collected and radio-tagged at Foster and Dexter dams to estimate behavior and final distribution of recycled steelhead (i.e., those captured at a trap and then released downstream to increase angler opportunity).

We used an anesthetic (AQUI-S 20E) when tagging all salmonids in 2013 and 2014 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.

Winter steelhead: We collected and radio-tagged 184, 170, and 212 winter steelhead at Willamette Falls during the 2012, 2013, and 2014 run years, respectively. The samples were 2.4-4.0% of the winter steelhead counted at the project from 1 November through 31 May. The timing of the winter steelhead run as a whole was early in 2012 compared to the 10-year average whereas the 2013 and 2014 runs were some of the latest timed. In all 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 through the main stem Willamette River at rates up to ~50 rkm/d (*mean* ~30 rkm/d) and that they moved more slowly as they migrated through successive upstream river reaches.

We inferred spawning distribution from the maximum upstream detection records for each adult. Across the three study years, the highest percentages of tagged winter steelhead returned to the North and South Santiam rivers (20% each), the Molalla River (15%), and the Middle Fork Willamette River (10%), on average. After adjusting for known transmitter loss, 81% (2012) to 84% (2013 and 2014) 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 and 2014. Using logistic regression models, we found that fork length and weight were positively associated with tagged winter steelhead escaping to a tributary in 2014, with larger fish having increased probabilities of escaping. For the 2013 winter steelhead, tag date, weight, and fork length were not statistically associated with escaping to a tributary. Tag date was a significant

($P < 0.05$) predictor of escapement in 2012, with fish tagged later in the year having increased probabilities of escaping.

Most (59-68%) of the tagged winter steelhead showed post-spawn kelt movements downstream and were was last detected downstream from Willamette Falls Dam or in the lower main stem each year. Smaller percentages of tagged steelhead were last recorded in the Santiam (11-14%), Molalla (3-8%), and the Middle Fork (4-8%) rivers. Two percent or less was last recorded in the upper main stem each year. The distributions of last detections of tagged winter steelhead were similar in all years. 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.

Summer steelhead: Overall, 75-90% of radio-tagged summer steelhead were last detected in Willamette River tributaries in the three years. In all years, the highest percentage of tagged summer steelhead was last recorded in the South Santiam River (range = 26-37%). On average, 18% returned to the Middle Fork, 16% returned to the McKenzie River, 10% returned to the North Santiam River, and smaller percentages (<2%) returned to other tributaries each year. An annual mean of 9% of tagged summer steelhead was last detected in the upper main stem. 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 all years indicated that there is potential for summer steelhead to overlap spatially and temporally with winter steelhead in some tributaries. 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, 8-14% of the Foster-tagged fish and 16-26% of the Dexter-tagged fish were reported as harvested during 2012-2014. The lack of a transmitter reward program likely resulted in under-reporting of harvest in 2012 (8%) but recovery rates were also low in 2013 (14%) and 2014 (9%) when a reward program was in place. The low recovery rates may indicate that the recycling programs increase the likelihood that non-harvested summer steelhead interact with winter steelhead during winter and spring, including potential spawning periods.

Spring Chinook salmon: The collection of Chinook salmon in 2013 and 2014 were the first years when samples of clipped and unclipped salmon were tagged in proportion to the run using a collection and handling protocol that only included anesthesia with AQUI-S 20E. In contrast, the 2011 and 2012 samples included a mix of anesthetized and manually restrained fish. The 2012 sample also 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.

Over the four study years, 762 spring Chinook salmon were in the anesthetized handling group. Escapement to tributaries for this subset was similar for males and females and for wild and hatchery fish, but differed among years (annual *range* 79-90%). Several fish traits were statistically associated with lower escapement, including presence of head injuries, descaling, and marine mammal injuries. In a multi-model multiple logistic regression comparison, Chinook salmon survival in the main stem was best explained with a combination of individual fish traits and, to a lesser degree, with river environment. The highest escapement to tributaries was in 2014, a year with relatively warm water temperatures. Salmon migrated through the main stem very rapidly in 2014 and we have hypothesized that faster passage may offset the increased mortality risk associated with warm water exposure in the main stem. Escapement to tributaries was notably lower for salmon in the manual restraint handling treatment tested in 2011 and 2012 and this technique is not recommended for radio-tagging adult Chinook salmon. In all years, small percentages of adipose-clipped radio-tagged Chinook salmon last recorded or recaptured in tributaries were reported as recaptured by anglers (*range* = 1.7 to 4.1% of those released).

Chinook salmon migrated through the main stem faster as water temperature and migration date increased, with the highest migration rates observed in the lower main stem reaches. The mean main stem migration rate for spring Chinook salmon each year ranged from 22.2 rkm/day in 2011 to 27.3 rkm/d in 2013. A few (5-10%) tagged salmon exhibited downstream movements in the main stem during migration in all three years. Similarly, we detected little temporary straying by salmon into presumed non-natal tributaries (i.e., tributaries other than their final tributary), though we note that it was not possible to directly assess either temporary or permanent straying.

The relatively early migration timing of the 2013 and 2014 spring Chinook salmon runs was consistent with expectations given relatively warm river temperatures and low to moderate discharge. Chinook salmon populations passing Willamette Falls Dam were well-mixed in all years and the composition differences between clipped and unclipped samples were modest. Run composition for fin-clipped Chinook salmon last recorded in tributaries in all years typically showed that the three most abundant return groups (i.e., Santiam, McKenzie, and Middle Fork) were represented throughout the run. Run composition for the unclipped salmon last recorded in tributaries was characterized by the McKenzie group making up higher percentages early and in the middle of the runs and the South and North Santiam groups making up higher percentages later in the runs.

Coho salmon: In a single study year (2014), 81% of the 219 coho salmon radio-tagged at Willamette Falls in 2014 were last detected in Willamette River tributaries. The highest percentage of tagged salmon was last recorded in the Yamhill River (47%), followed by the Tualatin River (19%), and the North Santiam and Molalla rivers (5% each). Tagged coho salmon that returned to the Yamhill and Santiam rivers in 2014 spent roughly equivalent times (median ~ 1 day) in the lowest section of the main stem. The run composition of coho salmon was well-mixed throughout the run.

Acknowledgments

Many people assisted with the field work and data compilation for this report and its successful completion was made possible through their efforts. University of Idaho (UI) personnel included: Theresa Tillson tagged adult salmon and steelhead; Matt Knoff and Mark Morasch maintained and downloaded receivers, and Christopher Noyes coordinated permit acquisition. Jennifer Adams, Cort Anderson, and Lisette Waits conducted the steelhead genetics evaluations. Oregon Department of Fish and Wildlife (ODFW) 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, Dan Peck, Brett Boyd, and Tim Wright. Tom Murtagh assisted with coordination, particularly with the coho tagging study. Justin Huff and Brian Franklin performed mobile-tracking surveys for steelhead and Officer Christopher Culp piloted the plane used for mobile tracking surveys in November-December 2014. 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), and Michele Weaver and Shivonne Nisbit (ODFW) for their assistance with securing permits for the study. We are grateful to Bonnie Johnson, US Fish and Wildlife Service, for coordinating the use of AQUI-S 20E under the Investigational New Animal Drug program and Christopher Noyes (UI) 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 UI’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 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, Fenton Kahn, Glen Rhett, and Deberay Carmichael.

Table of Contents

Introduction

The overarching 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*), Chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*) in the Willamette River basin. 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 regarding 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 episodically 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 water temperatures can affect the reproductive success of salmonids well before spawning (McCullough et al. 2001) and temperature has 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. 2010a; Naughton et al. 2013; Naughton et al. 2014) and in other species such as sockeye salmon (*O. nerka*, Naughton et al. 2005; Rand et al. 2006). In the Willamette basin, dams in tributaries affect water temperature in the Willamette main stem and tributaries including in dam tailraces (e.g., below Dexter Dam) during the migration, pre-spawn staging, and spawning times of Chinook salmon. Water storage and release protocols, combined with thermal stratification of reservoirs, can result in downtream temperatures that are cooler than historical levels in summer and warmer than historic levels in fall (Rounds 2007; 2010). Understanding the relationships among temperature exposure, migration behavior, and prespawn mortality is an important research objective for Chinook salmon in the Willamette River basin. 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 2014, we continued a radiotelemetry study to monitor adult steelhead (winter- and summer-run) and spring Chinook salmon and initiated a coho salmon study 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 post-spawn kelt migrations (for steelhead), using a fixed-site radio receiver array and mobile tracking. Based on our previous experience collecting, radio-tagging, and monitoring adult Chinook salmon (e.g., Keefer et al. 2005; Jepson et al. 2010) and summer steelhead (e.g., Keefer et al. 2009; Caudill et al. 2007, 2014), we think that radiotelemetry is an effective method and that most of the tagged fish in the 2014 Willamette River study behaved similarly to untagged fish.

This report addresses five general research questions, including four questions addressed using fish collected and radio-tagged at Willamette Falls and one using steelhead collected and radio-tagged at Dexter and Foster dams. The study questions for Willamette Falls-tagged fish were: 1) what is the behavior, migration success, and final distribution of adult salmonids upstream from Willamette Falls?; 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 and can genetic stock identification (GSI; Van Doornik et al. 2015) in combination with telemetry be used to quantify interactions? The Dexter and Foster study question was: 1) what is the fate of "recycled" adult summer steelhead that are captured at the dam traps and then released downstream to increase angler opportunity? The Willamette Falls tagging began in 2011 and 2014 was our fourth study year for Chinook salmon and the third study year for winter and summer steelhead (see Jepson et al. 2012, 2013, 2014 for previous results). Tagging of recycled steelhead in tributaries began in 2012 and 2014 was the third study year (see Jepson et al. 2013, 2014 for previous results).

Specific 2014 objectives addressed in this report include:

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

Note that this report is part of a larger adult salmon and steelhead study program in the Willamette River basin. Additional study elements have focused on adult Chinook salmon disease status at Willamette Falls Dam (Benda et al. 2015) and on prespawn mortality of Chinook salmon in tributaries during the holding and spawning periods. The latter component used radio- and PIT-tagging adult salmon captured and outplanted in the

Middle Fork Willamette and North Santiam rivers (e.g., Mann et al. 2011; Naughton et al. 2014; Naughton et al. 2015) and is ongoing.

Methods

Tagging site, procedures, and fish measurements

Adult steelhead, Chinook salmon, and coho 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. 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. It was also unknown whether fish ascending the Denil represented a random sample of fish passing Willamette Falls.

In 2014, all collected fish were anesthetized with AQUI-S 20E (AquaTactics Kirkland, Washington) prior to tagging following methods described in Caudill et al. (2014). 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-S 20E 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. Scale samples were collected from behind the dorsal fin and above the lateral line to determine age, origin, and iteroparity rates (steelhead only). A caudal fin punch was collected from each fish for genetic analysis. Adults to be radio-tagged received an appropriately-sized transmitter (i.e., model MCFT-3A, 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 legal harvest). A PIT tag was inserted into the pelvic girdle (adipose-clipped) or dorsal sinus (adipose-intact) of all adults lacking a PIT tag as a secondary mark. A subsample of the Chinook salmon were tagged with archival temperature pods in 2011-2013 (see summary in Keefer et al. 2015), but not in 2014.

Telemetry sites and mobile tracking efforts

A total of 54 fixed-site radio receivers were distributed throughout the study area (Figure 3 and Table 1). Monitoring efforts also included mobile tracking via truck. Truck mobile tracking by Oregon Department of Fish and Wildlife (ODFW) personnel occurred on 46 unique days from 18 March to 3 June, with the highest number of surveys conducted in the Santiam River basin (i.e., 21 surveys in the South Santiam River downstream from Foster Dam and 12 surveys in the North Santiam River). Mobile telemetry was conducted along fixed routes so that the probability of tag detection was relatively constant from survey to survey. Extensive mobile tracking surveys were conducted via truck or fixed-wing aircraft in all tributaries depicted in subsequent escapement graphics (e.g., Figure 19) in November-December 2014.

Figure 1. Overhead view of the Denil (left), trap, and ladder return (right) used to collect adult salmon and steelhead at Willamette Falls Dam in 2011-2014.

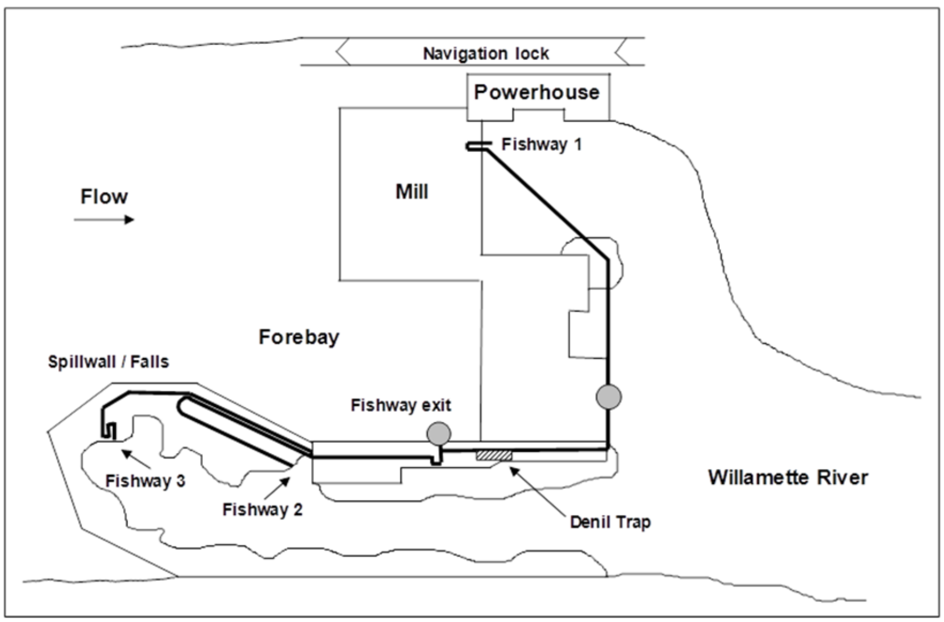

Figure 2. Schematic drawing of Willamette Falls Dam, Oregon, showing the location of three fishways, and the two fixed-location radio receiver sites (●) deployed at the dam in 2014. Additional antennas were located in the dam tailrace (0.5 km downstream).

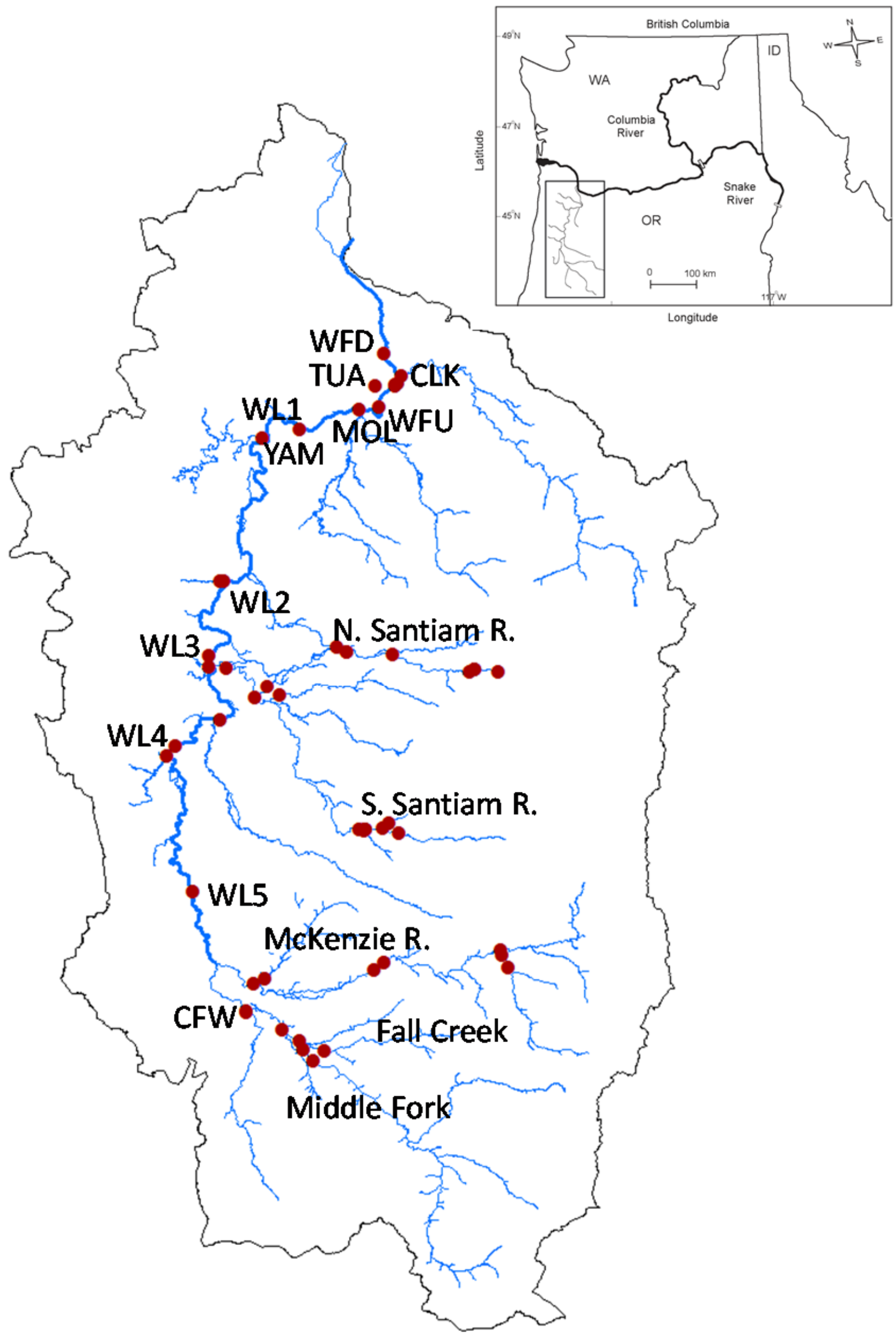

Figure 3. Map of the Willamette River basin and locations where fixed-site radio receivers (red dots) were deployed by the University of Idaho in 2014.

Table 1. List of radio receivers deployed in the Willamette River basin in 2014, 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
Thomas Creek	THC	365.9
Foster Dam tailrace	SSF	416.6
Wiley Creek	WLY	417.9
Foster Dam trap	FST	418.0
Foster Dam South Fishway Entrance	FSE	418.2
Foster Dam North Fishway Entrance	FSB	418.2
Foster Dam Fishway – lower weirs	FSZ	418.2
South Santiam at Riverbend	RVB	427.6
Middle Santiam Reservoir	MSR	424.1
South Santiam Reservoir	SFR	422.0
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 Fallback Monitor	2MT	424.2
Minto Fishway Entrance	MTL	424.2
Minto Collection Facility	MCF	424.3
Big Cliff Tailrace	1BC	429.8
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	501.8
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 (Jasper)	WMF	478.4
Fall Creek Mouth	FCR	484.0
Fall Creek Dam tailrace	FCT	493.3
Dexter Dam tailrace	1DX	486.7
Dexter Fishway Entrance	DXL	487.1

One important difference between 2014 and previous years' evaluations included a criterion by which we considered fish to have successfully migrated to the Middle Fork. Specifically, fish that were last detected at the MFC site (rkm 465.2) were conservatively considered to have not successfully migrated to a tributary in Jepson et al. (2012, 2013, and 2014) because they may have been technically in the upper edge of the main stem Willamette River at last detection. We have retroactively assigned successful migration to these fish given their proximity to both the Coast Fork and Middle Fork confluences and this has resulted in modest (1-2%) increases in overall escapement estimates compared to those previously reported.

Results

Environmental data

In 2013 and 2014, water temperatures were generally warmer and Willamette River discharge was generally lower than in both 2011 and 2012 (Figure 4). Water temperature measured in 2014 at the USGS gauge near Albany, OR, increased from April through August, reached a maximum of 22.3 °C on 16 July (with a secondary peak of 22.0 °C on 8 July), and then decreased through September and October. Albany data are presented in Figure 4 to illustrate the relative differences among years. In 2014 (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). Water temperatures in the Middle Fork, McKenzie, South Santiam and North Santiam rivers were consistently cooler than the main stem Willamette, while the lower Santiam River at the Jefferson gauge was similar to the middle main stem Willamette.

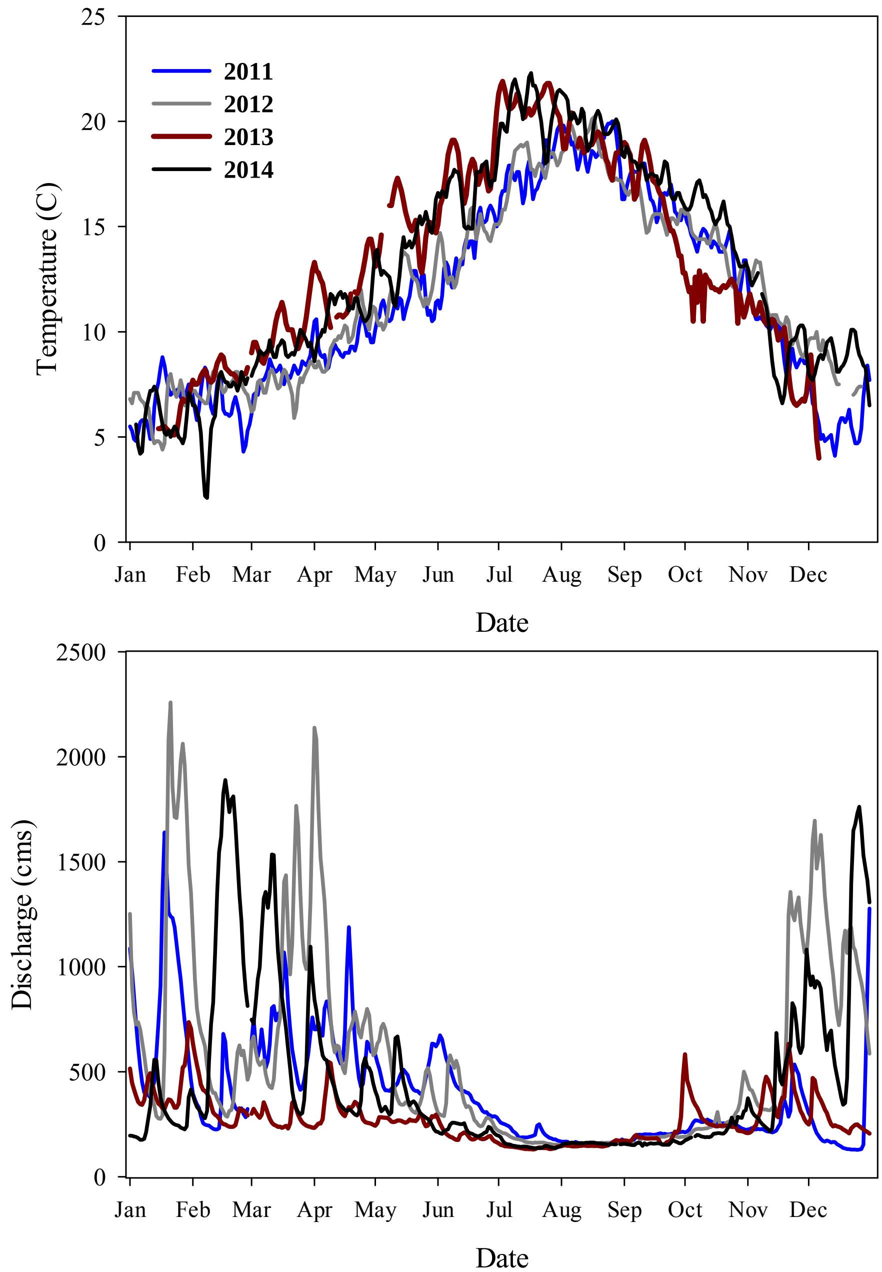

Figure 4. Mean daily Willamette River water temperature (°C, top panel) and mean daily Willamette River discharge (cms) recorded at the USGS gauge at Albany, OR, in 2011-2014 (bottom panel). Data were collected from http://ida.water.usgs.gov/.

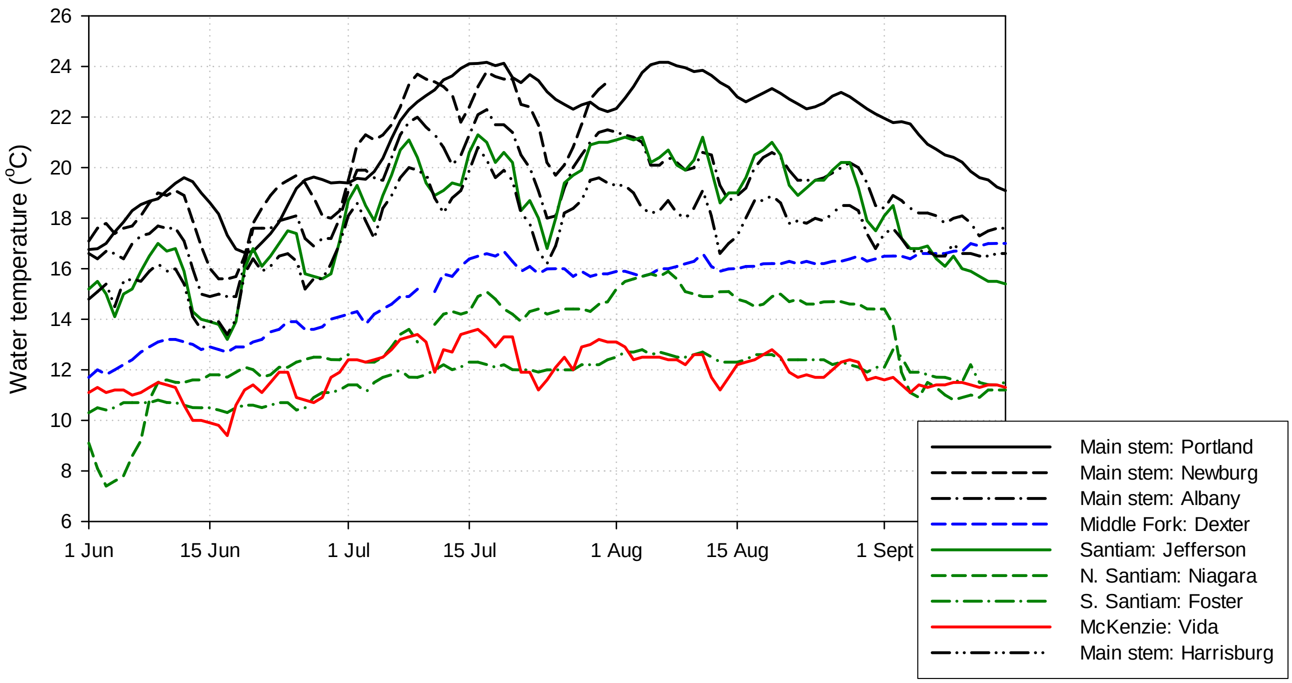

Figure 5. Mean daily water temperatures (°C) recorded at USGS gauge sites in the main stem Willamette, Middle Fork Willamette, Santiam, and McKenzie rivers during the spring Chinook salmon migration in 2014.

Steelhead collection and tagging

Annual counts of winter steelhead at Willamette Falls Dam by ODFW personnel begin on 1 November and end on 15 May (31 May after 2010) the ensuing year. For clarity, we have opted to define the 2012 'run', for example, as fish that spawn in 2012, regardless of their passage timing at Willamette Falls Dam.

Willamette Falls Dam – A total of 31,629 adult steelhead were counted passing Willamette Falls Dam from 1 November 2011 through 31 July 2012, which was 115% of the ten year average of 27,463 (Figure 6). Adult steelhead counted in the same date ranges for 2012-2013 (17,604) and 2013-2014 (26,407) were 68% and 104% of the respective 10-year averages of 25,858 and 25,227 steelhead.

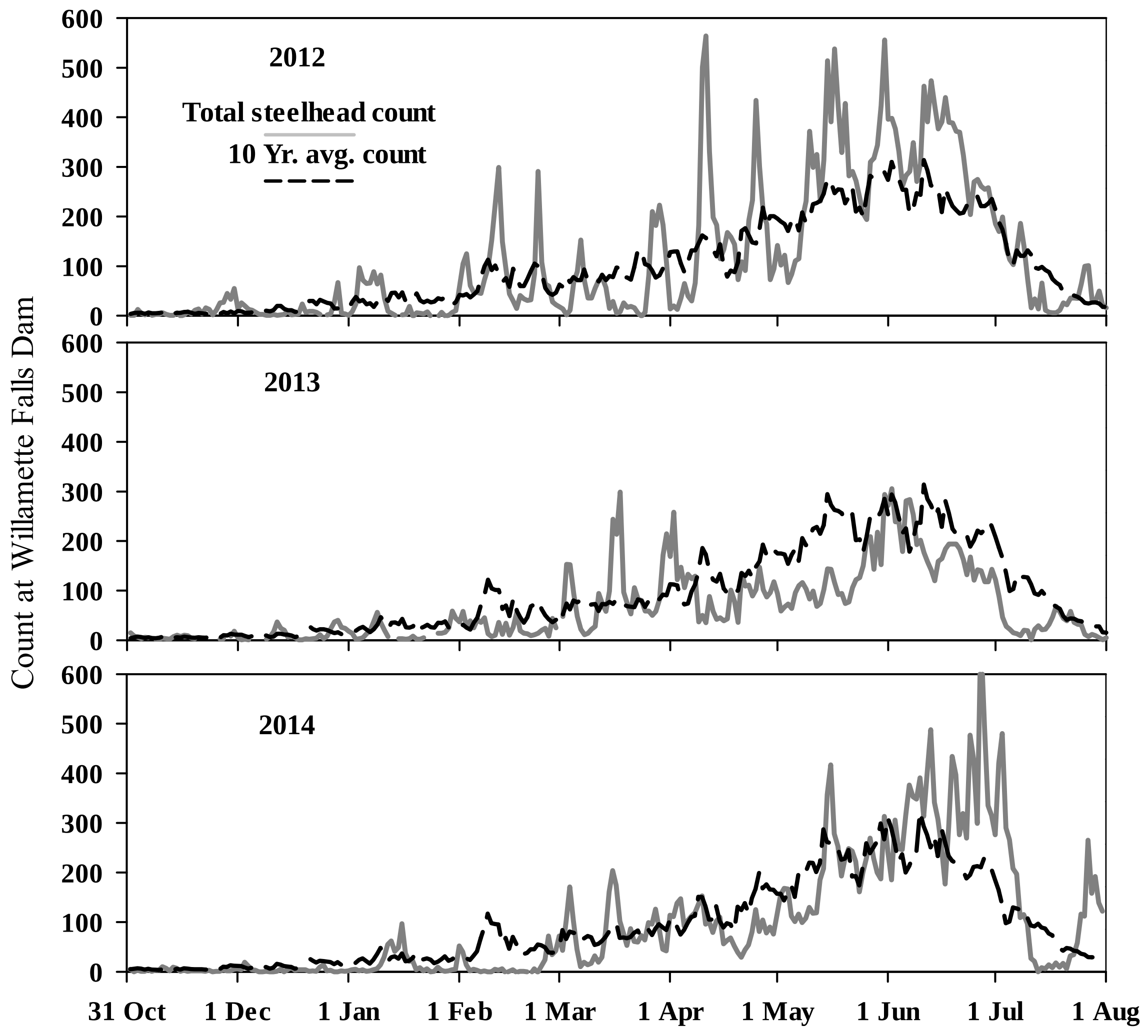

Figure 6. The number of adult steelhead (clipped and unclipped combined) counted at Willamette Falls Dam in 2012-2014 and the ten-year average counts. Count data from http://www.cbr.washington.edu/dart/adult.html and http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

All adult steelhead with clipped adipose fins were considered summer steelhead of hatchery origin. Run assignment for steelhead with intact adipose fins was more challenging because some summer steelhead were likely progeny of summer-run fish that spawned in the wild. For this report, however, we defined any adult steelhead with an intact adipose fin as a winter steelhead. In 2012, 13 steelhead with intact adipose fins collected from 19 May to 1 July were classified as summer steelhead (and reported here as winters). In 2013 and 2014, six and seven steelhead with intact adipose fins, respectively, (tag date ranges = 11-28 May 2013 and 5 May to 10 June 2014) were classified as summer steelhead (and reported here as winters). One adipose-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.

In the 2012 run year, we radio-tagged 184 steelhead with intact adipose fins, which was 2.4% of the 7,616 winter steelhead counted from 1 November 2011 through 31 May 2012 (Table 2 and Figure 7). The 31 May cutoff date was the end of the winter run, as defined by ODFW. Ten unclipped steelhead were tagged after 31 May 2012. Of the 184 winter steelhead tagged in 2012, 94 (51%) received the anesthetic treatment and 90 were restrained. 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). Overall, we radio-tagged 1.2% of all steelhead (winter and summer) counted (379/31,629) counted at Willamette Falls Dam from 1 November 2011 through 31 July 2012.

In the 2013 run year, 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). One unclipped steelhead was tagged after 31 May. Approximately half the winter steelhead tagged in 2012 were restrained and half were anesthetized. All steelhead were radio-tagged using anesthetic in 2013 and 2014. We radio-tagged 250 summer steelhead from 22 January to 26 June 2013, which was 2.0% of the 12,661 summer steelhead counted from 1 March through 31 July (Figure 9). Overall, we radio-tagged 2.4% of all steelhead counted (420/17,604) at Willamette Falls Dam from 1 November 2012 through 31 July 2013.

In the 2014 run year, we radio-tagged 212 winter steelhead, which was 4.0% of the 5,349 winter steelhead counted from 1 November 2013 through 31 May 2014 (Figure 7). Thirty-eight of the 212 fish total were early-run winter steelhead tagged before 15 February 2014 and are considered by ODFW to be descendants of the introduced Big Creek stock based on date of passage (Figure 8). Four unclipped steelhead were tagged after 31 May 2014. We radio-tagged 196 summer steelhead from 14 April to 24 June, which was 0.9% of the 21,135 summer steelhead counted from 1 March through 31 July (Figure 9) and the sample was biased toward the early run due to temperature-related tagging restrictions in mid-June and July. Overall, we radio-tagged 1.5% of all steelhead counted (408/26,407) at Willamette Falls Dam from 1 November 2013 through 31 July 2014. One unclipped steelhead mortality occurred during handling on 20 May 2014; all other 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 2012-2014.

	Adipose fin	Number of steelhead		
Year	status	Tagged	Restrained	Anesthetized
2012	intact	184	90	94
	clipped	195	194	1
2013	intact	170	-	170
	clipped	250	-	250
2014	intact	212	-	212
	clipped	196	-	196

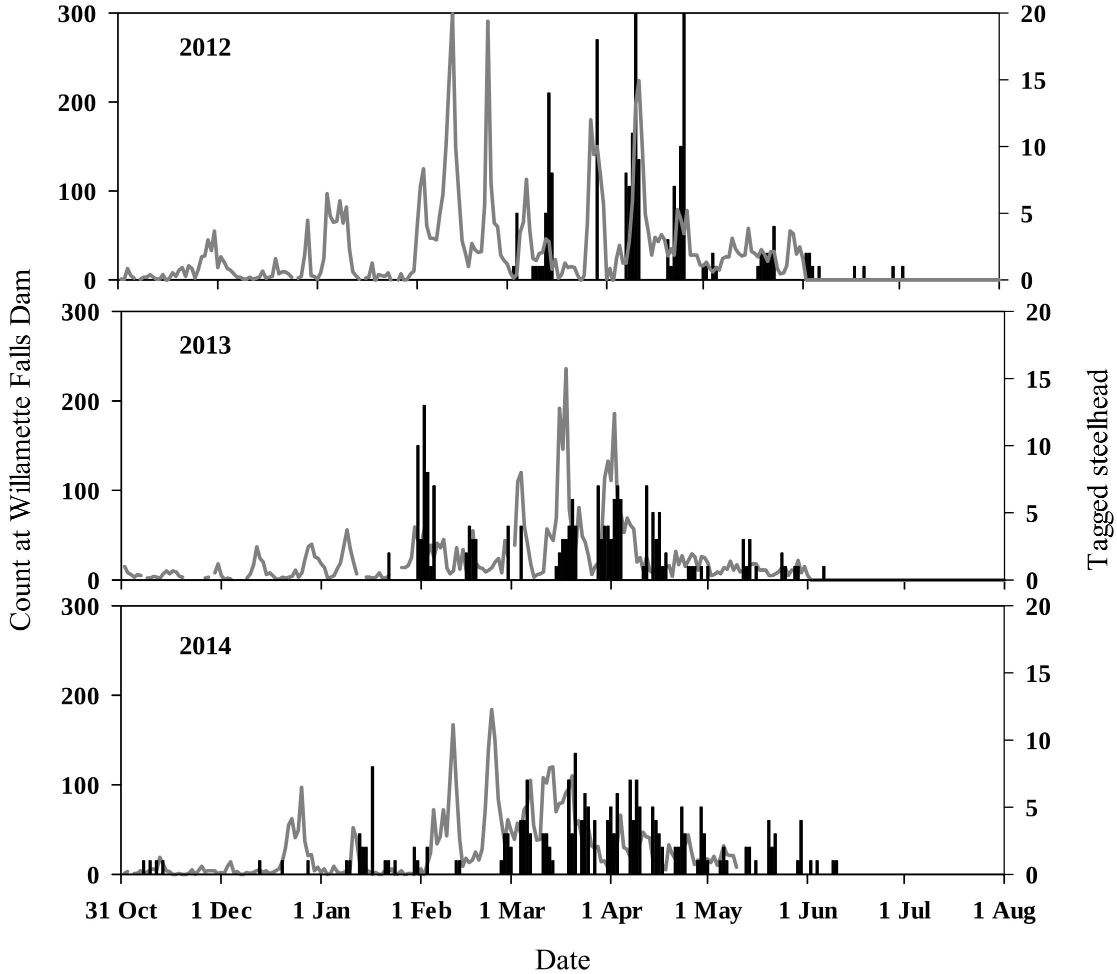

Figure 7. The number of winter steelhead counted (line) and radio-tagged (bar) at Willamette Falls Dam in 2012-2014.

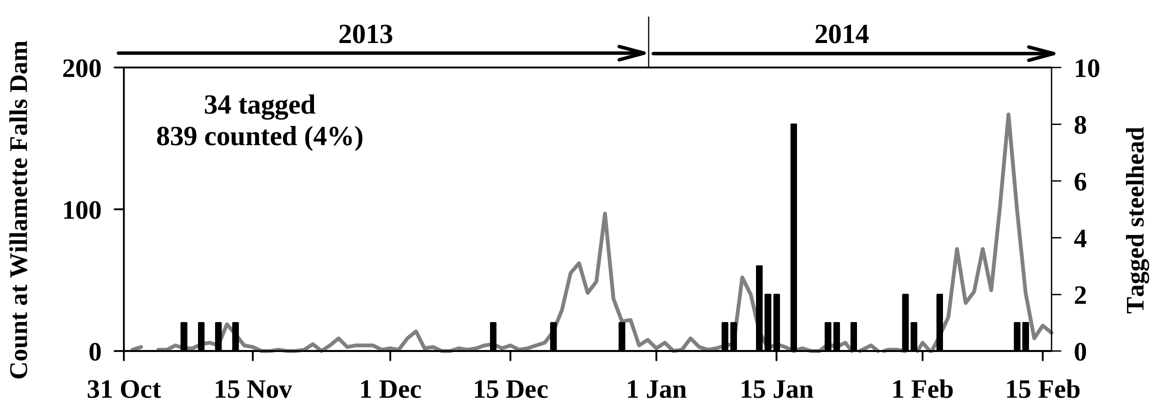

Figure 8. The number of early-run winter steelhead counted (line) and radio-tagged (bar) at Willamette Falls Dam from 1 November 2013 through 15 February 2014.

