TECHNICAL REPORT 2013-1

MIGRATORY BEHAVIOR, RUN TIMING, AND DISTRIBUTION OF RADIO-TAGGED ADULT WINTER STEELHEAD, SUMMER STEELHEAD, AND SPRING CHINOOK SALMON IN THE WILLAMETTE RIVER – 2012

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For

U. S. Army, Corps of Engineers
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Summary

In this study, we collected information on run composition, run timing, and migration behaviors of adult winter and summer steelhead and spring Chinook salmon during migration in the Willamette River basin. Adults were collected at Willamette Falls Dam, radio-tagged using anesthetic (AQUI-S®E, unclipped) or with a fish restraining device (FRD, some unclipped and all clipped adults). Upstream movements and final distribution were monitored using an array of fixed site antennas, mobile tracking, and returns to collection facilities. Adults tagged in the FRD handling treatment were more likely to exit to the Willamette Falls tailrace after tagging and were less likely to escape to monitored tributaries. The apparent negative handling effect of the FRD was larger for spring Chinook salmon than for winter steelhead.

After adjusting for known transmitter loss, 83% of 169 radio-tagged winter steelhead escaped to Willamette River tributaries, based on maximum upstream detection sites. The remaining fish were last detected downstream from Willamette Falls Dam (12%), at the dam (<1%), or in the lower (4%) or upper (2%) main stem. Later migrants were more likely to reach monitored tributaries than early migrants, but the mechanism behind this result was unclear. We found that winter steelhead migrated at rates up to ~50 rkm/d. They also moved more slowly through upstream sections of the main stem Willamette River. The timing of the 2012 winter steelhead run as a whole was early in 2012 compared to the 10-year average. We found that early-run fish were a well-mixed combination from lower basin populations (i.e., Clackamas, Tualatin, Molalla, and Yamhill rivers). Mid-basin populations (i.e., Santiam and Calapooia rivers) were intermediately-timed and upper basin populations (i.e., McKenzie, Coast Fork and Middle Fork Willamette rivers, and Fall Creek) tended to be relatively late-timed at Willamette Falls in 2012. We observed considerable kelting behaviors in the radio-tagged sample. About 60% of the winter steelhead that entered tributaries moved downstream during the presumed post-spawn period. Many of the kelts were detected below Willamette Falls. The ODFW Life History Project provided scale interpretations on the tagged adults and our scale-based iteroparity estimate for the aggregate Willamette River sample of winter-run fish in this study was 8.5%.

Overall, 71% of radio-tagged summer steelhead were last detected in Willamette River tributaries. The remaining fish were last detected downstream from the Willamette Falls Dam (8%), at the dam (2%), in the lower main stem (8%), or in the upper (11%) main stem. In contrast to the winter run fish, summer steelhead tagged in 2012 would have spawned in 2013. 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 2012 indicated that there is high potential for summer steelhead to overlap spatially and temporally with winter steelhead. Generally, the three most abundant summer-run groups (i.e., Santiam, McKenzie, and Middle Fork) were present throughout the nominal summer-run period at Willamette Falls.

In the separate evaluation of summer steelhead recycling below Foster and Dexter dams, 4% of the Foster-tagged fish and 17% of the Dexter-tagged fish were reported as harvested. The lack of a reward program likely resulted in under-reporting of harvest rates. However, these low recovery rates suggest that the recycling programs increase the likelihood that summer steelhead interact with winter steelhead.

The 2012 sample of radio-tagged Chinook salmon included a disproportionate number of unclipped salmon because of our effort to radio-tag McKenzie River wild fish in collaboration with the Eugene Water and Electric Board (EWEB). About half of the unclipped salmon were anesthetized in 2012 as part of the experimental test of AQUI-S®E. Anesthetized salmon were less likely to exit the Willamette Falls fishway to the tailrace and were substantially more likely to escape to upriver tributaries than were fish tagged using the FRD. Overall, 61% of 496 radio-tagged Chinook salmon escaped to Willamette River tributaries (adjusted for tag loss with fin-clipped and unclipped samples combined and restrained and anesthetized samples combined). The remaining fish were last detected downstream from the dam (27%), at the dam (3%), or in the lower (7%) or upper (1%) main stem. Escapement estimates for the Chinook salmon sample components were: 82% (anesthetized, unclipped), 47% (restrained, unclipped), and 56% (restrained, fin-clipped). In statistical models examining Chinook salmon fate in relation to fish traits, behavior and environmental factors, later-timed salmon were less likely to escape to tributaries. We observed no relationship between estimated initial lipid content and fate of adult fish, suggesting energetic reserves at river entry were sufficient to fuel upstream migration to tributaries in 2012.

Chinook salmon migrated through the main stem faster as water temperature and date increased. The median main stem migration rates for Willamette River spring Chinook salmon in 2012 was 22.9 rkm/day. Ten percent of tagged salmon exhibited downstream movements in the main stem in 2012. Similarly, we detected little temporary straying into non-natal tributaries by tagged salmon (it was not possible to assess permanent straying).

Chinook salmon that returned to Dexter Dam to the Middle Fork Willamette River spent one day to six weeks holding in the tailrace prior to collection. Data recovered from temperature loggers indicated that fish held in water that was ~14-16°C in the Dexter tailrace. The moderately late timing of the 2012 spring Chinook salmon run was consistent with relatively cool river temperatures and high discharge. We found that hatchery fish were a well-mixed combination from the Santiam, McKenzie, and Middle Fork Willamette rivers. Those that returned to the Molalla River were relatively early-timed and those that returned to the Clackamas River were late-timed in 2012. Run composition of the 'wild' sample was characterized by the two largest return groups (Santiam and McKenzie rivers) making up 57-100% of all the returns within each 10-day tagging interval.

The below-average Willamette River water temperatures in 2011 and 2012 limited possible inferences about the relationship between main stem thermal conditions, Chinook salmon behavior and prespawn mortality in this study. Reconstructed temperature exposure histories for salmon in the logger-tagged sample indicated that the highest temperatures most fish experienced were in main stem reaches. The predictive models we developed of temperature exposure using USGS data paired with radiotelemetry detections showed promise for recreating thermal histories for salmon without temperature loggers.

Acknowledgments

Many people assisted with the field work and data compilation for this report and its successful completion was made possible through their efforts. U. Idaho personnel included: Travis Dick, Steve Lee, Theresa Tillson, Eric Johnson, and Jacob Uber for performing the tagging of adult salmon and steelhead, and Matt Knoff and Mark Morasch for downloading receivers. Oregon Department of Fish and Wildlife personnel that contributed to the success of the project included: Wayne Vandernaald, Todd Alsbury, Jeff Ziller, Kelly Reis, Joy Vaughan, Shivonne Nesbit, Tom Friesen, Kirk Schroeder, and Craig Tinus. Justin Huff and Brian Franklin performed mobile-tracking surveys for steelhead. We thank 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, for their assistance with securing federal permits for the study. We are grateful to Bonnie Johnson, USFWS, for coordinating the use of AQUI-S®E under the Investigational New Animal Drug program and George Naughton, U. Idaho, for serving as INAD monitor. We also appreciate the contributions made by Tim Shibahara of the Portland Gas and Electric Company and Doug Drake of the Oregon Department of Environmental Quality. We thank the University of Idaho's Institutional Animal Care and Use Committee for reviewing the animal procedures used in this study. This study was funded by the U.S. Army, Corps of Engineers (USACE), Portland District, with assistance provided by Robert Wertheimer, Rich Piaskowski and David Griffith.

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Introduction

Our goal for this study was to gather information on the run timing, stock composition, migration behavior, distribution among spawning areas, and survival of radio-tagged adult winter and summer steelhead (*Oncorhynchus mykiss*) and Chinook salmon (*O. tshawytscha*) in the Willamette River. We assessed potential effects of the river environment and operations of Willamette Valley dams by the United States Army Corps of Engineers (USACE) on these salmonids. We also evaluated effects of two handling treatments on the post-release behavior of the tagged fish. They received either an experimental anesthetic treatment, AQUI-S®E, under the Investigational New Animal Drug (INAD) program, or a fish restraint device (FRD) treatment modeled after Larson (1995). Application of AQUI-S®E was restricted to unclipped adults that were illegal for harvest by regulations in place at the time of tagging.

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

Dams without upstream fish passage facilities and habitat loss have contributed to the decline of ESA-listed spring Chinook salmon in the upper Willamette River (NMFS 1999). Moreover, naturally-produced Chinook salmon and hatchery salmon spawning in the wild have experienced high prespawn mortality (PSM) in many Willamette River tributaries (Schroeder et al. 2007; Kenaston et al. 2009) in the last several decades. This mortality may be negatively affecting population recovery efforts (NMFS 2008). High temperatures can affect the reproductive success of salmonids well before spawning (McCullogh et al. 2001) and they have been implicated in the mortality of adult Chinook salmon in the Willamette River main stem and tributaries (Schreck et al. 1994; Mann et al. 2009; Keefer et al. 2010; Naughton et al. 2012) and in other species such as sockeye salmon (*O. nerka*, Naughton et al. 2005; Rand et al. 2006). Upstream dams have an important effect on water temperature in the Willamette River in the mainstem and in tailrace holding areas (e.g., below Dexter Dam) as a result of augmented flows as well as modified temperature releases over the course of summer and autumn (Rounds 2007; 2010). Understanding the relationships among temperature exposure, migration behavior, and prespawn mortality is an important current research objective in the Willamette basin. We note that adult reproduction requires succesful migration, summer holding in tributaries, and spawning. Here we focus on the former (migration success) and the potential for indirect or carry-over effects during upstream migration to affect holding and spawning success.

In 2012, we conducted a radiotelemetry study to monitor adult steelhead (winter- and summer-run) and spring Chinook salmon in the main stem Willamette River and its major tributaries. Collection and tagging occurred at the Willamette Falls trap near Oregon City. Radio-tagged fish were monitored during their upstream migration, on spawning grounds, and during any post-spawn kelt migrations (for steelhead), using a fixed-site radio receiver array and mobile tracking. The general research questions addressed were: 1) how do operational and environmental factors affect adult salmonid migration behavior and survival?; 2) are there differences in adult life history, behavior, or survival among tributary populations?; and 3) to what degree might winter and summer steelhead interact during migration and spawning? There were two study components for Chinook salmon. The first focused in tributaries, began in 2008, and included radio- and PIT-tagging adult salmon in the Middle Fork Willamette River, outplanting them in tributaries to spawn naturally, and monitoring their spawning success (Mann et al. 2011; Naughton et al. 2012). The second study component was initiated in 2011 and included radio-tagging adult Chinook salmon at Willamette Falls and monitoring their behaviors and survival as they migrated to natal streams (Jepson et al. 2012). This is the second year of the latter study component, which builds upon main stem migration data collected by Schreck et al. (1994). Steelhead components were new in 2012.

The 2012 Chinook salmon study at Willamette Falls was a collaborative effort with the Eugene Water and Electric Board (EWEB), which owns the Leaburg-Walterville hydroelectric project on the McKenzie River. EWEB was required to conduct biological evaluations of tailrace barriers and fish ladders at these dams as part of their licensing agreement with the Federal Energy Regulatory Commission. We radio-tagged a disproportionate number of salmon with unclipped adipose fins (compared to the run at large) to maximize the potential number of tagged fish that would enter the McKenzie river for the EWEB evaluation.

Specific 2012 objectives addressed in this report include:

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

Separate companion reports include summaries of 2012 research on adult Chinook salmon outplanted in the Middle Fork Willamette River basin (Naughton et al. 2013) and on adult Chinook salmon disease status at Willamette Falls (Schreck et al. *in review*).

Methods

Tagging site, procedures, and fish measurements

Adult steelhead and Chinook salmon were collected and tagged at the Willamette Falls Dam adult fish trap (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 top of the cage so that trapped fish could volitionally ascend the Denil and enter a chute from which they were diverted into a holding tank with or without anesthetic. Samples were not truly random because only fish passing via fishway 1 (Ackerman and Shibahara 2009) at Willamette Falls Dam were sampled, proportions sampled each day varied, and no fish were sampled at night.

Prior to tagging, collected fish were either anesthetized or restrained as part of a handling experiment. The experimental anesthetic treatment, AQUI-S®E, was used under the Investigational New Animal Drug program, sponsored by the U.S. Fish and Wildlife Service. The active ingredient of AQUI-S®E is eugenol, an essential oil derived from cloves and used as an antiseptic and anesthetic (INAD 2011). Only clipped adults could be anesthetized and released under the INAD protocol in 2012. The second treatment was a fish restraint device (FRD) modeled after Larson (1995). The device consisted of two padded panels, hinged at the bottom in a V-shape, which contoured to the ventral shape of the fish (Figure 3). The cradle was closed using adjustable straps that allowed the fish to be secured. Individual adults were randomly assigned to treatments under most sampling conditions, though adults were selected for a single randomly selected treatment over the period of several hours during times of high passage rate due to logistical constraints at the trap.

When the fish was properly restrained or sedated, length, weight, marks and injuries, signs of disease, and an estimate of sex were recorded. Lipid content was also estimated using a Distell Fatmeter (Distell Industries Ltd., West Lothian, Scotland) and each fish was scanned for the presence of a PIT-tag. Adults to be radio-tagged received an appropriately-sized transmitter (e.g., model MCFT-3A or -7A; Lotek Wireless Inc., Newmarket, Ontario) that did not include a reward label (i.e., there was no monetary incentive for anglers to return transmitters). A PIT tag was inserted into the pelvic girdle of all adults lacking a PIT tag. A sub-sample of 99 Chinook salmon was additionally tagged with an archival temperature pod (models DS1921G, DS1921Z, and DS1922L Thermochron iButton, Embedded Data Systems, Lawrenceburg, KY).

Telemetry sites and mobile tracking efforts

A total of 44 fixed-site radio receivers were distributed throughout the study area (Figure 4 and Table 1). These were augmented by 18 receivers deployed by Eugene Water and Electric Board (EWEB) within the McKenzie River, primarily near the Walterville and Leaburg dams (not depicted in Figure 4 or listed in Table 1; EWEB will report the results of that study portion separately). Monitoring efforts also included mobile tracking via truck and boat. Truck mobile tracking by Oregon Department of Fish and Wildlife (ODFW) personnel occurred on 45 days from 4 April to 28 June, with the highest number of surveys conducted in the Santiam River basin.

Figure 1. Overhead view of the Denil and trap used to collect adult steelhead and Chinook salmon at Willamette Falls Dam in 2012.

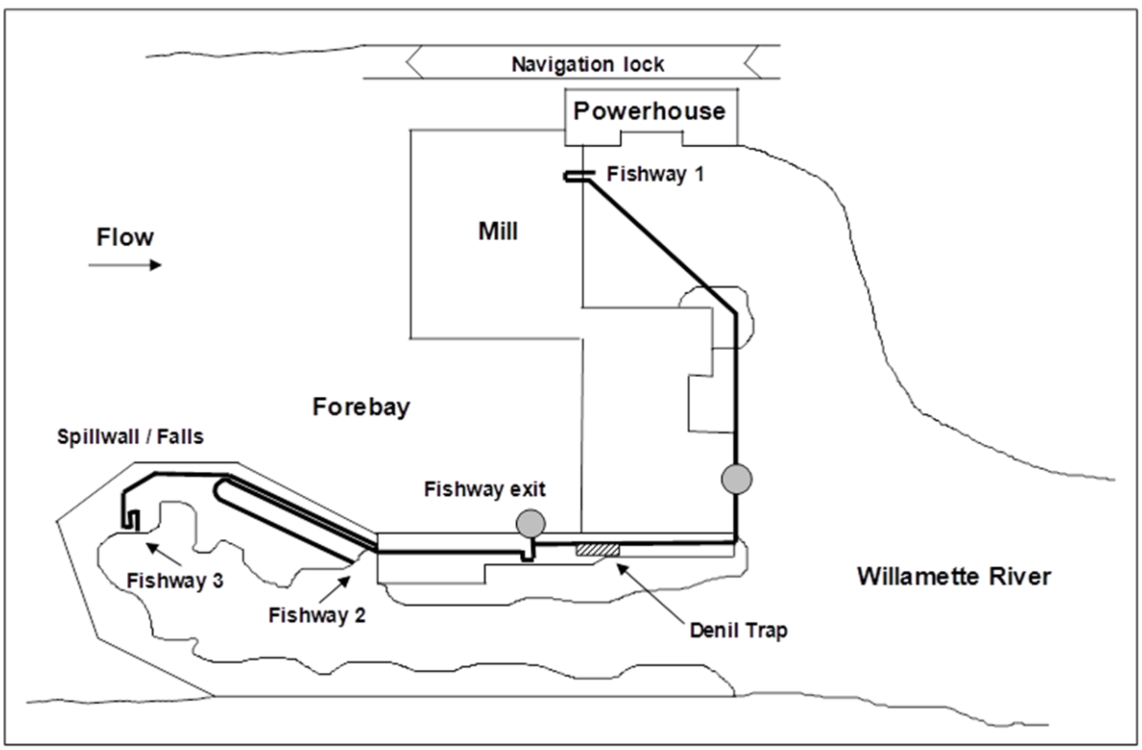


Figure 2. Schematic drawing of Willamette Falls Dam, Oregon, showing the location of three fishways, the two fixed-location radio receiver sites (●) deployed at the dam in 2012. Additional antennas were located in the dam tailrace (0.5 km downstream).

Figure 3. Photographs of restrained (left panel) and anesthetized (right panel) adult Chinook salmon being weighed at Willamette Falls Dam trap.

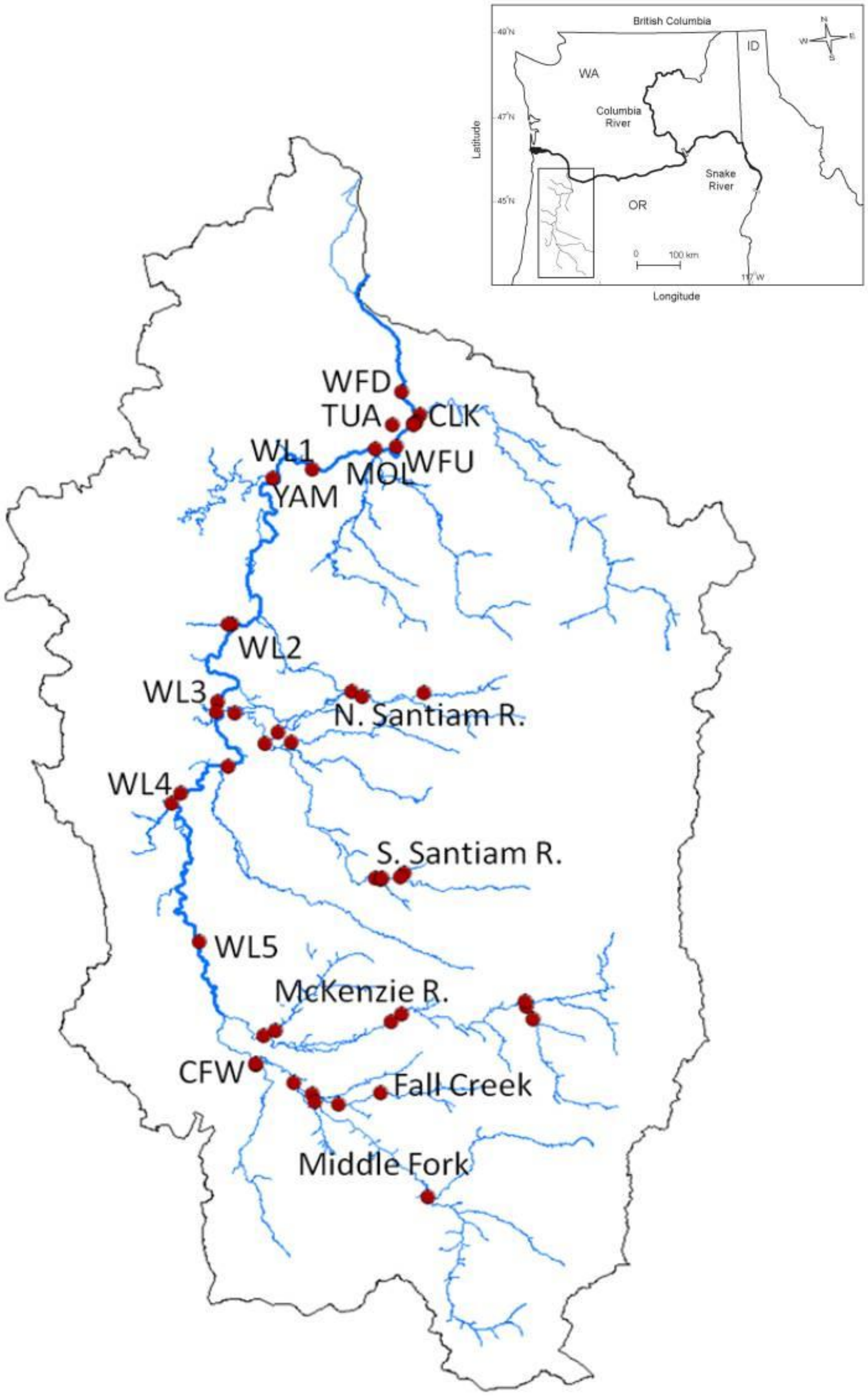


Figure 4. Map of the Willamette River basin and locations where fixed-site radio receivers (red dots) were deployed by the University of Idaho in 2012. Sites monitored by EWEB in the McKenzie River basin are not shown.

Table 1. List of radio receivers deployed in the Willamette River basin in 2012, their site name abbreviations, and the river kilometer (rkm, from the Columbia River mouth) where they were deployed.

Monitoring site	Site code	River kilometer
Willamette Falls (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 (upstream)	WFU	212.9
Willamette main stem 1 (Champoeg)	WL1	237.1
Yamhill River	YAM	252.9
Willamette main stem 2 (Eola)	WL2	304.9
Rickreall Creek	RIC	306.0
Willamette main stem 3 (Buena Vista)	WL3	334.8
Luckiamute River	LUK	336.5
Santiam River Mouth	STM	343.9
Santiam River (South Fork)	SST	357.9
Middle Santiam Reservoir	MSR	423.5
South Fork Santiam Reservoir	SFR	422.0
Thomas Creek	THC	365.9
Foster Dam tailrace	SSF	416.6
Wiley Creek	WLY	417.9
Foster Dam trap	FST	418.0
Santiam River (North Fork)	STN	362.0
Little North Santiam River	LNS	406.0
Lower Bennett Dam	NS1	385.2
Upper Bennett Dam	NS2	389.3
Calapooia River	CAL	356.2
Willamette main stem 4 (Corvallis)	WL4	374.4
Mary's River	MRR	376.4
Willamette main stem 5 (Harrisburg)	WL5	417.9
McKenzie River	MCK	453.9
Mohawk River	MOH	464.5
McKenzie River Hatchery Trap	MHT	489.7
McKenzie River (Leaburg Dam)	MKL	492.9
McKenzie River (South Fork)	MKS	527.5
McKenzie River (Cougar Dam)	COG	531.1
McKenzie River (upstream from South Fork confluence)	MSU	527.2
Coast Fork Willamette R.	CFW	465.2
Middle Fork (near Coast Fork Confluence)	MFC	465.2
Willamette Middle Fork	WMF	478.4
Fall Creek Mouth	FCR	484.0
Fall Creek Dam tailrace	FCT	493.3
Dexter Dam tailrace	DEX	486.7
North Fork Middle Fork	NMF	523.7

Results

Environmental data

In both 2011 and 2012, Willamette River water temperatures were generally cooler and discharges were higher than the ten-year means (Figures 5). Water temperature measured at the USGS gauge near Albany, OR increased from April through August, reached a maximum of 20.2 °C on 17 August, and then decreased through September and October. Mean daily temperature and discharge were likely higher in the main stem Willamette River downstream from Albany but the USGS datasets for 2011 and 2012 were incomplete for downstream stations. Albany data are presented here to illustrate the relative differences among years.

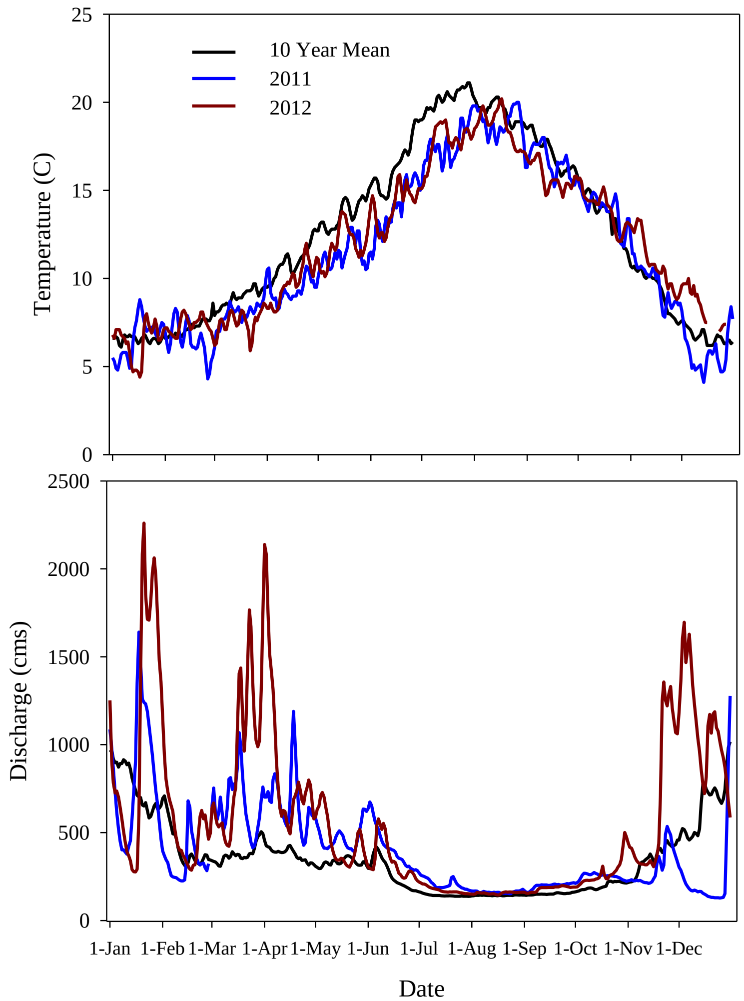


Figure 5. Mean daily Willamette River water temperature (°C) and ten-year mean temperature (top panel) and mean daily Willamette River discharge (cms) and ten-year mean discharge recorded at the USGS gauge at Albany, OR, in 2011 and 2012 (bottom panel). Data were collected from http://ida.water.usgs.gov/. See Figure 44 below for additional USGS thermographs.

Steelhead collection and tagging

Willamette Falls Dam - We radio-tagged a total of 171 adult winter steelhead, which was 3.6% of the 4,743 winter steelhead counted from 15 February through 31 May (Figure 6). The 31 May cutoff date was the end of the winter run, as defined by ODFW. We note that three unclipped steelhead that were likely winter-run fish (based on coloration) were tagged in June. We radio-tagged 208 summer steelhead from 28 March to 1 July, which was 0.9% of the 24,103 summer steelhead counted through 31 July (Figure 6). Thirteen (6.3%) of the presumed summer-run steelhead that we tagged had intact adipose fins, suggesting non-hatchery origin. Overall, we radio-tagged 1.3% of all steelhead (winter and summer) counted (379/27,756) at Willamette Falls from 15 February through 31 July 2012. No mortality events occurred during tagging and all steelhead were released in good condition.