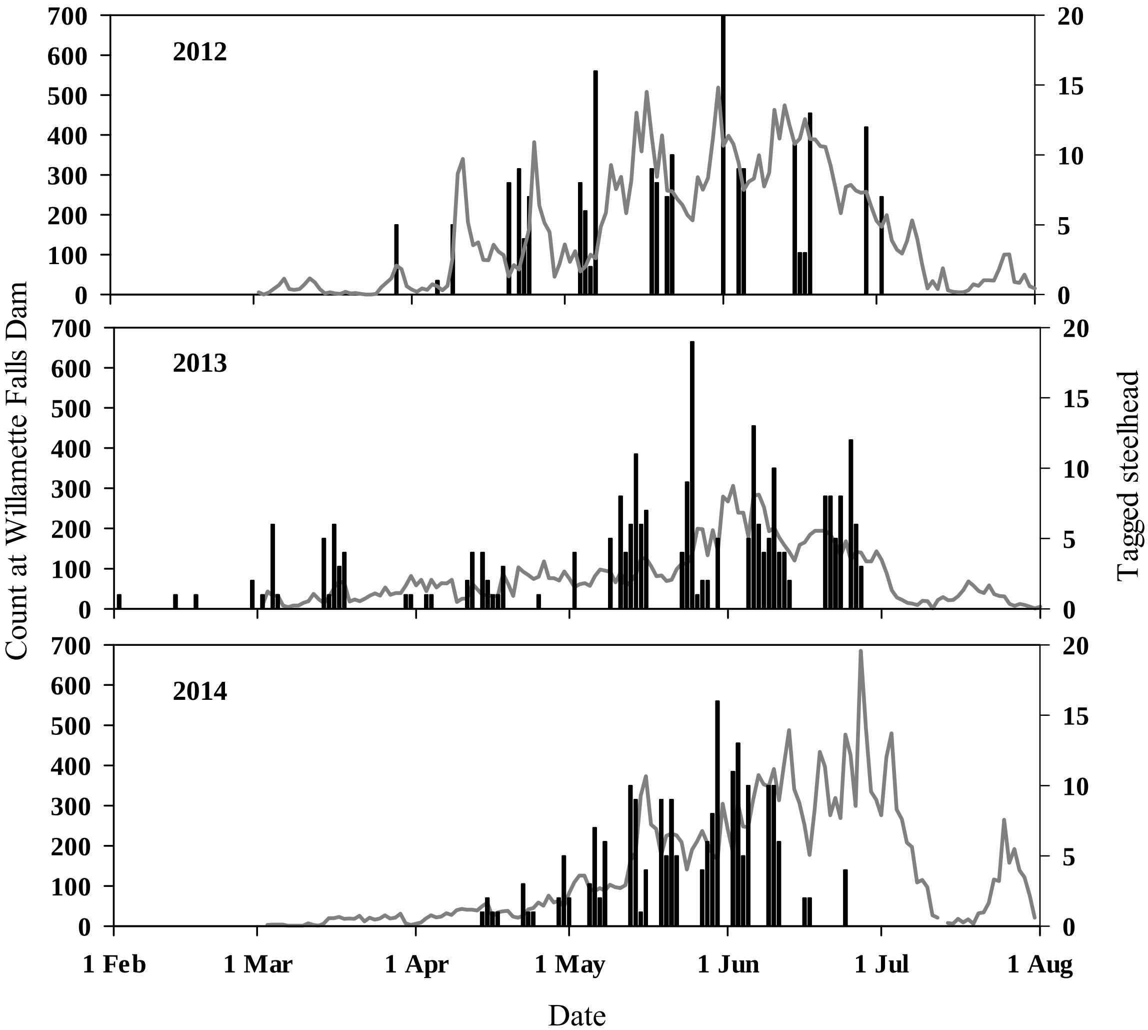

Figure 9. The number of summer steelhead counted (line) and radio-tagged (bar) at Willamette Falls Dam in 2012-2014. Count data from http://www.cbr.washington.edu/dart/adult.html and http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Two of the 184 (1.2%) transmitters used 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 from winter or summer steelhead in 2013 were recovered in Fishway 1. However, five winter steelhead transmitters and one summer steelhead transmitter were detected only at Willamette Falls Dam receivers in 2013. Similarly, two winter and one summer transmitter had limited post-release detections in 2014. Some or all of these fish may have regurgitated transmitters but they were included in all analyses.

Recycled steelhead at Foster and Dexter dams - A total of 295 summer steelhead were collected at the Foster Fish Facility and recycled downstream in the South Santiam River in 2012-2014. All fish were radio-tagged and then either released directly into the Foster Dam tailrace (2014 only) or transported via truck by ODFW and released downstream from the dam at a variety of release locations in the South Santiam River. Release locations during all three study years included Waterloo County Park (22.6 rkm downstream from Foster Dam) and the Pleasant Valley Boat Launch in Sweethome, OR (6.4 rkm downstream). In 2013, radio-tagged adults were also released near the mouth of Wiley Creek (<1 rkm downstream from Foster Dam).

Releases dates varied among years; they were restricted to July-August in 2012 and June-July in 2013-2014 (Figure 10).

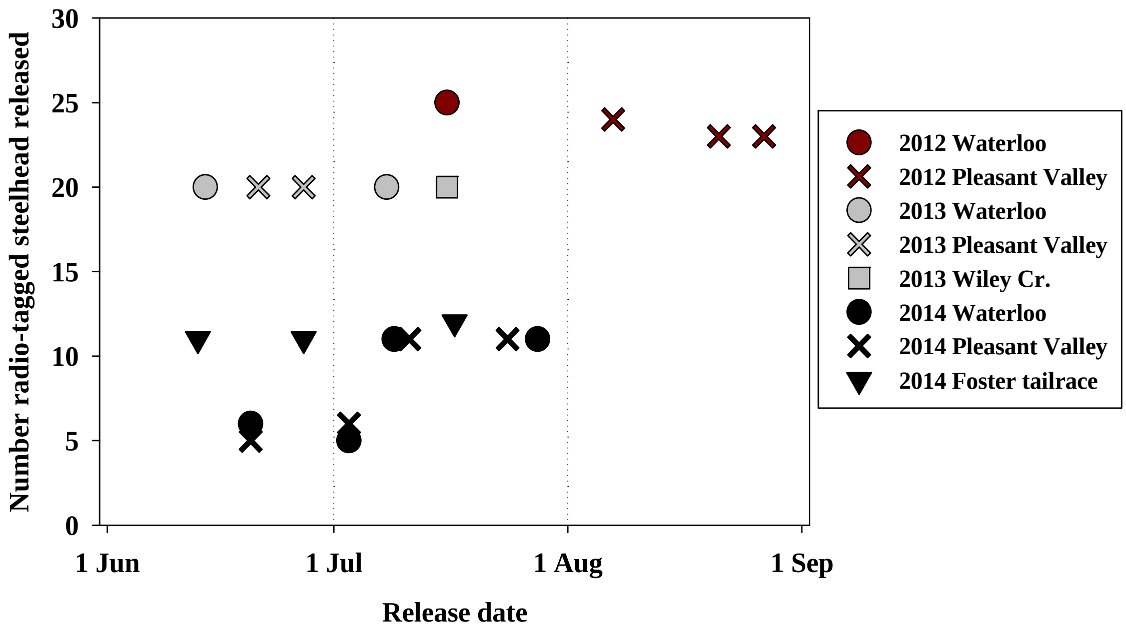

Figure 10. Number of radio-tagged summer steelhead recycled by release location and date in the South Santiam River, 2012-2014.

A total of 149 summer steelhead were collected at the Dexter Fish Facility, radio-tagged, and released directly into the Dexter Dam tailrace in 2012-2014 (Figure 11). Tagged individuals were released on two dates in 2012 and four dates in 2013 and 2014. Movements were monitored using the fixed-site array of receivers and mobile tracking, by returns to the Foster and Dexter dam traps, and by reported recapture events by anglers.

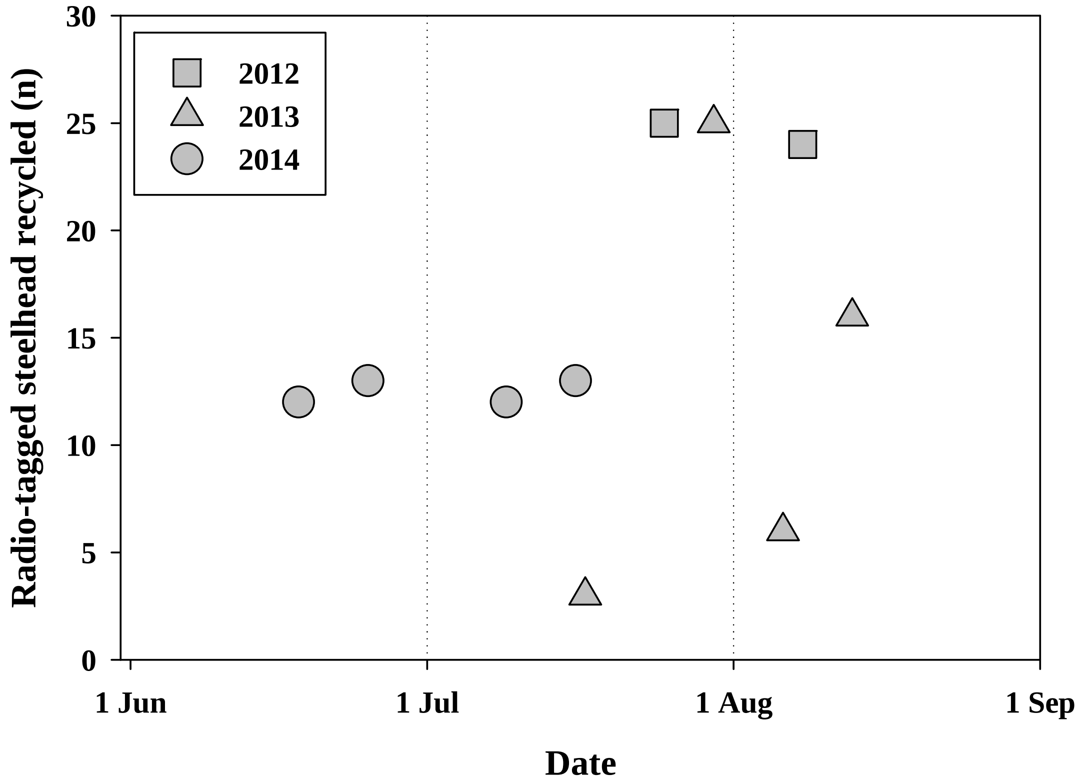

Figure 11. Numbers of radio-tagged steelhead recycled by date to the Dexter Dam tailrace, 2012-2014.

Chinook salmon collection and tagging

We radio-tagged a total of 1,249 Chinook salmon from 2011 through 2014 at Willamette Falls Dam (Table 3 and Figure 12). The 150 salmon tagged in 2011 represented ~0.3% of the 43,543 Chinook salmon counted through 31 July, which was 85% of the ten year average. Twenty-five percent (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). Almost all (145/150) radio-tagged salmon also had an archival temperature logger (Thermochron iButton, Embedded Data Systems, Lawrenceberg, Kansas) attached to the transmitter in 2011.

The 2012 sample included a disproportionate number of unclipped Chinook 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). The 500 salmon tagged in 2012 represented 1.4% of the 35,717 Chinook salmon counted through 31 July, which was 71% of the ten year average. About half of the unclipped salmon were anesthetized in 2012 as part of a second year of experimental tests of AQUI-S 20E versus fish restraint (see Jepson et al. 2013 and Caudill et al. 2014 for experiment summaries). Ninety-nine of the clipped salmon had a temperature logger in 2012.

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, 2011-2014.

	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)
2014	300	224	76	-	300	0

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 12). The 2013 count was approximately 61% of the ten year average. 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 for 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 archival 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. See Keefer et al. (2015) for a summary of the 2011-2013 temperature logger data.

We radio-tagged 300 spring Chinook salmon in 2014 from 15 April through 24 June, which was 1.0% of the 29,877 adults counted at the dam from 1 April through 31 July (Figure 12). The 2014 count was approximately 75% of the ten year average. Seventy-six (25%) of the 300 tagged fish had intact adipose fins and 324 (75%) had clipped adipose fins. We estimated that 6,364 of the 29,877 salmon counted had unclipped adipose fins based on a 21.3% wild composition estimate provided by ODFW. The 76 radio-tagged salmon with intact adipose fins were 1.2% (76/6,364) of the estimated unclipped run. The 224 adipose-clipped salmon were ~1.0% (229/23,513) of the estimated clipped run. No mortality events occurred during tagging or handling in 2014 and all salmon were released in good condition. However, one tagged salmon was found dead in the trap one week after being released.

From 2011-2014, a total of 9 transmitters placed in radio-tagged Chinook salmon were recovered in Fishway 1 at Willamette Falls Dam during ladder dewatering events or found in the recovery/release chamber (annual range = 0 to 4 tags; 0.7% of all tags). Six were from unclipped salmon and three were from clipped salmon. These nine fish with presumed regurgitated transmitters were excluded from all analyses and modified sample sizes were: 147 (2011), 496 (2012), 297 (2013) , and 300 (2014). Among the four years, there were 23 Chinook salmon transmitters that produced detections only at Willamette Falls Dam (annual range = 2 – 13), but all tags had credible radio detections, suggesting that none of the 23 tags failed. There were no detections for tags placed in two Chinook salmon in 2012, suggesting that the tags may have failed. Salmon with no detections or detections only at the dam may have regurgitated their transmitters but we conservatively included these fish in all analyses.

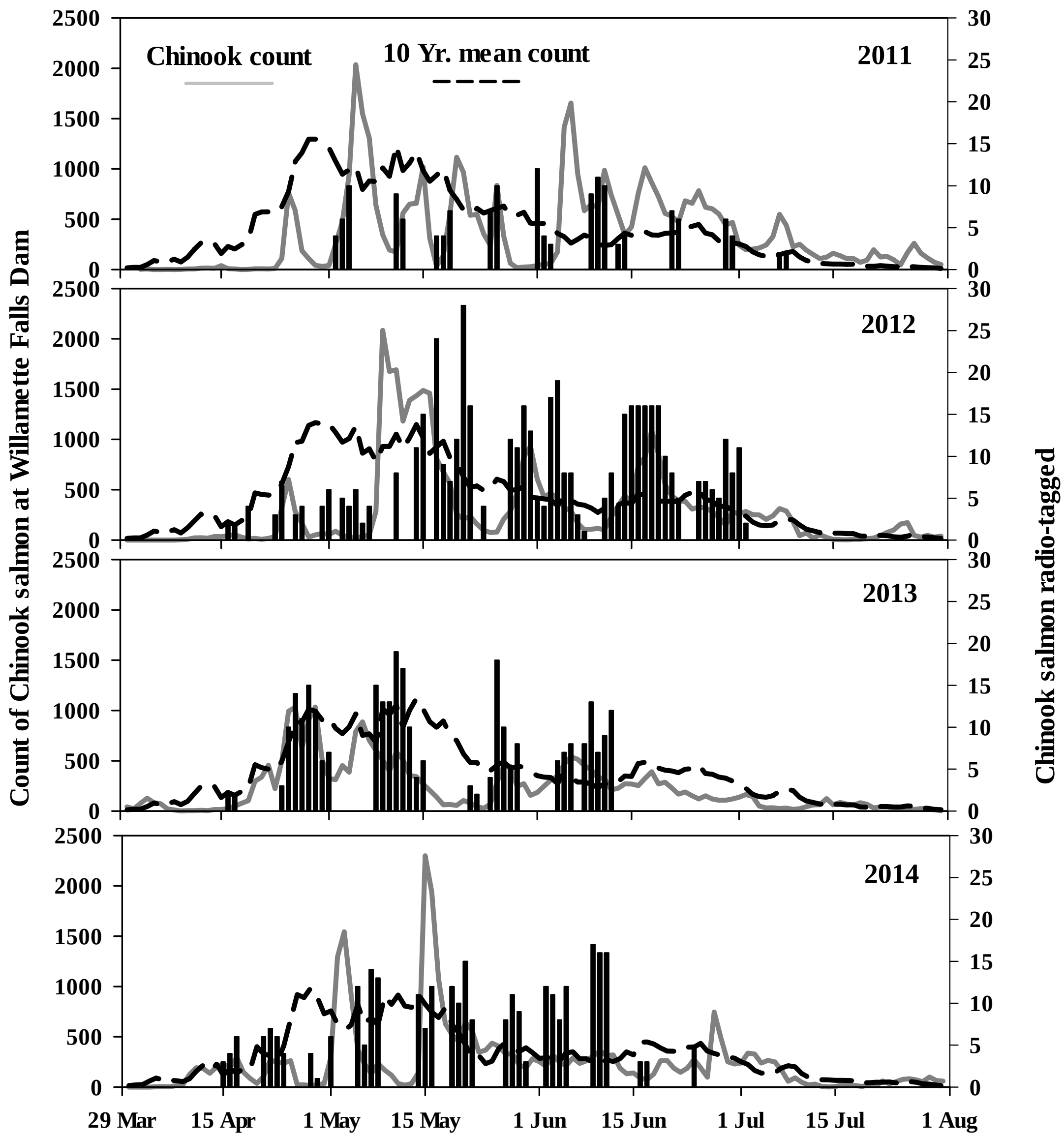

Figure 12. The number of adult Chinook salmon counted at Willamette Falls Dam (solid line), the ten-year average count (dashed line), and the number of Chinook salmon radio-tagged (bar) in 2011-2014. Count data from http://www.cbr.washington.edu/dart/adult.html and http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Coho salmon collection and tagging

We radio-tagged 219 adult coho salmon at Willamette Falls Dam from 12 September through 28 October 2014, which was 1.2% of the 18,045 adult coho salmon counted at the dam from 1 August through 1 December (Figure 13). The 2014 count was approximately two times the ten year average count. All tagged coho salmon had intact adipose fins. No mortality events occurred during tagging or handling and all salmon were released in good condition. However, one tagged salmon was found dead in the trap approximately one month after being released and after being detected on the receiver downstream from the trap in Fishway 1.

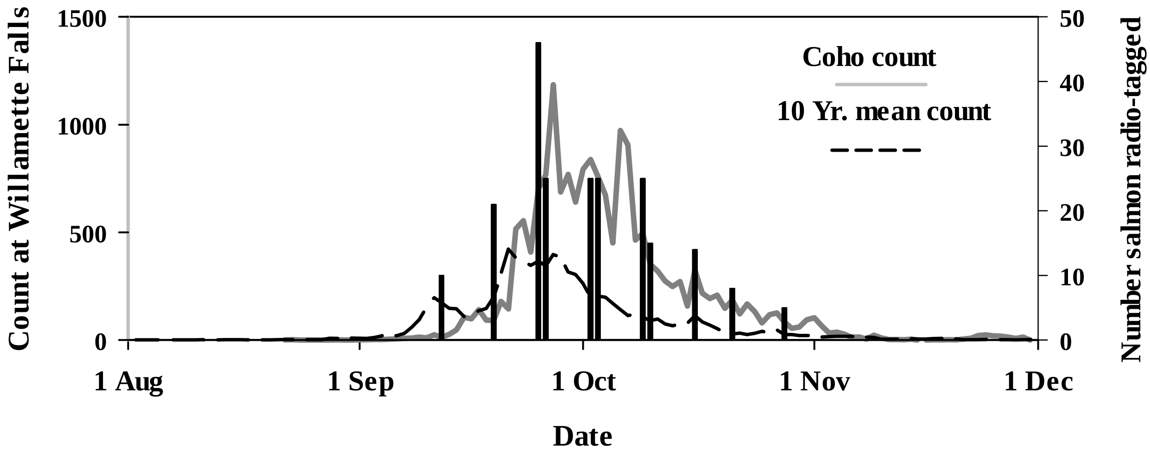

Figure 13. The number of adult coho salmon counted at Willamette Falls Dam (solid line), the ten-year average count (dashed line), and the number of Chinook salmon radio-tagged (bar) in 2014. Count data from http://www.cbr.washington.edu/dart/adult.html and http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Physical characteristics of tagged fish

In 2014, the mean fork lengths of winter steelhead, summer steelhead, spring Chinook salmon, and coho salmon radio-tagged at Willamette Falls Dam were 70.5, 68.1, 76.3, and 69.3 cm, respectively (Figure 14). The mean weights were 3.6, 3.2, 5.8, and 4.0 kg, respectively. Distributions for all groups were slightly right-skewed. Distell Fatmeter readings collected at the time of tagging decreased with increasing tag date for winter steelhead ($r^2 = 0.15$, $P < 0.001$), Chinook salmon ($r^2 = 0.15$, $P < 0.001$) and coho salmon ($r^2 = 0.10$, $P < 0.001$, Figure 15). Chinook salmon exhibited the highest absolute fatmeter values and the highest among-fish variation. There was no evidence for a seasonal pattern for summer steelhead fatmeter readings ($r^2 = 0.01$).

Marine mammal injuries were observed in all run/species radio-tagged in 2014 (Table 4). Forty-four percent of the winter steelhead had injuries ranging in type and severity from minor scrapes to major cuts. A smaller percentage of the summer steelhead tagged (38%) had injuries attributable to marine mammals, 31% of the tagged spring Chinook salmon showed signs of such injuries, and coho salmon exhibited the smallest percentage (15%).

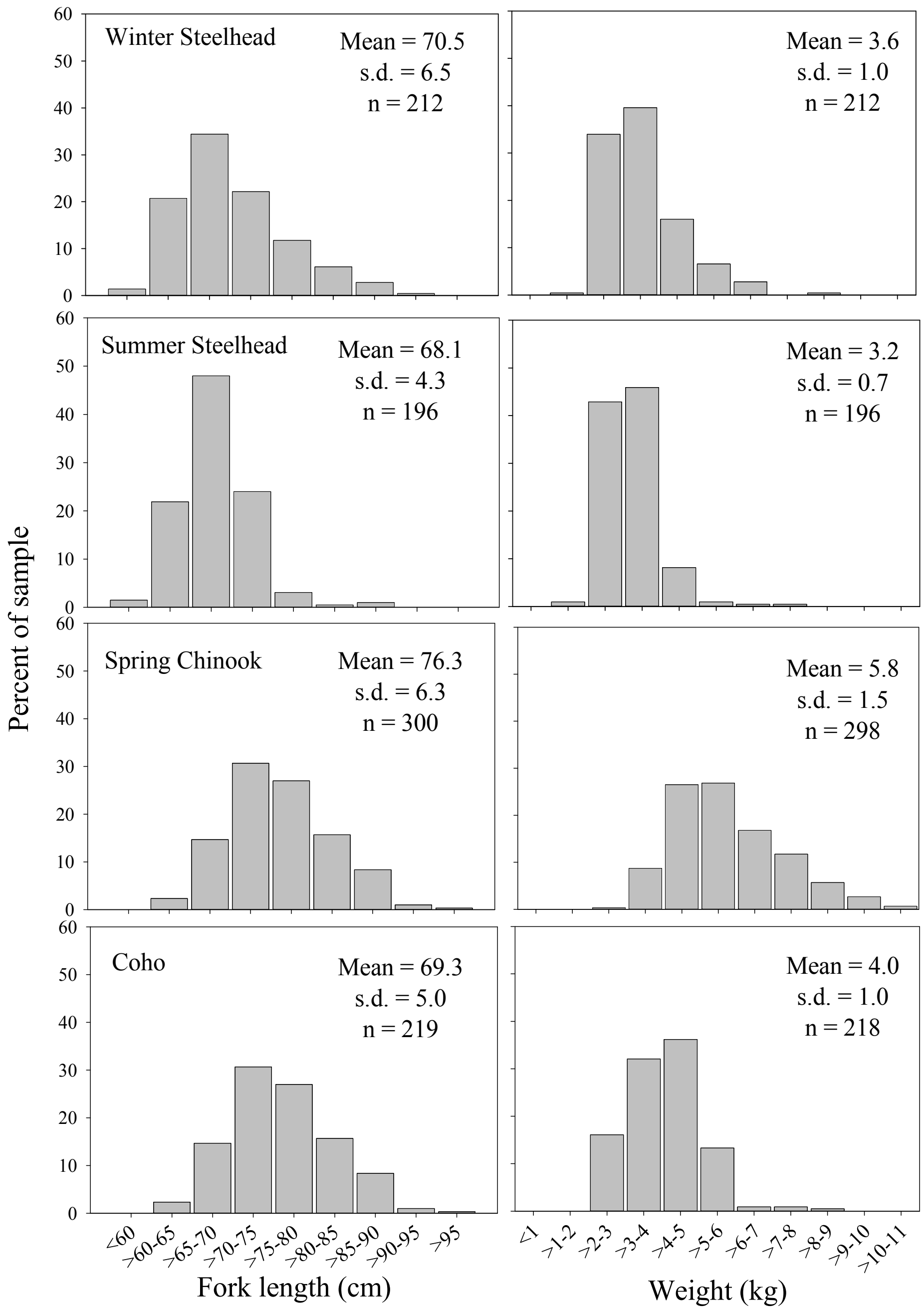

Figure 14. Histograms of fork lengths (cm) and weights (kg) of winter steelhead, summer steelhead, spring Chinook salmon, and coho salmon that were radio-tagged at Willamette Falls Dam in 2014.

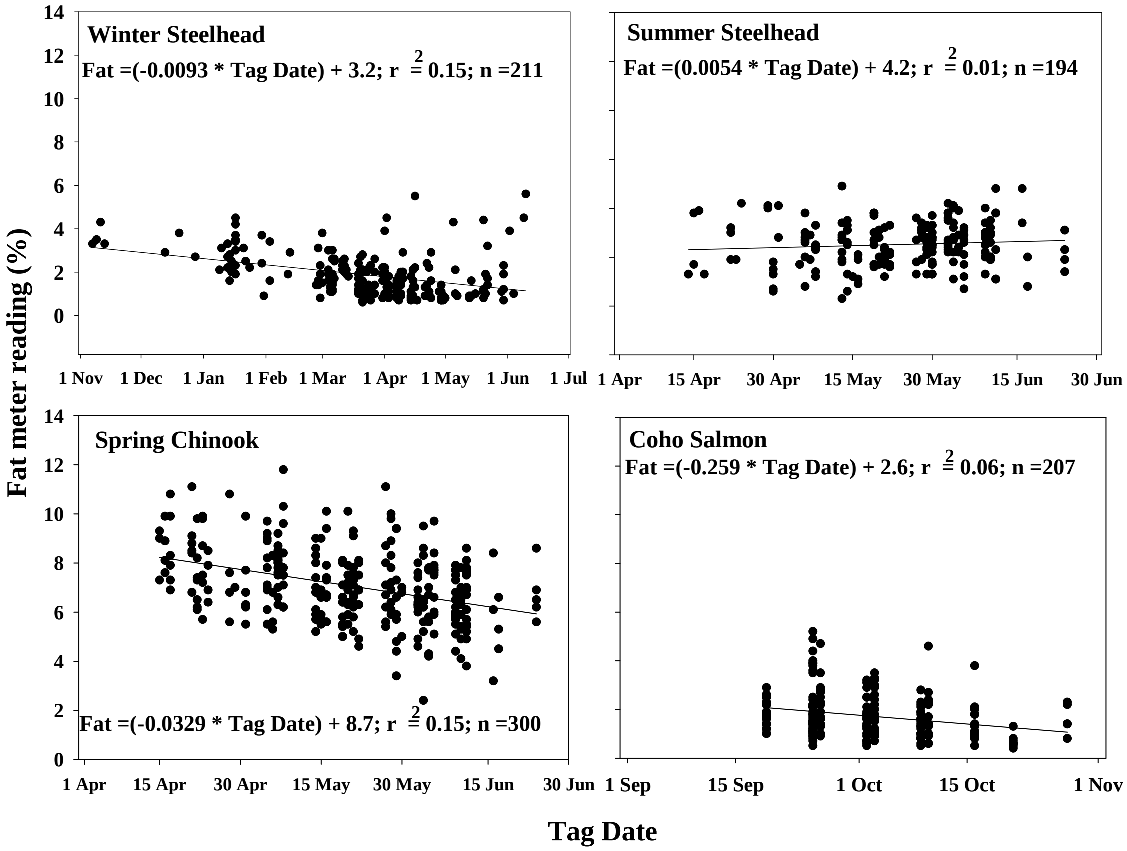

Figure 15. Relationship between Distell fatmeter readings and fish tag date for winter steelhead, summer steelhead, spring Chinook salmon, and coho salmon radio-tagged at Willamette Falls Dam in late 2013 through 2014. Note different ranges along the x-axes.

Table 4. Frequencies and percentages (parentheses) of marine mammal injuries in salmon and steelhead radio-tagged at Willamette Falls Dam in 2014.

	Marine mammal injuries					
Run/species	None	Minor Scrape(s)	Major Scrape(s)	Minor Cut(s)	Major Cut(s)	Total
Winter SH	119 (56)	22 (10)	3 (1)	34 (16)	34 (16)	212 (100)
Spring CK	206 (69)	30 (10)	1 (<1)	33 (11)	30 (10)	300 (100)
Summer SH	122 (62)	20 (10)	5 (3)	30 (15)	19 (10)	196 (100)
Coho	187 (85)	14 (6)	0 (0)	14 (6)	4 (2)	219 (100)

Results: Winter steelhead

Historic count data and run timing

The number of adult winter steelhead counted passing Willamette Falls Dam from 1 November 2013 to 30 May 2014 was 5,050 (Figure 16). This was at the low end of the range of counts since 1971 but was approximately 3,250 more fish than the lowest count of 1,801 in 1996. The 2014 winter steelhead run was the latest-timed run in the last thirteen years (Figure 17). The 2014 median passage date was 23 March, compared to medians that ranged from 19 February to 16 March in 2002-2013.

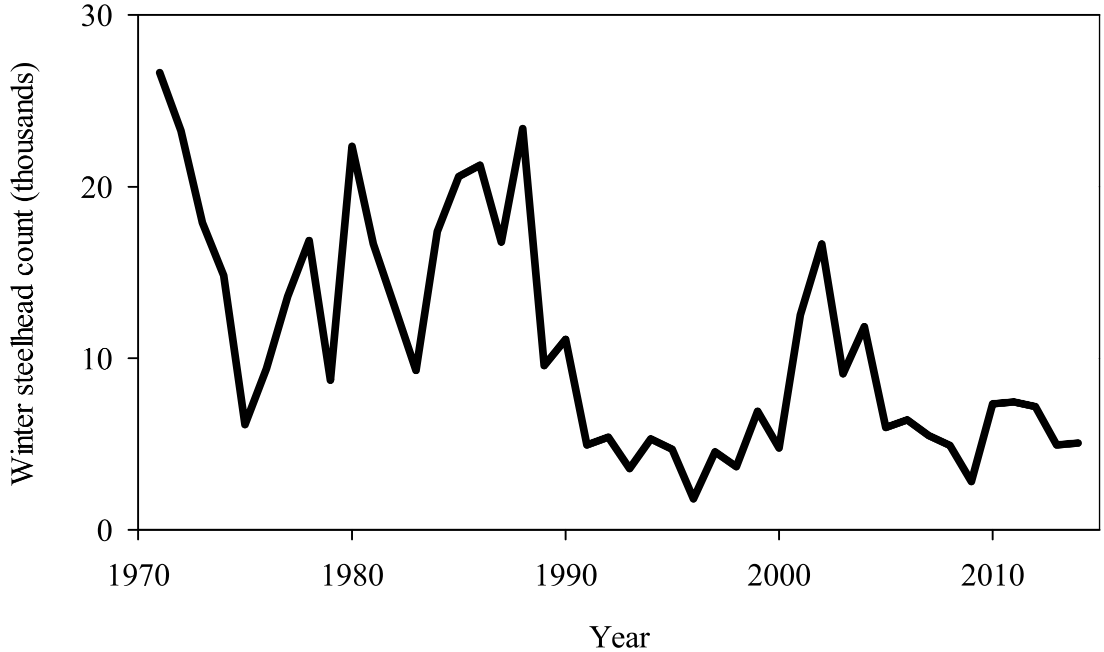

Figure 16. Total annual numbers of adult winter steelhead counted passing Willamette Falls Dam, 1971-2014. Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

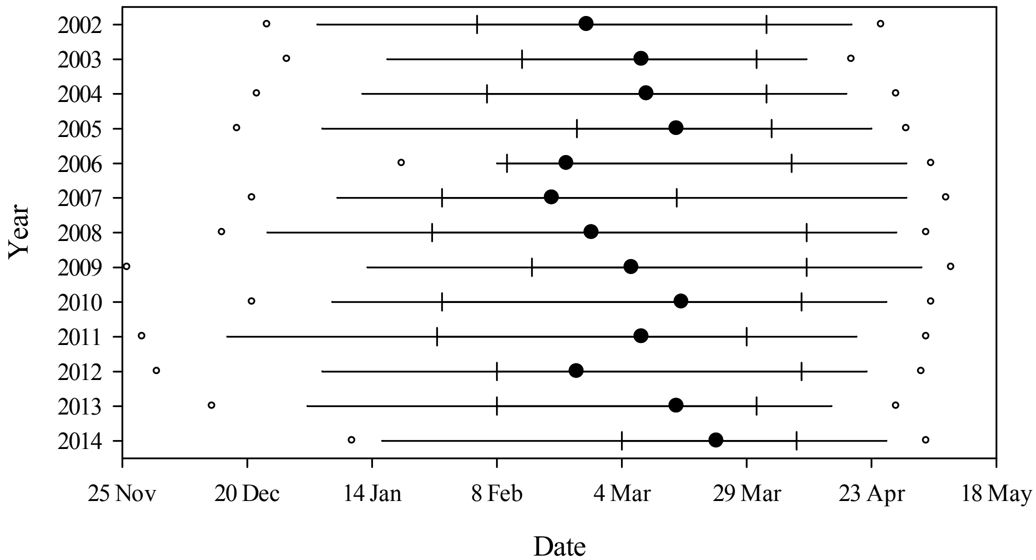

Figure 17. Annual migration timing distributions for winter steelhead counted at Willamette Falls Dam, 2002-2014. Symbols show median (●), quartile (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (○). Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

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 all study years (Figure 18). On median, 26 winter steelhead took 7.7 d (*range* = 5.5-23.7 d) to migrate through the 205-km main stem reach from above Willamette Falls Dam (receiver WFU) to near Harrisburg (receiver WL5) in 2014. This was similar to the 7.2 d and 7.0 medians for the same reach in 2012 and 2013, respectively. Other main stem reach 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 18).

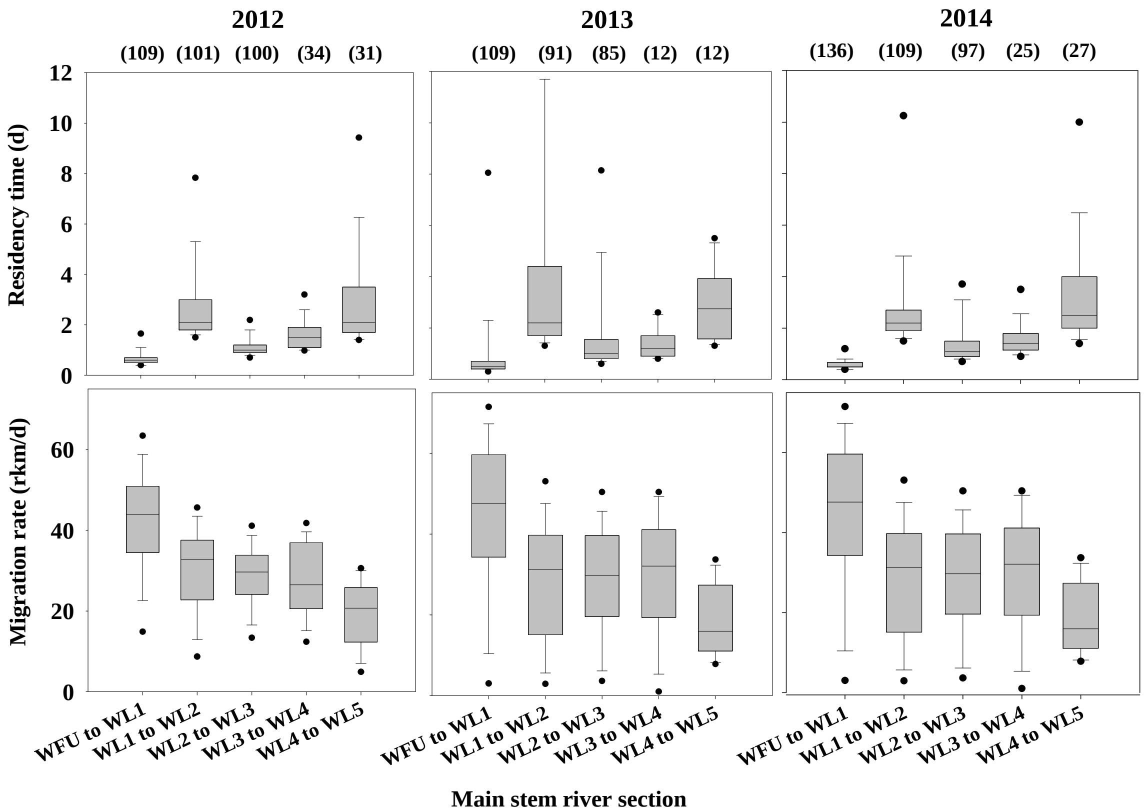

Figure18. Box plots of residence times (days, upper panels) and migration rates (rkm/d, lower panels) of radio-tagged winter steelhead in reaches of the main stem Willamette River in 2012 (left panels), 2013 (middle panels), and 2014 (right panels). Box plots show: median) and quartile (box), 10^{th} and 90^{th} (whisker), and 5^{th} and 95^{th} percentiles (filled circles). Sample sizes are listed in parentheses above panels.

Last (post-spawn) and maximum upstream (pre-spawn) radio detections - 2014

Almost two-thirds of tagged winter steelhead in 2014 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 19 and 20). Smaller percentages were last recorded in the Santiam (15%), Middle Fork (6%) and Molalla (3%) rivers. Two percent were last recorded in the upper main stem. These distributions of last detections of tagged winter steelhead were similar among all three study years.

We also estimated distribution by the maximum river kilometer where steelhead were detected to better approximate spawning distribution among tributaries. In 2014, the highest percentage (46%) of tagged winter steelhead was in the Santiam River (N. Santiam 24%; S. Santiam 21%; Figures 21 and 22). Fourteen percent had their most upstream records in the Molalla River. Smaller percentages were in the Middle Fork (8%),Clackamas (5%), Yamhill (3%), Calapooia (3%), and McKenzie (1%) rivers. Eleven radio-tagged winter steelhead were detected in the Clackamas River and two of the 11 had their final detections there (i.e., nine were detected as probable kelts– see kelting section below). It was not known whether these fish originated from the

Clackamas River or from a site upstream from Willamette Falls Dam. The eleven 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 5). Mean fate-specific fork lengths ranged from 64.3 cm to 81.5 cm. Steelhead assigned to the Fall Creek, Santiam, Middle Fork and Rickreall Creek groups were larger, on average, than those assigned to the Clackamas, Calapooia, Molalla, Tualatin, Coast Fork, and Yamhill groups. Mean fork length for steelhead from the North Santiam group (71.6 cm, n = 51) was similar to the mean for South Santiam steelhead (71.4 cm, n = 45). Mean fatmeter readings among fate groups ranged from 0.8 to 5.6%, with the highest estimates for Coast Fork, McKenzie, Fall Creek, and upper main stem groups. There were also among-group differences in tagging date. The earliest mean dates were for the 'at Willamette Falls Dam', Yamhill, Calapooia, Clackamas, and Rickreall Creek groups (mid-February to early March). The latest mean dates were for Coast Fork, McKenzie, upper main stem, Middle Fork, and lower Santiam groups (mid-April to early June). The distribution of mean tag dates among groups varied among study years but steelhead that returned to the Yamhill, Tualatin, and Molalla rivers tended to have earlier mean tag dates and steelhead that returned to the McKenzie River and the Middle Fork had later mean tag dates.