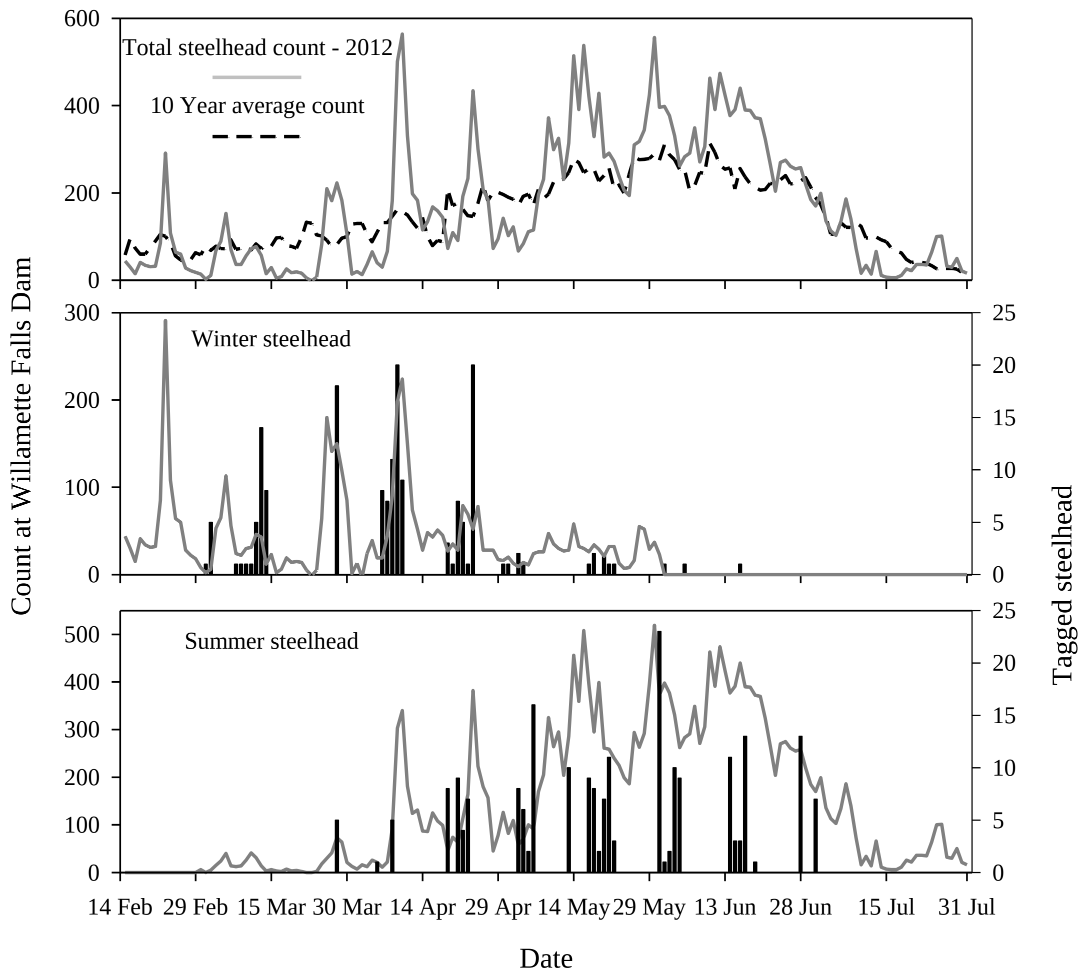


Figure 6. Top panel: the number of adult steelhead counted at Willamette Falls Dam in 2012 and the ten-year average count. Middle panel: the number of winter steelhead counted (line) and radio-tagged (bar). Bottom panel: the number of summer steelhead counted and radio-tagged. Note different scales on y-axes. Count data from http://www.cbr.washington.edu/dart/adult.html and http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Approximately 49% (84/171) of the winter steelhead received the experimental anesthetic treatment, and 51% (87/171) received the restraint (FRD) treatment (Table 2). All clipped summer steelhead were in the FRD treatment group with the exception of one that was inadvertently anesthetized prior to its tagging and release on 28 March 2012. Thirteen unclipped steelhead were classified as summer-run by the taggers based on body morphology, fin condition, and skin coloration: ten of these 'wild summers' were in the anesthetic treatment and three were in the FRD treatment.

Table 2. Numbers of adult steelhead radio-tagged at Willamette Falls Dam trap in 2012 that had clipped or unclipped adipose fins and received an experimental anesthetic (AQUI-S®E) or a fish restraint (FRD) treatment during tagging. 'Unclipped summer' fish were classified as summer-run based on body morphology, fin condition, and bright skin coloration.

	Handling treatment		
Adipose fin	# AQUI-S®E	# FRD	Total
Clipped (summer)	1	194	195
Unclipped (summer)[1]	10	3	13
Unclipped (winter)	84	87	171

Two of the 171 (1.2%) transmitters placed in winter steelhead were recovered in Fishway 1 during an August 2012 dewatering event. We concluded that these two steelhead regurgitated their transmitters some time after release so we excluded them from analyses (modified n = 169). Both steelhead received the anesthetic handling treatment. One other radio-tagged winter steelhead had detections at the dam only and may have regurgitated its transmitter. We included this fish in all analyses.

None of the transmitters placed in the 208 radio-tagged summer steelhead were recovered in the fishway during an August 2012 dewatering event. There were four tags placed in summer steelhead that produced detections at Willamette Falls Dam only and may have been consistent with regurgitated transmitters. We included these four tags in all analyses.

Recycled steelhead at Foster and Dexter dams - A total of 95 summer steelhead were collected at Foster Dam on four days from 16 July through 27 August. These fish were radio-tagged and released downstream from the dam at one of two release locations: either 48.8 rkm downstream from Foster Dam (near Waterloo, OR), or 6.4 rkm downstream from the dam (near Pleasant Valley, OR). A total of 49 summer steelhead were collected at Dexter Dam on 25 July and 8 August, radio-tagged, and released 4.6 kilometers downstream from the dam. Movements were monitored using the fixed-site array of receivers, mobile tracking, and returns to the Dexter and Foster dam traps.

Chinook salmon collection and tagging

At Willamette Falls Dam, we radio-tagged 500 Chinook salmon from 16 April through 2 July, which was 1.4% (500/35,717) of the adult Chinook salmon counted at the dam from 1 April through 31 July (Figure 7). We estimated that 8,286 of the 35,717 salmon counted had unclipped adipose fins based on a 23.2% wild composition estimate provided by ODFW counts at the Willamette Falls count station. The 311 radio-tagged salmon with unclipped adipose fins were 3.8% (311/8,286) of the estimated unclipped run. The 189 fin-clipped salmon were 0.7% (189/27,431) of the estimated clipped run. No mortality events occurred during tagging and all salmon were released in good condition.

One hundred fifty-four (~50%) unclipped Chinook salmon were anesthetized and 157 (~50%) were in the FRD treatment (Table 3). All 189 clipped Chinook salmon received the FRD treatment because they could be harvested and consumed. Ninety-nine radio-tagged salmon were tagged with archival temperature tags. All salmon with temperature loggers had clipped adipose fins and all were released after 30 May 2012.

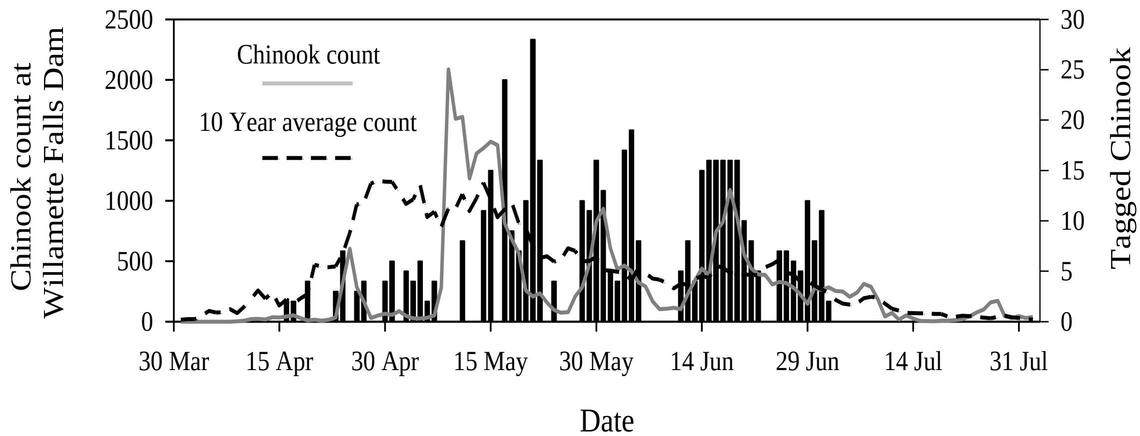


Figure 7. The number of adult Chinook salmon counted at Willamette Falls Dam (solid line), the ten-year average count (dashed line), and the number of Chinook salmon radio-tagged (bar) in 2012. Count data from http://www.cbr.washington.edu/dart/adult.html and http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Table 3. Numbers of adult Chinook salmon radio-tagged at Willamette Falls Dam trap in 2012 that had clipped or unclipped adipose fins and received an experimental anesthetic (AQUI-S®E) or a fish restraint (FRD) treatment during tagging.

	Handling treatment		
Adipose fin	# AQUI-S®E	# FRD	Total
Clipped	0	189	189
Unclipped	154	157	311

Four of the 500 (0.8%) transmitters placed in radiotagged Chinook salmon were recovered in Fishway 1 at Willamette Falls Dan during an August 2012 dewatering event. Three of the four recovered tags were from unclipped salmon; two received the anesthetic treatment and one received the FRD treatment. The fourth recoverd transmitter was from an adipose-clipped salmon that received the FRD treatment. There were 13 tags placed in salmon that produced detections at Willamette Falls Dam only and two tags for which we had no radio detections. This may have been caused by regurgitated transmitters or tag failure. We included these 15 fish in all analyses, but excluded the recovered tags (modified n = 496).

The mean fork lengths of the winter steelhead, summer steelhead, and spring Chinook salmon radio-tagged at Willamette Falls Dam were 71.5, 69.1, and 76.7 cm, respectively (Figure 8). The mean weights were 3.8, 3.8, and 6.0 kg, respectively. Distributions for all groups were slightly right-skewed.

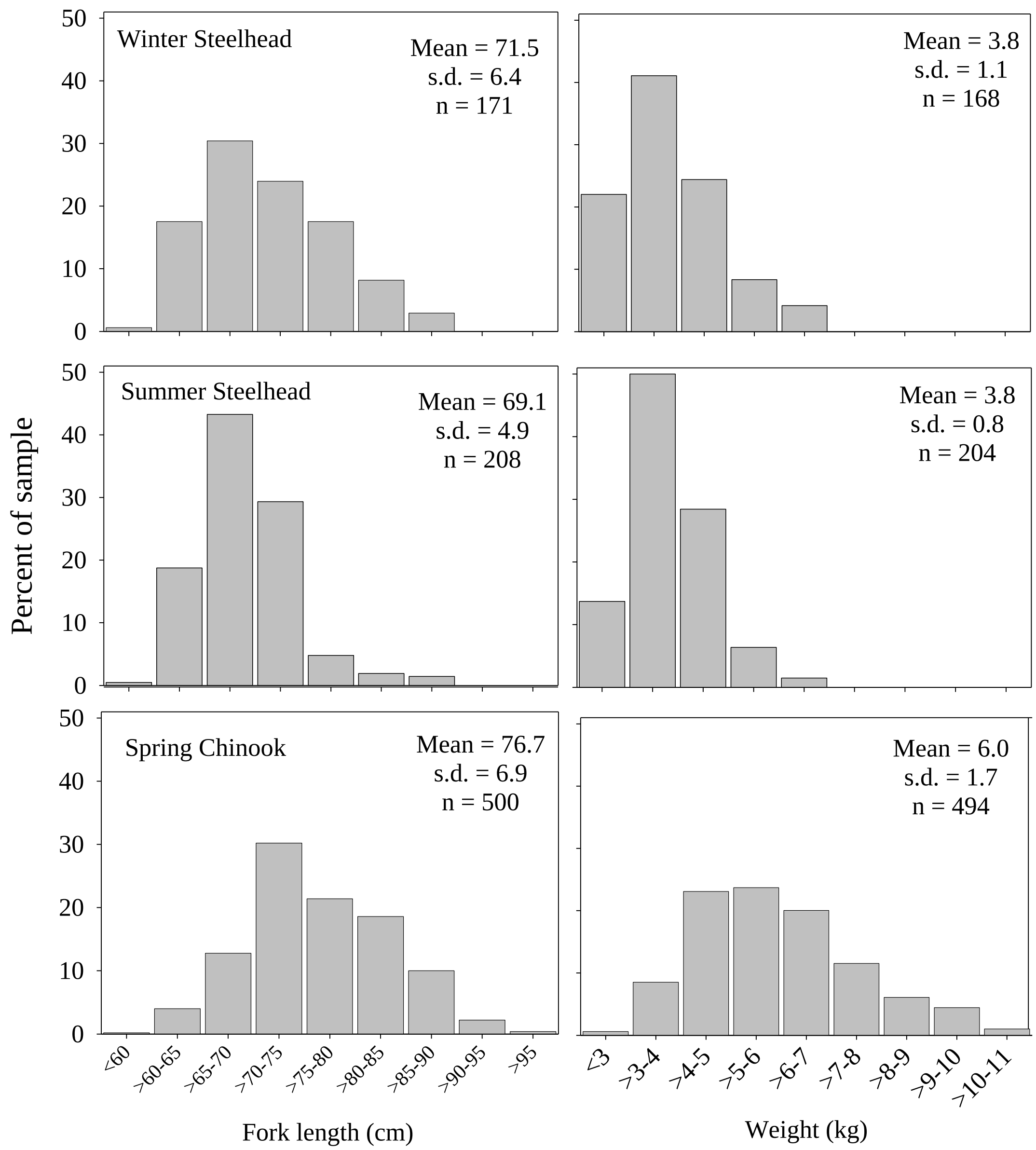


Figure 8. Histograms of winter steelhead, summer steelhead, and spring Chinook salmon fork lengths (cm) and weights (kg) for samples that were radio-tagged at Willamette Falls Dam in 2012.