Overall, 178 (84.0%) of the 212 winter steelhead tagged in the 2014 run year were considered to have escaped to a tributary and considered successful migrants (please note: escapement to a tributary can not be considered equivalent to spawning success). Of the 34 'early' winter steelhead radio-tagged in late 2013 and early 2014 (before 15 February), only 18 (53%) escaped to a tributary and 16 (47%) had fates in the main stem downstream from Willamette Falls Dam, at the dam, or in the lower main stem (Figure 23). In contrast, 160 (90%) of the 178 winter steelhead tagged after 15 February 2014 migrated successfully to a tributary. This was higher than the tributary escapement rate observed in both 2012 (80.7%; 147 escaped/182 tagged) and 2013 (83.5%; 142 escaped/170 tagged).

We used the logistic regression model [Escape to tributary (y/n) = tag date + weight + fork length + head injuries (y/n) + marine mammal injuries (y/n) + descaling (y/n)] to evaluate potential predictors of escapement in individual years. We excluded a weight variable because of its correlation with fork length. Tag date was a significant predictor of tagged winter steelhead escaping to a tributary in 2012 and 2014 (Tag date P = 0.01-0.03; Table 6), with fish tagged later in the run having increased probabilties of escaping. The presence of a head injury was a significant predictor of escaping to a tributary in one of the three years (2012), with fish having a head injury having a decreased probability of escaping.

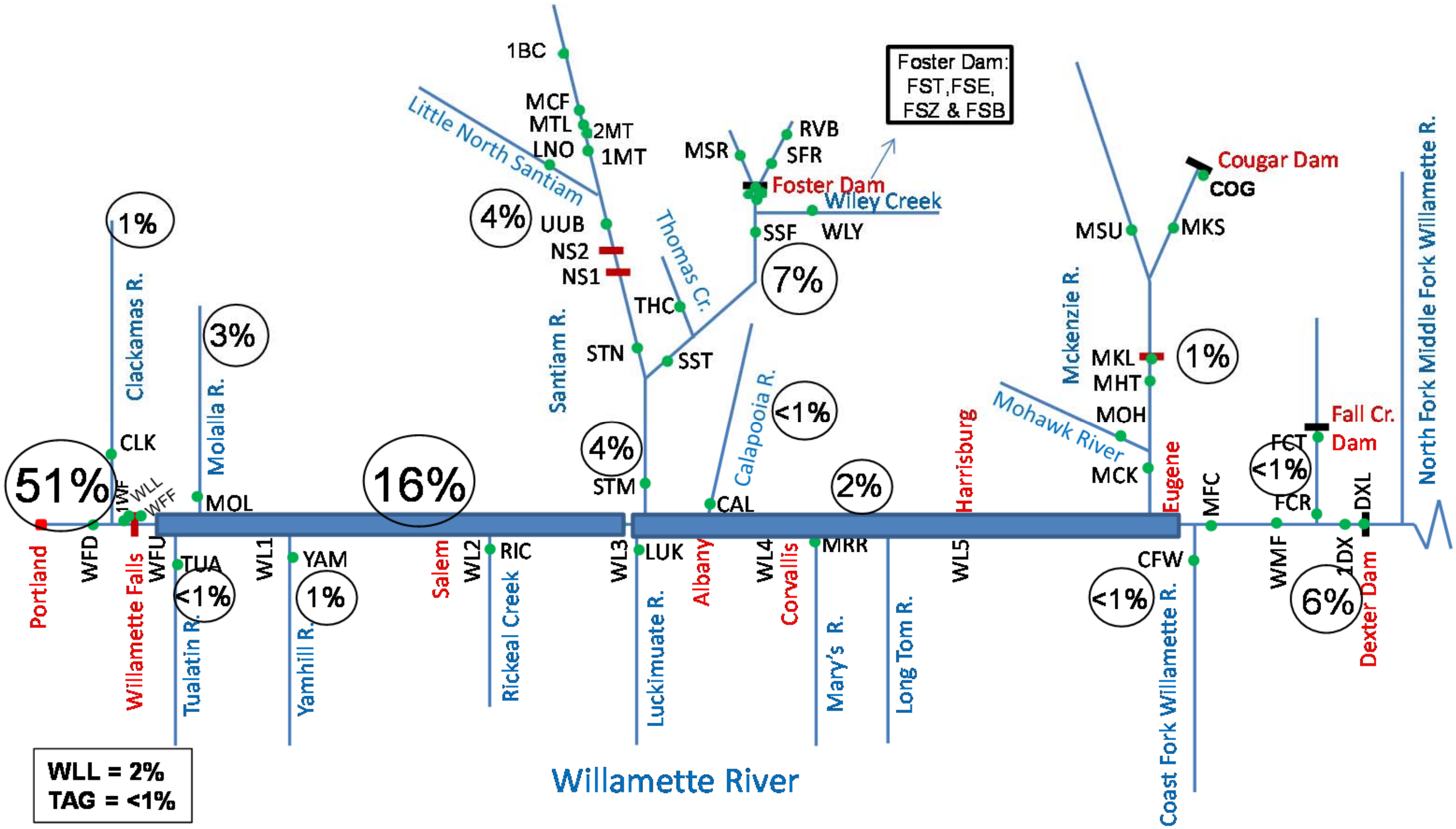

Figure 19. Sites and river basins where radio-tagged adult winter steelhead were **last detected** in 2014 (i.e., includes post-spawn kelt movements) shown as percentages. Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference. The blue rectangles represent the upper and lower main stem.

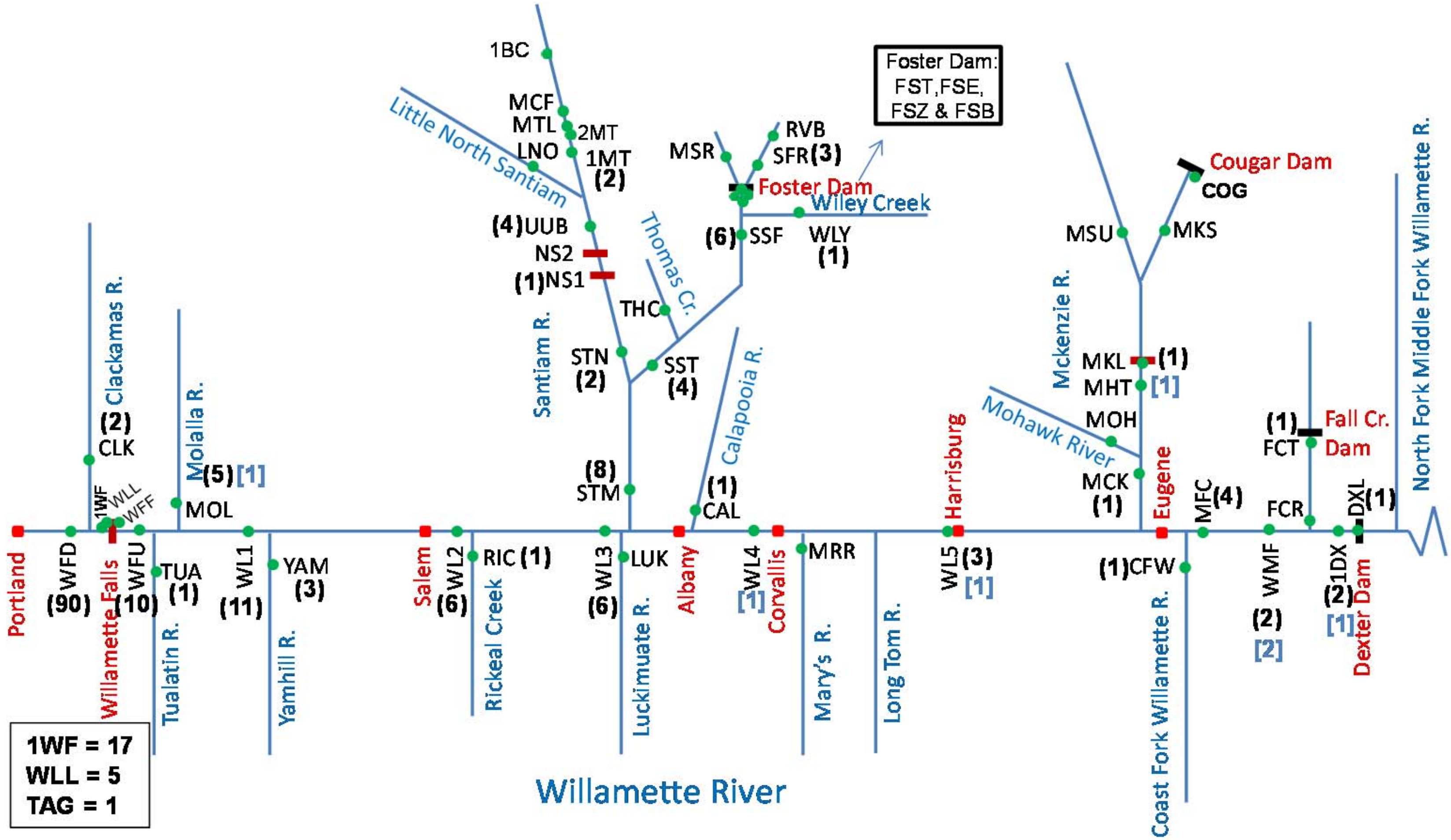

Figure 20. Sites and river basins where radio-tagged adult winter steelhead were **last detected** in 2014 (i.e., includes post-spawn kelt movements) or where they were recaptured (blue font and brackets) shown as numbers of steelhead. Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference.

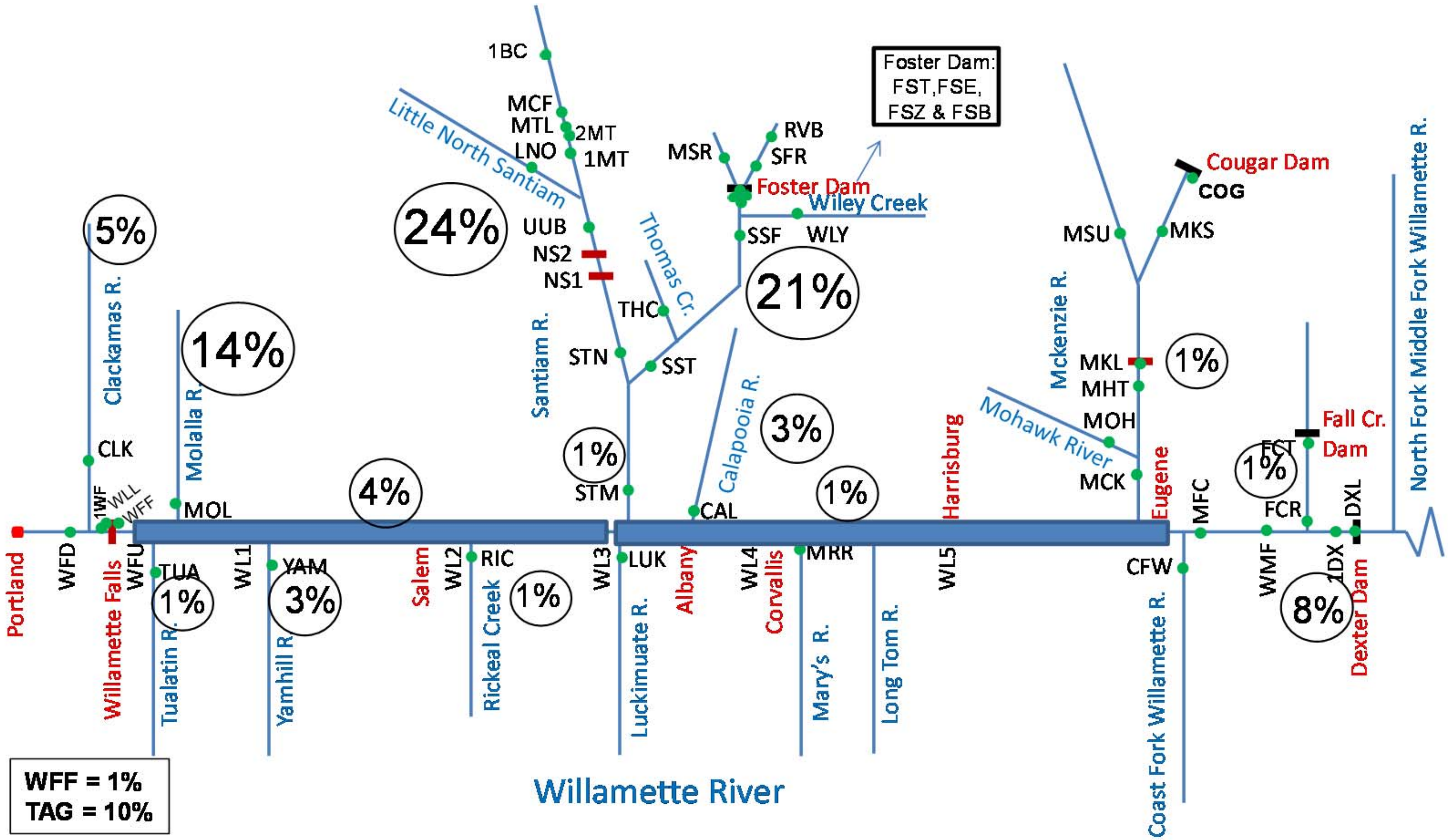

Figure 21. Sites and drainages where adult winter steelhead radio-tagged and released at Willamette Falls Dam in 2014 migrated for potential spawning based on their **maximum river kilometer** ($n = 212$) shown as percentages. The blue rectangles represent the upper and lower main stem.

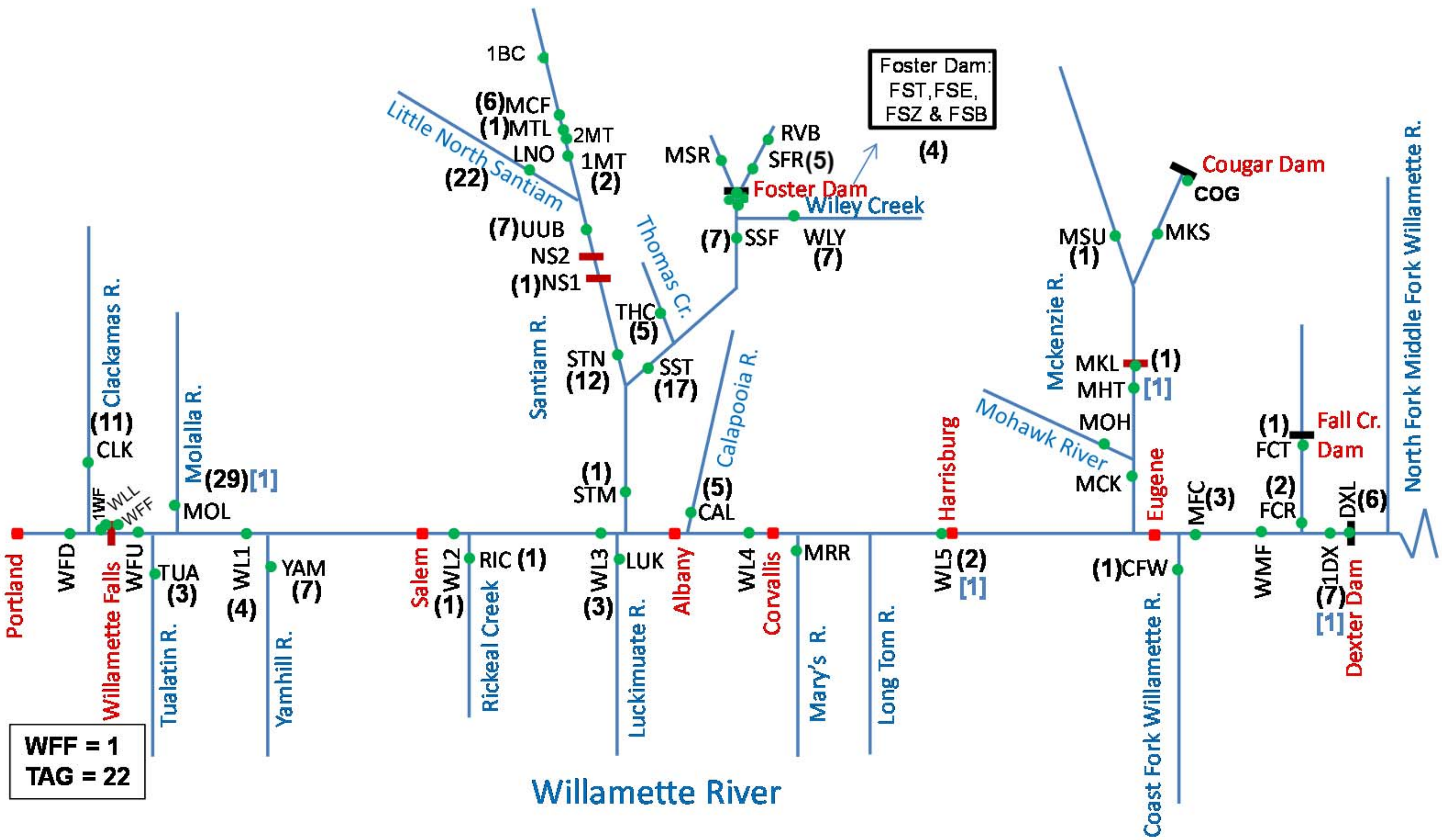

Figure 22. Sites and drainages where adult winter steelhead radio-tagged and released at Willamette Falls Dam in 2014 migrated for potential spawning based on their **maximum river kilometer** shown or where they were recaptured (blue font and brackets) shown as numbers of steelhead.

Table 5. Fate-specific sample sizes and mean tag date, fork length, weight, and fatmeter readings for radio-tagged adult winter steelhead within the Willamette River basin in 2014.

Fate	*n*	Mean tag date	Mean fork length (cm)	Mean weight (kg)	Mean fatmeter (%)
Clackamas River	11	5 Mar.	70.2	3.69	1.8
At Dam	5	12 Feb.	65.9	3.00	3.2
Lower main stem[1]	8	7 Apr.	67.6	3.24	1.8
Tualatin River	3	15 Mar.	68.7	3.35	0.8
Molalla River	30	19 Mar.	69.0	3.31	1.9
Yamhill River	7	1 Mar.	66.9	3.05	1.8
Rickreall Creek	1	6 Mar.	81.5	5.67	1.2
S. Santiam River	45	29 Mar.	71.4	3.62	1.7
N. Santiam River	51	23 Mar.	71.6	3.77	1.7
Santiam R. (lower)	1	14 Apr.	72.0	3.46	0.8
Calapooia R.	5	5 Mar.	69.3	3.50	1.7
Upper main stem[2]	3	8 May	68.0	3.21	2.5
McKenzie River	3	19 May	64.3	2.54	4.2
Coast Fork	1	10 Jun.	68.0	2.87	5.6
Fall Creek	2	30 Mar.	75.8	4.14	2.5
Middle Fork	18	5 May	71.3	3.62	1.7

[1] reach between Willamette Falls Dam and the WL3 receiver site (Buena Vista)
[2] reach between the WL3 receiver site and the confluence of the Coast Fork Willamette and Middle Fork Willamette rivers

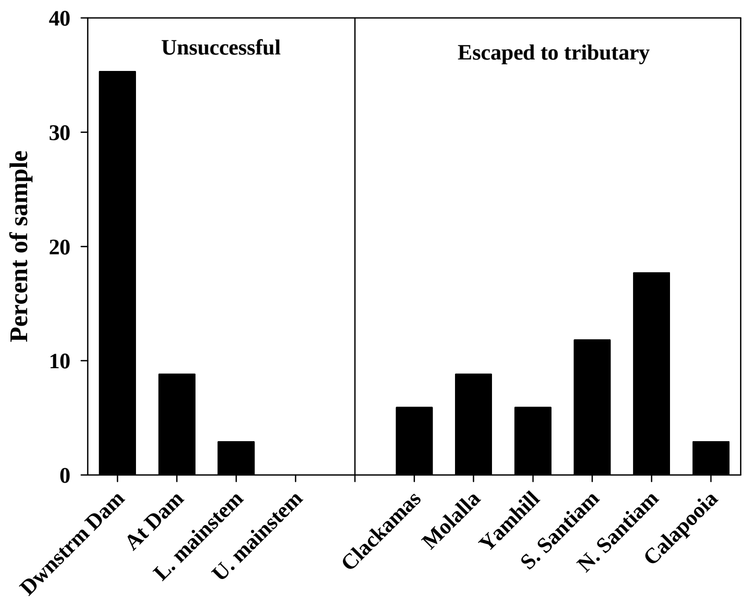

Figure 23. Histogram of maximum river kilometer for early-run winter steelhead (n = 34) radio-tagged at Willamette Falls Dam from 7 November 2013 through 13 February 2014.

Table 6. Logistic regression output for [Escape to tributary (y/n) = tag date + fork length+ fat + head injuries (y/n) + marine mammal injuries (y/n) + descaling (y/n)] model for winter steelhead radio-tagged at Willamette Falls, 2012-2014. P<0.05 in bold

	2012 (n = 182)		2013 (n = 170)		2014 (n = 211)	
	χ^2	$P>\chi^2$	χ^2	$P>\chi^2$	χ^2	$P>\chi^2$
Tag date	**7.47**	**0.01**	1.47	0.23	**4.88**	**0.03**
Fork length	0.17	0.68	1.75	0.19	0.84	0.36
Fat	0.98	0.32	1.77	0.18	1.81	0.18
Head injury	**7.20**	**0.01**	0.03	0.87	0.39	0.53
Marine mammal inj.	0.00	0.99	0.45	0.50	0.45	0.50
Descaling	0.09	0.76	3.42	0.06	0.06	0.81

Estimated returns by sub-basin

We used the 2014 distribution of radio-tagged fish and winter steelhead counts at Willamette Falls Dam to estimate total escapement to individual tributaries (Table 7). We expanded the escapement proportions of the tagged fish (n = 212) using two ODFW count scenarios: 1) the count beginning 15 February 2014 (the nominal start of the 'native' run) through 31 May 2014; and 2) the count from 1 November 2013 (start of the winter run according to ODFW) through 31 May 2014. The number of winter steelhead counted during the tagging interval (7 Nov. 2013 – 10 June 2014) differed from the count between 1 November 2013 through 31 May 2014 by just fourteen fish so we did not estimate escapement based on a 'tagging interval' scenario in 2014 (in contrast to previous study years). 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 estimated number of adults returned to the South Santiam River, with point estimates ranging from 1,085 to 1,287 individuals across the two scenarios (Table 7). The next highest estimates were to the N. Santiam (957-1,135) and Molalla rivers (638-757). Fewer than 100 winter-run steelhead were estimated to have returned to the McKenzie River under either scenario.

Table 7. 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 = 212) and three scenarios of ODFW count data from Willamette Falls Dam in 2014.

			Winter Steelhead Counted	
			From 15 Feb. n = 4,510	From 1 Nov. n = 5,349
Tributary	n	% (95% ci)	Estimate	Estimate
None	34	16.0 (11.7 – 21.6)	723 (528 - 973)	858 (626 – 1,154)
Clackamas	11	5.2 (2.9 – 9.0)	234(132 - 408)	278 (156 - 484)
Tualatin	3	1.4 (0.5 – 4.1)	64 (22 - 184)	76 (26 - 218)
Molalla	30	14.2 (10.1 – 19.5)	638 (455 - 879)	757 (540 – 1,042)
Yamhill	7	3.3 (1.6 – 6.7)	149 (73 - 300)	177 (86 - 356)
Rickreall Cr.	1	0.5 (0.1 – 2.6)	21 (4 - 118)	25 (4 - 140)
N. Santiam	45	21.2 (16.3 – 27.2)	957 (733 – 1,228)	1,135 (870 – 1,456)
S. Santiam	51	24.1 (18.8 – 30.2)	1,085 (848 – 1,364)	1,287 (1,006 – 1,618)
Santiam R. (lower)	1	0.5 (-.1 – 2.6)	21 (4 - 118)	25 (4 - 140)
Calapooia	5	2.4 (1.0 – 5.4)	106 (46 - 244)	126 (54 - 289)
McKenzie	3	1.4 (0.5 – 4.1)	64 (22 - 184)	76 (26 - 218)
Coast Fork	1	0.5 (0.1 – 2.6)	21 (4 - 118)	25 (4 - 140)
Fall Creek	2	0.9 (0.3 – 4.4)	43 (12 - 152)	50 (14 - 180)
Middle Fork	18	8.5 (5.4 – 13.0)	383 (245 - 587)	454 (291 - 696)

We compared the tributary escapement estimates to ODFW winter steelhead counts (http://www.dfw.state.or.us/fish/fish_counts/) at several sites. From January through June 2014 there were 784 steelhead at Upper Bennett Dam and 110 at Lower Bennett Dam on the North Santiam River. The combined ODFW count total (n =894) was within the 95% confidence intervals of both estimates based on radio-tagged fish (Table 7). Two hundred fifteen winter steelhead were counted at Foster Dam on the South Santiam River from April through early June 2014, which was considerably lower than the 95% confidence interval minima for all three telemetry-based estimates (*range* = 1,085-1,287). This was presumably because radio-tagged individuals could spawn in the South Santiam at sites downstream from Foster Dam (i.e., the count was not a complete census). A single steelhead without an adipose clip (i.e., nominal winter run) was counted at Leaburg Dam on the McKenzie River in June 2014 but it may have been a naturally-produced summer-run steelhead based on migration timing. Escapement estimates using the three radio-tagged winter steelhead that returned to the McKenzie River in 2014 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 radio-tagged winter steelhead considered to have escaped to tributaries in all years (Figure 24). In 2012, lower basin populations typically passed Willamette Falls Dam earlier in the run. The tributaries to which winter steelhead tagged from March through April 2012 were most likely to return were the North and South Santiam rivers. Smaller probabilities were associated with the Molalla, Clackamas, Middle Fork, Calapooia, and Yamhill rivers. For fish tagged after April, the Middle Fork, Clackamas, and Calapooia rivers were the tributaries to which migrants were most likely to return. In 2013, lower basin populations also typically passed Willamette Falls Dam relatively early in the run (Figure 24). For steelhead radio-tagged from late January through April, the Molalla, and South and North Santiam rivers were the most probable return sites for successful migrants. Population composition in 2014 was well-mixed throughout the run, with the highest return probabilities again associated with the Molalla, and the South and North Santiam rivers.

Kelting frequencies, distributions, and tributary residency times

Of the tagged winter steelhead considered to have escaped to tributaries, 58% (2012) and 57% (2013), and 62% (2014) exhibited kelt behavior (Table 8). Tributary-specific kelting percentages for sites that produced kelts ranged from 20 to 73% in 2012, from 38 to 100% in 2013, and 17 to 100% in 2014 (please note small samples sizes for many locations).

Table 8. Numbers of radio-tagged winter steelhead that entered Willamette River tributaries in 2012-2014 and the numbers and percentages that exhibited kelt behavior.

	Prespawn steelhead			Kelts			Kelt Rate (%)			Rate (%)
	2012	2013	2014	2012	2013	2014	2012	2013	2014	All Yrs.
Clackamas	10	3	11	7		9	70	0	82	67
Tualatin	3	13	3	2	7	2	67	54	67	58
Molalla	22	31	30	16	17	24	73	55	80	69
Yamhill	7	8	7	5	3	2	71	38	29	45
Rickreall		1	1		1			100	0	50
Santiam (lower)			1			1			100	100
S Santiam	29	39	45	17	28	28	59	72	62	65
N Santiam	35	29	51	27	20	36	77	69	71	72
Calapooia	3	7	5	1	3	4	33	43	80	53
McKenzie	5	3	3	1	1		20	33	0	18
Coast Fork	1		1				0		0	0
Fall Creek	2	1	2		1	1	0	100	50	40
Middle Fork	33	7	18	11		3	33	0	17	24
Annual Total	150	142	178	87	81	110	58	57	62	

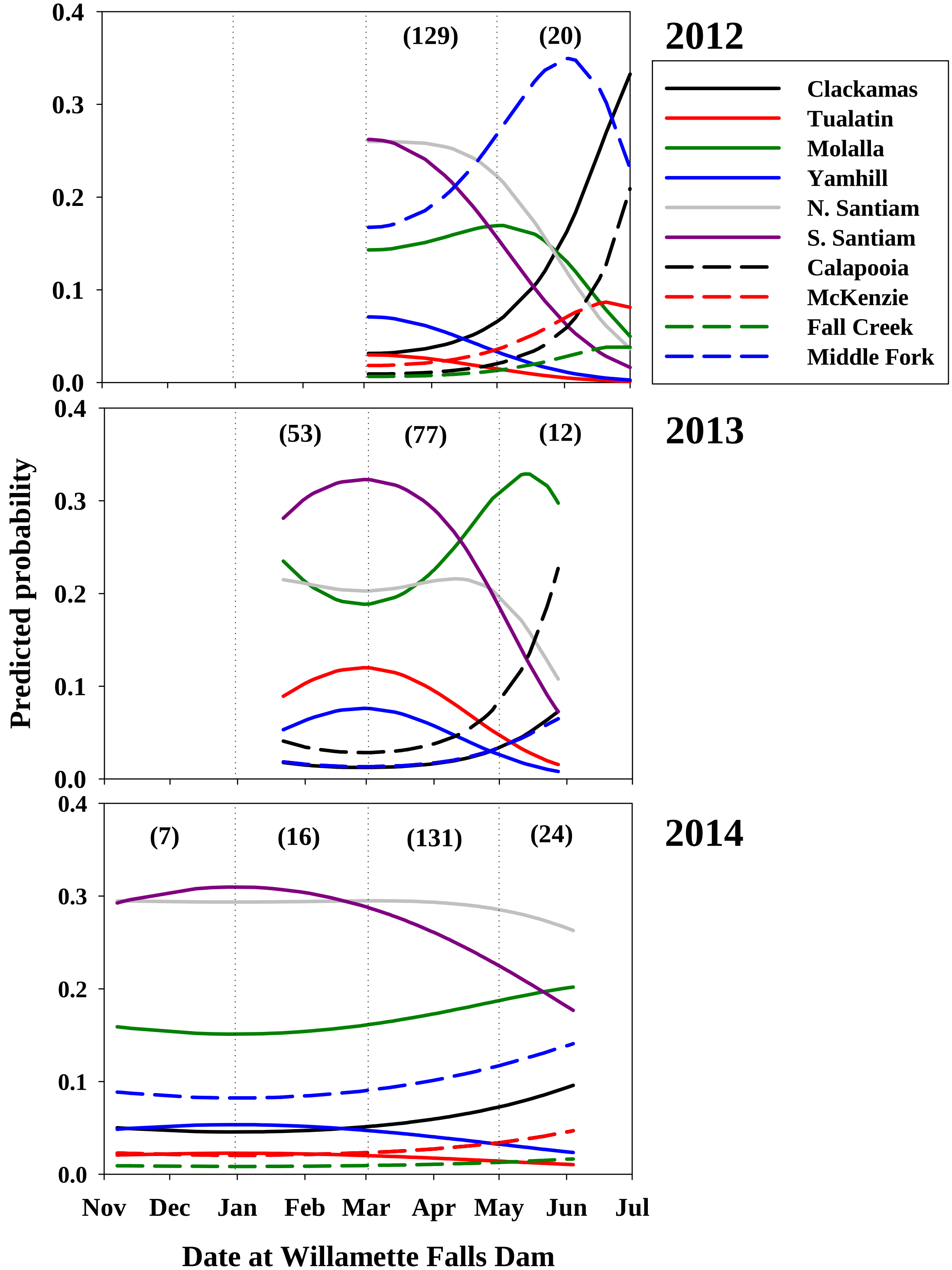

Figure 24. Estimates of run composition based on predicted probabilities from multinomial logistic regressions of 'escaped' winter steelhead radio-tagged at Willamette Falls Dam in 2012 (upper panel), 2013 (middle panel), and 2014 (lower panel). Sample sizes for each bi-month are in parentheses.

Mean tributary entry dates for prespawn steelhead that eventually showed kelt behaviors ranged from 17 March to 14 May and mean residency times ranged from 13 to 38 days (Table 9). 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 9).

Table 9. 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 2014. Note: sex was estimated at time of tagging.

Tributary	Estimated Sex	Mean entry date	Mean exit date	Residence time (d) mean	s.d.	*n*
Clackamas	F	29 March	15 April	17.3	11.4	6
	M	28 March	3 April	7.0	2.4	3
	All	29 March	11 April	13.8	10.5	9
Tualatin R.	F	1 March	24 March	23.0	-	1
	M	26 March	16 May	51.1	-	1
	All	13 March	19 April	37.1	19.9	2
Molalla R.	F	1 April	26 April	25.6	9.5	8
	M	24 March	27 April	33.5	22.2	16
	All	27 March	27 April	30.8	19.1	24
Yamhill R.	F	1 April	17 April	16.0	5.1	2
N. Santiam R.	F	2 April	30 April	28.2	27.0	27
	M	30 March	1 May	31.8	23.4	9
	All	1 April	30 April	25.9	25.9	36
S. Santiam R.	F	15 April	30 April	14.8	5.2	14
	M	12 March	26 April	45.4	38.8	14
	All	29 March	28 April	30.1	31.3	26
Santiam R. (lower)	F	20 April	27 April	6.9	-	1
Calapooia R.	F	27 March	15 April	18.6	10.2	3
	M	1 April	20 April	18.1	-	1
	All	28 March	16 April	18.5	8.4	4
McKenzie R.	M	31 May	22 June	21.1	-	1
Fall Creek	M	31 March	25 April	25.1	-	1
Middle Fork	F	10 May	18 May	8.2	4.5	3

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. All 212 winter steelhead tagged in 2014 had scale samples collected from them. Personnel from ODFW Fish Life History Analysis Project aged fish tagged in 2012-2013 and samples collected in 2014 are currently being processed by University of Idaho staff. 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 25). 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.

Results: Summer steelhead

Historic count data and run timing

The annual count of adult summer steelhead passing Willamette Falls Dam in 2014 was 22,941 (Figure 26). This was approximately 7,500 more fish than the average count since 1971 (15,290) and approximately 18,000 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 27). The 2014 run was one of the latest timed since 2001. The median passage dates were 1 June (2012), 2 June (2013), and 16 June (2014); medians ranged from 17 May to 11 June in 2001-2011.

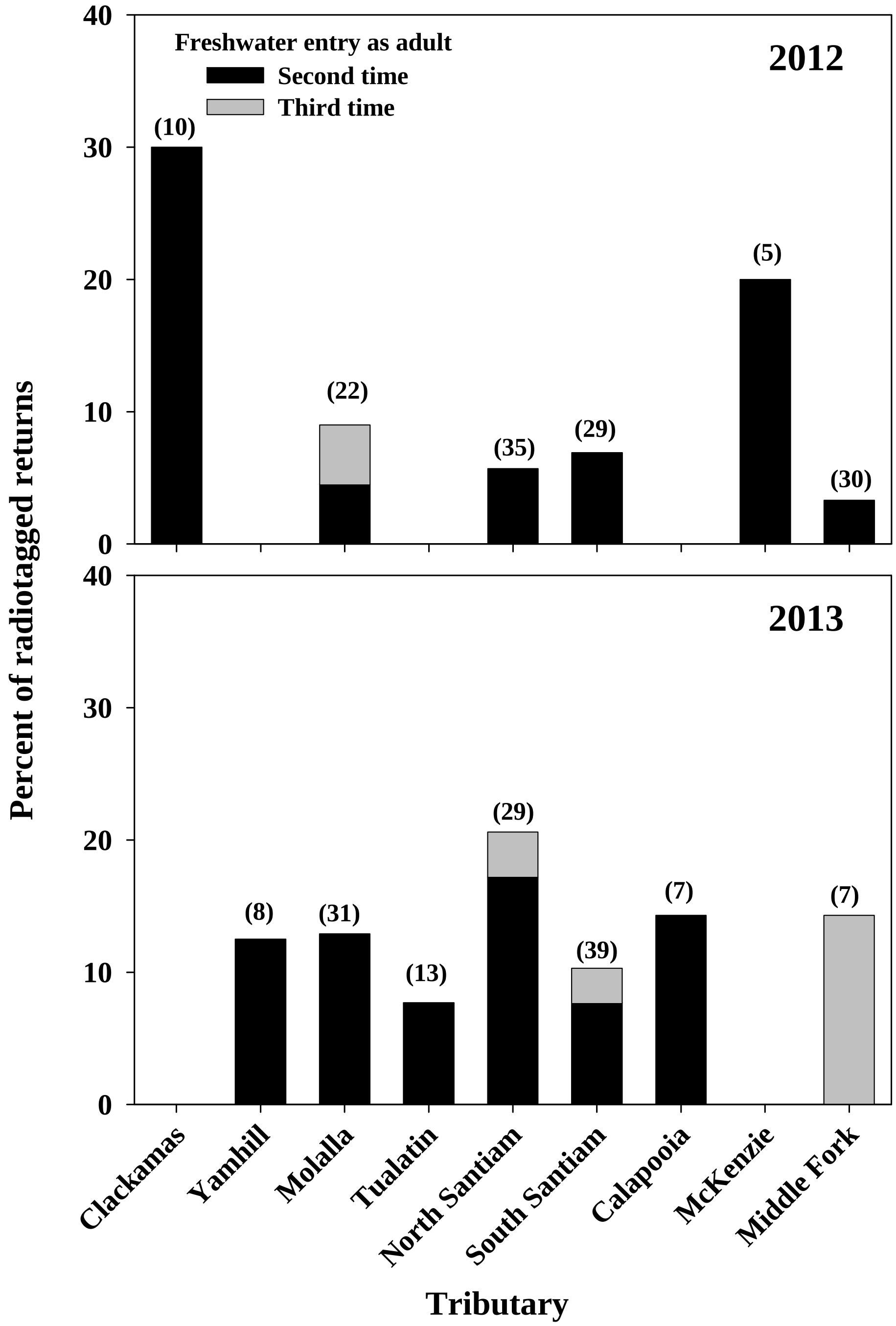

Figure 25. Percentage of radio-tagged winter steelhead that were estimated to be on their second or third migration into freshwater based on scale analyses, by tributary in 2012-2013. Total tributary sample sizes in parentheses are above each bar.

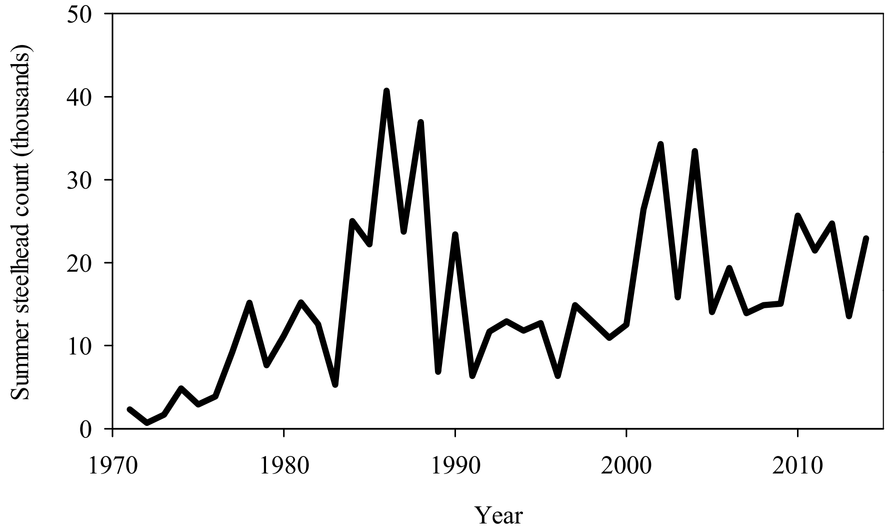

Figure 26. Total annual numbers of adult summer steelhead counted passing Willamette Falls Dam, 1971-2014. Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

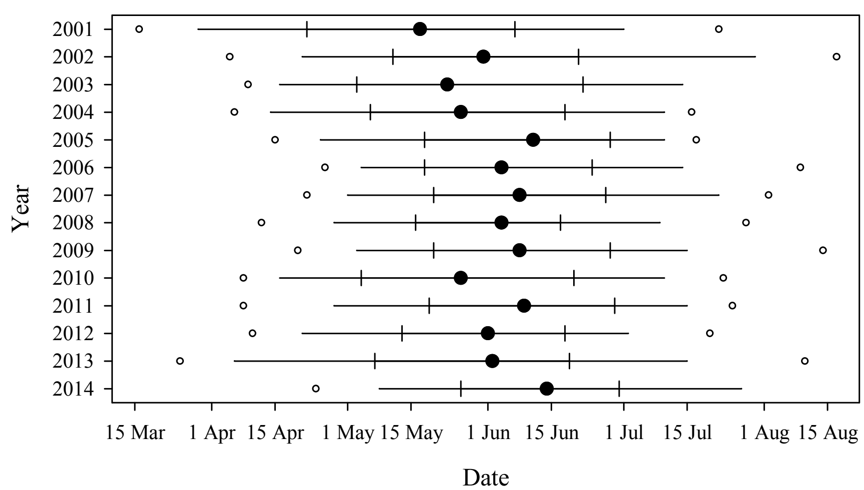

Figure 27. Annual migration timing distributions for summer steelhead counted at Willamette Falls Dam, 2001-2014. Symbols show median (●), quartile (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (○). Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Main stem residence times and migration rates

Tagged summer steelhead that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers in 2012 through 2014 were in each of the monitored main stem sections for ~1-3 days, on median (Figure 28). 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 all three years (Figure 29).

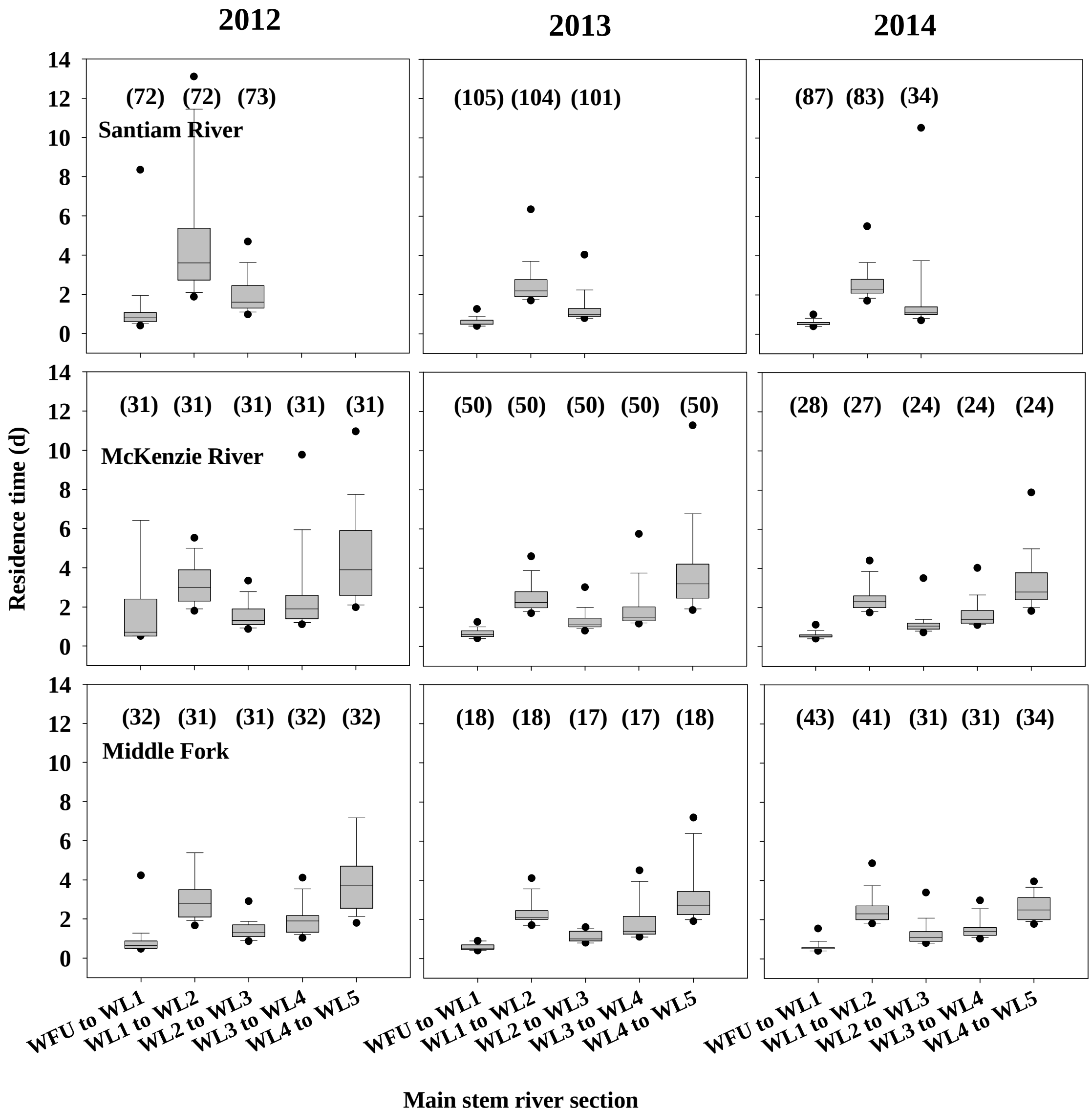

Figure 28. Box plots of residence times (days) of radio-tagged summer steelhead in reaches of the main stem Willamette River in 2012 (left panels), 2013 (middle panels), and 2014 (right panels). The three rows are for steelhead that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles (●). Sample sizes are listed in parentheses above boxes.

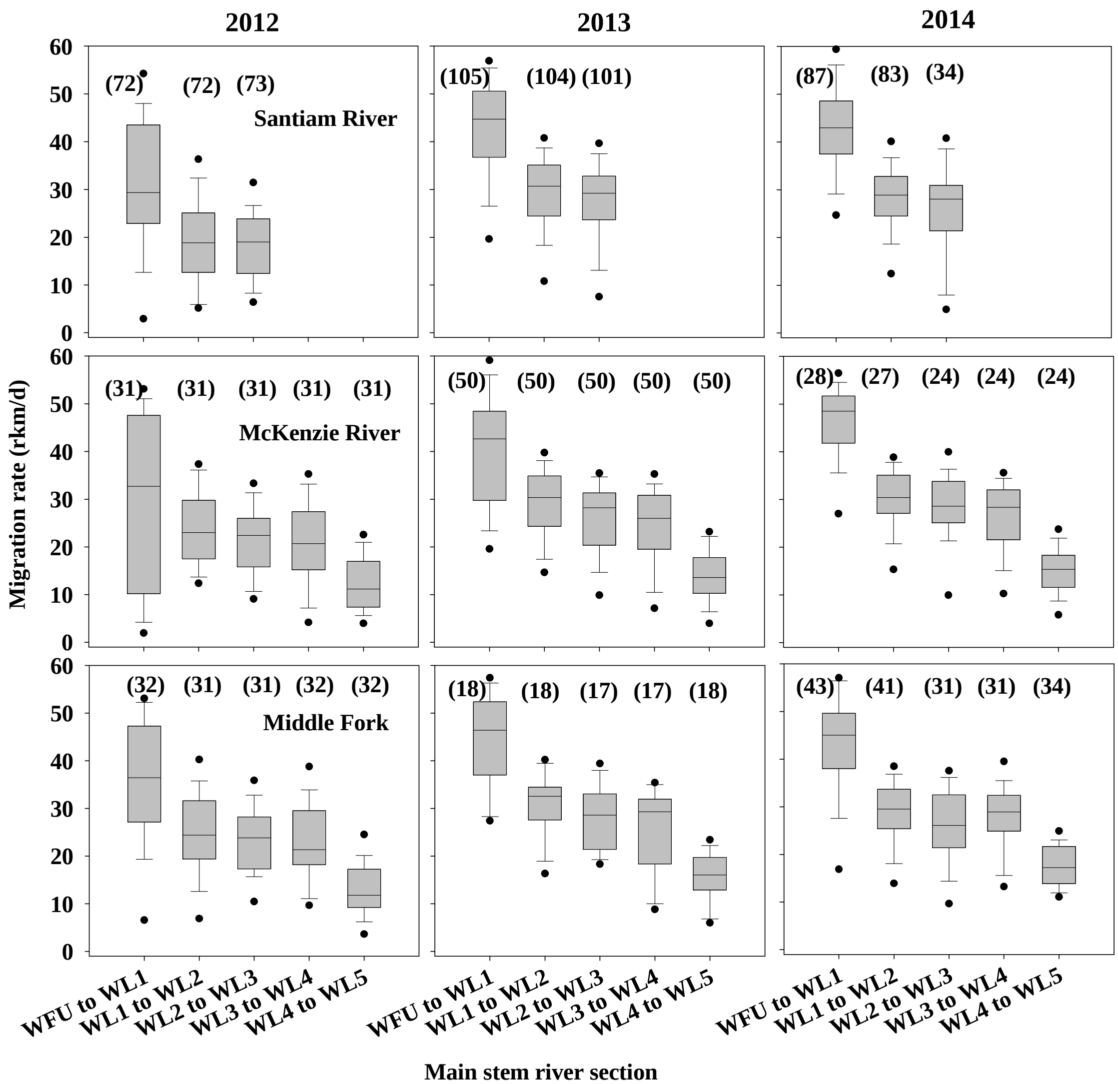

Figure 29. Box plots of migration rates (river kilometers/day) of radio-tagged summer steelhead in reaches of the main stem Willamette River in 2012 (left panels), 2013 (middle panels), and 2014 (right panels). Three panels are for steelhead that returned to the Santiam, McKenzie, and the Middle Fork 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, 2014)

Overall, 75-90% of radio-tagged summer steelhead were last detected in Willamette River tributaries in the three study years. In 2014, the highest percentage of tagged summer steelhead was last recorded in the South Santiam River (29%), followed by the Middle Fork (22%), the North Santiam River (15%), and the McKenzie River (14%; Figures 30 and 31).

In all years, the highest percentage of tagged summer steelhead was last recorded in the South Santiam River (*range* = 26-37%; Figure 32). On average, 18% returned to the Middle Fork, 16% returned to the McKenzie River, 10% returned to the North Santiam River, and smaller percentages (<2%) returned to other tributaries each year. An annual mean of 9% of tagged summer steelhead was last detected in the upper main stem.

Across years, a mean of 19% of all tagged summer steelhead was reported recaptured by an angler, with the highest percentage (6%) in the South Santiam River (Figure 33). Sites with relatively high percentages of tagged summer steelhead recaptured by anglers included the McKenzie River (5%), the Middle Fork (3%), and the upper main stem (3%). Nine percent of all tagged steelhead were reported recaptured at a hatchery, on average, with the highest percentage at Foster Dam (for South Santiam Hatchery).

In 2014, mean fork length for the different groups ranged from 60.0 cm to 71.0 cm, with minor differences among fate groups (Table 10). The few steelhead assigned to below Willamette Falls Dam and to the Molalla River were heavier, on average, than those assigned to other groups. Mean fatmeter readings among fate groups varied widely (*range* = 3.9 to 6.9%). There were also among-group differences in tagging date. The earliest mean dates were for below Willamette Falls Dam and the lower main stem groups. The latest mean dates were for the lower Santiam River and the Clackamas River groups (early June).

No explanatory variable in the logistic regression model [Escape to tributary (y/n) = tag date + fork length+ fat + head injuries (y/n) + marine mammal injuries (y/n) + descaling (y/n)] was significant for summer steelhead in any year (Table 11).

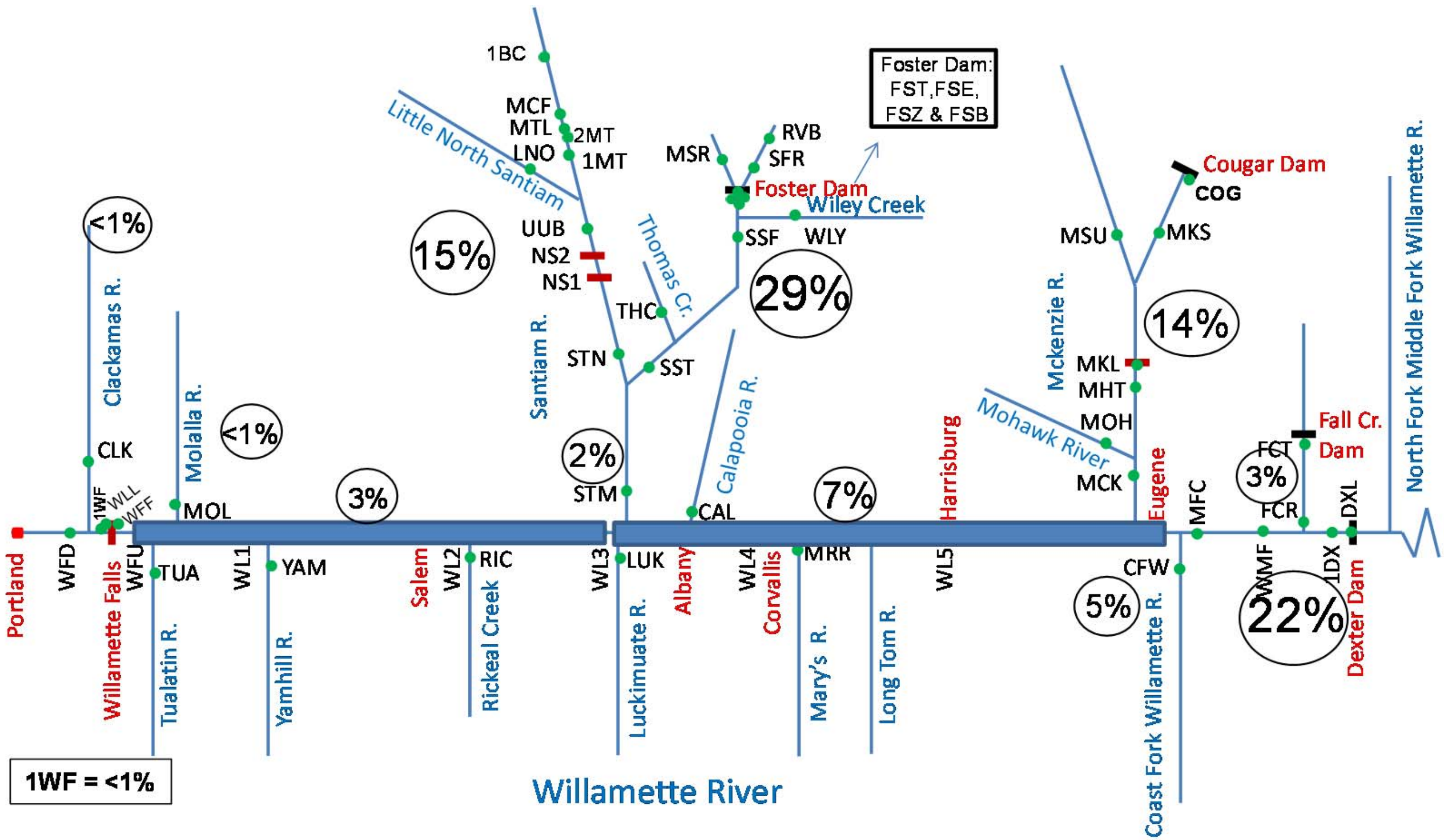

Figure 30. Sites and drainages where adult summer steelhead radio-tagged and released at Willamette Fall Dam in 2014 migrated based on their **last radio detections** (n = 196). The blue rectangles represent the upper and lower main stem.

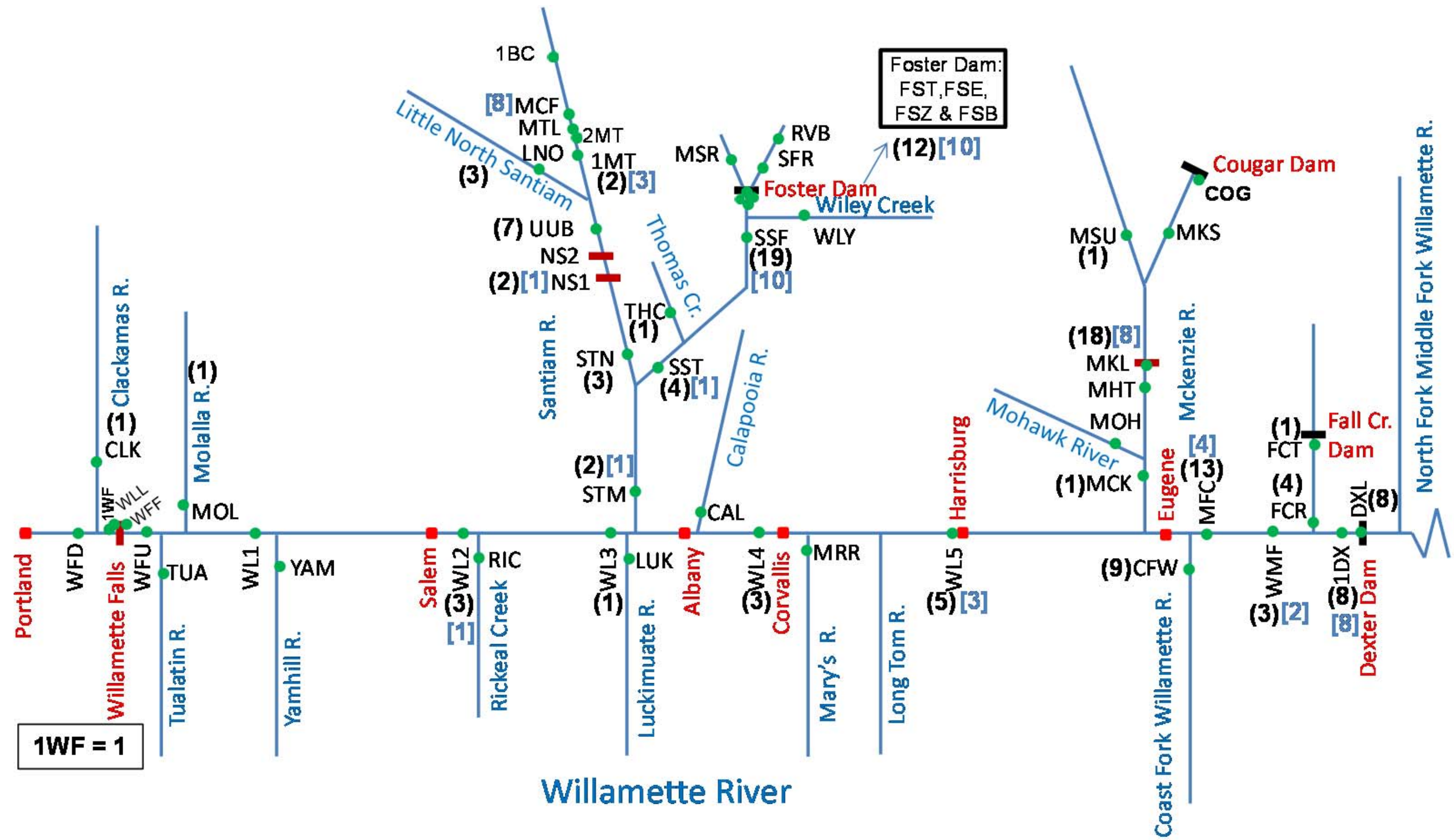

Figure 31. Sites where adult summer steelhead radio-tagged and released at Willamette Fall Dam in 2014 were **last detected** (black font and parentheses) or where they were recaptured (blue font and brackets). Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference.

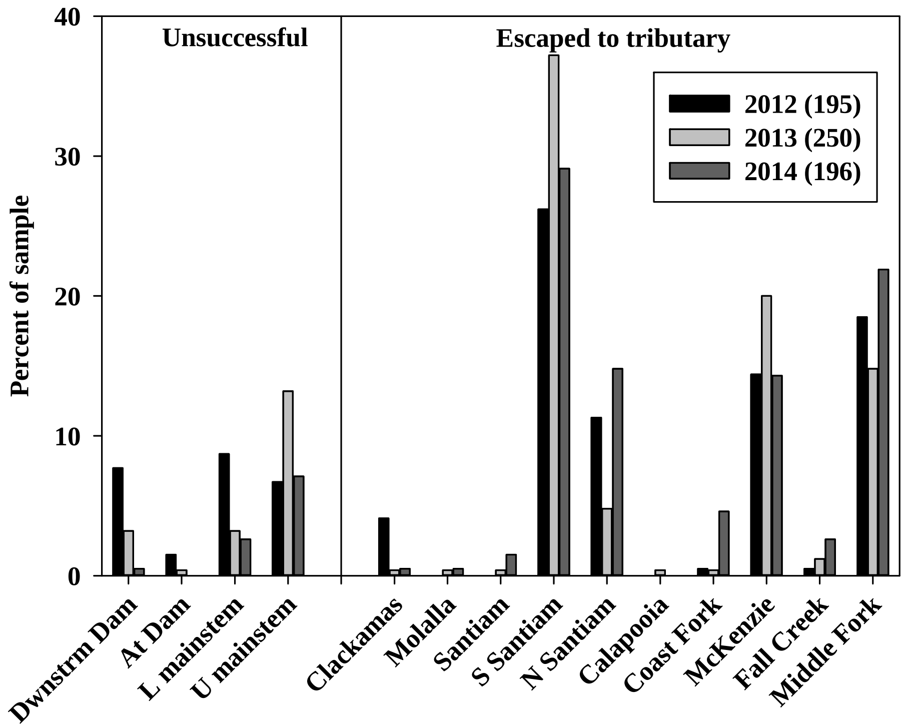

Figure 32. Annual distributions (%) of where adult summer steelhead radio-tagged at Willamette Falls Dam were last detected, 2012-2014. Sample sizes are in parentheses in the legend.

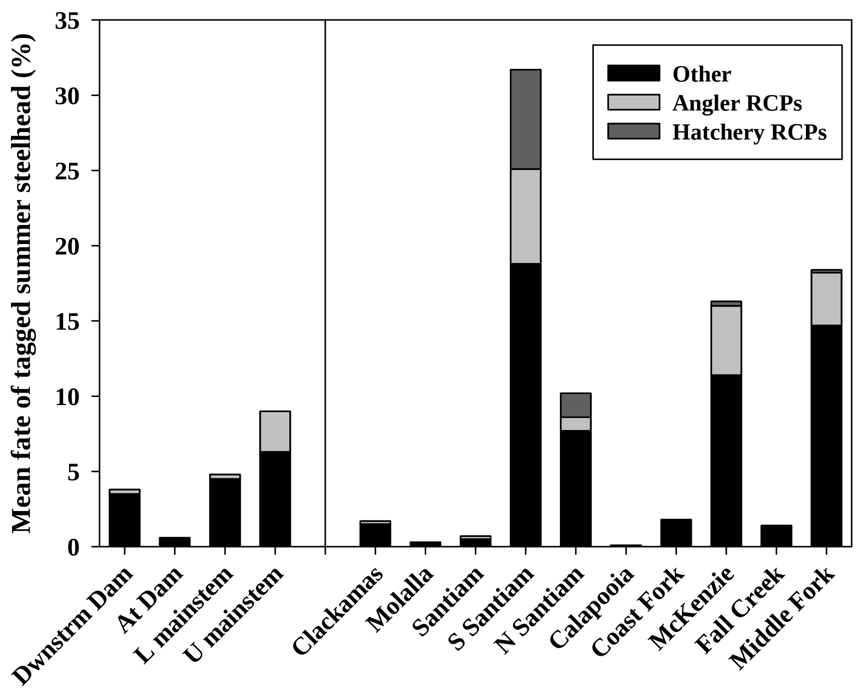

Figure 33. Histogram of mean distributions (%) of where adult summer steelhead radio-tagged at Willamette Falls Dam were last detected, recaptured by an angler, or recaptured at a hatchery, 2012-2014. Sample sizes are identical to Figure 32.

Table 10. Fate-specific sample sizes and mean tag date, fork length, weight, and fatmeter readings for radio-tagged adult summer steelhead the Willamette River basin in 2014.

Fate	*n*	Mean Tag date	Mean length (cm)	Mean weight (kg)	Mean fatmeter (%)
Clackamas R.	1	10 June	60.0	2.0	3.9
Downstream from Dam	1	13 May	71.0	3.6	6.9
Lower main stem[1]	5	31 May	66.7	2.9	4.1
Santiam R. (lower)	3	5 June	66.8	2.9	4.5
S. Santiam R.	57	23 May	67.7	3.2	4.7
N. Santiam R.	29	24 May	67.2	3.0	4.4
Upper main stem[2]	13	24 May	68.7	3.4	3.9
McKenzie R.	28	25 May	68.5	3.2	4.6
Coast Fork	9	21 May	66.1	3.0	4.3
Fall Creek	5	31 May	68.7	3.4	5.4
Middle Fork	44	23 May	69.5	3.4	4.5

[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 Willamette and Middle Fork Willamette rivers.

Table 11. Logistic regression output for [Escape to tributary (y/n) = tag date + fork length+ fat + head injuries (y/n) + marine mammal injuries (y/n) + descaling (y/n)] model for winter steelhead radio-tagged at Willamette Falls, 2012-2014.

	2012 (n = 192)		2013 (n = 250)		2014 (n = 195)	
	χ^2	P>χ^2	χ^2	P>χ^2	χ^2	P>χ^2
Tag date	0.02	089	0.96	0.33	0.58	0.45
Fork length	2.57	0.11	1.49	0.23	0.07	0.80
Fat	0.16	0.69	2.02	0.16	3.40	0.07
Head injury	2.38	0.12	0.34	0.56	2.29	0.13
Marine mammal inj.	0.18	0.67	1.00	0.32	1.25	0.26
Descaling	<0.01	0.98	<0.01	0.99	<0.01	0.99

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 2014 escapement (Table 12). We expanded the escapement proportions of the tagged fish (n = 196) using two ODFW count scenarios: 1) summer steelhead counted during the radio-tagging interval; and 2) the total summer count 1 March – 31 October 2014.

The highest estimated number (4,059-6,672) of summer steelhead returned to the South Santiam River using the two scenarios (Table 12). The next highest estimates were to the Middle Fork (3,133-5,150), the North Santiam (2,065-3,394), and the McKenzie (1,994-3,277) basins. All point estimates were < 1,000 fish for the Clackamas, Molalla, Coast Fork Willamette, and lower Santiam rivers 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.

Table 12. Estimated returns of adult summer steelhead to Willamette River tributaries based on return numbers and percentages of radio-tagged summer steelhead (n = 196) and two scenarios of ODFW count data from Willamette Falls Dam in 2014.

			Summer steelhead counted	
			Tag interval	1 Mar-31 Oct
			n = 13,957	n = 22,941
Tributary	n	% (95% ci)	Estimate	Estimate
None	19	9.7 (6.3-14.6)	1,353 (878-2,043)	2,224 (1,443-3,359)
Clackamas	1	0.5 (0.1-2.8)	71 (13-395)	117 (21-649)
Molalla	1	0.5 (0.1-2.8)	71 (13-395)	117 (21-649)
N. Santiam	29	14.8 (10.5-20.4)	2,065 (1,467-2,854)	3,394 (2,411-4,691)
S. Santiam	57	29.1 (23.2-35.8)	4,059 (3,234-4,995)	6,672 (5,315-8,211)
Santiam (lower)	3	1.5 (0.5-4.4)	214 (73-614	351 (119-1,009)
McKenzie	28	14.3 (10.1-19.9)	1,994 (1,407-2,775)	3,277 (2,312-4,561)
Coast Fork	9	4.6 (2.4-8.5)	641 (339-1,185)	1,053 (557-1,948)
Fall Creek	5	2.6 (1.1-5.8)	356 (152-814)	585 (250-1,337)
Middle Fork	44	22.4 (17.2-29.1)	3,133 (2,396-4,056)	5,150 (3,939-6,667)

The ODFW summer steelhead counts were 3,195 at Upper Bennett Dam and 1,007 at Lower Bennett Dam on the North Santiam River in 2014. The combined ODFW count total (n =4,202) was within the 95% confidence interval of the telemetry-based estimate but was over two times more than the point estimate generated using the tagging interval (Table 9). The summer steelhead count at Foster Dam on the South Santiam River was 3,126 in 2014, which was slightly less than the lower 95% confidence interval of the estimate based on the radio-tagged interval. The count of summer steelhead at Foster Dam was within the confidence intervals for the annual, telemetry-based estimate. In contrast, the 2014 count from Leaburg Dam on the McKenzie River (n = 540) was only 12-27% of telemetry-based point estimates.

As for winter steelhead, these telemetry-based estimates included all summer 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 for summer steelhead that successfully migrated to tributaries varied less across sampling dates than it did for winter steelhead (Figure 34). In all years, composition was characterized as well-mixed throughout the runs, with the highest return probabilities for the Middle Fork, the North and South Santiam, and the McKenzie rivers in all months. 2014 was notable in its increased number of summer steelhead returning to the Coast Fork Willamette compared to the two previous years.

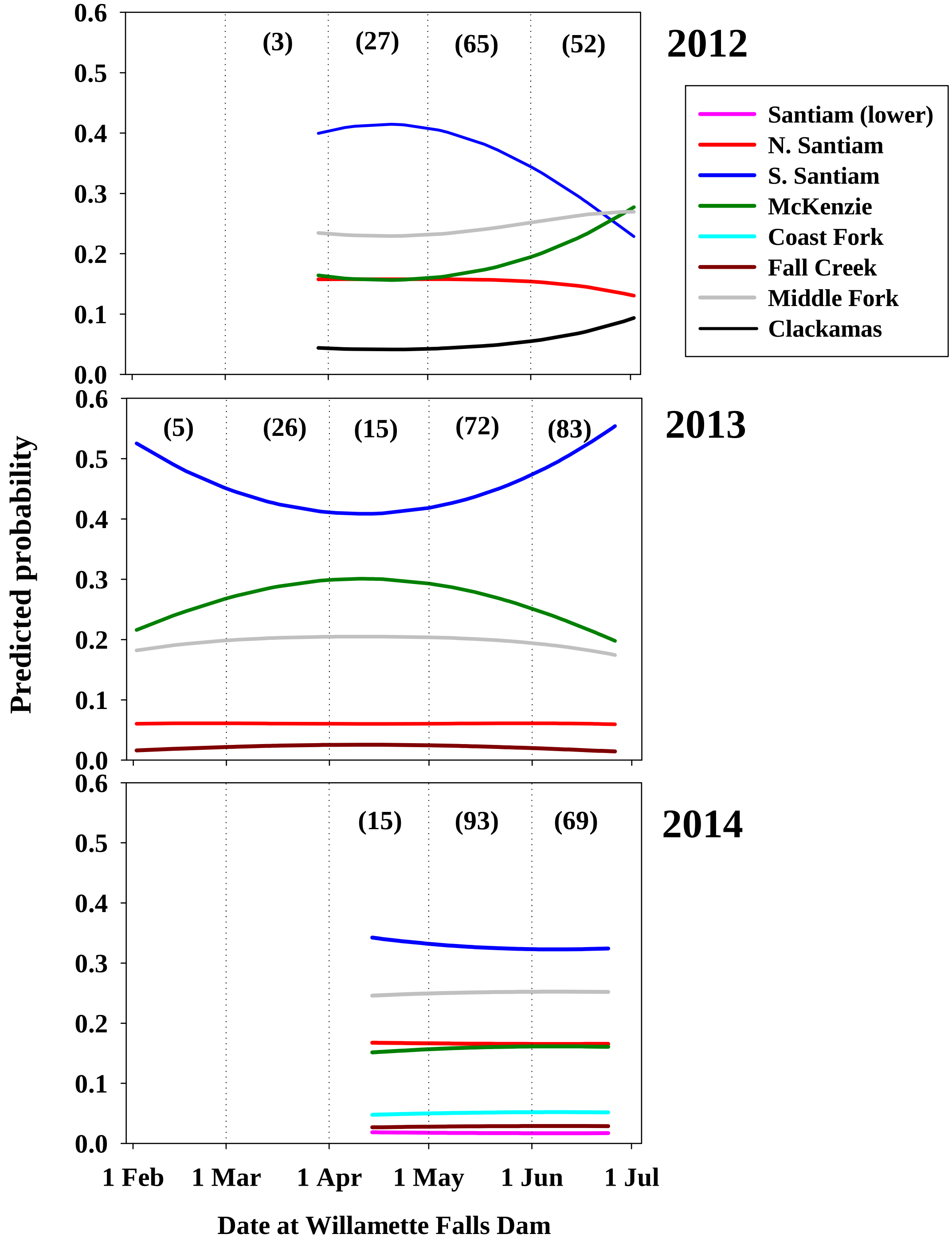

Figure 34. Estimates of run composition based on predicted probabilities from multinomial logistic regressions of 'escaped' summer steelhead radio-tagged at Willamette Falls Dam in 2012 (upper panel), 2013 (middle panel), and 2014 (lower panel). Sample sizes for each month are in parentheses.

Kelting frequencies and distributions

Less than 5% of the summer steelhead tagged in 2012 or 2013 exhibited kelt behavior based on the following criteria: 1) Willamette tributary entry in summer, fall, or late winter; 2) substantial downstream movements in spring after tributary entry; and 3) the downstream movements occurred after 1 March (Table 13). We were less confident about some summer steelhead kelt assignments than others because some fish did not meet all criteria (Table 14). For example, we tagged one unclipped steelhead (i.e., a nominal winter steelhead) that exhibited a summer steelhead migration pattern, suggesting it was a naturally-produced summer steelhead. Additionally, a summer steelhead that overwintered in the Middle Fork emigrated to the lower Columbia River the ensuing spring, was recaptured by an angler, and reported to have retained its eggs. Another exhibited overwintering behavior in the upper main stem, emigrated downstream from Willamette Falls Dam the ensuing spring, but was never recorded entering a tributary. These observations illustrate some of the ambiguities associated with estimating steelhead kelting rates using telemetry data. Nevertheless, five summer steelhead tagged in 2012 and three tagged in 2013 met all criteria, which produced a minimum estimated summer steelhead kelting rates of 2.5 to 1.5%, respectively. The highest estimated kelting frequencies were produced by summer steelhead that migrated to the North Santiam River in 2012 and to the Middle Fork in 2013. Estimates for summer steelhead tagged in 2014 were not available because some fish were still active at this writing.

Table 13. Estimated minimum and maximum numbers of radio-tagged summer steelhead that were in Willamette River tributaries and the minimum and maximum numbers and percentages that were considered kelts in 2012 and 2013.

	Entered (*n*)		Min. kelt (*n*)		Max. kelt (*n*)		Kelt (%)	
Tributary	2012	2013	2012	2013	2012	2013	2012	2013
N. Santiam	22	12	3	0	3	1	14	0-8
S. Santiam	51	93	1	0	2	0	2-4	0
McKenzie	28	50	0	1	1	1	0-4	2
Fall Creek	1	4	0	1	1	1	0	25
Middle Fork	36	38	1	1	2	4	5	3-10
Other	9	4	0	0	0	0	0	0
Total tagged	195	201	5	3	9	7	3-5%	2-3%

Table 14. List of radio-tagged summer steelhead that exhibited kelting behavior in 2013 and 2014. All fish were last detected on the WFD site downstream from Willamette Falls Dam except where noted. Rows shaded in grey denote less certain kelt assignments.

Year	Chan	Code	Clips	Pheno-type	Trib. entry date m/d/y	Trib. entry site	Putative spawn trib.	Trib. Exit date m/d/y	Trib. Exit site	Comments
2012	2	388	Ad.	-	6/28/12	MFC	Middle Fork	3/6/13	MFC[1]	
2012	2	413	Ad.	-	5/14/12	STM	L. North Santiam	3/28/13	STM	
2012	17	405	Ad.	-	5/23/12	STM	N. Santiam	3/1/13	STM	
2012	17	408	Ad.	-	5/15/12	STM	S. Santiam	3/20/13	STM	
2012	17	509	None	Summer	6/19/12	MFC	Middle Fork	3/2/13	MFC	Nominal winter - excluded from summary table 10.
2012	22	398	Ad.	-	6/12/12	STM	N. Santiam	3/21/13	STM	
2012	2	390	Ad.	-	-	-	McKenzie	1/26/13	MCK	Exit = PIT rec. at Walterville
2012	17	391	Ad.	-	5/13/12	STM	S. Santiam	1/25/13	SST	
2012	22	419	Ad.	-	7/8/12	WL5	U. main stem	2/28/13	WL5	Not considered to have escaped – excluded from table 10.
2012	22	430	Ad.	-	10/13/12	MFC	Middle Fork	1/30/13	WL4	Uncertain trib. exit date
2013	1	213	Ad.	-	5/19/13	MCK	McKenzie	3/29/14	WL5	Uncertain trib. exit date
2013	22	192	Ad.	-	7/14/13	MFC	Middle Fork	3/23/14	WL5	Uncertain trib. exit date
2013	22	231	Ad.	-	2/10/14	FCR	Fall Creek	3/28/14	FCR	
2013	1	177	Ad.	-	5/30/13	STM	N. Santiam	1/15/14	STM	
2013	1	222	Ad.	-	5/19/13	MFC	Middle Fork	2/14/14	WL5	Uncertain trib. exit date
2013	1	224	Ad.	-	5/24/13	MFC	Middle Fork	2/15/14	MFC[2]	
2013	22	236	Ad.	-	10/1/13	MFC	Middle Fork	2/1/14	WL5	Uncertain trib. exit date

[1] last detected at WFU site at rkm 212.9
[2] recaptured in Columbia River at rkm 40.2 on 6 April 2014; angler reported that fish held eggs/did not spawn

Spatial and temporal overlap of radio-tagged summer and winter steelhead

We compared the final detections of summer steelhead radio-tagged in 2012 and 2013 (that may have spawned in 2013 and 2014) to the maximum rkms for winter steelhead radio-tagged in 2013 and 2014 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 that were associated with recapture events. Similarly, we excluded steelhead that were captured at Foster Dam and released upstream because only unclipped steelhead were released there. Finally, we excluded summer steelhead that exited tributaries before the winter steelhead were tagged in the ensuing year.

There was evidence for spawning habitat overlap in the South and North Santiam rivers and in the Middle Fork Willamette River (Table 15). We found likely overlap within the upper and lower reaches of the North Santiam River but none in the Little North Santiam River in 2013 and little in 2014 (Figure 35). The most overlap was in the South Santiam River near Foster Dam (Figure 36). In the Middle Fork Willamette, overlap extended from the mouth to Dexter Dam and into Fall Creek (Figure 37). We found little or no spatial overlap among winter- and summer-run fish in the Tualatin, Molalla, Yamhill, or Calapooia rivers (Table 15). Steelhead from both runs were recorded entering the Clackamas River but their distributions within the tributary were not monitored by mobile tracking in the spring of any year.

Table 15. Frequencies of last detections of summer steelhead radio-tagged in 2012 and 2013 and the maximum river kilometer reached by winter steelhead radio-tagged in 2013 and 2014, respectively.