Fatmeter readings collected at the time of tagging decreased with increasing tag date for Chinook salmon ($r^2 = 0.09$, $P < 0.01$, Figure 9). Chinook salmon also exhibited the highest absolute fatmeter values and the highest variation among fish. There was no evidence for seasonal effects on fatmeter readings for either winter or summer steelhead. Linear regression models explained little variation in the observed values for all species/runs ($0.01 \leq r^2 \leq 0.09$).

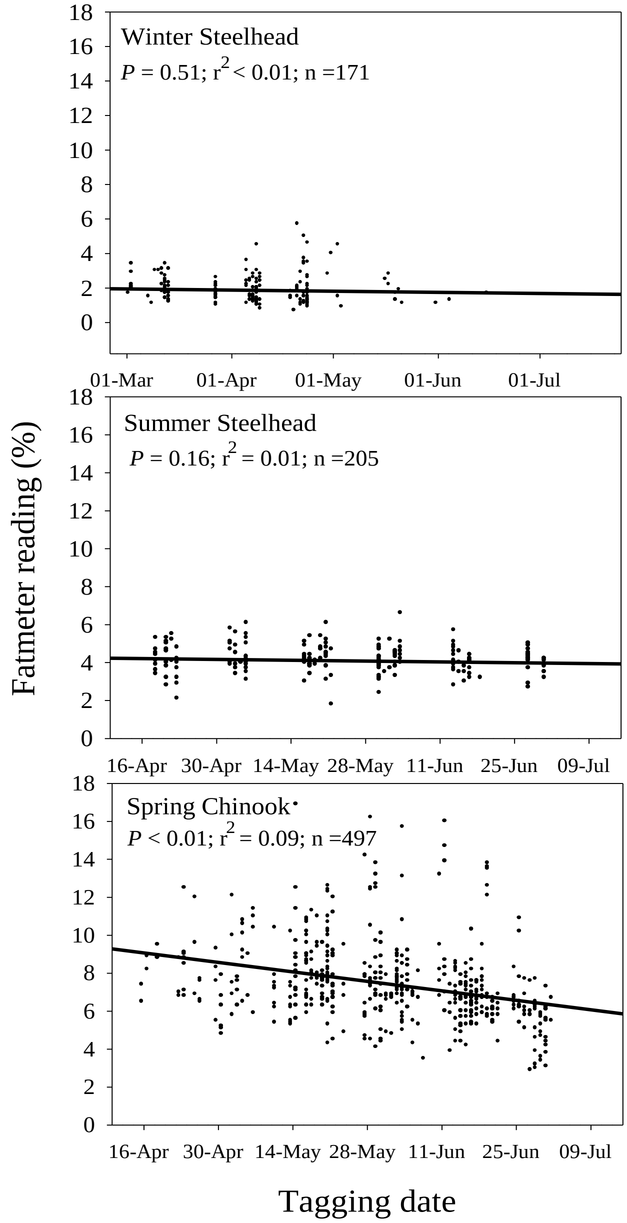


Figure 9. Scatterplots of fatmeter readings versus tag date for winter steelhead, summer steelhead, and spring Chinook salmon radio-tagged at Willamette Falls Dam in 2012. Note different date ranges along the x-axes.

Results: Winter steelhead

Historic count data and run timing

The number of adult winter steelhead counted passing Willamette Falls Dam from 1 November 2011 to 30 May 2012 was 7,172 (Figure 10). This was at the low end of the range of counts since 1971 but was approximately 5,300 more fish than the minimum count of 1,801 in 1996. The 2012 winter steelhead run was among the earliest-timed runs in the last ten years (Figure 11). The date of median passage in 2012 was 24 February, compared to medians that ranged from 19 February to 16 March in 2002-2011.

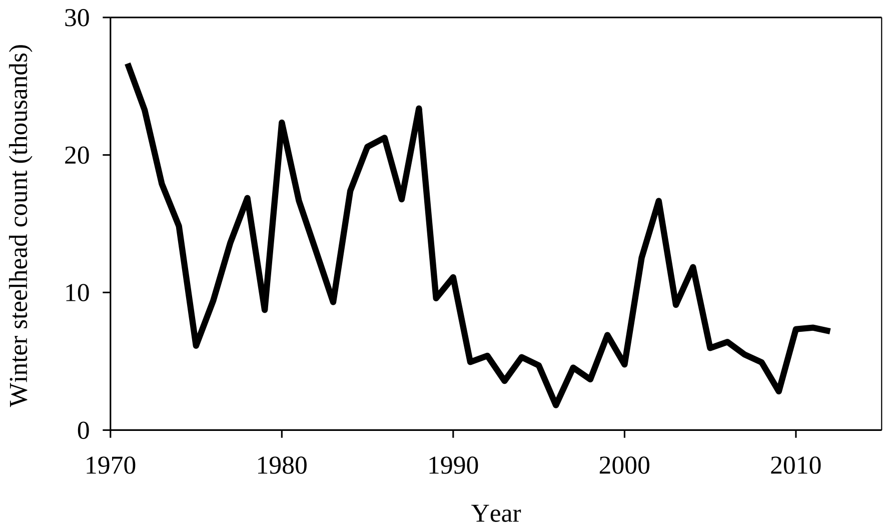


Figure 10. Total annual numbers of adult winter steelhead counted passing Willamette Falls Dam, 1971-2012.

Behaviors at Willamette Falls Dam (FRD vs. anesthetic)

Of the 84 tagged, winter steelhead that received the FRD treatment, 15 (18%) exited the dam to the tailrace after release (Table 4). A slightly lower percentage (16%) of the 85 winter steelhead that received the anesthetic treatment exited to the tailrace after release. These proportions did not statistically differ ($P = 0.84$, χ^2 test). None of the exiting salmon that received the FRD treatment (0/15) subsequently ascended the dam whereas two of the fourteen anesthetized steelhead that exited did ascend.

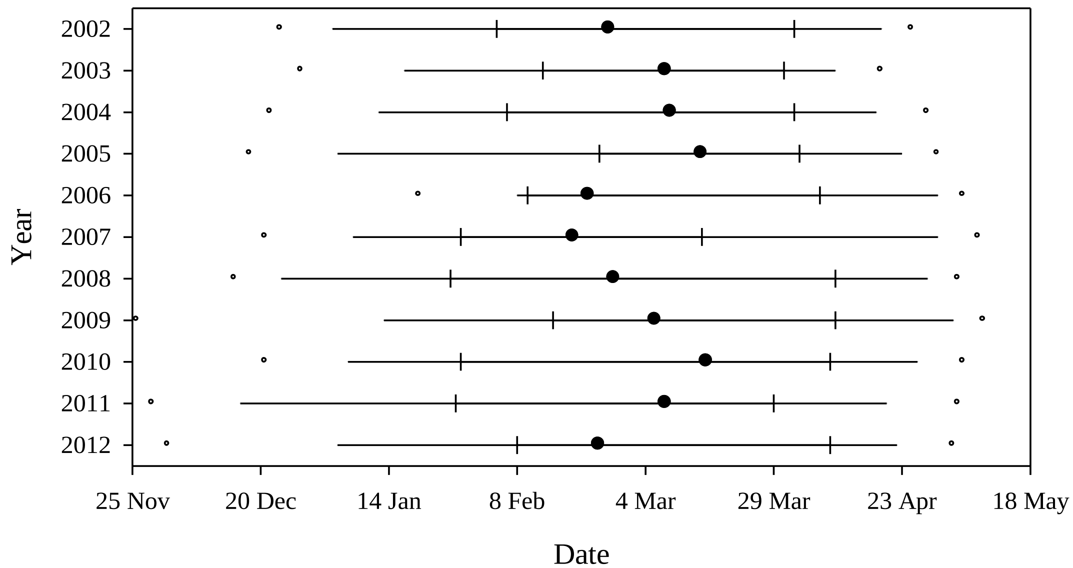


Figure 11. Annual migration timing distributions for winter steelhead counted at Willamette Falls Dam, 2002-2012. Symbols show median (●), quartile (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (○). Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Table 4. Numbers of adult winter steelhead that were radio-tagged at Willamette Falls Dam in 2012, that exited the dam to the tailrace after release and that eventually ascended the dam by handling treatment.

Handling Trt.	Number released	Number that exited dam (%)	Number that exited and ascended dam (%)
FRD	84	15 (18)	0 (0)
AQUI-S®E	85	14 (16)	2 (14)

Main stem residence times and migration rates

Tagged winter steelhead that returned to the Yamhill, Santiam, and Middle Fork Willamette rivers typically resided in each of the monitored main stem sections for approximately 1-2 days (Figure 12). On median, winter steelhead took 7.9 d (*range* = 5.0-27.2 d) to migrate through the main stem from above Willamette Falls (WFU) to near Harrisburg (WL5). Section lengths were 24.2 rkm from Willamette Falls to Champoeg (WFU-WL1), 67.8 rkm from Champoeg to Eola (WL1-WL2), 29.9 rkm from Eola to Buena Vista (WL2-WL3), 39.6 rkm from Buena Vista to Corvallis (WL3-WL4), and 43.5 rkm from Corvallis to Harrisburg (WL4-WL5). Migration rates indicated that steelhead moved more slowly as they migrated through successive upstream sections (Figure 12).

Environmental and date effects on fish migration rates were modest in the five main stem reaches. In general, steelhead moved more rapidly as water temperature and migration date increased and more slowly when discharge was higher. However, correlations were low ($-0.25 \le r \le 0.25$) and there were several outliers in each reach (i.e., fish that took much longer than the median value). Some steelhead with longer residence times held position or made downstream movements in the main stem.

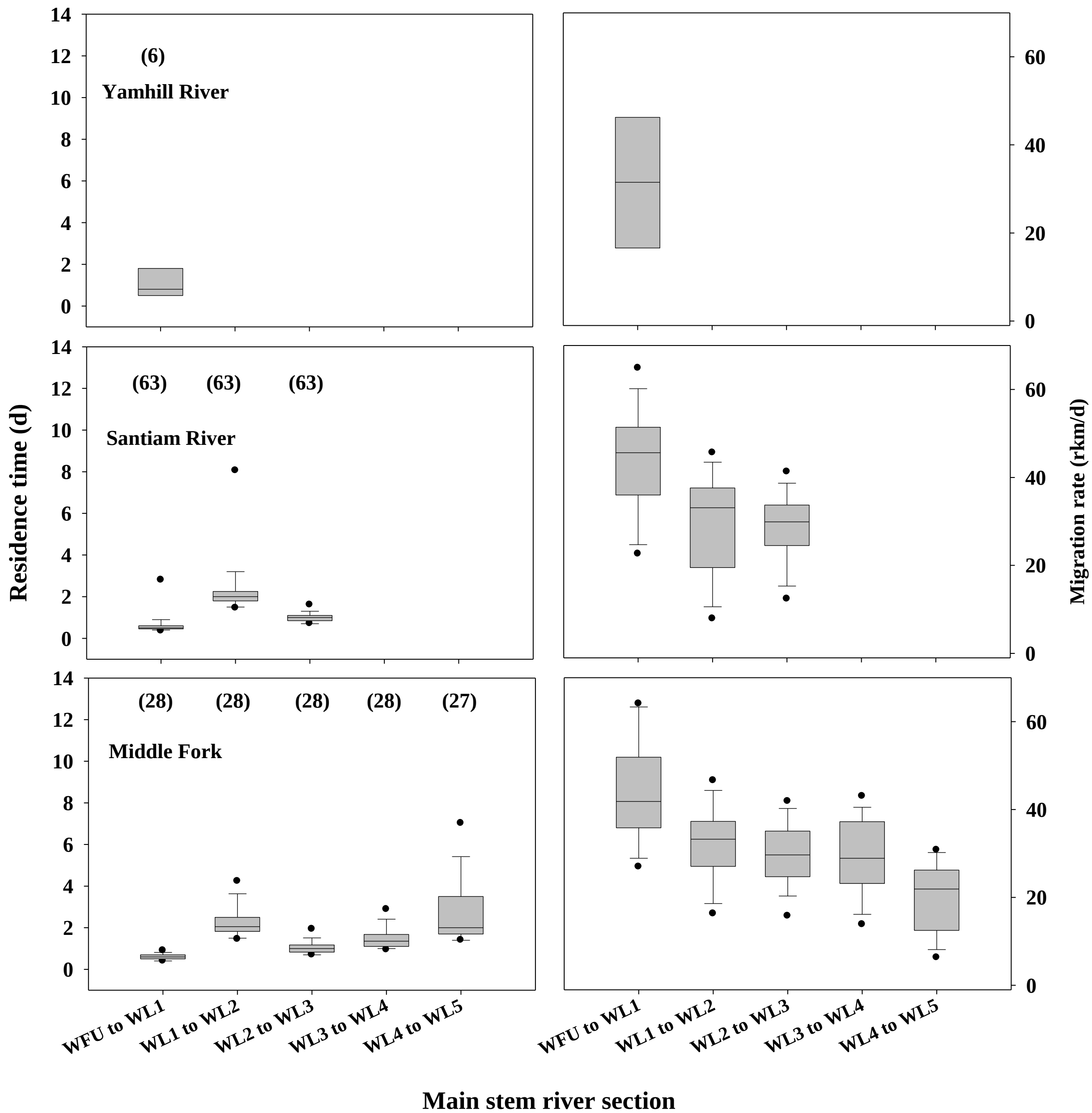


Figure 12. Box plots of residence times (days, left panel) and migration rates (rkm/d, right panel) of radio-tagged winter steelhead in reaches of the main stem Willamette River in 2012. Three panels are for steelhead that returned to the Yamhill, Santiam, and the Middle Fork Willamette rivers. Box plots show: median (line), quartile (box), 10^{th} and 90^{th} (whisker), and 5^{th} and 95^{th} percentiles. Sample sizes are listed in parentheses above boxes.