	Numbers of radio-tagged steelhead			
Tributary	2012 Summer	2013 Winter	2013 Summer	2014 Winter
Clackamas	8	3	1	11
Tualatin	1	13	1	3
Molalla		31	1	30
Yamhill		8		7
Rickreall		1		1
L. Santiam				1
S. Santiam	30	32	38	34
N. Santiam	21	29	7	51
Calapooia		7		5
McKenzie	28	3	50	3
Coast Fork				1
Fall Creek	1	1	3	2
Middle Fork	24	**7**	24	15

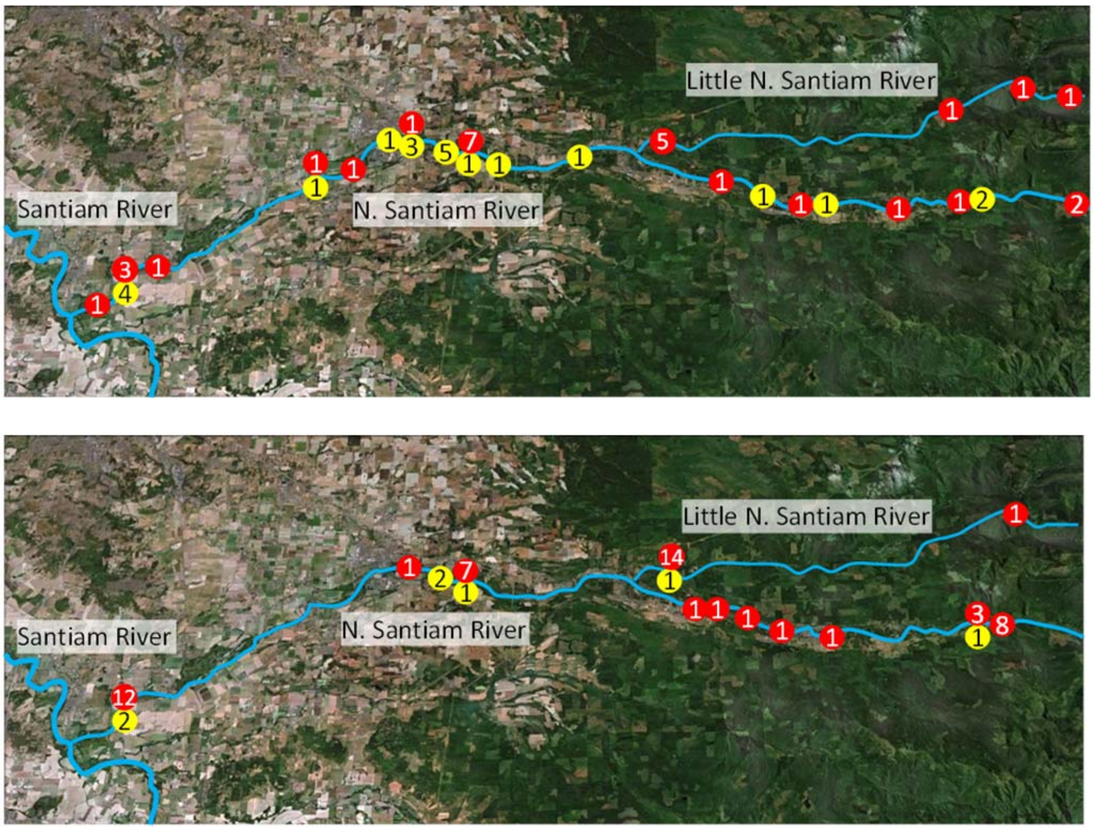

Figure 35. Distribution of maximum river kilometer detections in the North Santiam River for winter steelhead radio-tagged in 2013 (upper panel) and 2014 (lower panel; red circles) and last detections for summer steelhead radio-tagged in 2012 (upper panel) and 2013 (lower panel; yellow circles). Numbers 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.

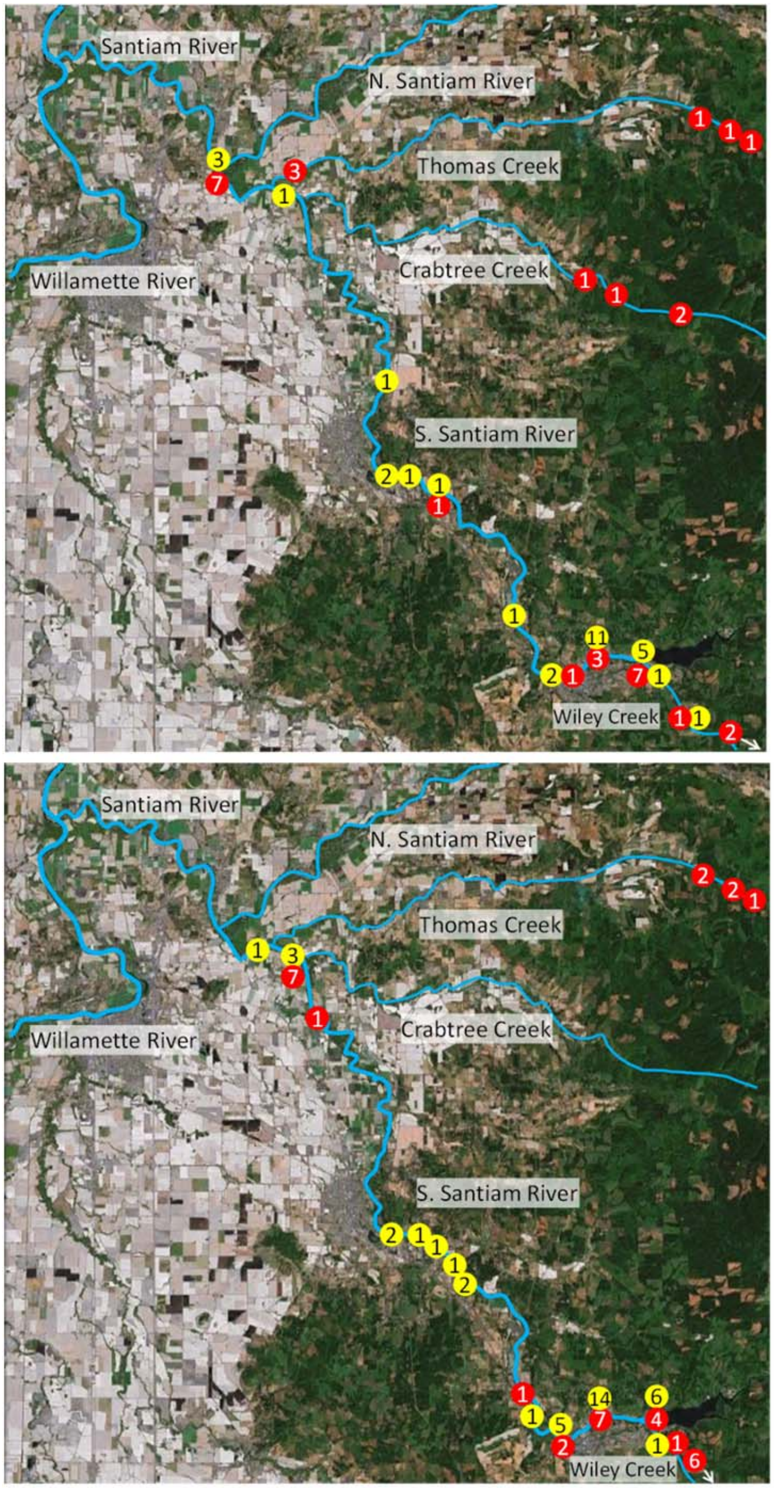

Figure 36. Distribution of maximum river kilometer detections in the South Santiam River for winter steelhead radio-tagged in 2013 (upper panel) and 2014 (lower panel; red circles) and last detections for summer steelhead radio-tagged in 2012 (yellow circles). Numbers indicate number of tagged fish at each site. This figure demonstrates the spatial overlap of the two runs; only a sub-sample of these detections also overlapped temporally.

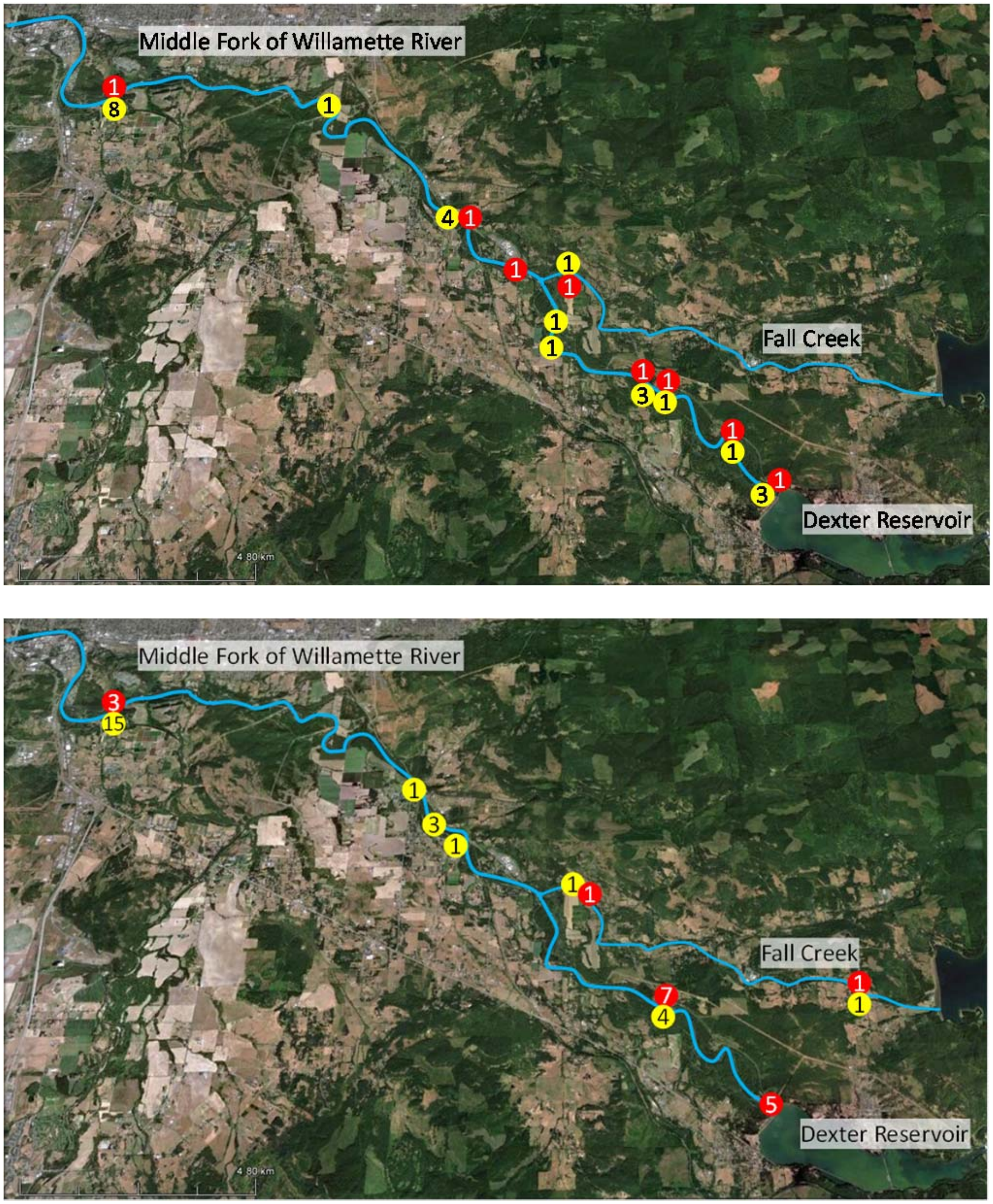

Figure 37. Distribution of maximum river kilometer detections in the Middle Fork Willamette River for winter steelhead radio-tagged in 2013 (upper panel) and 2014 (lower panel; red circles) and last detections for summer steelhead radio-tagged in 2012 (upper panel) and 2013 (lower panel; yellow circles). Note that one summer steelhead tagged in 2012 was last detected in Norton Creek and one tagged in 2013 was last detected in Little Fall Creek. Neither is shown because they fall outside the map borders. Numbers are 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 and 2014 winter steelhead kelts were in tributaries to the maximum dates the 2012 and 2013 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 the very few summer steelhead estimated to be kelts, we found no evidence for temporal overlap of the runs in the Middle Fork Willamtte. In the North and South Santiam rivers, temporal overlap appeared to be most likely to have occurred between mid-February and mid- March, assuming that the timing of kelt outmigration corresponded to the end of spawning by the entire summer steelhead population (Figure 38). However, we note that it is unknown if non-kelting summer steelhead spawn longer or later than those kelting and several summer steelhead were detected in the North and South Santiam rivers after 1 April of each year but were not designated as kelts (i.e., they did not meet the other criteria for kelt assignment). Whether these detections represented an extended spawning period or whether the detections were of spawned-out carcasses is unknown.

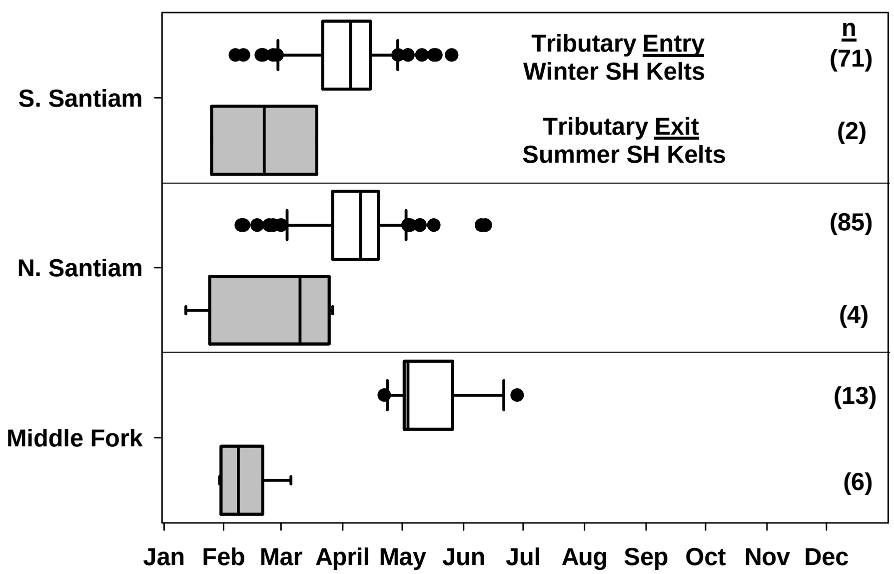

Figure 38. Range of minimum tributary entry dates by prespawn winter steelhead radio-tagged in 2013 and 2014 that had kelt behaviors (light bars) and the range of maximum tributary exit dates by summer steelhead kelts radio-tagged in 2012-2014 (black bars) in the Middle Fork Willamette and North and South Santiam rivers. Any 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. We are currently evaluating the 196 scale samples collected from summer steelhead radio-tagged at Willamette Falls in 2014.

Genetic diversity of summer and winter steelhead

DNA was extracted from fin clips (n=198, approximately evenly split between winter and summer steelhead) using the DNeasy Blood and Tissue Kit (Qiagen, Inc.) protocol with the modification that DNA was eluted in 100 µL of buffer AE. Fifteen microsatellite loci were screened to assess diversity and allele sizes (Table 16). Nine microsatellite loci were then multiplexed into three polymerase chain reactions (PCR). Multiplex one contained 0.2 µM of OGO4, OMY1001 and SSA408, 1X Qiagen Multiplex PCR Kit Master Mix and 1 µL of DNA extract in a 10 µL reaction volume. Multiplex two had the same reagents at the same concentrations as Multiplex 1 but contained OKE4, OMY7 and OKI23. Multiplex 3 was the same as Multiplex 1 but contained OMY77, OMY1011 and ONE14. The reaction conditions for Multiplex one were an initial denaturation step of 94 °C for 15 min followed by 35 cycles of 94 °C for 30 sec, 57° for 90 sec, 72 °C for 60 sec followed by a final elongation step of 60 °C for 30 min. The reaction conditions for multiplexes 2 and 3 were the same as for multiplex one except an annealing temperature of 60 °C was used. PCR products were run on a 3130xl Genetic Analyzer according to the manufacturer's protocol (Applied Biosystems). Allele sizes were visualized and sized using GeneMapper Software 5 (Applied Biosystems). The number of alleles and observed and expected heterozygosities were calculated using Genalex 6 (Peakall & Smouse 2006).

Microsatellite loci OTS3 and OTS4 are still undergoing PCR reaction condition optimization so no genetic diversity information for these loci is included in Table 16. Loci OMY105, OMY2, OTS100, SSA289 and SSA407 have been tested on a few samples thus heterozygosity estimates are not included in Table 1. The number of alleles per locus ranged from 2 to 23 with an average of 13 alleles across loci (Table 16). The average observed and expected heterozygosities are high, which will benefit future analyses of population sub-structure.

Table 16. The dye label (Dye), allele sizes (Size (bp)), number of samples analyzed (N), number of alleles (Na) and observed (Ho) and expected (He) heterozygosities for the 15 microsatellite loci screened in steelhead.

Locus	Dye	Size (bp)	N	Na	Ho	He	Reference
OGO4	Red	119-142	198	11	0.78	0.81	Olsen *et al.* 1998
OKE4	Yellow	234-271	161	11	0.68	0.69	Buchholz *et al.* 1999
OKI23	Blue	126-190	161	15	0.80	0.85	Smith *et al.* 1998
OMY1001	Yellow	171-220	198	20	0.83	0.89	Spies *et al.* 2005
OMY1011	Blue	130-205	84	16	0.83	0.84	Spies *et al.* 2005
OMY7	Green	231-267	161	16	0.76	0.75	Stephenson *et al.* 2009
OMY77	Green	155-193	83	13	0.76	0.83	Morris *et al.* 1996
ONE14	Yellow	149-167	84	8	0.68	0.74	Scribner *et al.* 1996
SSA408	Green	170-240	198	23	0.91	0.93	Cairney *et al.* 2000
OMY105	Yellow	127-232	7	11	na	na	McConnell *et al.* 1997
OMY2	Blue	108-155	7	9	na	na	Heath *et al.* 2001
OTS100	Blue	168-213	8	10	na	na	Nelson & Beacham 1999
SSA289	Blue	107-109	8	2	na	na	McConnell *et al.* 1995
SSA407	Red	168-200	8	6	na	na	Cairney *et al.* 2000
OTS3	optimization						Banks *et al.* 1999
OTS4	optimization						Banks *et al.* 1999
Average				13	0.70	0.73	

Behavior and distribution of recycled steelhead

South Santiam – Reported angler recapture rates of radio-tagged steelhead released downstream from Foster Dam ranged from 8-14% among years (Table 17). Twenty-five of the 31 recaptured steelhead (81%) were recaptured in the South Santiam River, one (3%) was recaptured in the lower main stem Willamette River, and five (16%) were recaptured in the lower Santiam River, below the confluence of the North and South Santiam rivers. Release sites closest to Foster Dam (i.e., the tailrace and near Wiley Creek) were associated with the highest rates of angler recaptures (20-29%) but comparisons were confounded by having no releases at these sites in some years. Annual percentages of tagged steelhead reported as returning to Foster Dam, where they were used for broodstock or surplused, ranged from 23-40% among years. Approximately one-third to one-half of the tagged steelhead were last detected (i.e., stayed) within the South Santiam River basin each year and 3-15% of last detections were outside the river.

Table 17. Distribution (percentages in parentheses) of last detection locations and fates for summer steelhead radio-tagged at Foster Dam and released at downstream sites, 2012-2014.

Year	Fate	Release site				Row sum
		Pleasant Valley	Waterloo	Wiley Creek	Foster tailrace	
2012	Tag record only	2 (2)	1 (1)			3 (3)
	Exited S. Santiam R.	11 (12)	4 (4)			15 (16)
	Stayed S. Santiam R.	32 (34)	14 (15)			46 (48)
	Found Tags	1 (1)	0 (0)			1 (1)
	Angler recapture	5 (5)	3 (3)			8 (8)
	Foster Dam return/recapture	19 (20)	3 (3)			22 (23)
	Annual total	70 (74)	25 (26)	-	-	95 (100)
2013	Tag record only	0 (0)	1 (1)	0 (0)		1 (1)
	Exited S. Santiam R.	5 (5)	2 (2)	3 (3)		10 (10)
	Stayed S. Santiam R.	10 (10)	16 (16)	8 (8)		34 (34)
	Found Tags	1 (1)	0 (0)	0 (0)		1 (1)
	Angler recapture	7 (7)	3 (3)	4 (4)		14 (14)
	Foster Dam return/recapture	17 (17)	18 (18)	5 (5)		40 (40)
	Annual total	40 (40)	40 (40)	20 (20)	-	100 (100)
2014	Tag record only	1 (1)	2 (2)		0 (0)	3 (3)
	Exited S. Santiam R.	3 (3)	0 (0)		0 (0)	3 (3)
	Stayed S. Santiam R.	14 (14)	17 (17)		18 (18)	49 (49)
	Found Tags	1 (1)	0 (0)		0 (0)	1 (1)
	Angler recapture	2 (2)	1 (1)		6 (6)	9 (9)
	Foster Dam return/recapture	12 (12)	13 (13)		10 (10)	35 (35)
	Annual total	33 (33)	33 (33)	-	34 (34)	100 (100)

Middle Fork Willamette River – The distribution of last detections for radio-tagged summer steelhead recycled to the Dexter Dam tailrace was generally similar among years (Table 18). Annual percentages of steelhead that exited the Middle Fork ranged from 14-26% and percentages that remained (i.e., stayed) ranged from 47-54% among years. Angler recaptures rates ranged from 16-26%. In 2012, two fish (1.3%) were removed at the Dexter Fish Facility for the Oakridge hatchery but no tagged steelhead were reported as having returned or being recaptured there in 2013 or 2014.

Table 18. Distribution (percentages in parentheses) of last detection locations and fates for summer steelhead radio-tagged at Dexter Dam and released into the tailrace, 2012-2014.

Fate	2012	2013	2014
Tag record only	2 (4)	1 (2)	1 (2)
Exited M. Fork Willamette R.	12 (25)	13 (26)	7 (14)
Stayed M. Fork Willamette R.	23 (47)	27 (54)	27 (54)
Found Tags	0 (0)	1 (2)	2 (4)
Angler recapture	10 (20)	8 (16)	13 (26)
Dexter Dam return/recapture	2 (4)	0 (0)	0 (0)
Column sum	49 (100)	50 (100)	50 (100)

Results: Spring Chinook salmon

Historic counts and run timing

The annual count of adult spring Chinook salmon passing Willamette Falls Dam in 2014 was 30,071 (Figure 39). This was approximately 8,400 fewer fish than the average count of 38,470 since 1953. The 2014 run was intermediately timed among the last fourteen years (Figure 40). This was likely associated with the April-June water temperatures and discharges close to the recent ten-year averages. The date of median passage in 2014 was 20 May, compared to medians that ranged from 8 May – 13 June in 2001-2013.

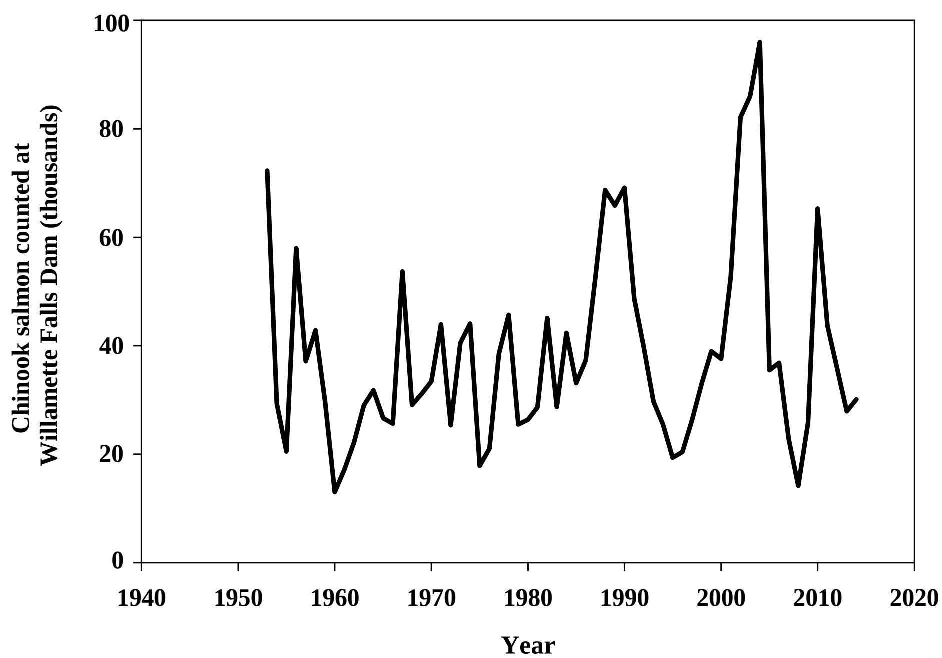

Figure 39. Total annual numbers of adult spring Chinook salmon counted passing Willamette Falls Dam,1953-2014. Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

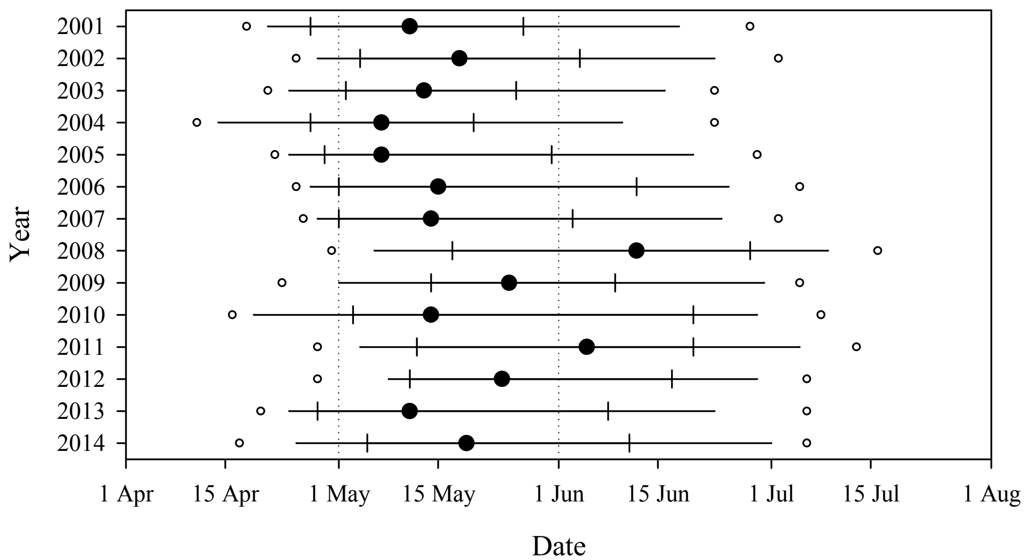

Figure 40. Annual migration timing distributions for spring Chinook salmon counted at Willamette Falls Dam, 2001-2014. Symbols show median (●), quartile (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (○). Data summarized from ODFW daily counts:
http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Main stem residence times and migration rates

Median times tagged salmon spent in the main stem were lower in 2013-2014 than in 2011-2012 for those that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers (Figure 41). Tagged salmon that returned to the Santiam River spent 12.0 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 or 2014 (*medians* = 5.9 and 6.0 d, respectively). 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 or 2014. Tagged salmon that returned to the Middle Fork in 2011 spent 32.0 d in the main stem on median, ten days more than those in 2012, and over two weeks more than in 2013 or 2014. Faster main stem migration times were associated with lower flows and warmer water temperatures in 2013 and 2014.

The time tagged salmon spent in different sections of the main stem Willamette River varied with reach length (Figure 42). 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.

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 43). As with 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 four years.

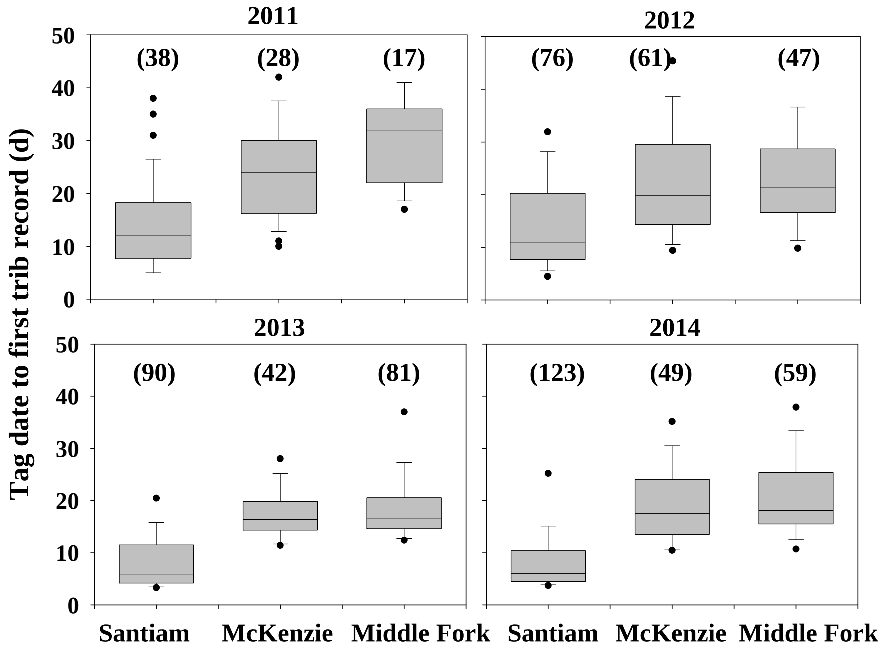

Figure 41. Box plots of radio-tagged spring Chinook salmon passage times (d) from their release at Willamette Falls Dam to first detection in the Santiam, McKenzie, or Middle Fork Willamette rivers in 2011-2014. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles (●). Sample sizes are in parentheses above boxes.

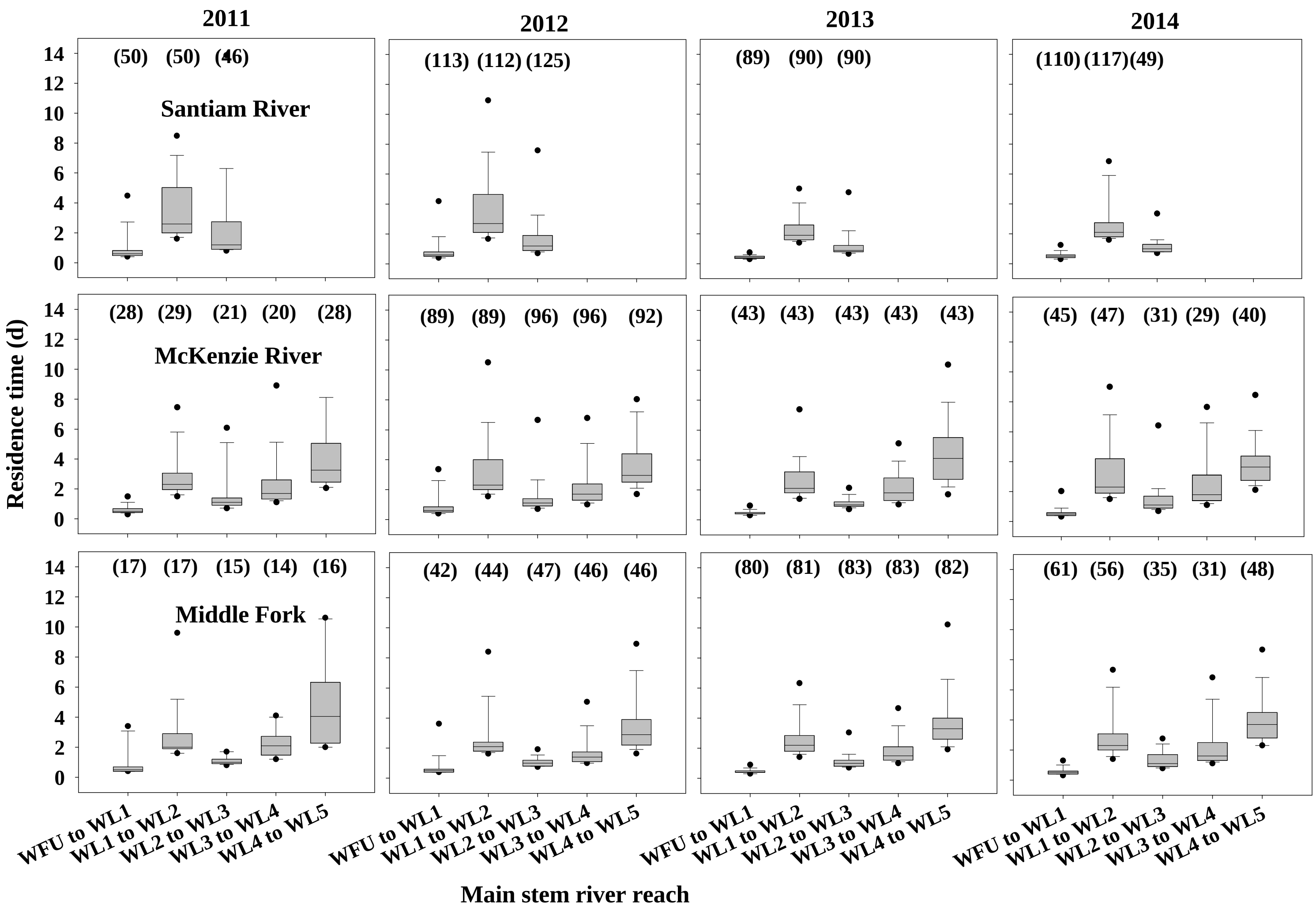

Figure 42. Box plots of times (days) radio-tagged spring Chinook salmon spent in reaches of the main stem Willamette River for salmon that returned to the Santiam, McKenzie, and the Middle Fork Willamette rivers in 2011-2014. Box plots show: median (line), quartile (box), 10^{th} and 90^{th} (whisker), and 5^{th} and 95^{th} percentiles (●). Sample sizes are in parentheses above boxes.

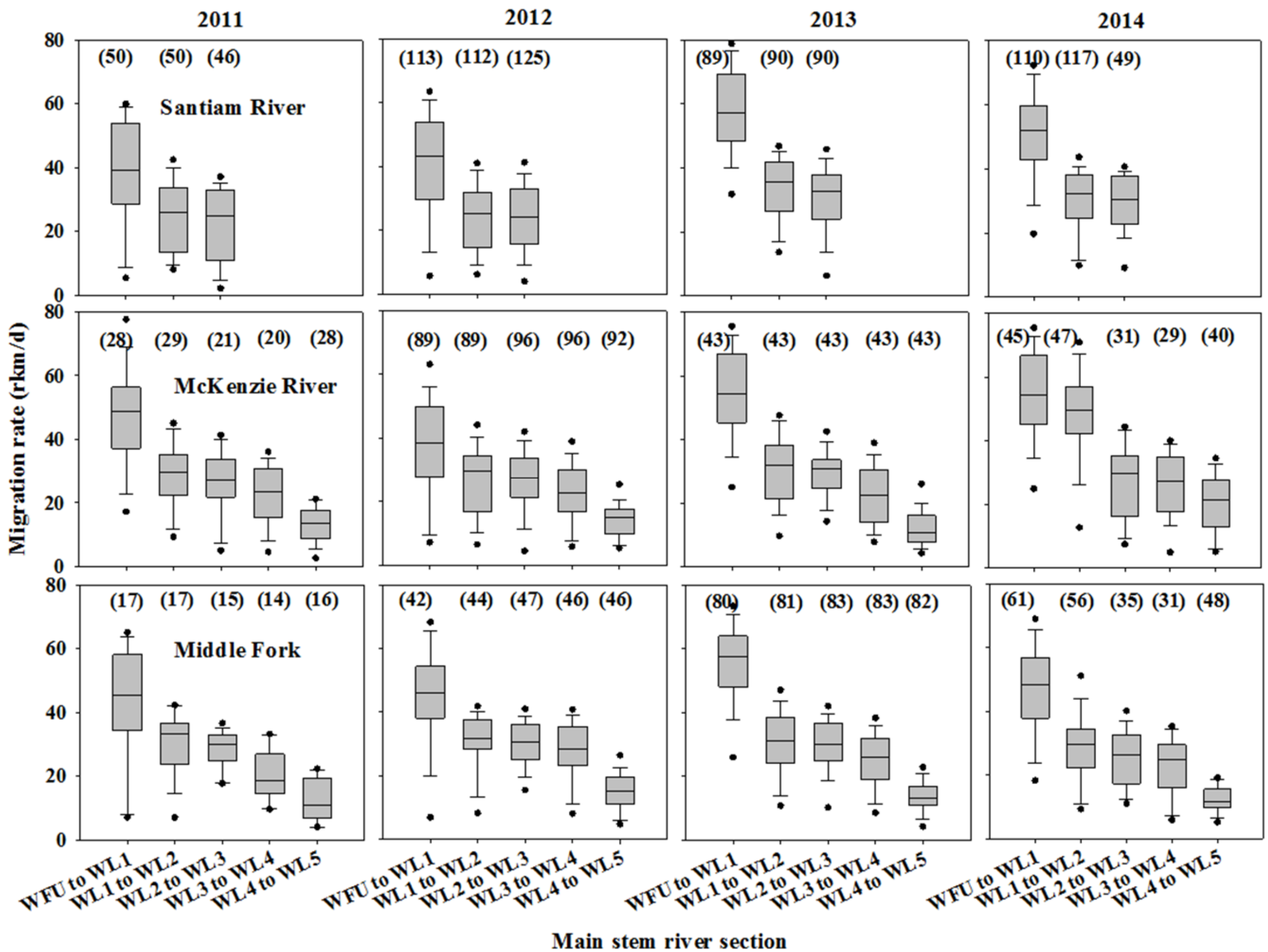

Figure 43. Box plots of rates (rkm/d) radio-tagged spring Chinook salmon used in reaches of the main stem Willamette River for salmon that returned to the Santiam, McKenzie, and the Middle Fork Willamette rivers in 2011-2014. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles (●). Sample sizes are in parentheses above boxes.

In 2014, the median 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 23.1 rkm/d; n = 145), which was approximately 1-2 rkm/d faster than the 2011-2012 medians and ~2 rkm/d slower than the 2013 median (Figure 44). Medians for groups of tagged salmon that returned to specific tributaries in 2014 ranged from 19.4 rkm/d (McKenzie River) to 35.2 rkm/d (Santiam River). The highest variation within a tributary grouping in 2014 was for salmon last detected in the Santiam River, with individual rates ranging from 6.8 to 38.3 rkm/d. The distributions of migration rates were generally similar in all four years.

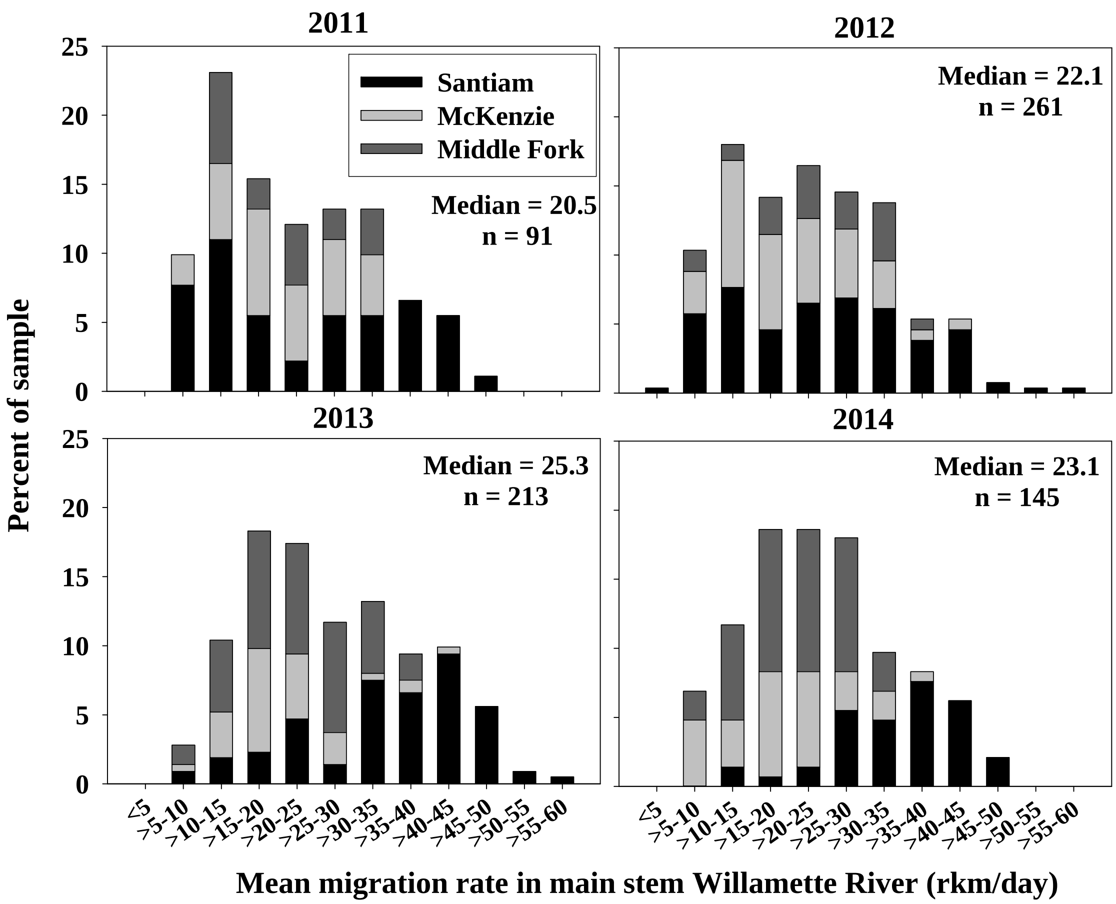

Figure 44. Histogram of radio-tagged Chinook salmon migration rates (rkm/d) in the main stem Willamette River (i.e., WFU to the WL3 or WL5 sites) for salmon that escaped to the Santiam, McKenzie, and Middle Fork Willamette rivers in 2011-2014.