Last radio detections

Approximately two-thirds of tagged winter steelhead were last detected downstream from Willamette Falls Dam or in the lower main stem, reflecting post-spawn kelt movements downstream (Figures13 and 14). Smaller percentages of tagged steelhead were last recorded in the Santiam (11%), Middle Fork (5%), and Molalla rivers (5%). Five percent were last recorded in the upper main stem.

We also estimated distribution using migration behavior and the maximum river kilometer where steelhead were detected to better approximate spawning distribution among tributaries. The highest percentage (37%) of tagged winter steelhead was detected in the Santiam River (Figures 15 and 16). Seventeen percent had their most upstream records in the Middle Fork Willamette River or Fall Creek and 13% were in the Molalla River. Smaller percentages were in the Yamhill (4%), Calapooia (2%), Tualatin (2%), and Coast Fork Willamette rivers (1%). Ten radio-tagged winter steelhead returned to the Clackamas River and three of them had their final detections there (i.e., seven exhibited kelt behavior – see kelting section below). It was not known whether these fish originated from the Clackamas or from a site upstream from Willamette Falls Dam. The ten 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 fork lengths ranged from 62.2 cm to 74.5 cm. Steelhead assigned to the Santiam, McKenzie and upper main stem groups were larger, on average, than those assigned to the Tualatin, Fall Creek, Calapooia and Coast Fork groups. Mean fatmeter readings among fate groups ranged from 1.5 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 Calapooia, the North and South Santiam, and lower main stem groups (first half of April). The latest mean dates were for Middle Fork, Clackamas, upper main stem, and McKenzie (late April or early May).

Among winter steelhead (n = 169), we found no significant difference in the proportion of steelhead that received the anesthetic treatment and escaped to a tributary (69/83 = 83%) compared to those that received the FRD treatment and escaped (68/86 = 79%) (P = 0.50, χ^2 test). Using the logistic regression model [Escape to tributary (y/n) = tag date + weight + fork length + handling treatment] neither weight, fork length, nor handling treatment was a significant predictor of tagged winter steelhead escaping to a tributary (weight P = 0.99, fork length P = 0.90, treatment P = 0.61, n =166). However, tag date was significant (P = 0.047), with later-tagged migrants more likely to escape than early-tagged fish. Mean tag date was eight days later for escaped steelhead than for those that did not escape.

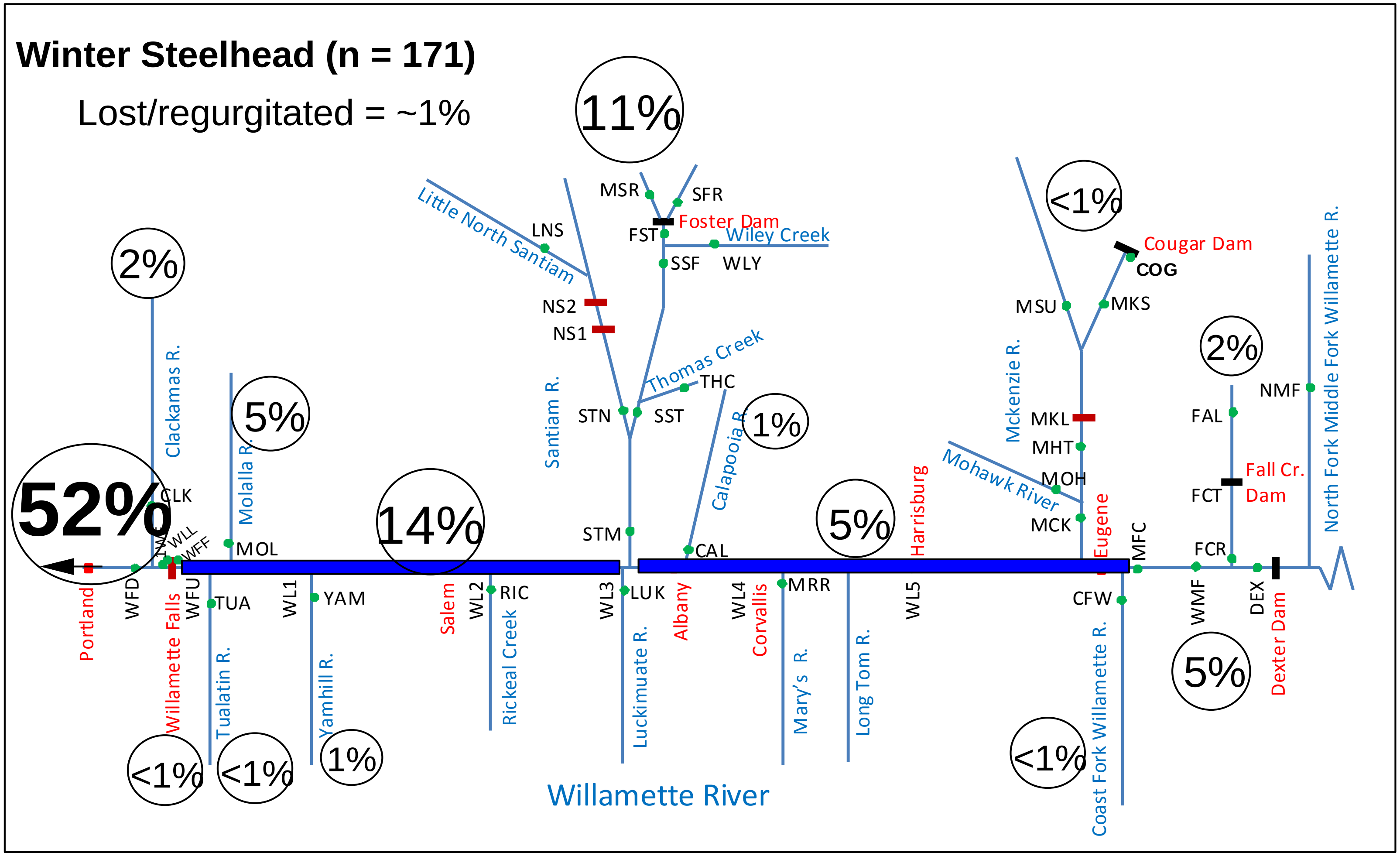


Figure 13. Sites and river basins where radio-tagged adult winter steelhead were last detected in 2012. Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference.

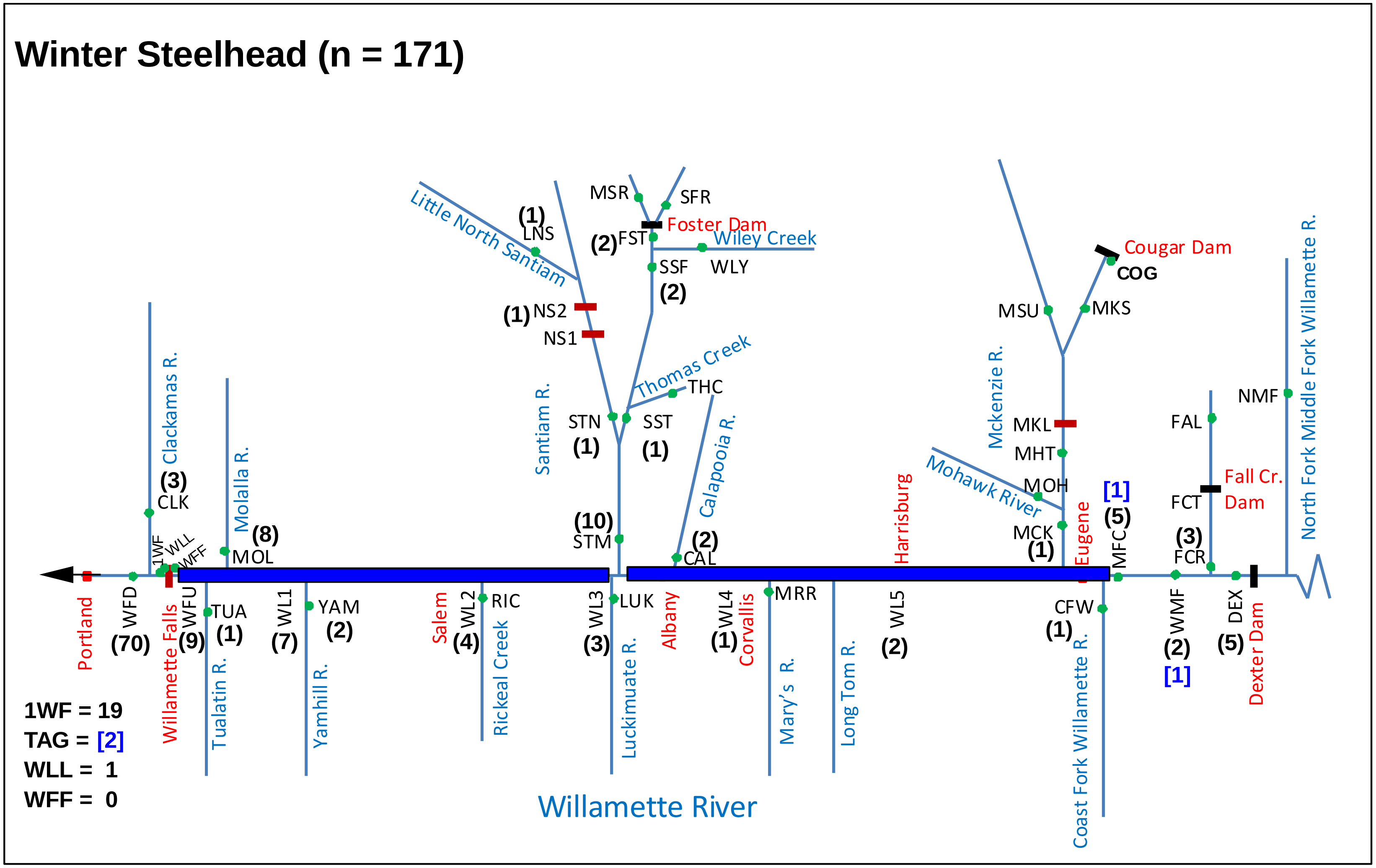


Figure 14. Sites where radio-tagged adult winter steelhead were last detected (black font and parentheses) or where they were recaptured (blue font and brackets). Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference.

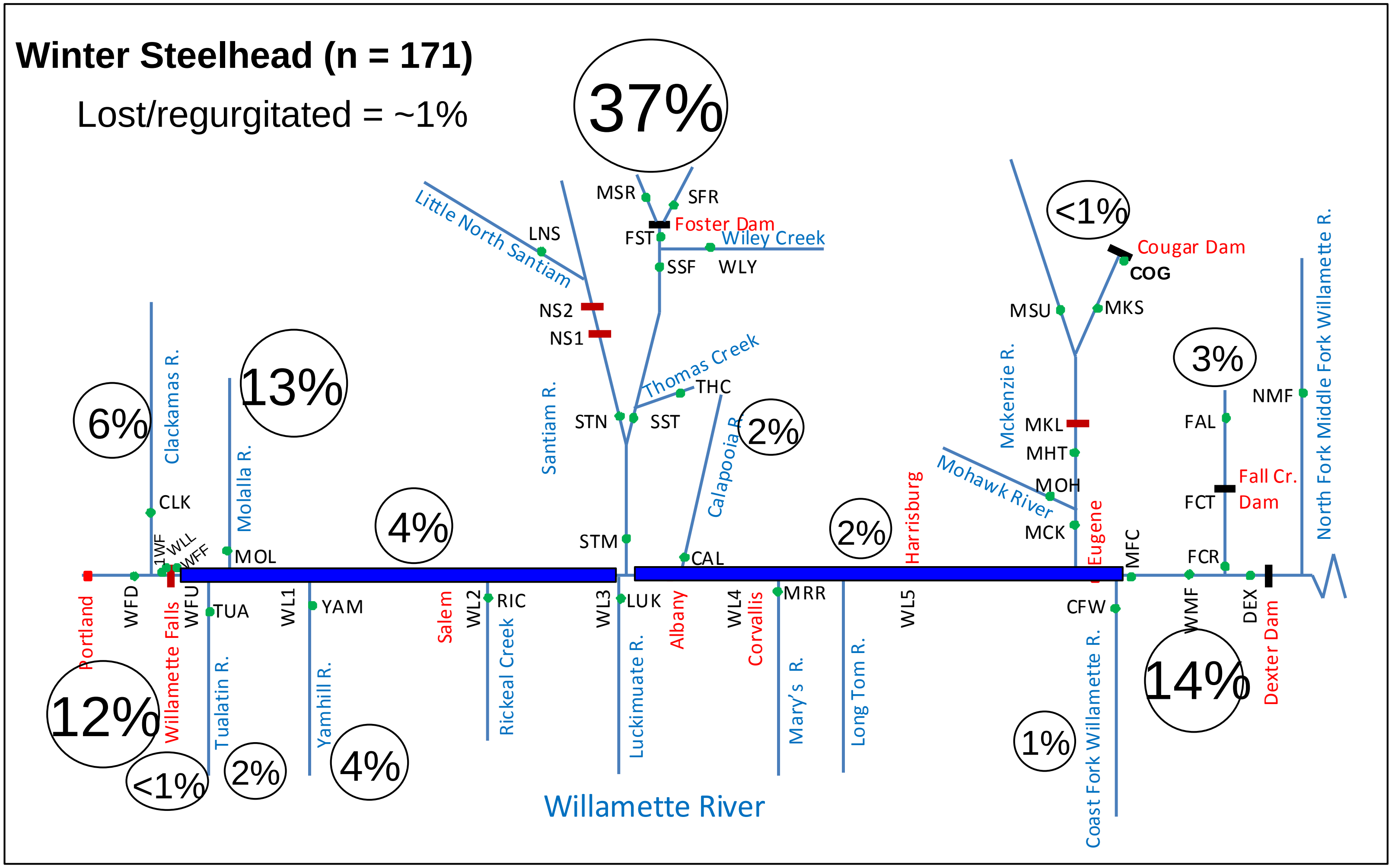


Figure 15. Sites and drainages where adult winter steelhead radio-tagged and released at Willamette Falls Dam migrated for spawning based on their maximum river kilometer.

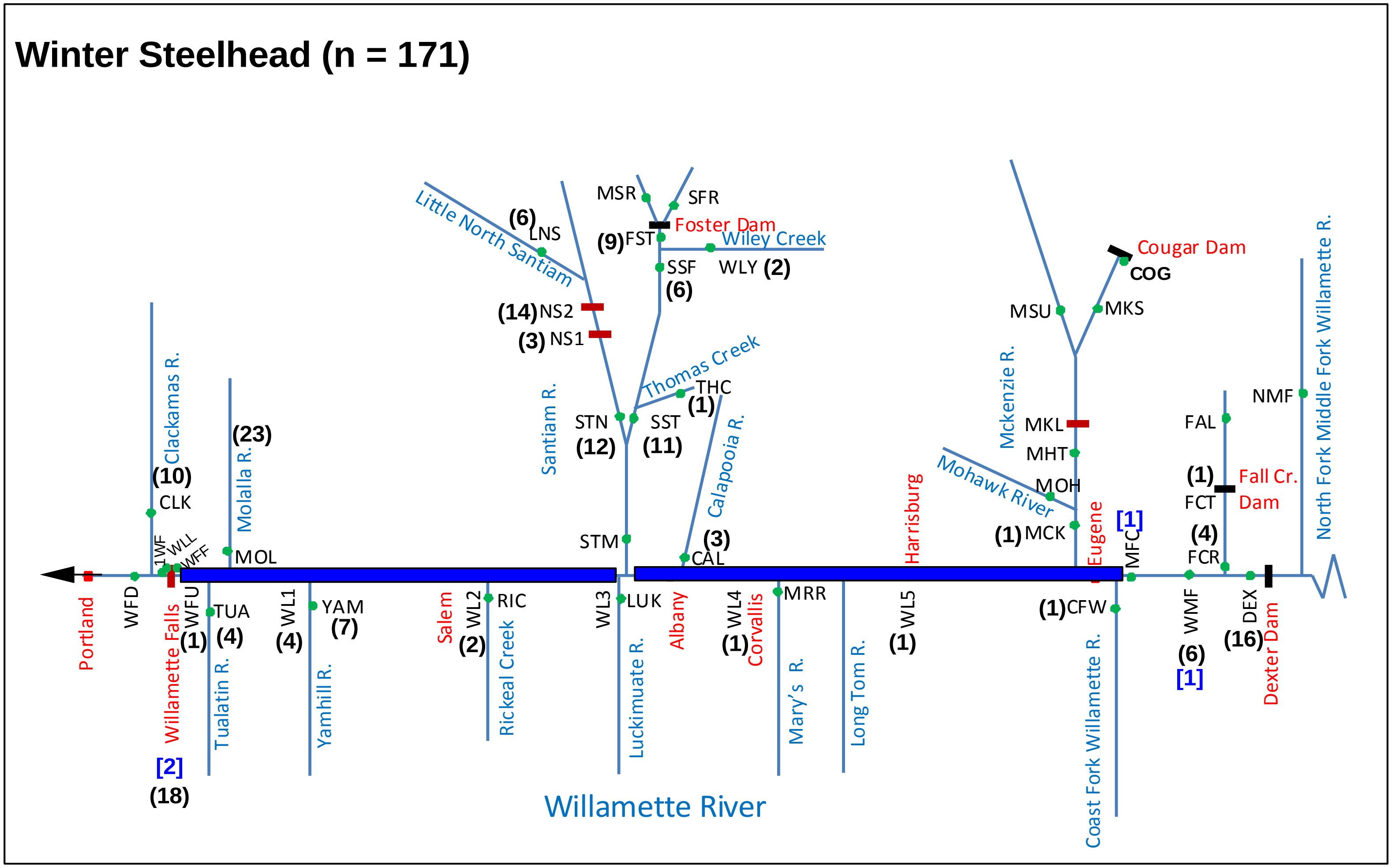


Figure 16. Sites and drainages where adult winter steelhead radio-tagged and released at Willamette Falls Dam migrated for spawning based on their maximum river kilometer or recapture site.

Table 5. Sample sizes, adipose fin clip status, mean tag date, mean fork length, mean weight, and mean fatmeter readings for radio-tagged adult winter steelhead that experienced different fates within the Willamette River in 2012.

Fate	*n*	Mean tag date	Mean fork length (cm)	Mean weight (kg)	Mean fatmeter (%)
Lost/Regurgitated	2	6 May	66.0	3.1	1.8
Downstream from Dam	21	24 Mar	70.9	3.8	1.9
Clackamas River	10	29 Mar	70.7	3.6	1.6
At Dam	1	14 Mar	74.5	4.3	2.2
Lower main stem	6	11 Apr	71.8	4.1	1.5
Tualatin River	3	18 Mar	62.2	2.5	1.5
Molalla River	23	27 Mar	72.1	3.9	1.7
Yamhill River	7	24 Mar	69.5	3.3	1.6
South Santiam River	29	12 Apr	71.7	3.8	1.6
North Santiam River	35	10 Apr	73.4	4.1	1.8
Calapooia River	3	5 Apr	66.7	3.1	1.5
Upper main stem	4	1 May	72.4	4.0	3.2
McKenzie River	1	3 May	72.5	4.4	4.4
Coast Fork	1	21 Apr	67.5	3.6	5.6
Fall Creek	1	23 Apr	64.0	2.4	3.4
Middle Fork	24	26 Apr	71.7	4.0	2.2

Estimated returns by sub-basin

We used the distribution of radio-tagged fish and winter steelhead counts at Willamette Falls Dam to estimate total escapement (Table 6). We expanded the escapement proportions of the tagged fish (n = 169) using three ODFW count scenarios: 1) the count of winter steelhead during the radiotagging interval, 2) the count beginning 15 February 2012 (the nominal start of the 'native' run), or 3) the count from 1 November 2011 (start of the winter run according to ODFW). Given the small total sample size, we did not weight the estimates by sampling date. The estimates assume the counts at the Falls were without error and are uncorrected for fallback. We calculated 95% confidence intervals for proportions derived from the radio-tag sample using the Wilson score for binomial proportions.

The highest number of adults returned to the Santiam River, with point estimates ranging from 1451 to 2716 individuals across the three scenarios (Table 6). The next highest estimates were to the Molalla (522-976) and Middle Fork (522-976). Fewer than 100 steelhead were estimated to have returned to the Coast Fork and McKenzie rivers under any scenario.

Table 6. 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 = 169) and three scenarios of ODFW count data from Willamette Falls Dam in 2012.

			Winter steelhead counted		
			Tag intrvl. n = 3832	From 15 Feb. n = 4743	From 1 Nov. n = 7172
Tributary	N	% (95% ci)	Estimate	Estimate	Estimate
None	28	16.6 (11.7-22.9)	635 (448-878)	786 (555-1,086)	1188 (839-1,642)
Clackamas	10	5.9 (3.3-10.6)	227 (126-406)	281 (157-503)	424 (237-760)
Tualatin	4	2.4 (0.9-5.9)	91 (34-226)	112 (43-280)	170 (65-423)
Molalla	23	13.6 (9.2-19.6)	522 (353-751)	645 (436-930)	976 (660-1,406)
Yamhill	7	4.1 (2.0-8.3)	159 (77-318)	196 (95-394)	297 (143-595)
South Santiam	29	17.1 (12.2-23.6)	655 (468-904)	811 (579-1119)	1226 (875-1693)
North Santiam	35	20.7 (15.3-27.4)	793 (586-1050)	982 (726-1300)	1485 (1097-1965)
Calapooia	3	1.8 (0.6-5.1)	68 (23-195)	84 (28-242)	127 (43-366)
Coast Fork	1	0.6 (0.1-3.3)	23 (4-126)	28 (5-157)	42 (7-237)
McKenzie	1	0.6 (0.1-3.3)	23 (4-126)	28 (5-157)	42 (7-237)
Fall Creek	5	3.0 (1.3-6.7)	113 (50-257)	140 (62-318)	212 (93-481)
Middle Fork	23	13.6 (9.2-19.6)	522 (353-751)	645 (436-930)	976 (660-1,406)

Run Composition

Run composition varied seasonally for the 141 radio-tagged winter steelhead considered to have escaped to tributaries (Figure 17), with lower basin populations typically passing Willamette Falls Dam earlier in the run. Among winter steelhead radio-tagged from mid-March to mid-April (n = 66), 56% returned to the Santiam River and smaller percentages returned to the Mollala (17%), Clackamas (9%), (Middle Fork (8%), and Calapooia (5%) rivers and Fall Creek (2%). Among winter steelhead tagged after mid-April (n =50), run composition included a relatively high percentage that returned to the Santiam (46%) and Middle Fork Willamette rivers (36%). The mean tag date for each population was: 17 March (Tualatin R.), 24 March (Yamhill R.), 28 March (Molalla R.), 29 March (Clackamas R.), 5 April (Calapooia R.), 11 April (Santiam R.), 21 April (Coast Fork), 22 April (Fall Creek), 27 April (Middle Fork), and 3 May (McKenzie R.) (Table 5).

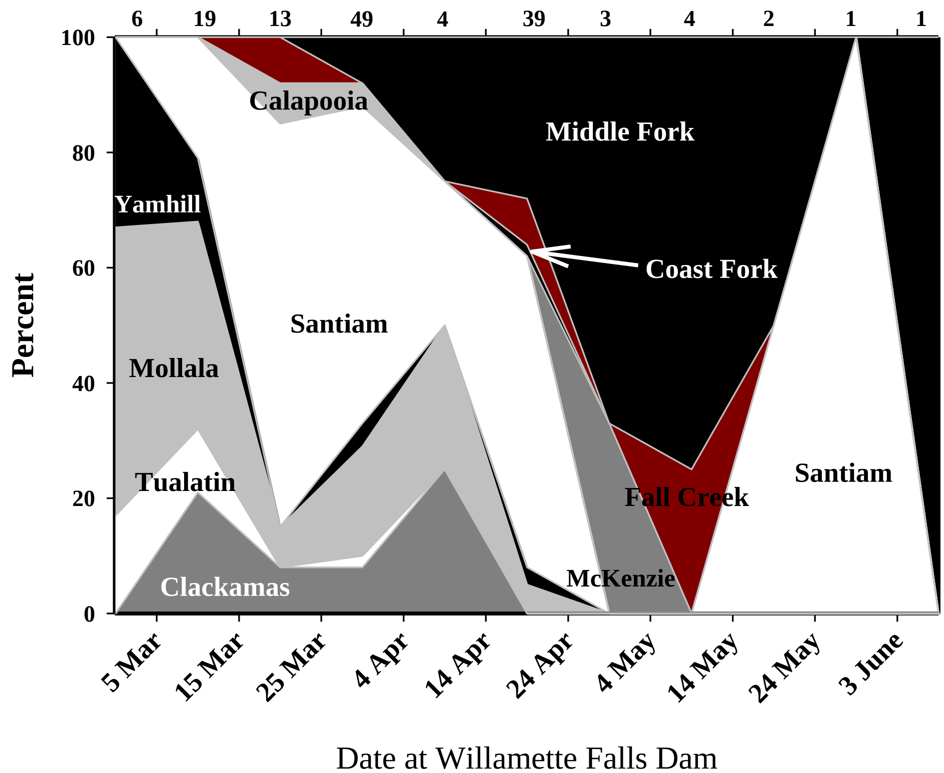


Figure 17. Composition of 141 'escaped' winter steelhead radio-tagged at Willamette Falls Dam in 2012. Data were binned using 10-d intervals based on release dates. Sample sizes for each 10-d interval are listed at top (note small samples in May and June).

Kelting frequencies, distributions, and tributary residency times

Of the 141 tagged winter steelhead considered to have escaped to a tributary, 84 (60%) exhibited kelt behavior (Table 7). Kelting percentages ranged from 33 to 71% among tributaries that had steelhead with the behavior.

Mean tributary entry dates for kelts ranged from 17 March to 14 May and mean residency times ranged from 13 to 38 days (Table 8). 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 8).

Table 7. Frequencies of radio-tagged winter steelhead that returned to tributaries in 2012 and the frequencies and percentages that exhibited kelt behavior.