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 except in 2011 when rates for salmon that returned to the McKenzie River were negatively associated with tag date (Table 19 and Figure 45). It was unclear why the McKenzie group migrated at slower rates later in 2011. 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 43 above).

Table 19. Linear regression parameters for Willamette River main stem migration rate versus release date of radio-tagged Chinook salmon that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers in 2011-2014.

Year	Tributary	Slope	Intercept	*n*	r^2	*P*
2011	Santiam	0.40	-36.4	46	0.37	<0.0001
	McKenzie	-0.09	34.2	28	0.03	0.38
	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
2014	Santiam	0.29	-9.7	43	0.22	0.001
	McKenzie	0.15	-1.7	41	0.13	0.02
	Middle Fork	0.15	1.1	61	0.11	0.007

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

Behavior at Willamette Falls Dam – In 2014, 44 of the 300 tagged salmon (15%) were detected downstream from the dam after release and of these, 26 ascended the dam, 10 were detected entering the Clackamas River, and 8 did not ascend the dam.

Downstream movements – Approximately 7% (20/300) of radio-tagged salmon moved downstream in the main stem Willamette River after moving upstream from Willamette Falls Dam (Table 20). There were a total of five fallback events at Willamette Falls Dam by five unique salmon (1.8% of the 272 tagged salmon that passed the dam at least once); three were ad-clipped salmon and two were unclipped. Each salmon fell back one time and none of the fallback events was followed by dam re-ascensions. One of the fallback salmon was last detected entering the Clackamas River. One salmon had migrated as far as the WL3 site near Buena Vista and two migrated to the WL2 site near Harrisburg before moving downstream. The last of the five fallback salmon migrated just upstream from the dam to the WFU site before falling back.

Three tagged salmon initiated downstream movements in the main stem and were not detected falling back at Willamette Falls Dam. Two of these salmon swam downstream, resumed upstream movements, and subsequently entered a tributary upstream from where they started to move downstream.

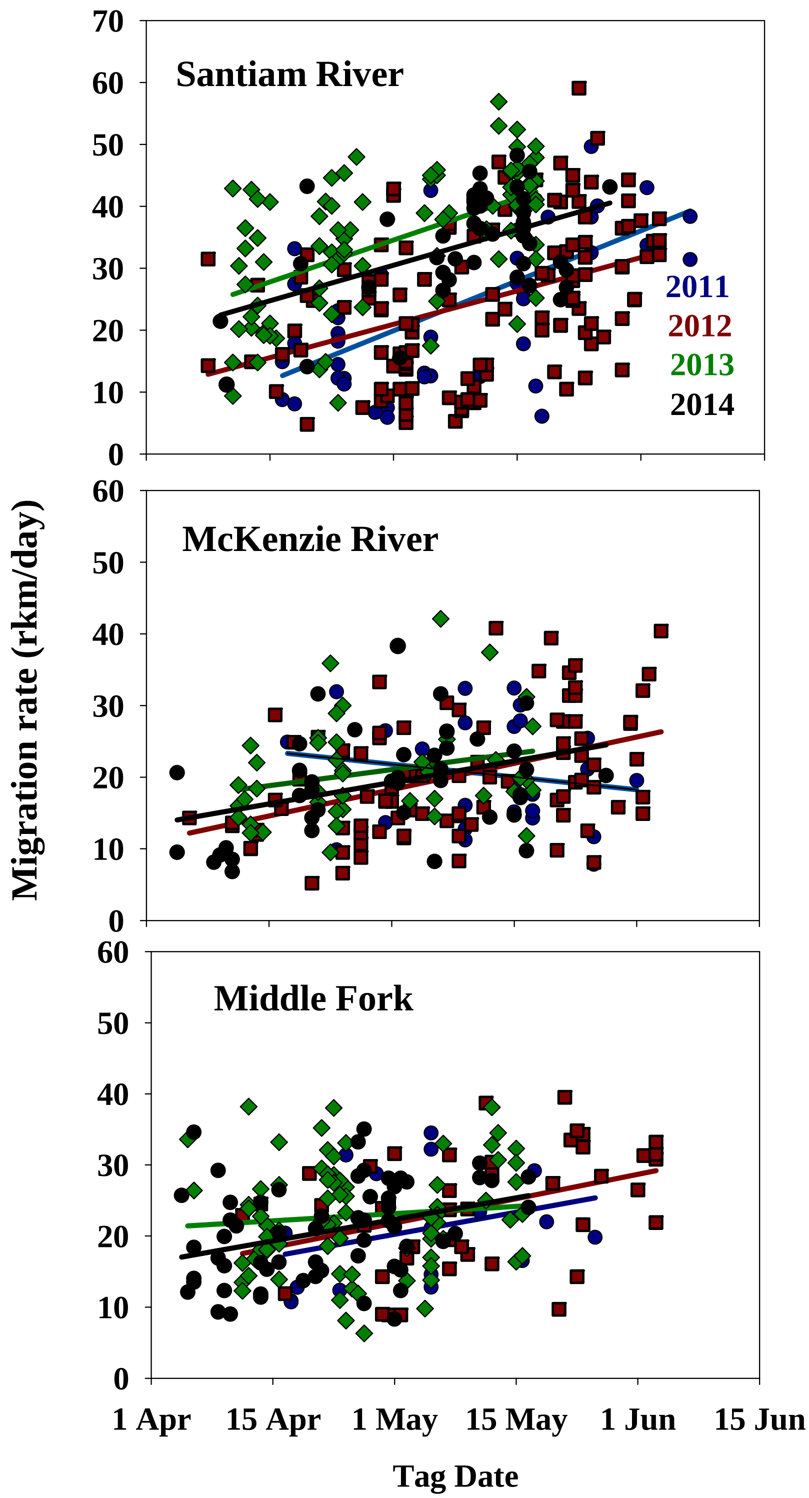

Figure 45. Relationships between radio-tagged Chinook salmon migration rates in the main stem Willamette River and tag date at Willamette Falls Dam in 2011-2014. Lines show separate linear regressions for different years. Note different y-axis scales.

Table 20. Numbers of adipose-clipped and unclipped Chinook salmon that moved downstream in the main stem Willamette River in 2014.

Downstream Behavior	Adipose clipped Chinook	Unclipped Chinook	Row sum	Group total
Fallback over WillametteFalls (no re-ascension)				5
WL3 to fallback		1		
WL2 to fallback then Clackamas R.	1			
WL2 to fallback	2			
WFU to fallback		1		
WFU to fallback then Clackamas R.				
Tributary to main stem				6
Foster Dam to WL1	1			
S. Santiam R. to WL1 to Molalla R.	1			
Santiam R. (STM) to WL2 to Santiam R.	1			
Dexter tailrace to WL3	1			
MKL to WL5 to CAL to WL1	1			
Middle Fork (MFC) to McKenzie R.	1			
Main stem				3
WL2 to WL1	1			
WL5 to WL4	2			
Overshoot				
WL2 to Molalla R.	1			6
WL4 to Molalla R. to N. Santiam R.	1			
WL4 to S. Santiam R.	3			
WL5 to N. Santiam R.	1			
Column Sum	18	2		20

Six tagged salmon were detected in a tributary before they returned to the main stem and migrated downstream. Two of these fish subsequently entered downstream tributaries and one exited and then re-entered the Santiam River. The other three were last detected in the main stem after leaving a tributary.

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). In 2014, six tagged salmon, all with clipped adipose fins, overshot the tributary to which they eventually escaped. Three salmon entered the South Santiam River after being detected near Corvallis (WL4) and one salmon entered the North Santiam River after being detected at WL4. One salmon migrated to the WL5 site near Harrisburg before migrating downstream to the North Santiam River and one salmon was detected near Champoeg (WL1) before entering the Molalla River.

Temporary straying – Only one radio-tagged salmon was detected temporarily entering a tributary downstream from the tributary to which it ultimately escaped. This adipose-clipped fish migrated to the WL4 site, swam downstream to the WL1 site, and then temporarily entered the Mollala River before migrating upstream to the South Santiam River. In addition, seven (all adipose-clipped) of the 44 tagged salmon that exited the Willamette Falls Dam fishway after tagging briefly entered the Clackamas River before ascending the dam.

Behavior in tributaries downstream from Willamette Valley projects

In the South Santiam River, we used a combination of Foster trap recapture records and detections on the Foster fishway receiver (FST) to estimate times that 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 total tailrace residency times for some fish.

In the Middle Fork Willamette River, we used detections at the tailrace antenna and recapture records at Dexter Dam to estimate tailrace residency times prior to 2014 because there was no antenna deployed in the Dexter Dam fishway. In 2014, we installed a receiver and antenna at the base of the fishway, which increased our sample size dramatically (n = 58) relative to prior years.

Annually, 15- 29 salmon were detected/recaptured at Foster Dam and 0- 58 at Dexter Dam had complete radio detection histories (i.e., detections at the tailrace and at the fishway or trap). 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.

In each year, salmon recaptured at Foster Dam spent a median of less than 15 d in the main stem Willamette and in the Santiam and South Santiam rivers downstream from the Foster tailrace antenna (Figure 46). After they were detected at the Foster tailrace, median tailrace residence times ranged from 25 to 52 days each year. 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 the total time from Willamette Falls Dam to recapture. 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 fish were small (Figure 47). 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 48). Estimated tailrace residency times varied between years, with medians ranging from 17 days in 2014 to 61 days in 2011. These estimates represented 41-62% of the total time from Willamette Falls to recapture at Dexter. Median Dexter tailrace residency times for tagged salmon with intact and clipped adipose fins were similar but sample sizes of 'wild' fish at were small (Figure 49).

One tagged salmon with an intact adipose fin was detected on the Cougar Dam fishway receiver (COG) for 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 at COG 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 at COG for one day and its transmitter was last detected via mobile tracking approximately eight river kilometers upstream from the dam in early November. A single, unclipped salmon was detected on the Cougar Dam fishway receiver on three different days in 2014, ranging from late August to mid-September. It was allegedly recaptured in the South Santiam River downstream from Foster Dam but there were no telemetry data to support these movements between tributaries.

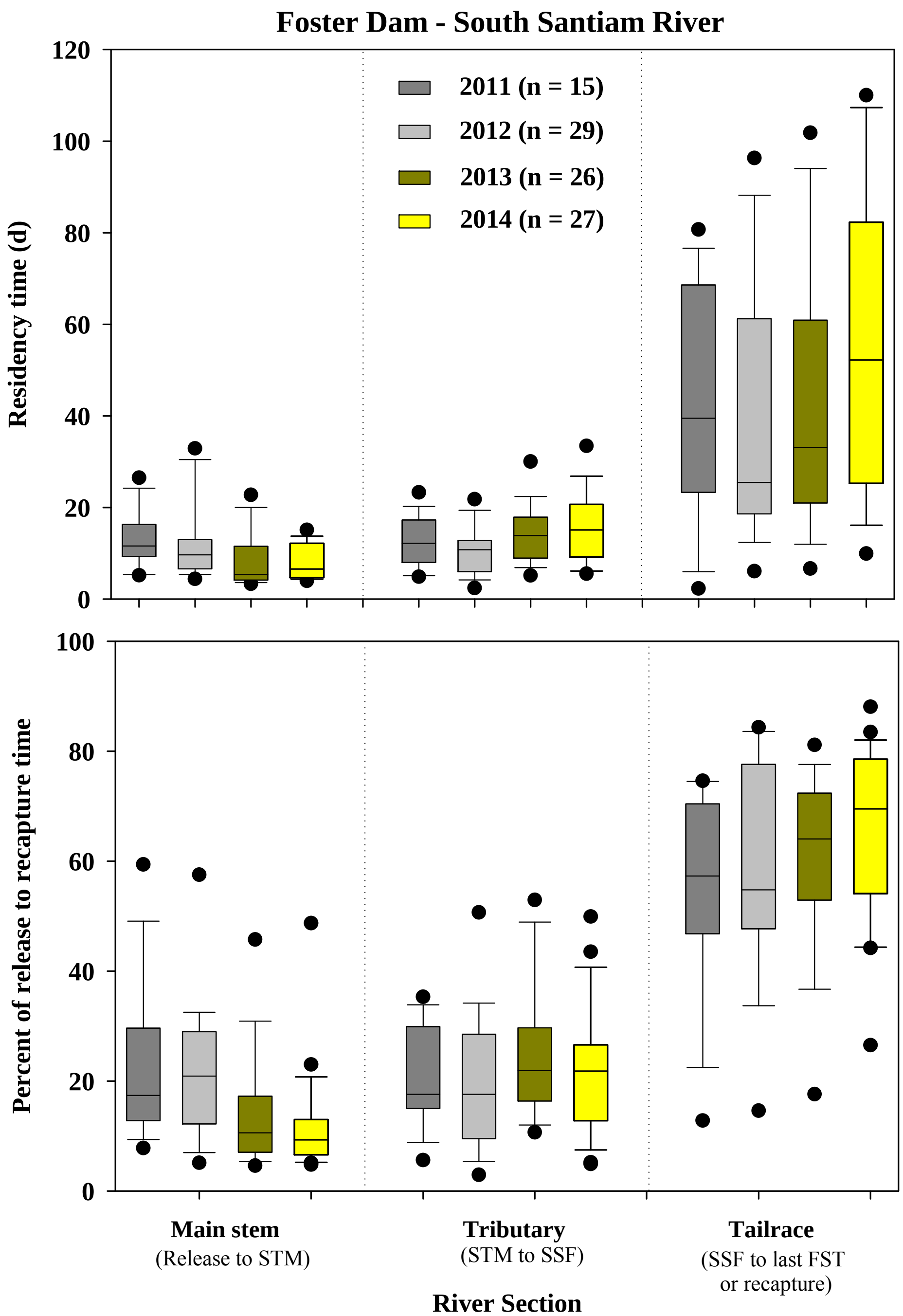

Figure 46. Box plots of times (days – upper panel) and percentages of release-to-recapture time (lower panel) that radio-tagged spring Chinook salmon spent in the main stem Willamette River (distance = 137.8 rkm), the lower Santiam and South Santiam rivers (distance = 72.7 rkm), and in the Foster tailrace (distance = 1.4 rkm) for salmon detected / recaptured at Foster Dam in 2011-2014. Box plots show: median (line), quartile (box), 10^{th} and 90^{th} (whisker), and 5^{th} and 95^{th} percentiles (●).

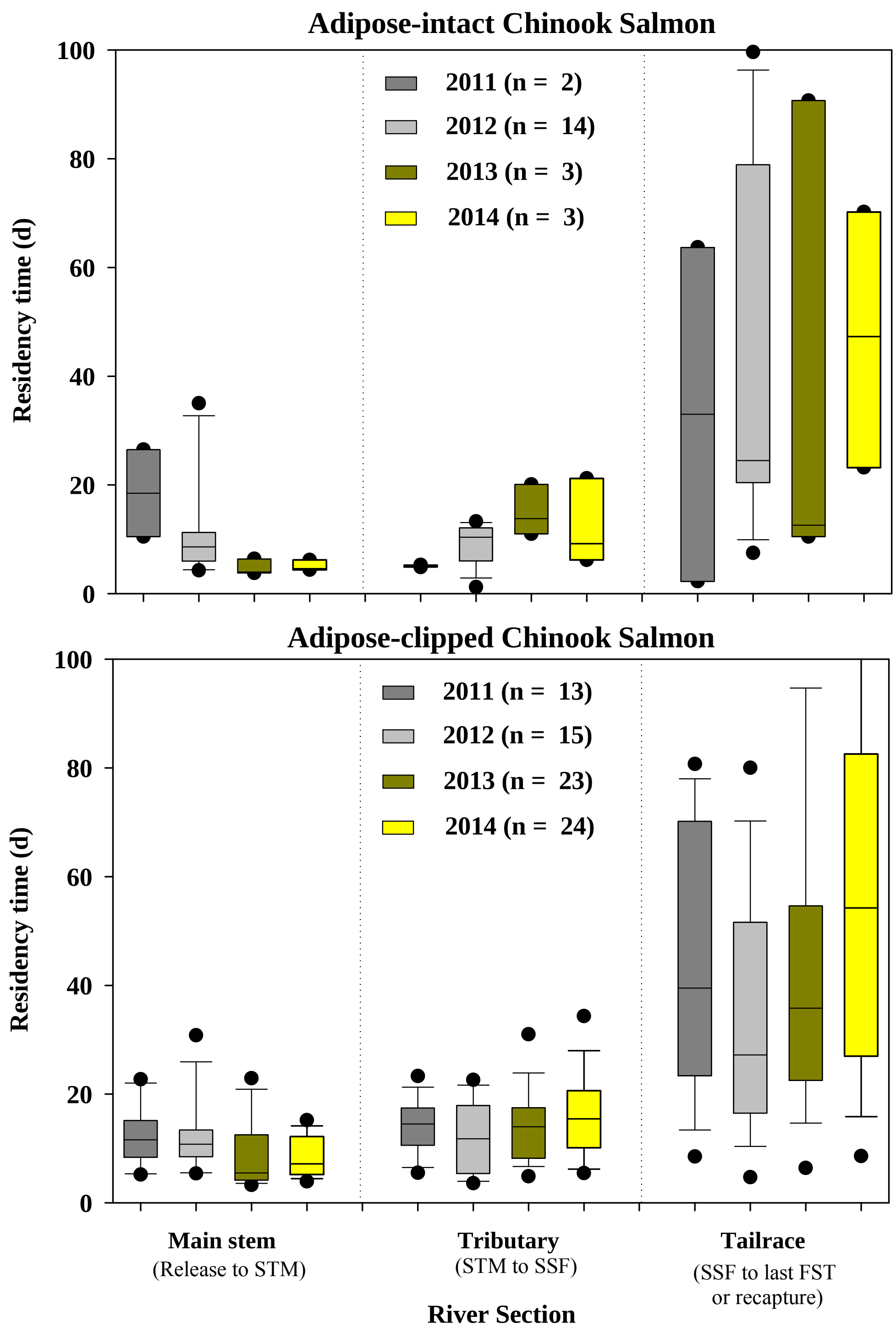

Figure 47. Box plots of times (days) that adipose-intact (upper panel) and adipose-clipped (lower panel), radio-tagged spring Chinook salmon spent in the main stem Willamette River (distance = 137.8 rkm), the lower and South Santiam rivers (distance = 72.7 rkm), and in the Foster tailrace (distance = 1.4 rkm) for salmon detected / recaptured at Foster Dam in 2011-2014. Box plots show: median (line), quartile (box), 10th and 90th (whiskers), and 5th and 95th percentiles (●).

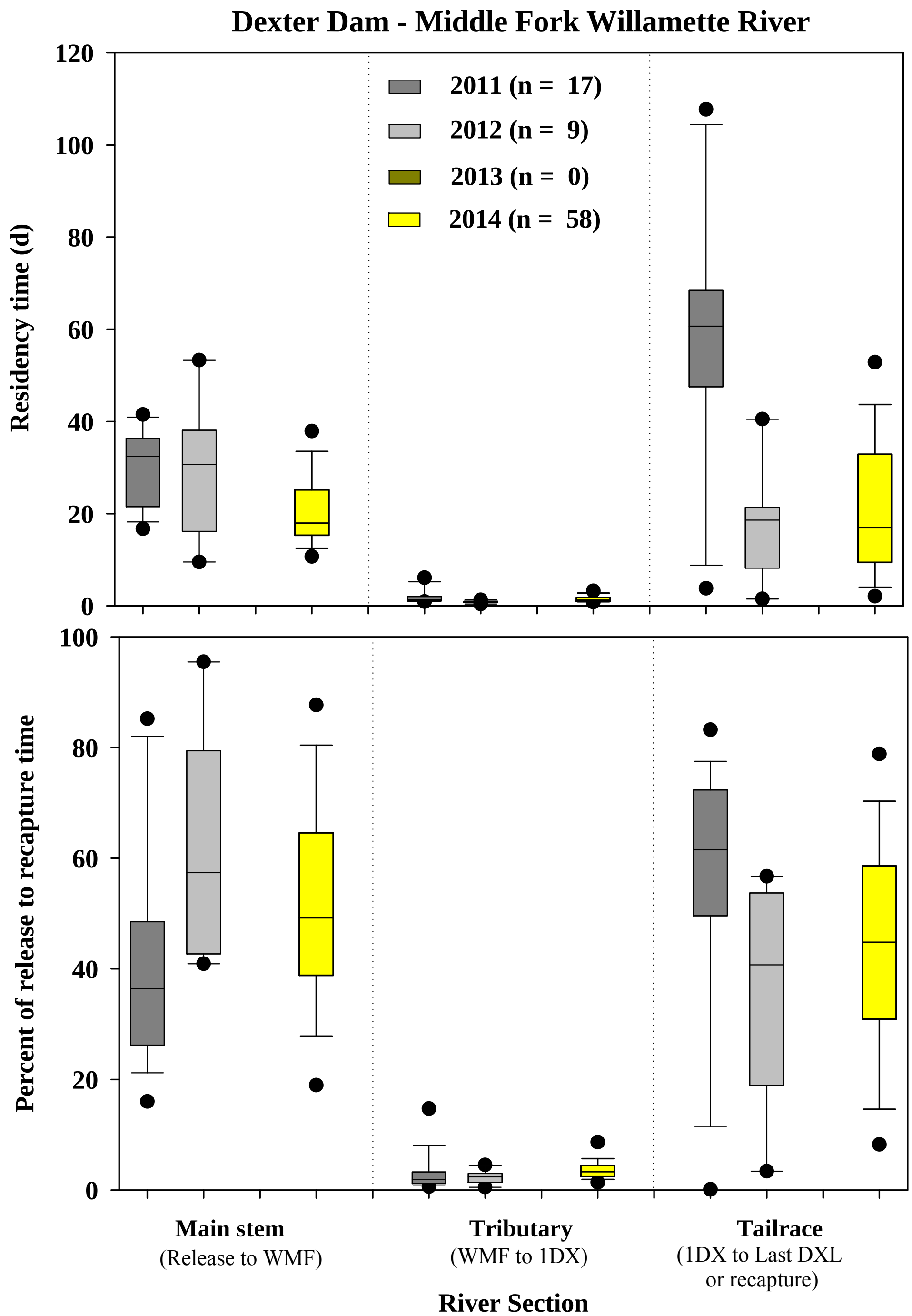

Figure 48. Box plots of times (days – upper panel) and percentages of release-to-recapture time (lower panel) that radio-tagged spring Chinook salmon spent in the main stem Willamette River (distance = 272.3 rkm), the Middle Fork Willamette River (distance = 8.3 rkm), and the Dexter Dam tailrace (distance = 4.5 rkm) for salmon last detected in the Dexter fishway or recaptured at Dexter Dam in 2011-2014. Box plots show: medians (line) and quartiles (box), 10th and 90th (whiskers), and 5th and 95th percentiles (●).

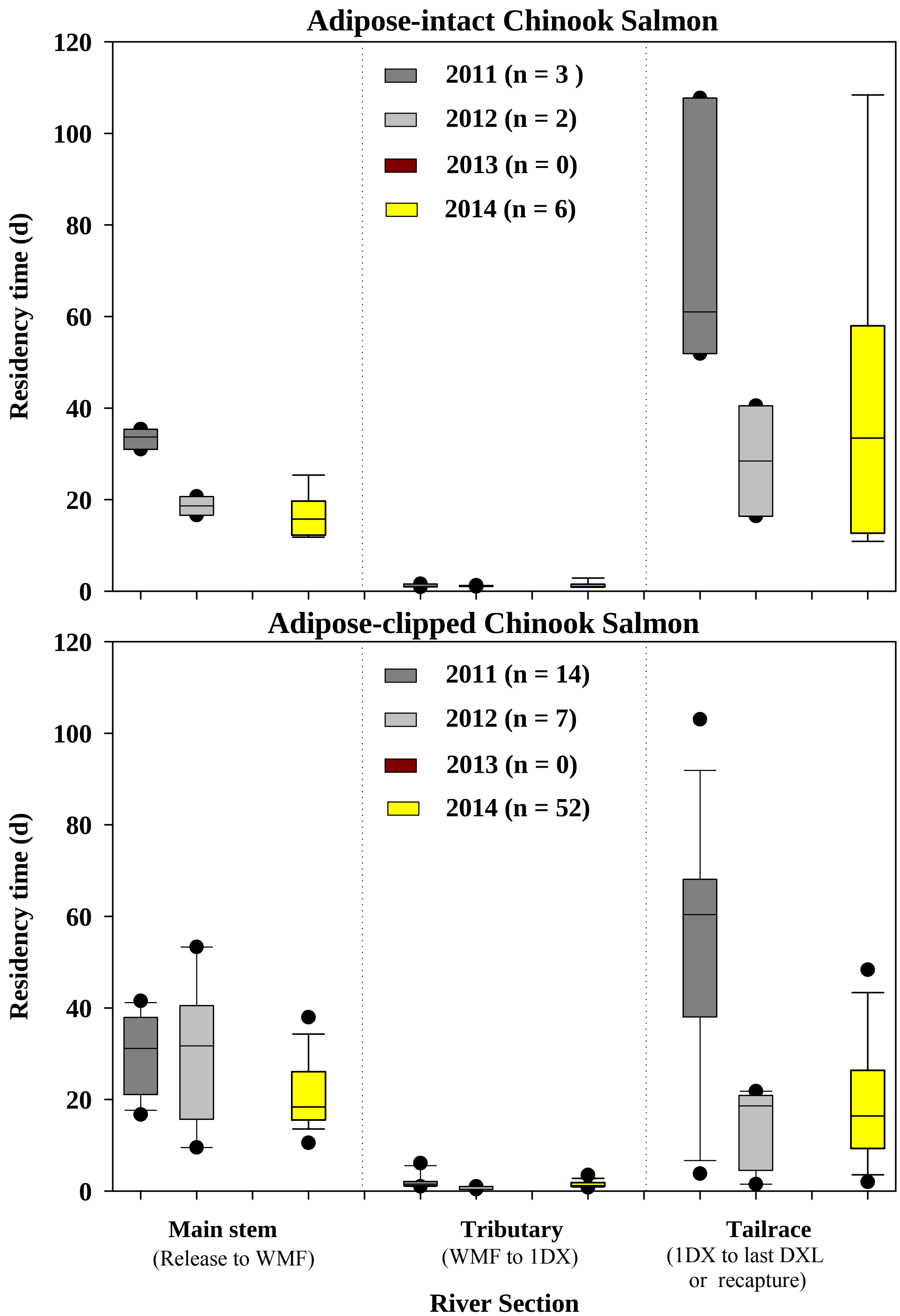

Figure 49. Box plots of times (days) that adipose-intact (upper panel) and adipose-clipped (lower panel), radio-tagged spring Chinook salmon spent in the main stem Willamette River (272.3 rkm), the Middle Fork Willamette River (distance = 8.3 rkm), and in the tailrace (distance = 4.5 rkm) for salmon last detected in the Dexter ladder or recaptured at Dexter Dam in 2011-2014. Box plots show: median (line), quartile (box), 10^{th} and 90^{th} (whisker), and 5^{th} and 95^{th} percentiles (●).

Escapement to tributaries: 2014

In 2014, 267 of 300 (89%) of Chinook salmon were last recorded or recaptured in Willamette River tributaries and 33 (11%) were last detected at main stem sites either upstream or downstream from Willamette Falls Dam (Table 20 and Figures 50 and 51). The overall percent escapement to tributaries in 2014 was higher than in 2011 (74%) and 2012 (62%), when salmon that were restrained during tagging were less likely to escape than were anesthetized salmon (Table 15; also see Caudill et al. 2014). The 2014 estimate was also higher than in 2013 (77%), when all tagged Chinook salmon were anesthetized.

Table 20. Percentages of radio-tagged salmon that escaped to Willamette River tributaries based on adipose fin status and handling treatment, 2011-2014. 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	62 (496)	56 (188)	64 (308)	52 (344)	83 (152)
2013	78 (297)	78 (227)	76 (70)	n/a	77 (297)
2014	89 (300)	87 (224)	95 (76)	n/a	89 (300)

Last radio detections and transmitter recoveries: 2014

In 2014, twelve (4%) tagged salmon were last recorded downstream from Willamette Falls Dam (Table 21 and Figures 46 and 47). Eleven (~4%) additional fish were last recorded in the Clackamas River, four (~1%) had their last detections at the WLL receiver site at the dam, and one was found dead in the trap one week after being released. A total of 272 were last recorded upstream from Willamette Falls Dam. Two fish (2%) were last detected in the Molalla River. Sixteen tagged salmon (~5%) were last detected on receivers in the main stem, including nine in the lower portion (from Willamette Falls Dam to the Santiam River mouth) and seven in the upper portion (from the Santiam River mouth to the confluence of the Coast and Middle Forks). Another 129 (43%) were last detected in the Santiam River, with 57, 70, and 2 in the South, North, and lower Santiam rivers, respectively. Forty-nine (16%) were in the McKenzie River, 11 (~4%) were in Fall Creek, and 64 (21%) were in the Middle Fork Willamette River. No radio-tagged salmon were detected on the Yamhill River, Rickreall Creek, Luckiamute River, or Mary's River receiver sites in 2014.

Among the 57 transmitters recovered in the South Santiam River in 2014, one salmon with an unclipped adipose fin was last detected upstream from Foster Dam (i.e., mobile tracked upstream from the RVB site), 26 were associated with Foster Dam (24 recaptures and two with final telemetry detections), five were captured by anglers, three were recovered during spawning ground surveys (downstream from Foster Dam), and one transmitter was found in Thomas Creek. In the North Santiam River, 21 transmitters were recaptured at the Minto Fish Collection Facility and three were recaptured by anglers downstream from the facility. The distribution of recovered transmitters in the

McKenzie River included 19 hatchery returns, two angler recaptures, and one tag recovered from a spawned out carcass between Leaburg Dam and McKenzie Hatchery. Among transmitters last detected the Middle Fork, 43 were associated with Dexter Dam (23 recaptures and 20 with last detection in the fishway), and one was reported recaptured by an angler downstream from the dam. Seven fish were mobile-tracked after outplanting, including five in the North Fork of the Middle Fork Willamette River and two in the southern end of Hills Creek Reservoir, near Oakridge.

In 2014, the 11 salmon last detected in the Clackamas River had the latest mean tag date (31 May) among groups and the 64 salmon last detected in the Middle Fork Willamette River had the earliest (10 May, Table 21). The 70 salmon last detected in the North Santiam River were the longest and heaviest, on average. Mean fatmeter readings among fate groups ranged from 5.4 to 8.3%.

Table 21. 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 2014.

Fate	*n*	# Ad-clipped (y:n)	Mean tag date	Mean fork length (cm)	Mean weight (kg)	Mean fatmeter (%)
Clackamas River	11	11:0	31 May	74.6	5.5	6.3
Downstream from Dam	12	10:2	12 May	75.6	5.5	7.7
Willamette Falls Dam	5	5:0	19 May	76.3	5.6	6.7
Molalla River	2	2:0	22 May	76.3	5.5	5.4
Lower main stem[1]	9	9:0	21 May	73.6	5.1	6.6
S. Santiam River	57	44:13	26 May	77.2	6.1	6.8
N. Santiam River	70	47:23	25 May	78.0	6.4	6.7
Santiam R. (Lower)	2	1:1	21 May	76.0	5.5	5.6
Upper main stem[2]	7	5:2	21 May	76.1	5.9	7.5
McKenzie River	49	34:15	21 May	76.7	5.9	7.5
Coast Fork	1	1:0	14 May	75.0	5.4	5.7
Fall Creek	11	0:11	16 May	76.3	5.8	8.1
Middle Fork Willamette River	64	55:9	10 May	74.1	5.2	7.2

[1] reach between Willamette Falls Dam and the WL3 receiver site (Buena Vista)
[2] reach between the WL3 receiver site and the confluence of the Coast Fork Willamette and Middle Fork Willamette rivers

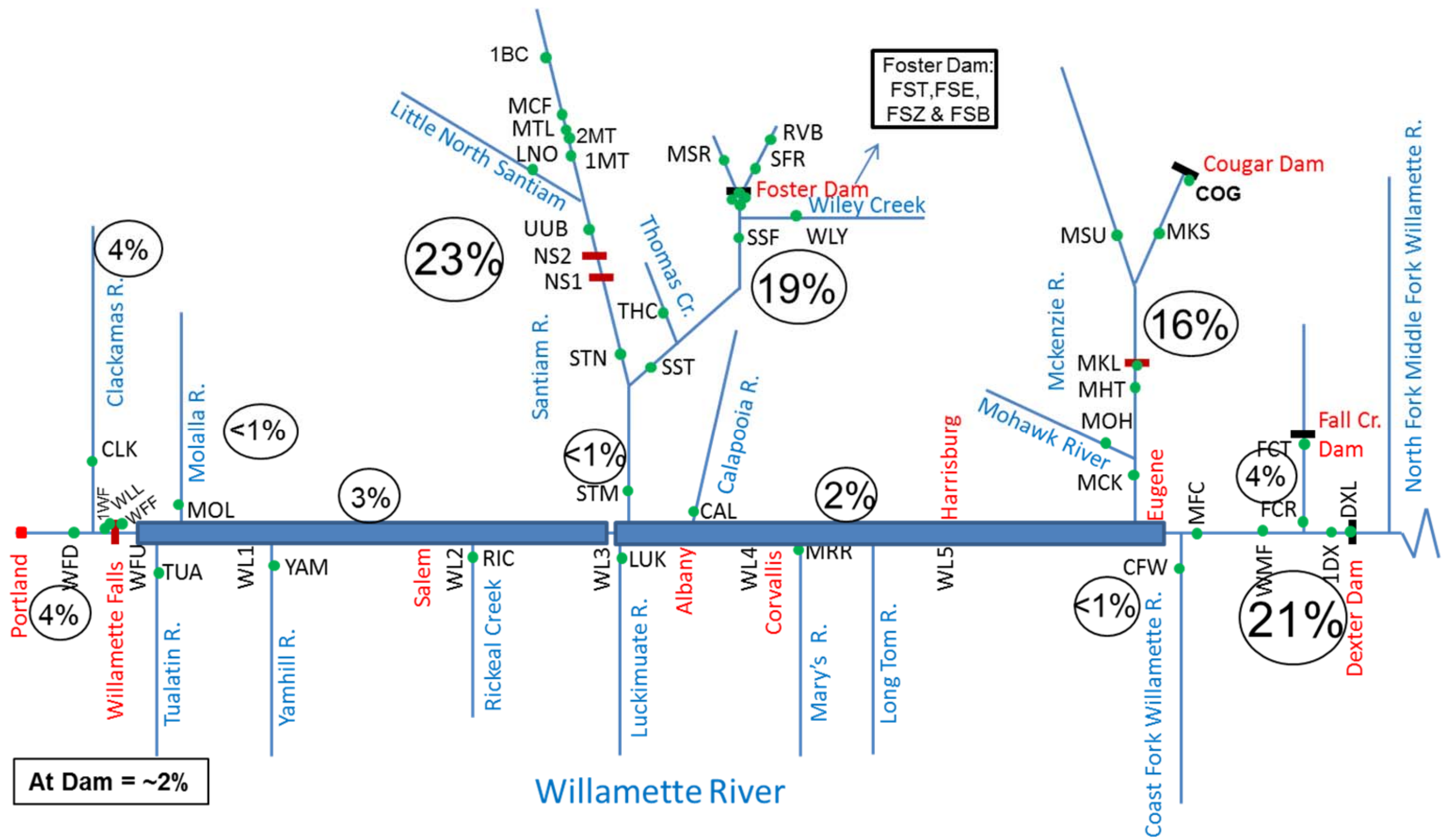

Figure 50. Sites and drainages where adult spring Chinook salmon radio-tagged and released at Willamette Fall Dam in 2014 migrated based on their **last radio detections** (*n* = 300) shown as percentages. Adipose-clipped and adipose-unclipped salmon are combined. The blue rectangles represent the upper and lower main stem.

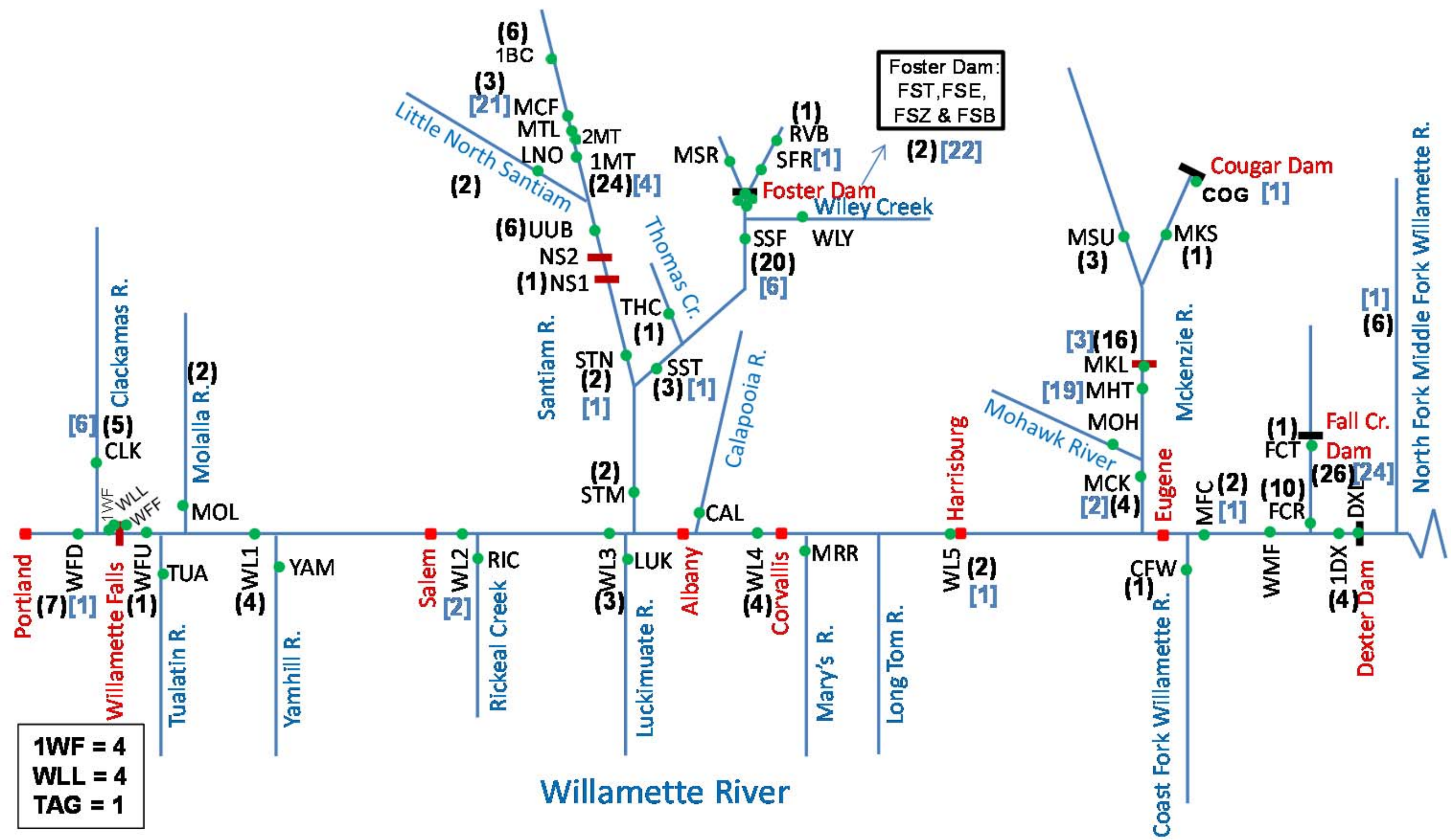

Figure 51. Sites where adult Chinook salmon radio-tagged and released at Willamette Falls Dam in 2014 were **last detected** (black font and parentheses) or where they were recaptured (blue font and brackets) shown as numbers of salmon. Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference. Adipose-clipped and adipose-unclipped salmon are combined.