Tributary	Returned *n*	Kelt *n*	Kelt %
Clackamas	10	7	70
Tualatin	4	2	50
Molalla	23	16	70
Yamhill	7	5	71
Santiam	64	43	67
Calapooia	3	1	33
McKenzie	1	0	n/a
Coast Fork	1	0	n/a
Fall Creek	5	0	0
Middle Fork	23	10	43
Total	141	84	60

Table 8. Mean (and standard deviations) of entry dates, exit dates, and residency times of radio-tagged female and male steelhead that exhibited kelting behavior in Willamette River tributaries in 2012. Note: sex was estimated at time of tagging.

Tributary	Estimated Sex	Mean entry date	Mean exit date	Mean res. Time (d)	s.d.	n
Clackamas R.	F	13 April	24 April	11.6	3.6	5
	M	6 April	24 April	17.9	3.2	2
	All	11 April	24 April	13.4	4.4	7
Tualatin R.	F	17 March	24 April	37.7	17.0	2
Molalla R.	F	8 April	26 April	16.7	5.3	7
	M	6 April	2 May	25.7	13.0	8
	All	7 April	29 April	21.5	10.9	15
Yamhill R.	F	5 April	2 May	26.6	31.2	3
	M	21 March	12 April	22.3	9.4	2
	All	30 March	24 April	24.9	22.7	5
Santiam R.	F	15 April	4 May	19.1	10.7	29
	M	20 April	6 May	15.6	10.1	13
	All	17 April	5 May	17.9	10.5	43[1]
Calapooia R.	F	8 April	4 May	26.4	-	1
Middle Fork	F	10 May	25 May	14.9	12.0	6
	M	25 May	1 June	7.7	6.3	3
	All	14 May	26 May	12.7	10.0	10[1]

[1] – sex not assigned to one fish in tributary category.

Iteroparity rates based on scale analysis

We collected 167 scale samples from the 171 radio-tagged winter steelhead and 165 were readable. Fourteen of the 165 scale samples (8.5%) were scored as having entered freshwater as an adult at least once before 2012 (i.e., they were likely repeat spawners in 2012). Twelve of the 14 appeared to have entered freshwater once before and two were scored as entering at least twice before. Eleven of the 14 steelhead with iteroparous scale patterns returned to tributaries, including the Clackamas, Molalla, Santiam, and McKenzie rivers, and Fall Creek (Figure 18). 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 other was last detected in the lower main stem Willamette River near Salem, OR. Within the tributaries, the percentage of tagged steelhead that were likely repeat spawners ranged from ~5-30% (excluding McKenzie River and Fall Creek groups where $n \leq 5$).

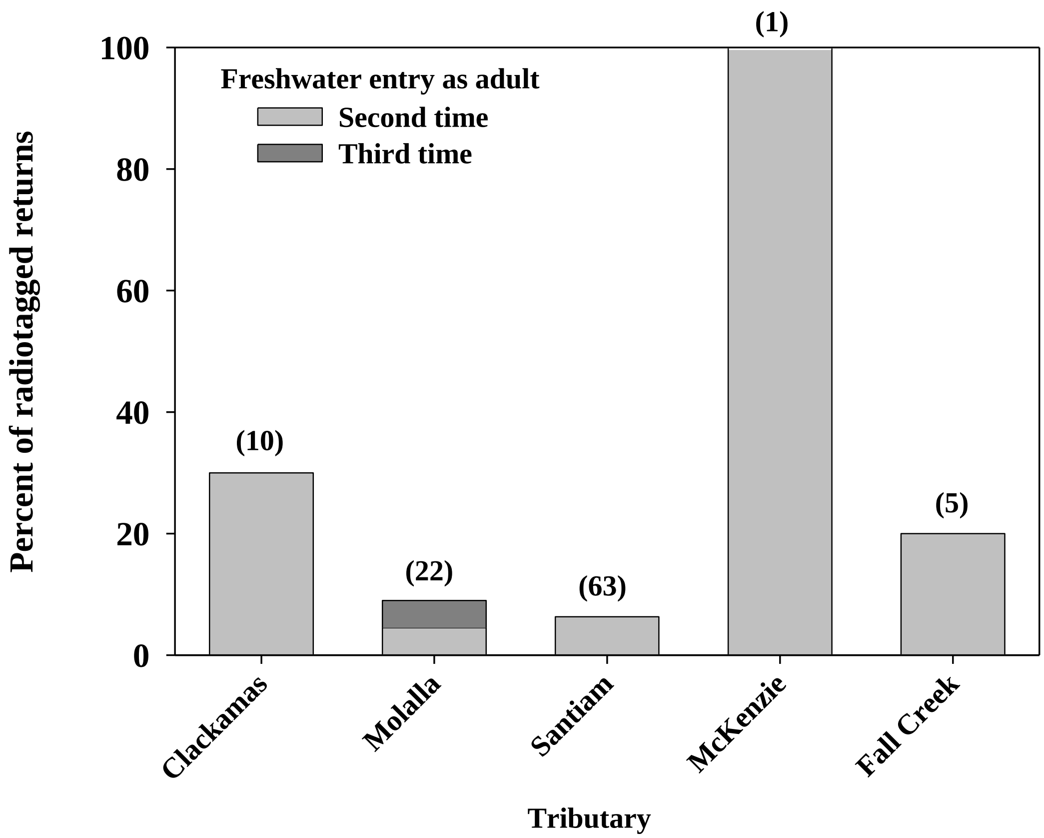


Figure 18. Percentage of radio-tagged winter steelhead that were estimated to be on their their second or third migration into freshwater based on scale analyses, by tributary in 2012 . Total tributary sample sizes in parentheses are above each bar.

Results: Summer steelhead

Historic count data and run timing

The number of adult summer steelhead counted passing Willamette Falls Dam in 2012 was 24,728 (Figure 19). This was approximately 10,000 more fish than the average count since 1971 (14,978) and approximately 16,000 fewer fish than the maximum count of 40,719, in 1986. The timing of the 2012 summer steelhead run past Willamette Falls was in the middle of the range since 2001 (Figure 20). The date of median passage in 2012 was 1 April, compared to medians that ranged from 17 March to 11 April in 2001-2011.

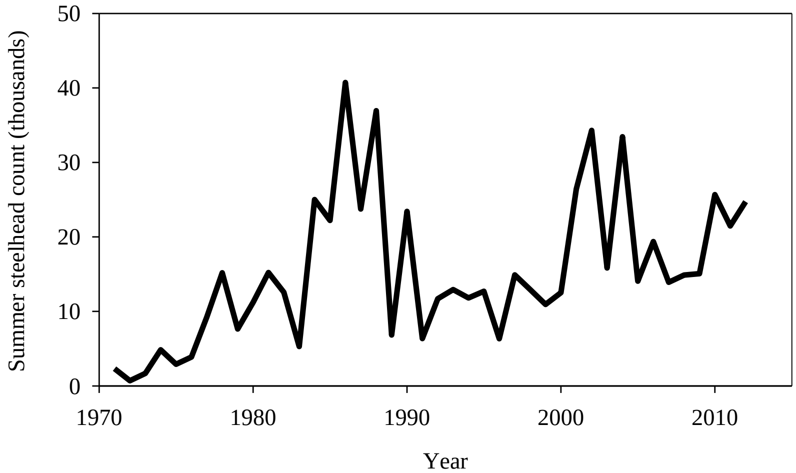


Figure 19. Total annual numbers of adult summer steelhead counted passing Willamette Falls Dam, 1971-2012.

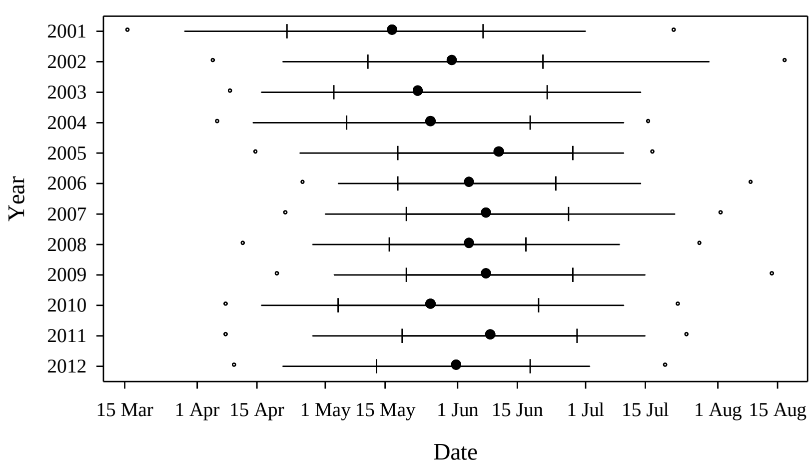


Figure 20. Annual migration timing distributions for summer steelhead counted at Willamette Falls Dam, 2001-2012. Symbols show median (●), quartile (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (○). Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Behaviors at Willamette Falls Dam (FRD vs. anesthetic)

Of the 194 tagged summer steelhead that received the FRD treatment, 35 (18%) exited to the tailrace after release. Thirteen steelhead were identified as summer run adults based on timing, coloration and morphology but were unclipped. Eleven of these received the anesthetic treatment and, 1 of 11 (9%) exited (Table 9). Only eleven of the 208 nominal summer steelhead received the anesthetic because these eleven were unclipped and not subject to legal harvest. As a consequence, the comparison of handling treatments within summer steelhead was limited by sample size and seasonal differences in timing. Slightly less than half of the summer steelhead that received the FRD treatment and exited to the tailrace subsequently ascended the dam; the single anesthetized summer steelhead that exited did ascend.

Table 9. Numbers of adult summer steelhead that were radio-tagged at Willamette Falls Dam in 2012, that exited the dam to the tailrace after release, and that eventually ascended the dam, by handling treatment and their adipose fin status.

Adipose/Trt.	Number released	Number that exited dam (%)	Number that exited and ascended dam (%)
Clipped/FRD	194	35 (18)	17 (49)
Clipped/AQUI-S®E	1	0 (0)	0 (0)
Unclipped/FRD	3	1 (33)	0 (0)
Unclipped/AQUI-S®E	10	1 (10)	1 (100)
Total FRD	197	36 (18)	17 (47)
Total AQUI-S®E	11	1 (9)	1 (100)

Main stem residence times and migration rates

Tagged summer steelhead that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers were in each of the monitored main stem sections for ~1-3 days, on median (Figure 21). As with winter steelhead, summer-run fish migrated more slowly through successive upstream reaches, though there was considerable variability in migration rates among fish. Seasonal environmental effects on upstream movement were similar to those for winter steelhead: fish moved faster in each reach later in migration and as water temperatures increased, whereas higher discharge was associated with slower rates. Correlations were generally higher ($-0.40 \leq r \leq 0.40$) than for winter steelhead, but these effects explained only a small portion of the behavioral variability among fish.

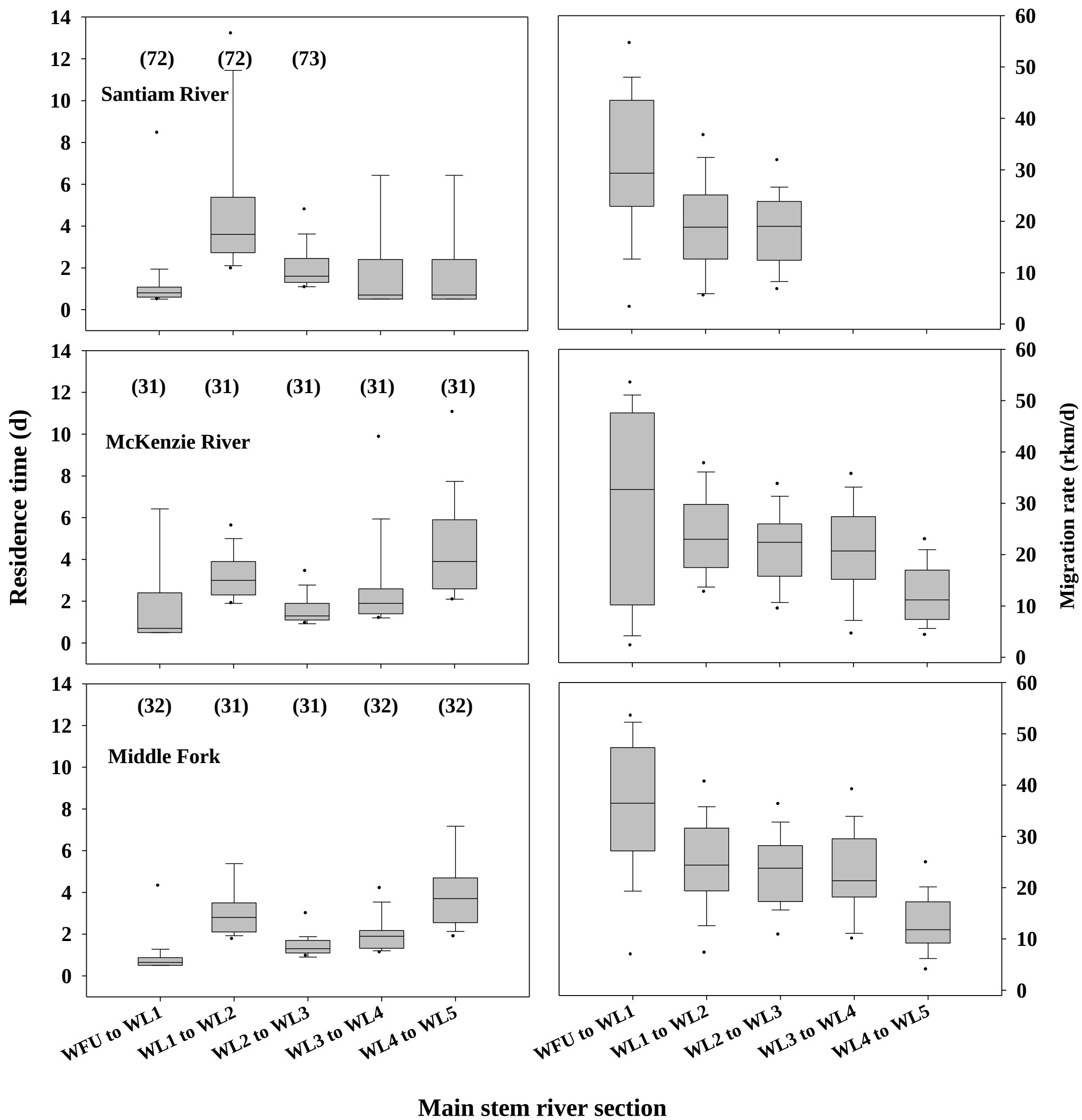


Figure 21. Box plots of residence times (days – left panel) and migration rates (rkm/d – right panel) of radio-tagged summer steelhead in reaches of the main stem Willamette River in 2012. Three panels are for steelhead that returned to the Santiam, McKenzie, and the Middle Fork Willamette rivers. Box plots show: median (line), quartile (box), 10^{th} and 90^{th} (whisker), and 5^{th} and 95^{th} percentiles. Sample sizes are listed in parentheses above boxes.