Estimated returns by sub-basin: 2014

We estimated the number of Chinook salmon returning to tributaries in 2014 using: 1) the percentage of the count past Willamette Falls Dam that was fin-clipped (78.7%) and unclipped (21.3%), 2) the percentage of each radio-tagged fate group that was clipped (*n* = 224) and unclipped (*n* = 76), and 3) two count scenarios: a) Chinook salmon counted during the radio-tagging interval (15 April – 24 June), and b) the total annual count (11 February – 15 August) (Table 22).

Table 22. Estimated returns of adult Chinook salmon to Willamette River tributaries based on return numbers and percentages of 300 radio-tagged salmon (*n* = 224 adipose-clipped and 76 unclipped) and two scenarios of ODFW count data from Willamette Falls Dam in 2014. Percentages were weighted by the ODFW-reported proportions of fin-clipped (78.7%) and unclipped (21.7%) salmon passing Willamette Falls Dam.

			Fin-clipped Chinook count	
			Tag interval	Annual
			n = 19,013	*n* = 23,666
Tributary	*n*	% (95% ci)	Estimate	Estimate
None	29	12.9 (9.2-18.0)	2,462 (1,743-3,419)	3,064 (2,170-4,255)
Clackamas	11	4.9 (2.8-8.6)	934 (525-1,631)	1,162 (653-2,031)
Molalla	2	0.9 (0.2-3.2)	170 (46-607)	211 (57-755)
Santiam (lower)	1	0.4 (0.1 -2.5	85 (15-473)	106 (19-589)
N. Santiam	47	21.0 (16.2-26.8)	3,989 (3,073-5,092)	4,996 (3,824-6,338)
S. Santiam	44	19.6 (15.0-25.3)	3,735 (2,846-4,818)	4,649 (3,543-5,997)
McKenzie	34	15.2 (11.1-20.5)	2,886 (2,105-3,890)	3,592 (2,620-4,842)
Coast Fork	1	0.4 (0.1 -2.5)	85 (15-473)	106 (19-589)
Fall Creek	-	-	-	-
Middle Fork	55	24.6 (19.4-30.6)	4,668 (3,683-5,814)	5,811 (4,584-7,237)

			Unclipped Chinook count	
			Tag interval	Annual
			n = 5,146	*n* = 6,405
Tributary	*n*	% (95% ci)	Estimate	Estimate
None	4	5.3 (2.1-12.8)	271 (106-657)	337 (132-817)
Clackamas	-	-	-	-
Molalla	-	-	-	-
Santiam (lower)	1	1.3 (0.2-7.1)	68 (12-365)	84 (15-454)
N. Santiam	23	30.3 (21.1-41.3)	1,557 (1,085-2,127)	1,938 (1,351-2,647)
S. Santiam	13	17.1 (10.3-27.1)	880 (529-1,395)	1,096 (658-1,738)
McKenzie	15	19.7 (12.3-30.0)	1,016 (635-1,546)	1,264 (790-1,925)
Fall Creek	11	14.5 (8.3-24.1)	745 (426-1,239)	927 (530-1,542)
Middle Fork	9	11.8 (6.4-21.0)	609 (327-1,081)	758 (407-1,345)

The tributary to which the highest estimated return of clipped Chinook salmon was the Middle Fork Willamette, based on the return percentages of 224 clipped, radio-tagged salmon (Table 22). Point estimates of adult returns to the Middle Fork Willamette ranged from 4,668-5,811 adipose-clipped individuals. The tributary to which the highest estimated return of unclipped Chinook salmon was the North Santiam River, based on return percentages of 76 unclipped, radio-tagged salmon (Table 18). Point estimates for the North Santiam ranged from 1,557-1,938 unclipped fish. Estimates for the McKenzie River were 2,886-3,592 fin-clipped fish and 1,016-1,264 unclipped fish.

The summed counts of adipose-clipped Chinook salmon passing Lower and Upper Bennett dams on the North Santiam River in 2014 was 5,421, which was 8-36% higher than our telemetry-based point estimates (Table 22). The discrepancy may have resulted from fallback and double-counting at the Bennett dams and/or under-sampling of the North Santiam group at Willamette Falls. In contrast, the 2014 count of adipose-clipped Chinook salmon at Foster Dam on the South Santiam River (n = 2,556) was 32-49% lower than telemetry-based estimates, perhaps because the telemetry-based estimate included fish that potentially spawned downstream from Foster Dam. No Chinook salmon count data from Leaburg Dam were available for 2014 at the time this was written.

The summed counts of unclipped Chinook salmon passing Lower and Upper Bennett dams in 2014 (n = 1,630) was within the 95% confidence intervals of both telemetry-based estimates. The count of unclipped Chinook salmon at Foster Dam in 2014 (n = 451) was 49-59% less than telemetry-based estimates, again potentially due to radio-tagged fish spawning downstream from the dam.

Summary of fates of radio-tagged salmon: 2011-2014

The relative distribution of radio-tagged Chinook salmon to tributaries differed among years (Figure 52). Independent of handling treatment and origin, the highest percentage of tagged salmon returned to the South and North Santiam rivers, the McKenzie River, and the Middle Fork Willamette River. The relative distribution between adipose-clipped and unclipped salmon also differed, with higher percentages of hatchery salmon returning to the Santiam and Middle Fork Willamette rivers. As noted previously, the use of a restraint device in 2011 and 2012 resulted in proportionately fewer salmon reaching tributaries.

In all years, small percentages of radio-tagged salmon last recorded were reported recaptured by anglers (range = 1.7 to 4.1%). Four tagged salmon were captured and kept in the McKenzie River in 2011 (n = 4/109 last detected in tributaries, 3.7%). In 2012, five radio-tagged salmon last recorded in tributaries were reported recaptured by anglers (n = 5/303, 1.7%): 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. 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%). Eleven salmon (4.1% of 267 in tributaries) were reported recaptured in 2014: five in the South Santiam River (four kept and one with unknown disposition), three in the North Santiam River (all kept), two in the McKenzie River (both unknown dispositions), and one in the Middle Fork (kept).

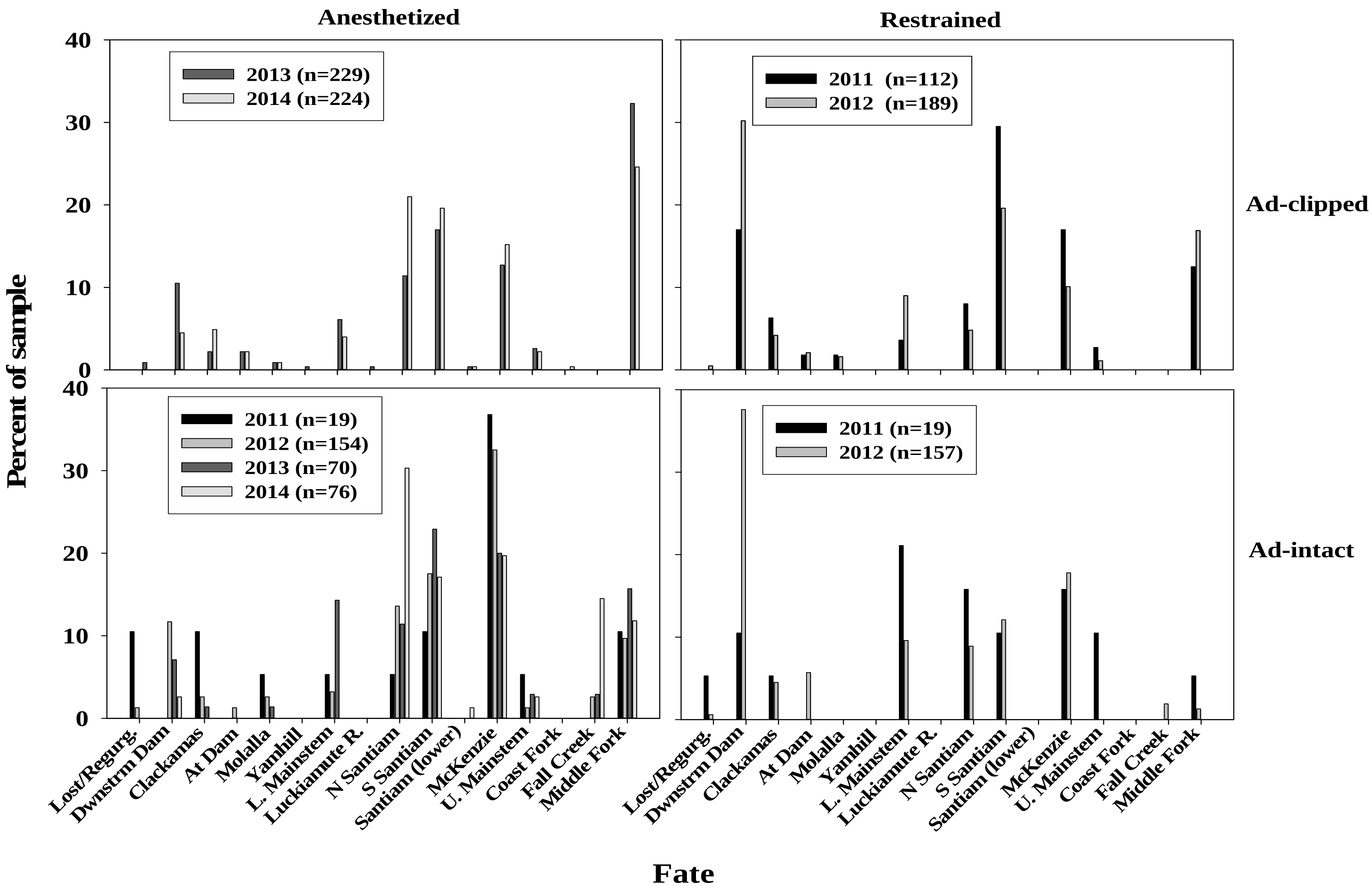

Figure 52. Histograms showing where all adipose-clipped (upper panels) and unclipped (lower panels), radio-tagged spring Chinook salmon that received the anesthetic (panels on left) or fish restraint device handling (panels on right) treatment were last recorded in 2011-2014.

Escapement to tributaries: Anesthetized Chinook salmon in 2011-2014

Over the four study years, 762 Chinook salmon that retained transmitters were in the anesthetized handling treatment. Escapement to tributaries for this sub-sample varied in relation to several categorical covariates (Figure 53), including year ($\chi2$ = 12.8, P = 0.005), descaling ($\chi2$ = 10.6, P = 0.001), head injuries ($\chi2$ = 5.1, P = 0.024), and marine mammal injuries ($\chi2$ = 12.3, P = 0.016). Escapement did not differ by salmon sex or origin (P > 0.10). In these models, escapement was lower for fish with >10% descaling, for fish with head injuries, and for those with marine mammal injuries. The year effect indicated relatively higher escapement to tributaries in 2014 and relatively low escapement in 2013.

Logistic regression models using single continuous covariates showed little association between these variables and Chinook salmon escapement to tributaries across years. These included salmon fork length, weight, condition (Fulton's K), and lipid content ($0.1 \leq \chi2 \leq 2.5$, $P \geq 0.11$). Similarly, date of release (tagdate) was not associated with escapement ($\chi2$ = 1.6, P = 0.39) and neither was the 7-d mean Willamette River flow ($\chi2$ = 1.0, P = 0.32) or 7-d mean water temperature ($\chi2$ = 0.1, P = 0.73) following salmon release (river environment data from the Albany USGS gage). (Note: five salmon missing Fatmeter data and two with outlying condition [K] values were excluded.)

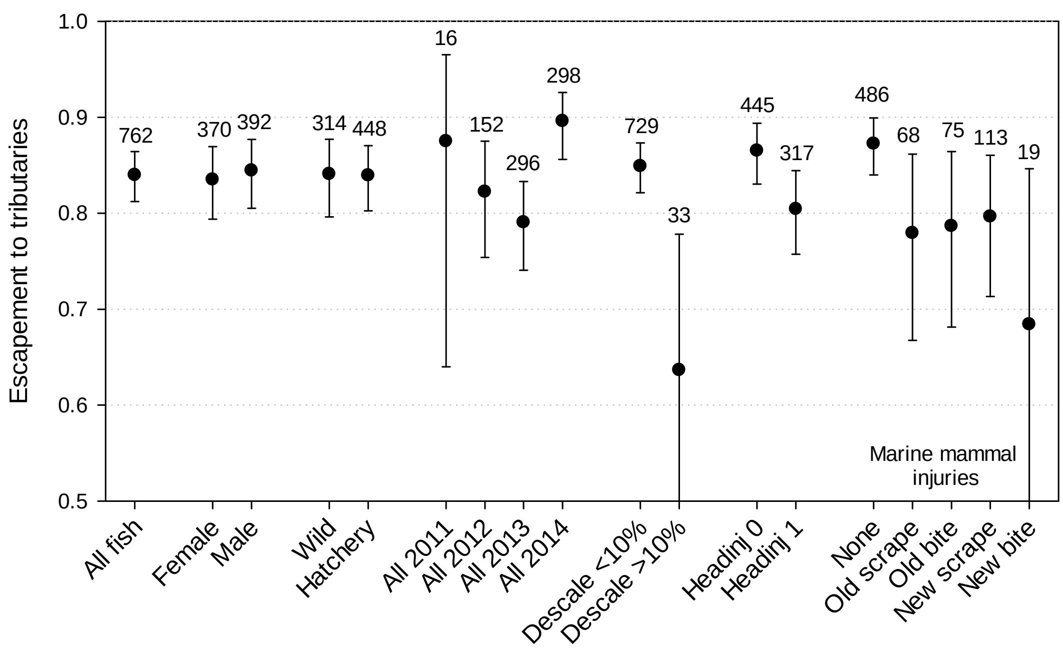

Figure 53. Escapement to tributaries for 762 salmon that were in the anesthetized handling treatment in 2001-2014, by sex, origin, and year, and by descaling, head injury, and marine mammal injury categories. Error bars are 95% Wilson binomial confidence intervals.

Relationships between individual salmon escapement and the suite of predictor variables was evaluated using a series of general linear models (GLM) and model selection via AIC corrected for small sample sizes (i.e., AICc, Burnham and Anderson 2002). All continuous variables were standardized prior to analyses so that relative effects could be assessed. The model comparison was conducted using the package MuMIn (Bartoń 2013) in R (R Core Development Team 2013). We first ran separate GLMs for each covariate to estimate 'baseline' parameter estimates. We then calculated model-averaged parameter estimates using a 95% confidence set of models (i.e., all models with cumulative AICc weights ≥ 0.95) that included combinations of predictor variables. The approach we used included all combinations of the predictor variables (except weight, which was excluded due to a high correlation with fork length). This approach is conservative and requires no a priori assumptions. However, we also looked at ~20 models that we selected based on expert opinion; the results were similar for the two multi-model approaches and so we include only the full comparison here.

Results from the multi-model comparison showed similar overall patterns as the univariate results. Descaling, head injuries, and marine mammal injuries were each associated with reduced escapement (Figure 54). Confidence intervals for the other modeled variables included 0, indicating greater uncertainty regarding the effects of those terms. We note that the significant year effect identified in the χ^2 test was less evident in the multi-model comparison, likely because of small sample size in 2011 (n = 14, with two fish excluded due to missing data) and because 2011 was used as the 'reference' year. We note, however, that the parameter estimates for year did indicate higher escapement in 2014 and relatively lower escapement in 2012 and 2013.

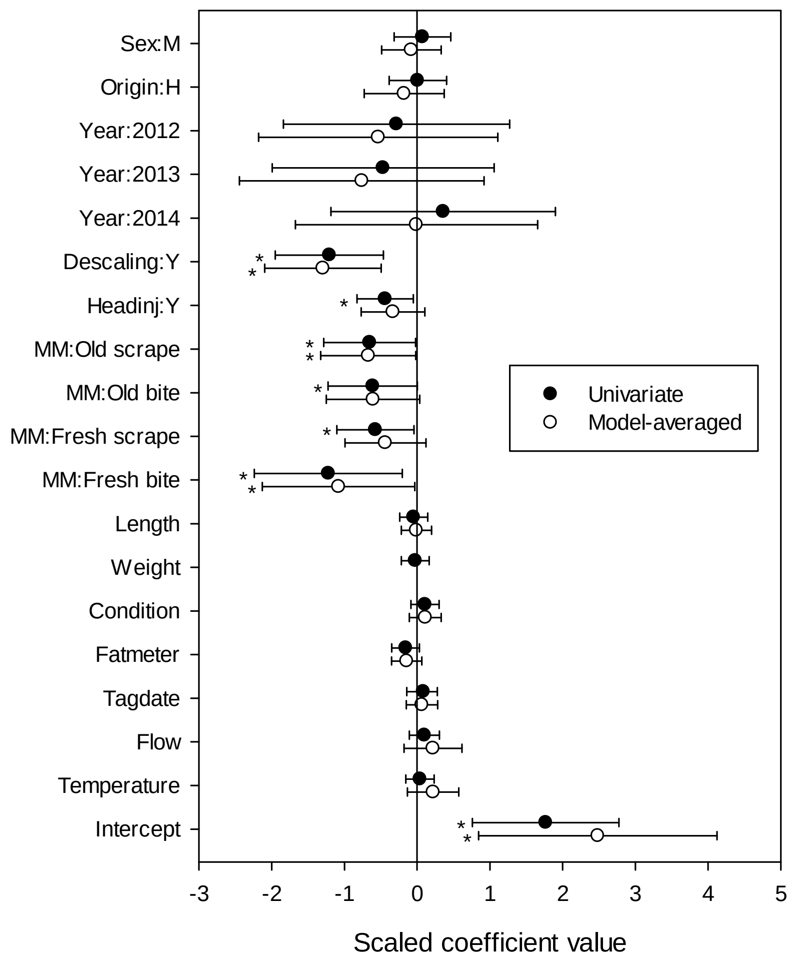

Figure 54. Standardized parameter estimates with 95% confidence intervals for GLM models of Chinook salmon escapement to tributaries in 2011-2014. Models included 755 radio-tagged fish in the anesthetized handling treatment with complete covariate data. Closed circles (●) are estimates from univariate models and open circles (○) are model-averaged estimates from the set of models that contributed up to 95% of model weight in the AIC model comparison exercise. No models included interaction terms and weight was excluded from the multi-model comparison because it was highly correlated with salmon length. Asterisks indicate significance ($P < 0.05$).

Run Composition

We included all Chinook salmon that reached tributaries in this summary, regardless of handling treatment, because we had no reason to suspect that handling affected which tributary 'successful' fish eventually entered. The run composition of unclipped Chinook salmon that successfully migrated to tributaries varied more than for adipose-clipped salmon within each year (Figures 55 and 56). While the relative abundance of individual populations varied among years for both clipped and unclipped groups, the unclipped group was generally less well-mixed in all years. Generally, we found that hatchery fish were a combination from the Santiam, McKenzie, and Middle Fork Willamette rivers throughout each migration season.

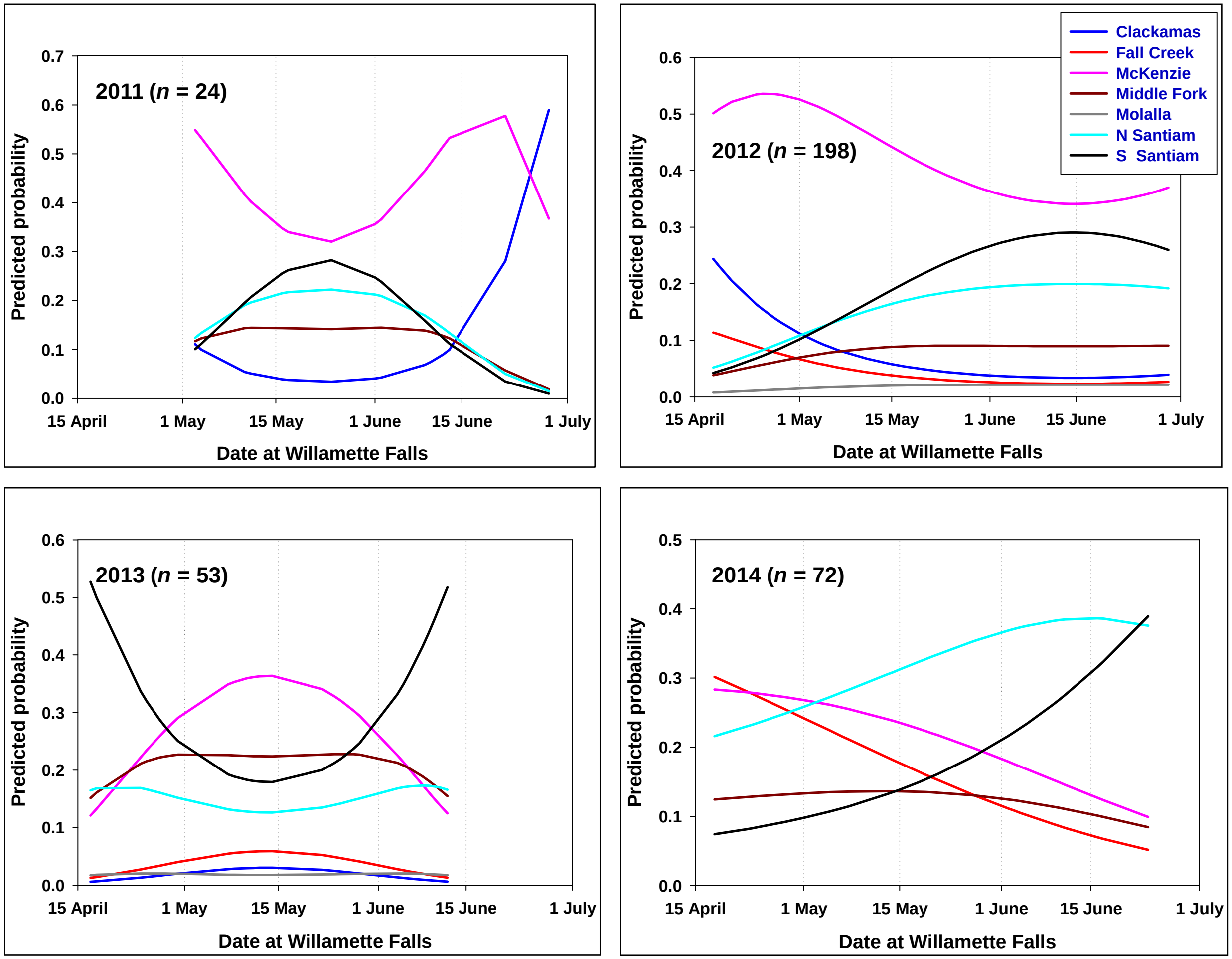

Figure 55. Estimates of unclipped Chinook salmon run composition based on predicted probabilities from multinomial logistic regressions of unclipped ‘escaped’ salmon radio-tagged at Willamette Falls Dam in 2011-2014. Models did not include tributaries with 1-3 fish per year.

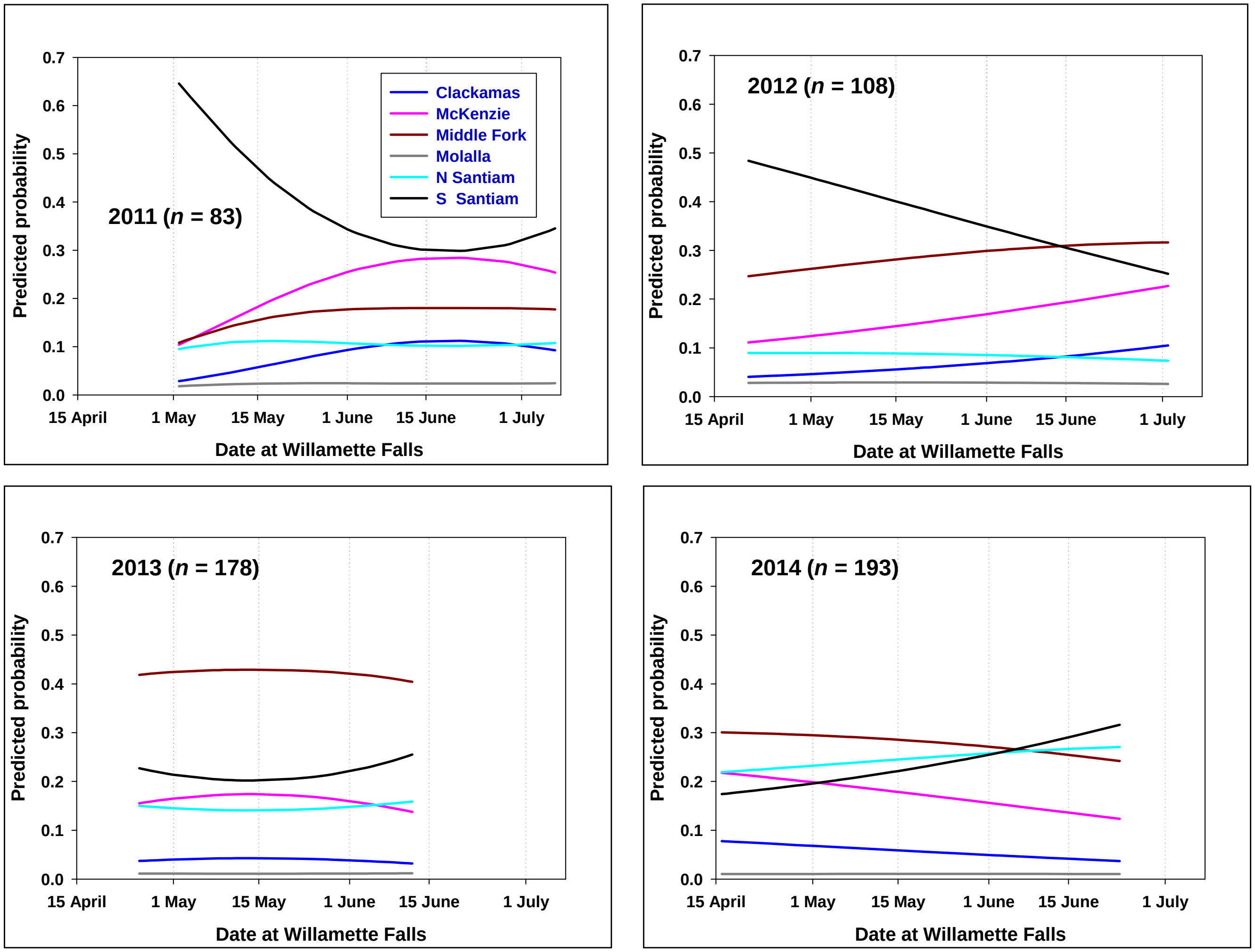

Figure 56. Estimates of adipose-clipped Chinook salmon run composition based on predicted probabilities from multinomial logistic regressions of adipose-clipped 'escaped' salmon radio-tagged at Willamette Falls Dam in 2011-2014. Models did not include tributaries with 1-3 fish per year.

Results: Coho salmon

Historic count data and run timing

The annual count of adult coho salmon passing Willamette Falls Dam in 2014 was 18,062 (Figure 57). This was approximately 7,000 more fish than the average count of 11,021 since 1954. The 2014 coho salmon run at Willamette Falls Dam was relatively late-timed compared to runs from the previous ten years, although the dates of median passage varied by only seven days among years (Figure 58).

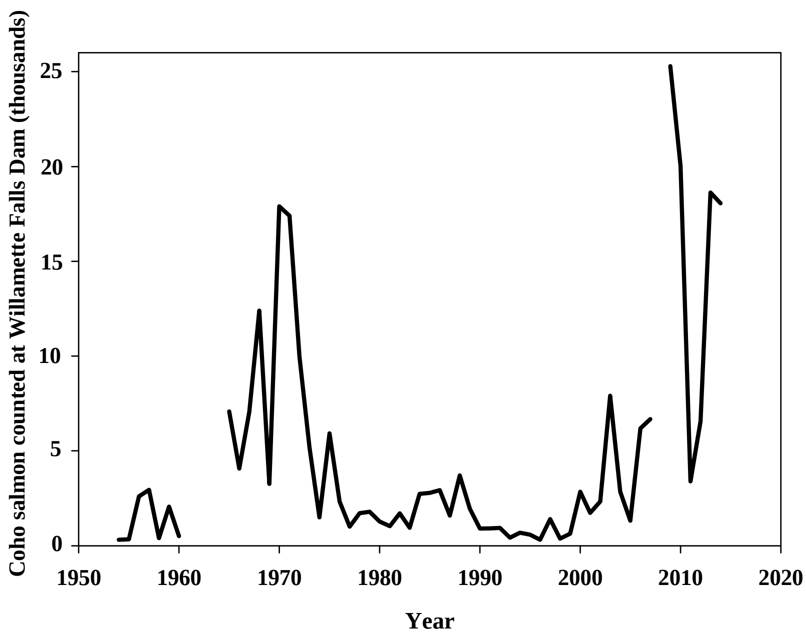

Figure 57. Total annual numbers of adult coho salmon counted passing Willamette Falls Dam, 1954-2014. No coho salmon count data were available in 1961-1964 and counts from 2008 were incomplete because fishway maintenance precluded count data from being collected 27 August – 21 September. Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

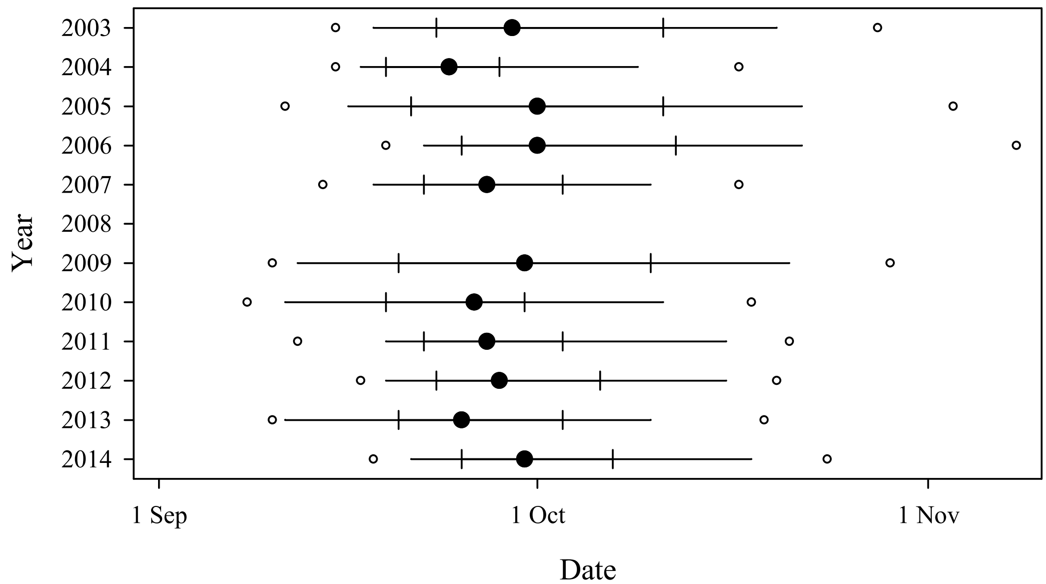

Figure 58. Annual migration timing distributions for coho salmon counted at Willamette Falls Dam, 2003-2014. Symbols show median (●), quartile (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (○). Counts were incomplete in 2008 because fishway maintenance precluded counting from 27 August – 21 September 2008. 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 coho salmon that returned to the Yamhill and Santiam rivers in 2014 spent roughly equivalent times (*median* ~ 1 day) in the lowest section of the main stem (Figure 59). This translated into median migration rates ranging from ~22 (Yamhill) to 25 rkm/d (Santiam) for the two groups. Coho salmon that returned to the Santiam River comprised a small portion of the run but median migration rates diminished with successive upstream sections for this group, which was consistent with steelhead and Chinook salmon migration patterns. Main stem migration rates were not estimable for salmon that returned to the Tualatin River because its mouth was upstream from the lowest main stem site above the Falls (the WFU site) but downstream from the next upstream site (the WL1 site).

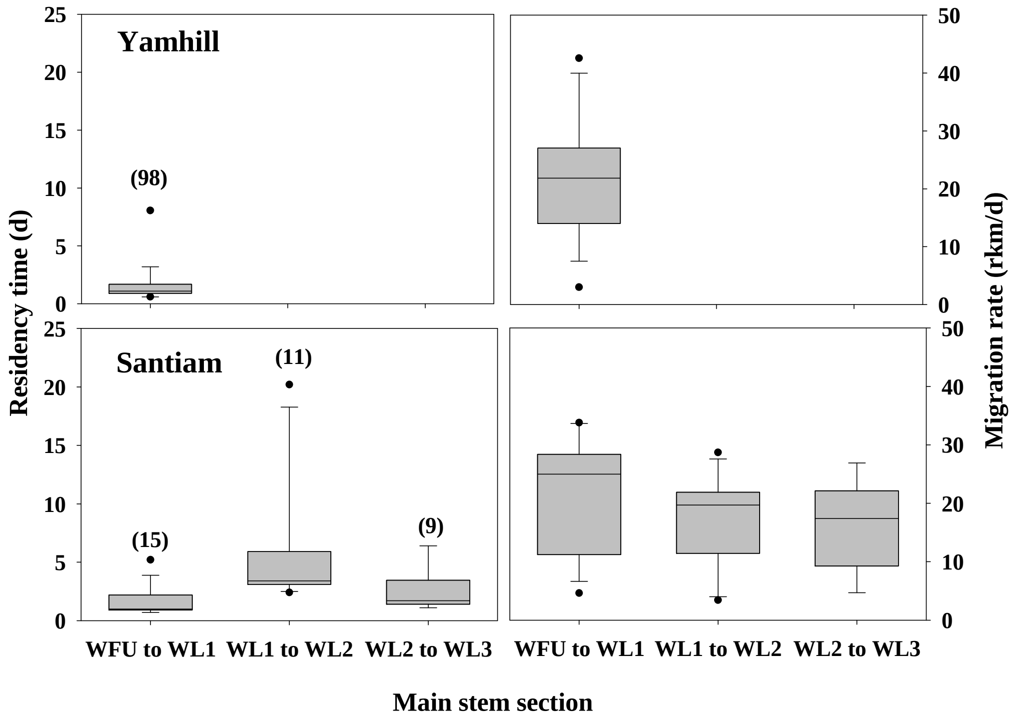

Figure 59. Box plots of residency times (days, left panels) and migration rates (rkm/day; right panels) radio-tagged coho salmon used in reaches of the main stem Willamette River for salmon that returned to the Yamhill and Santiam rivers in 2014. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th (●) percentiles. Sample sizes are listed in parentheses above boxes.

Last radio detections and transmitter recoveries

Of 219 coho salmon released in 2014, 81%were last detected in Willamette River tributaries. The highest percentage was last recorded in the Yamhill River (47%), followed by the Tualatin River (19%), and the North Santiam and Molalla rivers (5% each; Figures 60 and 61). Five (2%) of the 219 tagged salmon were reported recaptured by anglers; three in tributaries (1 each in the Molalla, North Santiam, and Lower Santiam) and two in the lower main stem near Champoeg, OR. No tagged coho salmon were detected in the main stem Willamette River upstream from the Santiam River confluence.

Coho salmon last detected in the Clackamas River had the earliest mean tag date among groups and the six salmon last detected at Willamette Falls Dam had the latest (Table 23). The three salmon last detected in Rickreall Creek were the longest and heaviest on average. Mean fatmeter readings among fate groups ranged from 1.0 to 2.7%.

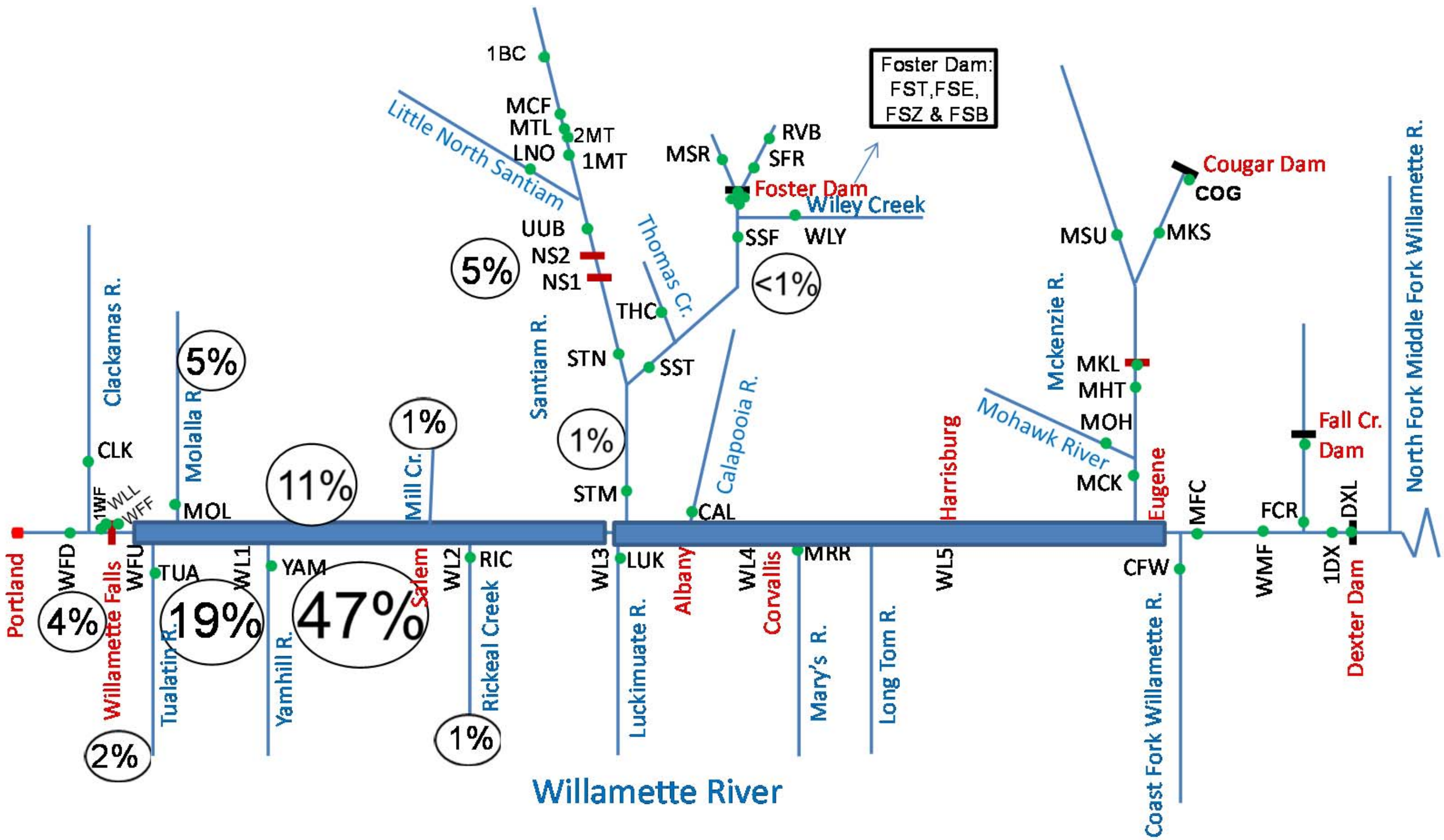

Figure 60. Sites and drainages where adult coho salmon radio-tagged and released at Willamette Fall Dam in 2014 migrated based on their **last radio detections** (n = 219) shown as percentages. The blue rectangles represent the upper and lower main stem.

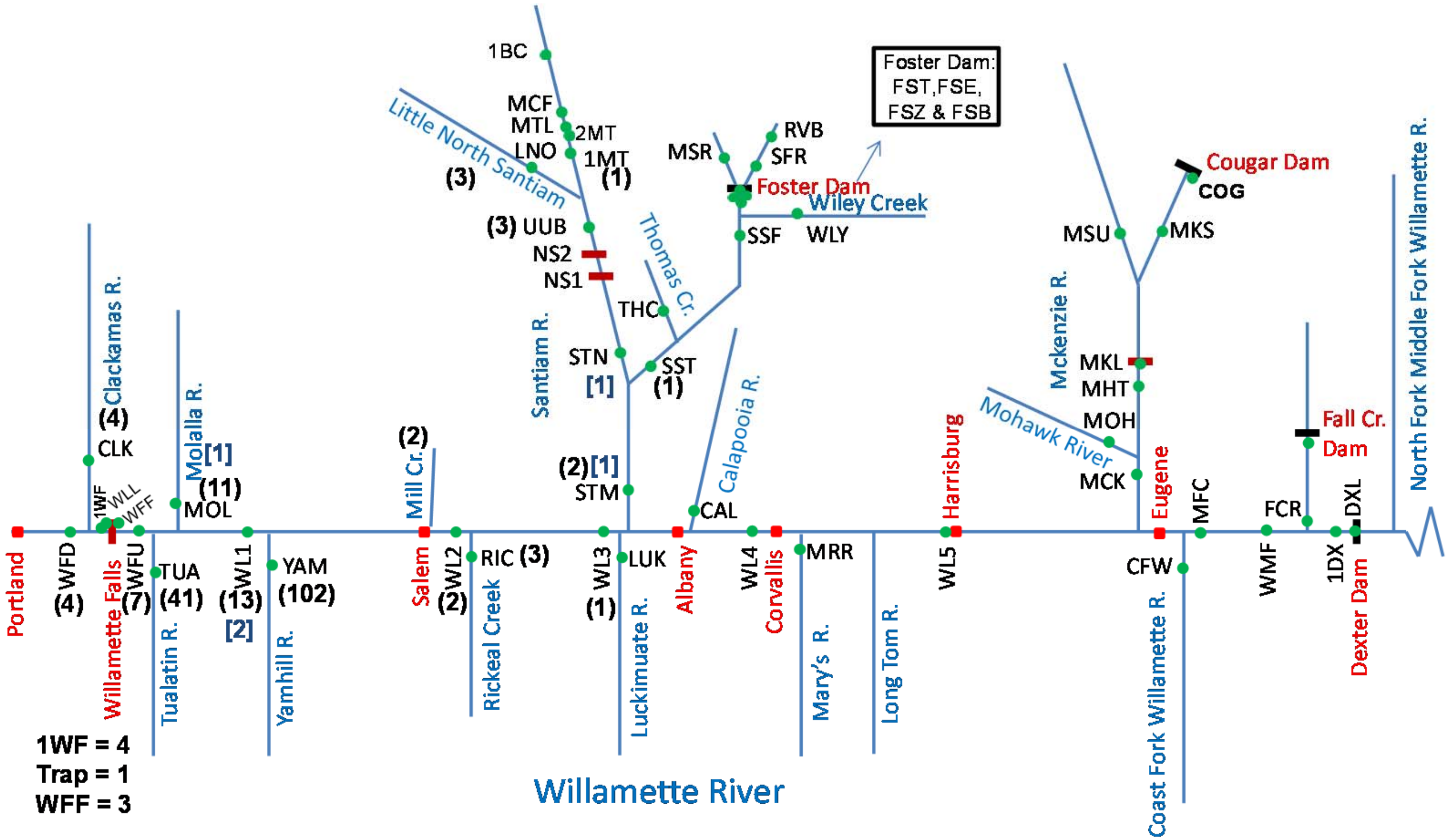

Figure 61. Sites where adult coho salmon radio-tagged and released at Willamette Falls Dam in 2014 were **last detected** (black font and parentheses) or where they were recaptured (blue font and brackets) shown as numbers of salmon. Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference.

Table 23. Sample sizes, mean tag date, mean fork length, mean weight, and mean fatmeter readings for radio-tagged adult coho salmon by final detection site within the Willamette River basin in 2014.

Fate	*n*	Mean tag date	Mean fork length (cm)	Mean weight (kg)	Mean fatmeter (%)
Clackamas River	4	25 Sept.	69.8	3.9	2.0
Downstream from Dam	8	3 Oct.	66.9	3.6	1.4
Willamette Falls Dam	6	5 Oct	69.1	3.8	1.1
Tualatin River	41	27 Sept.	69.5	4.2	1.8
Molalla River	12	1 Oct.	70.8	4.4	2.0
Yamhill River	102	2 Oct.	69.3	4.0	1.9
Rickreall Creek	3	30 Sept.	75.0	4.8	1.0
Lower main stem[1]	27	2 Oct.	69.4	3.9	1.6
S. Santiam River	1	26 Sept.	63.0	3.1	2.7
N. Santiam River	12	4 Oct.	68.5	4.0	1.7
Santiam R. (Lower)	3	27 Sept.	67.3	3.5	1.4

[1] reach between Willamette Falls Dam and the WL3 receiver site (Buena Vista).

Estimated returns by sub-basin

We used the 2014 distribution of radio-tagged fish and coho salmon counts at Willamette Falls Dam to estimate total escapement. We expanded the escapement proportions of the tagged fish (n = 219) using two ODFW count scenarios: 1) the count during the tagging interval (12 September – 28 October) and 2) the annual count.

The highest number of adults returned to the Yamhill River, with point estimates ranging from 8,074 to 8,664 individuals across the two scenarios (Table 24). The next highest estimates were to the Tualatin River (3,246-3,483), and the Molalla and North Santiam rivers (950-1,019 each). More than 200 coho salmon were estimated to have returned to Rickreall Creek under both scenarios.

Table 24. Estimated returns of adult coho salmon to Willamette River tributaries based on return numbers and percentages of radio-tagged coho salmon (n = 219) and two scenarios of ODFW count data from Willamette Falls Dam in 2014.

			Coho salmon counted	
			Tagging Interval	Annual
			n = 17,336	*n* = 18,602
Tributary	*n*	% (95% ci)	Estimate	Estimate
None	41	18.7 (14.1-24.4)	3,246 (2,446-4,232)	3,483 (2,625-4,545)
Clackamas	4	1.8 (0.7-4.6)	317 (123-799)	340 (132-858)
Tualatin	41	18.7 (14.1-24.4)	3,246 (2,446-4,232)	3,483 (2,625-4,545)
Molalla	12	5.5 (3.2-9.3)	950 (548-1,617)	1,019 (588-1,736)
Yamhill	102	46.6 (40.1-53.2)	8,074 (6,950-9,221)	8,664 (7,458-9,894)
Rickreall Cr.	3	1.4 (0.5-3.9)	237 (81-685)	255 (87-735)
N. Santiam	12	5.5 (3.2-9.3)	950 (548-1,617)	1,019 (588-1,736)
S. Santiam	1	0.5 (0.1-2.5)	79 (14-442)	85 (15-474)
Santiam R. (lower)	3	1.4 (0.5-3.9)	237 (81-685)	255 (87-735)

Run composition

The run composition of coho salmon was well-mixed throughout the run, with the highest return probabilities being associated with the Yamhill and Tualatin rivers throughout the migration. Lower predicted percentages returned to the Molalla and North Santiam rivers (Figure 62). We note that uncertainty was considerably higher for those sites with very small radio-tagged sample sizes (i.e., Clackamas and lower Santiam rivers and Rickreall Creek with $n \leq 4$).

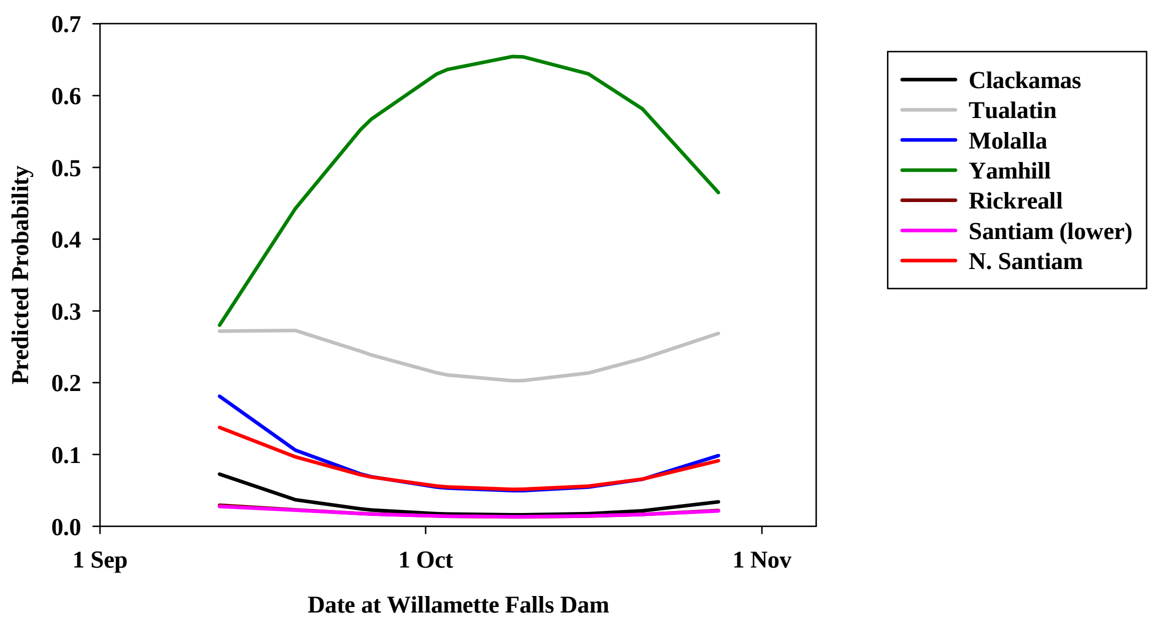

Figure 62. Estimates of run composition based on predicted probabilities from multinomial logistic regressions of ‘escaped’ coho salmon radio-tagged at Willamette Falls Dam in 2014 (n = 177).

Discussion

Winter Steelhead

The 2012-2014 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, winter steelhead escapement to tributaries was very consistent across years: 81% (2012) to 84% (2013 and 2014) 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 and 2014. 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), 81 fish in 2013 (48% of the 170 fish sample), and 110 fish in 2014 (52% of the 212 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 clearly kelt (n = 60 in 2012, 61 in 2013, and 68 in 2014) 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 mixed results among years. Tag date was a significant predictor of tagged winter steelhead escaping to a tributary in 2012 and 2014 but not in 2013. In 2012 and 2014, fish tagged later in the run had an increased probabilty of escaping. The presence of a head injury was a significant predictor of escaping to a tributary in only one of the three years (2012), with fish having a head injury having a decreased probability of escaping. 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, and 18 (53%) in fish in 2014. These percentages may indicate a modestly reduced handling effects in 2013 (for reasons unknown compared to 2014), a higher rate of predation by pinnipeds or 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 and 2014 (but not in 2012) may only partially explain the difference among 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) (Caudill et al. 2014). 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 of the Willamette River basin in all study years (ODFW 2012, 2013, and 2014), which reduced the likelihood that winter steelhead last detected downstream from the dam were captured and killed, though we cannot rule out capture-related mortality. Based on queries of the PTAGIS database in December 2012 (for 2012 fish), March 2014 (for 2013 fish), and March 2015 (for 2014 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 or to other PIT-tag monitoring sites. Alternately, the absence of PIT-detections at Bonneville Dam may be explained in part by the increased individual risk of predation of salmonids by marine mammals early in the season (Keefer et al. 2012). Similarly, Wright et al. (2014) reported that the majority of winter steelhead predation by pinnipeds downstream from Willamette Falls occurred early in the migration season.

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 ground speed 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) partially explain this behavior. Slower migration rates in upstream reaches was also observed in radio-tagged summer steelhead, spring Chinook salmon, and coho salmon in this study, suggesting a common cause.

The run timing of the aggregate native winter steelhead population has been considered to be later than that of the introduced Big Creek stock and the Big Creek stock was 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) and Van Doornik et al. (2015) found no empirical evidence of introgression of Big Creek stock into sampled native winter steelhead; 2) releases of the Big Creek 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 the 2013 and 2014 runs were relatively late, but we are not aware of any reported analyses of the factors that affect inter-annual variability in migration timing of winter steelhead 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 and Middle Fork Willamette rivers, and Fall Creek) tended to be relatively late-timed in all three 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. Approximately 60% of the winter steelhead that entered tributaries in all 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; 2014 estimates will be included in the final version of this report). The 2012-2013 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 was detected returning to spawn in the Willamette River basin in 2013 or 2014.

Summer Steelhead

As with winter steelhead, the 2012-2014 summer steelhead study provided some of the first basin-wide information on the distribution, behavior, and fate of summer-run fish. Overall, 75% (2012), 80% (2013), and 90% (2014) of radio-tagged summer steelhead were last detected (non-kelts) or had maximum river kilometers (kelts) in Willamette River tributaries. The remaining fish were last detected downstream from Willamette Falls Dam (1-8%), at the dam (~1%), or in the lower (3-9%) or upper (7-12%) main stem.

In contrast to the winter run fish, summer steelhead spawn in the spring after freshwater entry the previous year. 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 or 2013 (data were not yet available for the 2014-tagged summer steelhead as of this writing). 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, 10 of 57 (18%) recaptures of adipose-clipped steelhead by anglers occurred in the upper main stem in 2013 and four of 34 (12%) occurred there in 2014. 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 25% in 2012, 20% in 2013, and 10% in 2014. 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 all 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 indicated that there is 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 and 2013 summer-run fish indicated direct spatial overlap with the maximum upstream detections of 2013 and 2014 winter steelhead, respectively, 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 genetic study by Johnson et al. (2013) also indicated some winter-summer hybridization in the McKenzie and Santiam sub-basins. The observed three to six-fold difference between the winter steelhead count at Foster Dam and the radiotelemetry-based escapement estimates in the South Santiam suggests poor collection at Foster Dam of winter steelhead originating above and/or considerable production of winter steelhead below Foster Dam, including in Wiley, Thomas and Crabtree creeks (Table 12). The degree to which these adults represent summer-winter hybrids is unknown and will be examined using GSI assignments from radio-tagged adults when available in summer 2015.

Importantly, our assessment of summer-winter temporal overlap on spawning grounds was based on a comparison of the tributary residency dates of very few 2012-2013 summer-run kelts and the tributary residency dates for the 2013-2014 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. Moreover, it is plausible that summer steelhead that do not kelt continue spawning activity for a longer period, increasing the potential for temporal overlap. 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 portions of 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) 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, 8-14% of the Foster-tagged fish and 16-26% 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 modest recovery rates and the high percentages (34-54%) of tagged steelhead last detected in the river to which they were recycled suggests 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 results and by similar evaluations of recycled summer steelhead in the Clackamas (Schemmel et al. 2011) and Cowlitz (Kock et al. 2014) rivers.

Chinook salmon

2014 was the fourth 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. The experiment indicated that 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. 2014). 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, 78% (2013) to 89% (2014) of tagged salmon escaped to Willamette River tributaries compared to 74% in 2011 and 62% in 2012 (fin-clipped and unclipped samples combined and restrained and anesthetized samples combined for annual estimates). The remaining 2013-2014 fish were last detected downstream from the dam (4-10%), at the dam (~2%), or in the lower (4-8%) or upper (2-3%) main stem. Assuming that all tagged salmon last detected outside a tributary died before spawning, the maximum mortality estimates ranged from 11-38% among years. Estimates in all years except 2014 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% (2011), 82% (2012), 76% (2013), and 95% (2014), and these may be considered potential ‘best-case’ scenarios. Conversely, the ‘worst-case’ was 57% in 2012 for fin-clipped, restrained salmon.

The four percent of tagged salmon last detected downstream from Willamette Falls Dam in 2014 was the lowest among study years (2011 =14%, 2012 = 27%, and 2013 = 10%). While some downstream fish movement following tagging is common (Bernard et al. 1999; Mäkinen et al. 2000; Frank et al. 2009), the rates we observed in 2012 were at the high end of the reported range and the apparent short-term effect of the fish restraint handling 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 (2013) and four of five (2013) salmon that were recorded falling back at the dam did not re-ascend, indicating that potential injury or mortality may have resulted from this behavior (e.g., Keefer et al. 2005). Regardless, the fate of salmon last recorded downstream from the dam was largely unknown: two and one entered the Clackamas River in 2013 and 2014, respectively, none were reported as harvested, and none were detected at Columbia River PIT tag interrogation sites.

Migration rates and main stem behaviors

Chinook salmon typically 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 than 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 all years (annual medians = 20.5–25.3 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; 2014). 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 2011-2014 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 any year. This suggests that salmon were not seeking thermal refuge sites, despite main stem temperatures > 20 °C on many dates (also see Keefer et al. 2015 for summaries of thermal histories of Chinook salmon with archival temperature loggers).

Adult salmon spent one to more than six weeks in the main stem before reaching tributaries and time spent in the mainstem was longer, on median, 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 and almost all of the salmon with archival temperature loggers experienced their warmest temperatures in the lower main stem (Keefer et al. 2015). 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.

Several salmon traits were significantly associated with spring Chinook salmon escapement to tributaries in the evaluation of all anesthetized salmon. The largest negative effects were associated with fish injuries ranging from descaling, to head injuries and a variety of marine mammal injuries. These results indicate that even minor injuries may make salmon more vulnerable, perhaps by allowing infection by various pathogens (e.g. Benda et al. 2015). There was little evidence that salmon origin (hatchery versus wild), sex, size, tag date, or condition measures strongly affected survival to tributaries. Similarly, Willamette River flow and water temperature during the week after fish were released were not associated with escapement. This finding was somewhat surprising because of the higher water temperatures in the main stem in 2013 and 2014 versus 2011-2012 and the widespread association between higher salmon migration mortality during warm years (e.g., Naughton et al. 2005; Crozier et al. 2014; Keefer et al. 2014). 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 2013-2014 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 Willamette adult outplanting studies (Keefer et al. 2010b; Mann et al. 2011; Naughton et al. 2013; 2014).

Notably, although mean lipid content varied among years, we observed no relationship between estimated initial lipid content and fate of individual adult salmon. This suggests that energetic reserves at river entry were sufficient to fuel upstream migration to tributaries in 2011-2014. The metabolic costs of migration increase at higher temperatures, particularly at temperatures is 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 2013or 2014, 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 Dexter Dam tailrace prior to collection. Data recovered from temperature loggers indicated that the fish held in water consistent with the temperatures recorded by the USGS sites at Jasper and Dexter. Most fish encountered temperatures in the 14-16 °C range in 2012-2014, which 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; Keefer et al. 2015). We have hypothesized that the combination of long holding periods, high salmon density, and high angler activity 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 (Naughton et al. 2015).

Run timing and composition

The relatively early timing of the 2013 and 2014 spring Chinook salmon runs 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 2011-2014 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 throughout each migration season**.** Run composition of the adipose-intact sample was characterized by the three largest return groups (Santiam, McKenzie, and Middle Fork) having the highest predicted probabilities, percentages of all the returns within each 10-day tagging interval. These patterns may reflect differences in Chinook salmon spawn timing among tributary populations or selection for earlier timing in populations that require longer 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.

Coho Salmon

The current coho salmon population in the Willamette River is a composite of a native stock originating from the Clackamas River and hatchery introductions made in the 1950s to late 1990s (Keefer and Caudill 2010). Coho return to the Columbia-Willamette river system in the fall when water levels are low and it is likely that they were excluded from, or had limited access to upstream habitats by the Willamette Falls historically. The creation of fishways at the project in the early twentieth century facilitated upstream passage and the colonization of habitats above the Falls by what is now a self-sustaining and growing population.

Over 80% of the coho salmon radio-tagged in 2014 were last detected in Willamette River tributaries, with the highest percentages of tagged salmon last recorded in the Yamhill River (47%), the Tualatin River (19%), and the North Santiam and Molalla rivers (5% each). The sub-basin populations were well-mixed throughout the migration period. The limited use of west-side Willamette River tributaries by Chinook salmon suggests that the potential for them to interact with coho salmon on spawning grounds is low. It is possible that some early-timed coho salmon may interact with spawning Chinook salmon in the Santiam River system, but we are not aware of any evaluation of these potential interactions. Only five (~2%) of the 219 tagged coho salmon released were reported as being recaptured by an angler, which may have been partially explained by the absence of a reward program for coho salmon transmitters in 2014.

Literature Cited

Ackerman, N.K., and T. Shibahara. 2009. Assessment of flow control structure operation on adult fish use of Willamette Falls fish ladder, 2009. Willamette Falls Project (FERC 2233). Prepared by the Portland Gas and Electric Company.

Anderson, J. J., and W. N. Beer. 2009. Oceanic, riverine, and genetic influences on spring Chinook salmon migration timing. Ecological Applications 19:1989-2003.

Banks, M., M. Blouin, B. Baldwin *et al.* 1999. Isolation and inheritance of novel microsatellites in Chinook Salmon (*Oncorhynchus tschawytscha*). Journal of Heredity 90: 281–288.

BartońBea, K. 2013. MuMIN: Multimodel inference. R package version 1.9.0. http://CRAN.R-project.org/package=MuMIn

Beacham, T.D., C.G. Wallace, K.D. Le, and M. Beere. 2012. Population structure and run timing of steelhead in the Skeena River, British Columbia. North American Journal of Fisheries Management 32:262-275.

Benda, S.E., M.L. Kent, C.C. Caudill, C.B. Schreck, and G.P. Naughton. 2015. Cool, pathogen-free refuge lowers pathogen associated prespawn mortality of Willamette River Chinook Salmon *Oncorhynchus tshawytscha*. Transactions of the American Fisheries Society 144:1159-1172.

Bernard, D.R., J.J. Hasbrouck, and S.J. Fleischman. 1999. Handling-induced delay and downstream movement of adult Chinook salmon in rivers. Fisheries Research 44:37-46.

Bracis, C., and J.J. Anderson. 2013. Inferring the relative oceanic distribution of salmon from patterns of age-specific arrival timing. Transactions of the American Fisheries Society 142:556-567.

Buchholz, W., S.J. Miller, and W.J. Spearman. 1999. Summary of PCR primers for salmonid genetic studies, Alaska Fisheries Progress Report. Anchorage, AK.

Burnham, K.P., and D.R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretical approach. Springer-Verlag, New York.

Cairney, M., J.B. Taggart, and B. Hoyheim. 2000. Characterization of microsatellite and minisatellite loci in Atlantic salmon (*Salmo salar* L.) and cross-species amplification in other salmonids. Molecular Ecology 9: 2175–2178.

Caudill, C.C., W.R. Daigle, M.L. Keefer, C.T. Boggs, M.A. Jepson, B.J. Burke, R.W. Zabel, T.C. Bjornn, and C.A. Peery. 2007. Slow dam passage in Columbia River salmonids associated with unsuccessful migration: delayed negative effects of passage obstacles or condition-dependent mortality? Canadian Journal of Fisheries and Aquatic Sciences 64:979-995.

Caudill, C.C., M.A. Jepson, S.R. Lee, T.L. Dick, G.P. Naughton, and M.L. Keefer. 2014. A field test of eugenol-based anesthesia versus fish restraint in migrating adult Chinook salmon and steelhead. Transactions of the American Fisheries Society 143:856-863.

Chilcote, M.W. 1998. Conservation status of steelhead in Oregon. ODFW, Information Report 98-3, Portland, OR.

Chilcote, M.W. 2001. Conservation assessment of steelhead populations in Oregon. ODFW, Portland, OR.

Crozier, L.G., B.J. Burke, B.P. Sandford, G.A. Axel, and B.L. Sanderson. 2014. Passage and survival of adult Snake River sockeye salmon within and upstream from the Federal Columbia River Hydrosystem. Research report of NOAA-Fisheries to U.S. Army Corps of Engineers.

Eiler, J.H., T.R. Spencer, J.J. Pella, and M.M. Masuda. 2006. Stock composition, run timing, and movement patterns of Chinook salmon returning to the Yukon River basin in 2004. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-165.

Eiler, J.H., M.M. Masuda, T.R. Spencer, R.J. Driscoll, and C.B. Schreck. 2014. Distribution, stock composition and timing, and tagging response of wild Chinook salmon returning to a large, free-flowing river basin. Transactions of the American Fisheries Society 143:1476-1507.

English, K.K., D. Robichaud, C. Sliwinski, R.F. Alexander, W.R. Koski, T.C. Nelson, B.L. Nass, S.A. Bickford, S. Hammond, and T.R. Mosey. 2006. Comparison of adult steelhead migrations in the mid-Columbia hydrosystem and in large naturally flowing British Columbia rivers. Transactions of the American Fisheries Society 135:739-754.

Frank, H.J., M.E. Mather, J.M. Smith, R.M. Muth, J.T. Finn, and S.D. McCormick. 2009. What is "fallback"?: metrics needed to assess telemetry tag effects on anadromous fish behavior. Hydrobiologia 635:237-249.

Hinch, S.G., and P.S. Rand. 2000. Optimal swimming speeds and forward-assisted propulsion: energy-conserving behaviors of upriver-migrating salmon. Canadian Journal of Fisheries and Aquatic Sciences 57:2470-2478.

Heath D.D., S. Pollard, and C. Herbinger. 2001. Genetic structure and relationships among steelhead trout (*Oncorhynchus mykiss*) populations in British Columbia. Heredity 86, 618–627.

Investigational New Animal Drug (INAD). 2011. Study protocol for a compassionate aquaculture investigational new animal drug exemption for AQUI-20E under INAD #11-741. Aquatic Animal Drug Approval Program, Bozeman, MT.

Jepson, M.A., M.L. Keefer, G.P. Naughton, C.A. Peery, and B.J. Burke. 2010. Stock composition, migration timing, and harvest of Columbia River Chinook salmon in late summer and fall. North American Journal of Fisheries Management 30:72-88.

Jepson, M.A., T.S. Clabough, M.L. Keefer, and C.C. Caudill. 2012. Migration behavior, run timing, and distribution of radio-tagged adult spring Chinook salmon in the Willamette River – 2011. Technical Report 2012-1, University of Idaho to U.S. Army Corps of Engineers, Portland, OR.

Jepson, M.A., T.S. Clabough, M.L. Keefer, and C.C. Caudill, and C. Sharpe. 2013. Migration behavior, run timing, and distribution of radio-tagged adult winter steelhead, summer steelhead, and spring Chinook salmon in the Willamette River – 2012. Technical Report 2013-1, University of Idaho to U.S. Army Corps of Engineers, Portland, OR.

Jepson, M.A., T.S. Clabough, M.L. Keefer, C.C. Caudill, and C. Sharpe. 2014. Migration behavior, run timing, and distribution of radio-tagged adult winter steelhead, summer steelhead, and spring Chinook salmon in the Willamette River – 2013. Technical Report 2014-4, University of Idaho to U.S. Army Corps of Engineers, Portland, OR.

Johnson, M.A., T.A. Friesen, D.J. Teel, and D.M. Van Doornik. 2013. Genetic stock identification and relative natural production of Willamette River steelhead. ODFW report to U.S. Army Corps of Engineers, Portland, OR.

Keefer, M.L., C.A. Peery, T.C. Bjornn, M.A. Jepson, and L.C. Stuehrenberg. 2004a. Hydrosystem, dam, and reservoir passage rates of adult chinook salmon and steelhead in the Columbia and Snake rivers. Transactions of the American Fisheries Society 133:1413-1439.

Keefer, M.L., C.A. Peery, M.A. Jepson, and L.C. Stuehrenberg. 2004b. Upstream migration rates of radio-tagged adult chinook salmon in riverine habitats of the Columbia River basin. Journal of Fish Biology 65:1126-1141.

Keefer, M.L., C.A. Peery, W.R. Daigle, M.A. Jepson, S.R. Lee, C.T. Boggs, K.R. Tolotti, and B.J. Burke. 2005. Escapement, harvest, and unknown loss of radio-tagged adult salmonids in the Columbia River - Snake River hydrosystem. Canadian Journal of Fisheries and Aquatic Sciences 62:930-949.

Keefer, M.L., C.A. Peery, and C.C. Caudill. 2008a. Migration timing of Columbia River spring Chinook salmon: effects of temperature, river discharge, and ocean environment. Transactions of the American Fisheries Society 137:1120-1133.

Keefer, M.L., C.T. Boggs, C.A. Peery, and C.C. Caudill. 2008b. Overwintering distribution, behavior, and survival of adult summer steelhead: variability among Columbia River populations. North American Journal of Fisheries Management 28:81-96.

Keefer, M.L., C.C. Caudill, C.A. Peery, and C.T. Boggs. 2008c. Non-direct homing behaviours by adult Chinook salmon in a large, multi-stock river system. Journal of Fish Biology 72:27-44.

Keefer, M.L., C.A. Peery, and B. High. 2009. Behavioral thermoregulation and associated mortality trade-offs in migrating adult steelhead (*Oncorhynchus mykiss*): variability among sympatric populations. Canadian Journal of Fisheries and Aquatic Sciences 66:1734-1747.

Keefer, M.L., and C.C. Caudill. 2010a. A review of adult salmon and steelhead life history and behavior in the Willamette River basin: identification of knowledge gaps and research needs. Technical Report 2010-8, University of Idaho to U.S. Army Corps of Engineers, Portland, OR.

Keefer, M.L., G.A. Taylor, D.F. Garletts, G.A. Gauthier, T.M. Pierce, and C.C. Caudill. 2010b. Prespawn mortality in adult spring Chinook salmon outplanted above barrier dams. Ecology of Freshwater Fish 19:361-372.

Keefer, M.L., R.J. Stansell, S.C. Tackley, W.T. Nagy, K.M. Gibbons, C.A. Peery, and C.C. Caudill. 2012. Use of radiotelemetry and direct observations to evaluate sea lion predation on adult Pacific salmonids at Bonneville Dam. Transactions of the American Fisheries Society 141:1236-1251

Keefer, M.L., C.C. Caudill, L. Sullivan, C. Fitzgerald, and K. Hatch. 2014. PIT-tagged adult salmon and steelhead conversion from McNary Dam to Lower Granite Dam, 2002-1013. Technical Report 2014-2 of University of Idaho to U. S. Army Corps of Engineers, Walla Walla District.

Keefer, M.L., T.S. Clabough, M.A. Jepson, G.P. Naughton, T.J. Blubaugh, D.C. Joosten, and C.C. Caudill. 2015. Thermal exposure of adult Chinook salmon in the Willamette River basin. Journal of Thermal Biology 48:11-20.

Kenaston, K., K. Schroeder, F. Monzyk, and B. Cannon. 2009. Interim activities for monitoring impacts associated with hatchery programs in the Willamette Basin, USACE funding: 2008. ODFW, Portland, OR.

Kock, T.J., T.L. Liedtke, B K. Ekstrom, C. Gleizes, and W. Dammers. 2014. Summer steelhead in the Lower Cowlitz River, Washington, following collection and release, 2013-2014. U.S. Geological Survey Open-File Report 2014-1122.

Kostow, K.E. (Editor). 1995. Biennial report on the status of wild fish in Oregon. ODFW. Potland, Oregon.

Kostow, K.E., A.R. Marshall, and S.R. Phelps. 2003. Naturally spawning hatchery steelhead contribute to smolt production but experience low reproductive success. Transactions of the American Fisheries Society 132:780-790.

Kostow, K.E., and S. Zhou. 2006. The effect of an introduced summer steelhead hatchery stock on the productivity of a wild winter steelhead population. Transactions of the American Fisheries Society 135:825-841.

Larson, L.L. 1995. A portable restraint cradle for handling large salmonids. North American Journal of Fisheries Management 15:654-656.

Mäkinen, T.S., E. Niemelä, K. Moen, and R. Lindström. 2000. Behaviour of gill-net and rod-captured Atlantic salmon (*Salmo salar* L.) during upstream migration and following radio tagging. Fisheries Research 45:117-127.

Mann, R.D., C.A. Peery, A.M. Pinson, C.R. Anderson, and C.C. Caudill. 2009. Energy use, migration times, and spawning success of adult spring–summer Chinook salmon returning to spawning areas in the South Fork Salmon River in central Idaho: 2002-2007. Technical Report 2009-4, University of Idaho, Moscow.

Mann, R.D., C.C. Caudill, M.L. Keefer, A.G. Roumasset, C.B. Schreck, and M.L. Kent. 2011. Migration behavior and spawning success of spring Chinook salmon in Fall Creek and the North Fork Middle Fork Willamette River: relationships among fate, fish condition, and environmental factors, 2010. Technical Report 2011-8, University of Idaho, Moscow.

McConnell S., L. Hamilton, D. Morris *et al.* 1995. Isolation of salmonid microsatellite loci and their application to the population genetics of Canadian east coast stocks of Atlantic salmon. Aquaculture 137:19–30.

McConnell, S.K., D.E. Ruzzante, P.T. Oreilly, L.C. Hamilton, and J.M. Wright. 1997. Microsatellite loci reveal highly significant gentic differentiation among Atlantic salmon (*Salmo salar* L.) stocks from the east coast of Canada. Molecular Ecology 6: 1075–1089.

Morris, D.B., K.R. Richard, and J.M. Wright. 1996. Microsatellites from rainbow trout (Oncorhynchus mykiss) and their use for genetic study of salmonids. Canadian Journal of Fisheries and Aquatic Sciences 53:120–126.

McCullough, D., S. Spalding, D. Sturdevant, and M. Hicks. 2001. Issue Paper 5. Summary of technical literature examining the physiological effects of temperature on salmonids. Prepared as part of U.S. EPA Region 10 Temperature Water Quality Criteria Guidance Development Project. EPA-910-D-01-005. Available at http://yosemite.epa.gov/R10/WATER.NSF/1507773cf7ca99a7882569ed007349b5/ce95a3704aeb5715882568c400784499?OpenDocument

Narum, S.R., D. Hatch, A.J. Talbot, P. Moran, and M.S. Powell. 2008. Iteroparity in complex mating systems of steelhead trout. Journal of Fish Biology 72:45-60.

Naughton, G.P., C.C. Caudill, M.L. Keefer, T.C. Bjornn, L.C. Stuehrenberg, and C.A. Peery. 2005. Migration and survival of radio-tagged adult sockeye salmon in the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 62**:** 30-47.

Naughton, G.P., C.C. Caudill, T.S. Clabough, M.L. Keefer, M.J. Knoff, and M.A. Jepson. 2013. Migration behavior and spawning success of spring Chinook salmon in Fall Creek and the North Fork Middle Fork Willamette River: relationships among fate, fish condition, and environmental factors, 2012. Technical Report 2013-2, University of Idaho, Moscow.

Naughton, G.P., C.C. Caudill, T.S. Clabough, M.L. Keefer, M.J. Knoff, and M.A. Jepson. 2014. Migration behavior and spawning success of spring Chinook salmon in Fall Creek and the North Fork Middle Fork Willamette River: relationships among fate, fish condition, and environmental factors, 2013. Technical Report 2014-5, University of Idaho, Moscow.

Naughton, G.P., C.C. Caudill, T.S. Clabough, M.L. Keefer, M.J. Knoff, and M.A. Jepson. 2015. Migration behavior and spawning success of spring Chinook salmon in Fall Creek, the North Fork Middle Fork Willamette and Santiam Rivers: relationships among fate, fish condition, and environmental factors, 2014. Technical Report 2015-2, University of Idaho, Moscow.

Nelson, R.J.,and T.D. Beacham. 1999. Isolation and cross-species amplification of microsatellite loci useful for study of Pacific salmon. Animal Genetics 30.

NMFS (National Marine Fisheries Service). 1999. Endangered and threatened species: threatened status for three Chinook salmon evolutionarily significant units in Washington and Oregon, and endangered status for one Chinook salmon ESU in Washington. Federal Register 64(57):14517-14528.

NMFS (National Marine Fisheries Service). 2000. Consultation and Biological Opinion on the impacts from collecting, rearing, and release of salmonids associated with artificial propagation programs in the Upper Willamette River spring Chinook and winter steelhead evolutionarily significant units. NMFS, Portland, OR.

NMFS (National Marine Fisheries Service). 2008. 2008 Willamette Project Biological Opinion. NMFS.

Olsen J.B., P. Bentzen, and J.E. Seeb. 1998. Characterization of seven microsatellite loci derived from pink salmon. Molecular Ecology 7:1087–1089.

Peakall, R., and P.E. Smouse. 2006. GENALEX 6: genetic analysis in Excel. Population genetic software for teaching and research. Molecular Ecology Notes 6: 288–295.

Quinn, T.P., M.J. Unwin, and M.T. Kinnison. 2011. Contemporary divergence in migratory timing of naturalized populations of Chinook salmon *Oncorhynchus tshawytscha*, in New Zealand. Evolutionary Ecology Research 13:45-54.

Rand, P.S., S.G. Hinch, J. Morrison, M.G.G. Foreman, M.J. MacNutt, J.S. Macdonald, M.C. Healey, A.P. Farrell, and D.A. Higgs. 2006. Effects of river discharge, temperature, and future climates on energetics and mortality of adult migrating Fraser River sockeye salmon. Transactions of the American Fisheries Society 135:655-667.

Richter, A. and S.A. Kolmes. 2005. Maximum temperature limits for chinook, coho, and chum salmon, and steelhead trout in the Pacific Northwest. Reviews in Fisheries Science 13(1): 23-49.

Rounds, S.A. 2007. Temperature effects of point sources, riparian shading, and dam operations on the Willamette River, Oregon: U.S. Geological Survey Scientific Investigations Report 2007-5185, 34 p. http://pubs.usgs.gov/sir/2007/5185/

Rounds, S.A. 2010. Thermal effects of dams in the Willamette River basin, Oregon: U.S. Geological Survey Scientific Investigations Report 2010-5153, 64 p. http://pubs.usgs.gov/sir/2010/5153/

Salinger, D.H., and J.J. Anderson. 2006. Effects of water temperature and flow on adult salmon migration swim speed and delay. Transactions of the American Fisheries Society 135:188-199.

Schemmel, E., S. Clements, C. Schreck, and D. Noakes. 2011. Using radio-telemetry to evaluate success of a hatchery steelhead recycling program. American Fisheries Society Symposium 76:1-8.

Schreck, C B., J.C. Snelling, R.E. Ewing, C.S Bradford, L.E. Davis, and C.H. Slater. 1994. Migratory behavior of adult spring chinook salmon in the Willamette River and its tributaries. Oregon Cooperative Fish and Wildlife Research Unit for Bonneville Power Administration, Division of Fish and Wildlife, Report DOE/BP-92818-4, Portland, Oregon.

Schroeder, R.K, K.R. Kenaston, and L.K. McLaughlling. 2007. Spring Chinook salmon in the Willamette and Sandy Rivers. ODFW, Portland, OR.

Scribner, K., J. Gust, and R. Fields. 1996. Isolation and characterization of novel microsatellite loci: cross-species amplification and population genetic applications. Canadian Journal of Fisheries and Aquatic Sciences 53: 685–693.

Smith, C.R., B.F. Koop, and R.J. Nelson. 1998. Isolation and characterization of coho salmon (*Oncorhynchus kisutch*) microsatellites and their use in other salmonids. Molecular Ecology 7:1614–1616.

Spies, I.B., D.J. Brasier, P.T. O'Reilly, T.R. Seamons, and P. Bentzen. 2005. Development and characterization of novel tetra-, tri-, and dinucleotide microsatellite markers in Rainbow Trout (*Oncorhynchus mykiss*). Molecular Ecology Notes 5: 278–281.

Stephenson, J.J., M.R. Campbell, J.E. Hess *et al.* 2009. A centralized model for creating shared, standardized, microsatellite data that simplifies inter-laboratory collaboration. Conservation Genetics 10:1145–1149.

Thomson, R.E., and R.A.S. Hourston. 2011. A matter of timing: the role of ocean conditions in the initiation of spawning migration by late-run Fraser River sockeye salmon (*Oncorhynchus nerka*). Fisheries Oceanography 20:47-6

Tinus, C.A., and T.A. Friesen. 2010. Summer and winter steelhead in the Upper Willamette Basin: current knowledge, data needs, and recommendations. Technical report to U.S. Army Corps of Engineers. ODFW, Corvallis, OR.

Van Doornik, D.M., M.A. Hess, M.A. Johnson, D.J. Teel, T.A. Friesen, and J.M. Myers. 2015. Genetic population structure of Willamette River steelhead and the influence of introduced stocks. Transactions of the American Fisheries Society 144:150-162.

Wright, B., T. Murtagh, and R. Brown. 2014. Willamette Falls pinniped monitoring project, 2014. Oregon Department of Fish and Wildlife, Corvallis, OR.