Last radio detections (through Fall, 2012)

The highest percentage of tagged summer steelhead (35%) was last recorded in the Santiam River (Figures 22 and 23). Smaller percentages were last recorded in the McKenzie River (15%), and Middle Fork (15%). Nineteen percent were last recorded in the main stem upstream from Willamette Falls Dam. An unknown portion of these fish were presumed harvested.

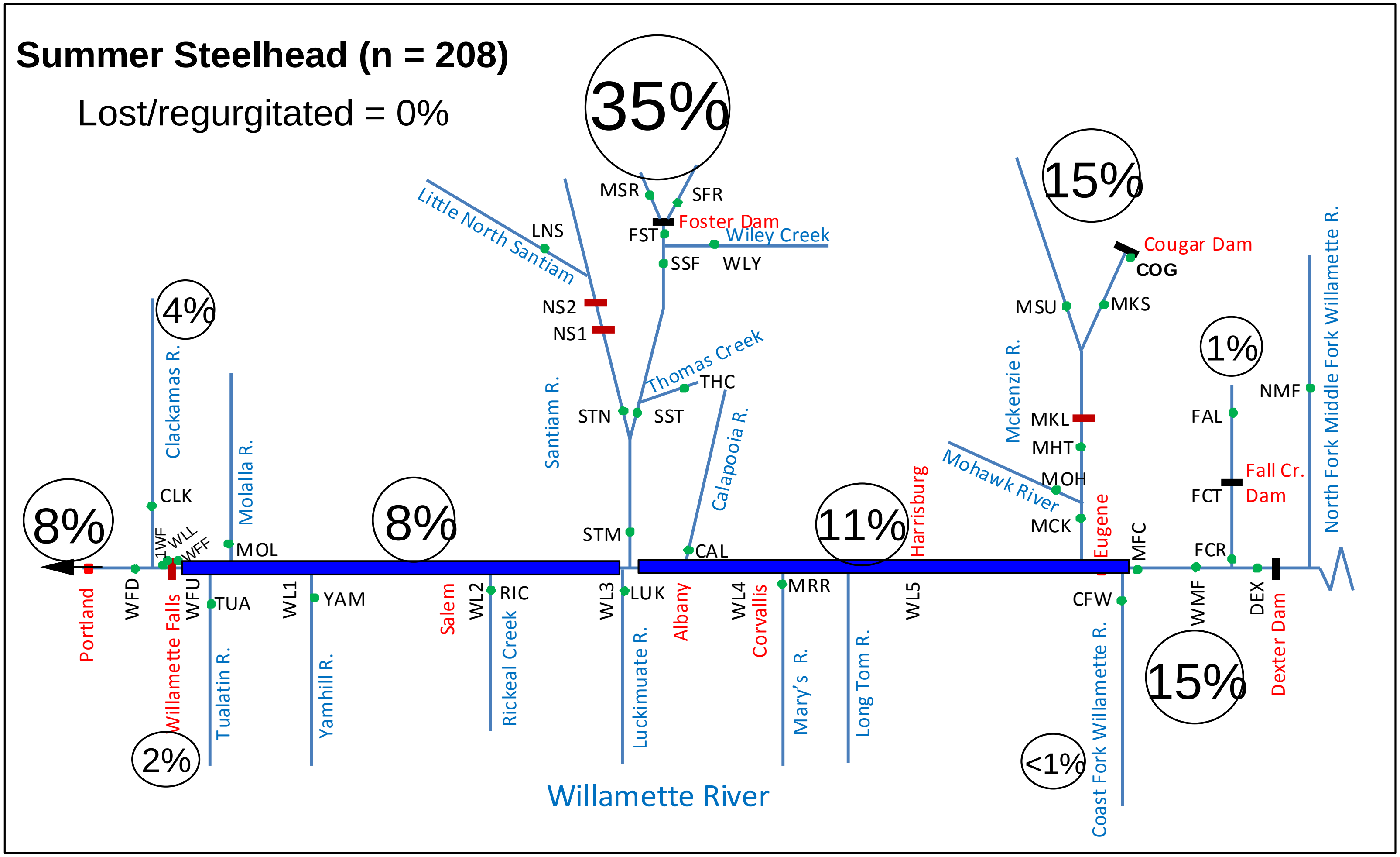


Figure 22. Sites and drainages where adult summer steelhead radio-tagged and released at Willamette Fall Dam migrated based on their last radio detections.

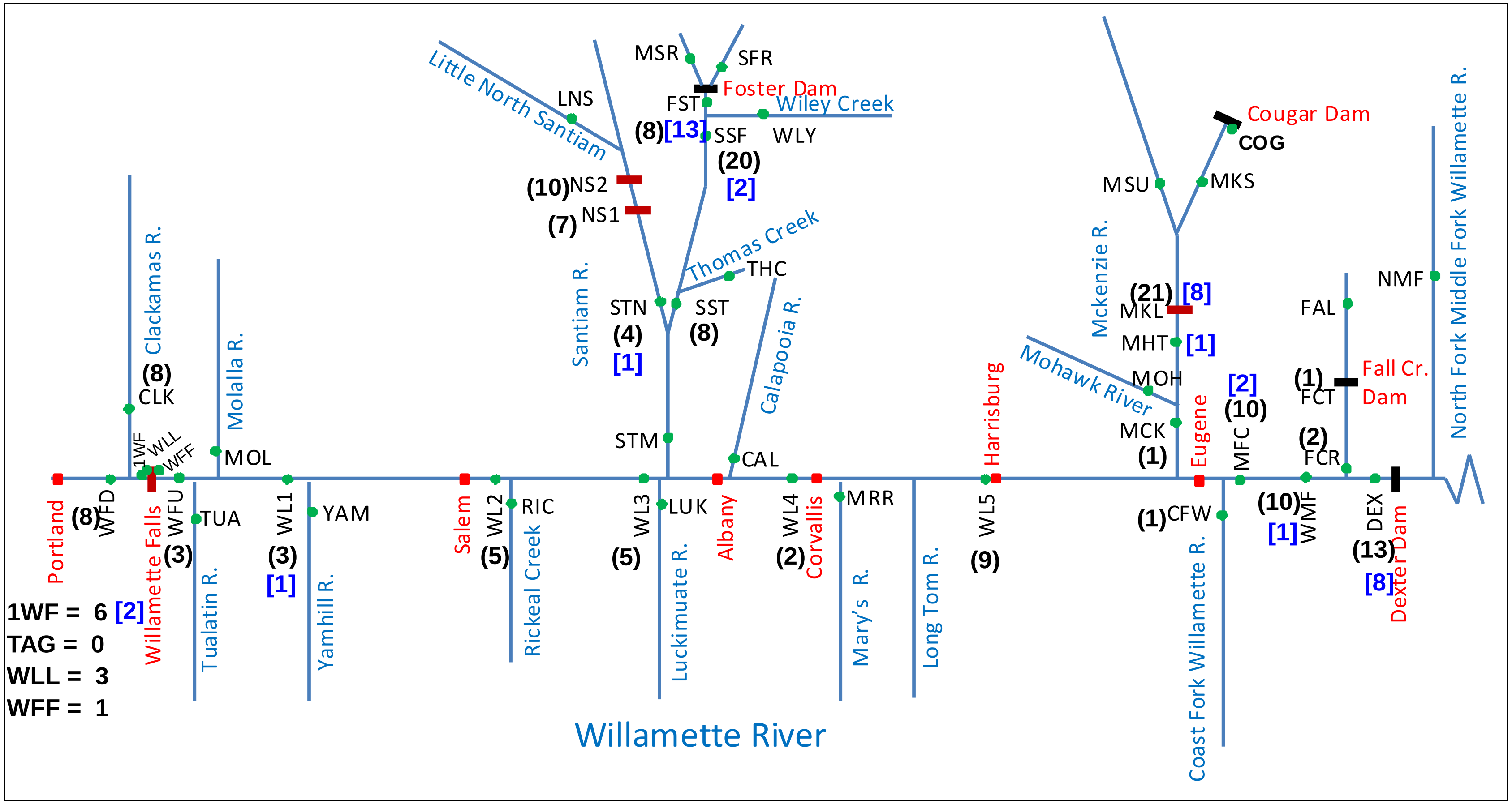


Figure 23. Sites where adult summer steelhead radio-tagged and released at Willamette Fall Dam were last detected (black font and parentheses) or where they were recaptured (blue font and brackets). Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference.

Mean fork length for the different groups ranged from 64.0 cm to 70.3 cm, with minor differences among the major categories (Table 10). Steelhead assigned to the groups below Willamette Falls and to the lower main stem were larger, on average, than those assigned to the tributaries. Mean fatmeter readings among fate groups varied little (*range* = 3.9 to 4.4%). There were among-group differences in tagging date. The earliest mean dates were for Coast Fork, lower main stem, and Santiam groups. The latest mean dates were for Fall Creek and upper main stem groups (early June).

Table 10. Sample sizes, adipose fin clip status, mean tag date, mean fork length, mean weight, and mean fatmeter readings for radio-tagged adult summer steelhead that experienced different fates within the Willamette River in 2012.

Fate	n	# Ad-clipped (y/n)	Mean tag date	Mean fork length (cm)	Mean weight (kg)	Mean fatmeter (%)
Lost/regurge.	0	0/0	-	-	-	-
At Dam	4	3/1	26 May	67.8	3.9	4.4
Downstream from Dam	24	23/1	19 May	70.3	4.1	3.9
Lower main stem	17	17/0	17 May	70.0	4.2	4.2
South Santiam R.	50	50/0	15 May	68.1	3.6	4.0
North Santiam R.	23	23/0	24 May	68.8	3.8	4.3
Upper main stem	23	22/1	4 Jun	69.9	3.9	4.2
McKenzie R.	31	27/4	22 May	69.8	3.9	4.2
Coast Fork	1	1/0	6 May	64.0	3.2	3.9
Fall Creek	3	2/1	20 Jun	68.7	3.9	4.0
Middle Fork	32	27/5	20 May	68.8	5.1	4.0

No covariates were significantly associated with summer steelhead escapement to tributaries in the logistic regression model [Escape to tributary (y/n) = tag date + weight + fork length]. With the full sample of 208 fish, *P* values were 0.37 (tag date), 0.77 (weight), and 0.11 (length).

Run Composition

Run composition for the 148 summer steelhead last recorded in tributaries varied less across sampling dates than it did for winter steelhead (Figure 24). The three largest return groups (i.e., Santiam, McKenzie, and Middle Fork) typically were represented in all of the 10-day tagging intervals. The few tagged steelhead that returned to the Coast Fork or Fall Creek passed Willamette Falls in mid-run and late run, respectively (Table 10).

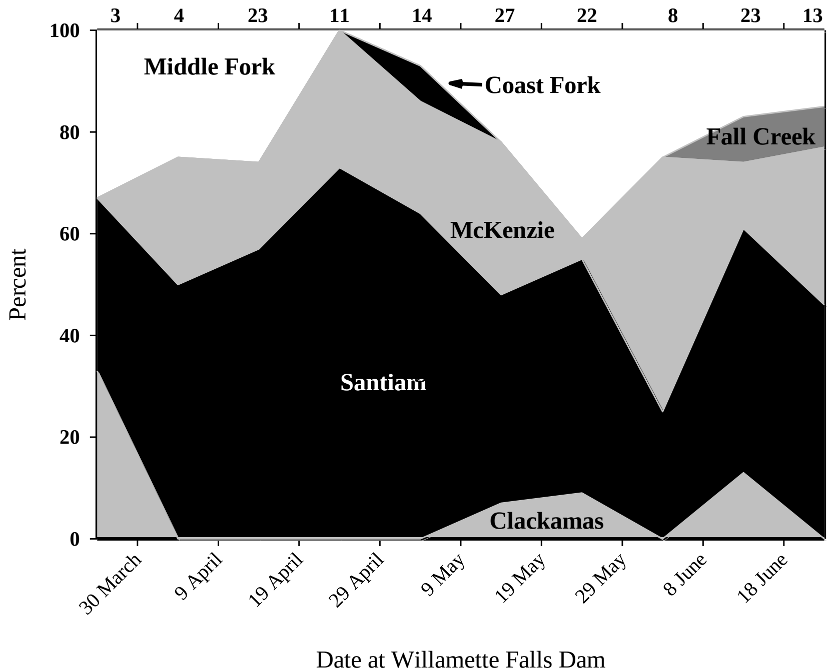


Figure 24. Composition of 148 'escaped' summer steelhead radio-tagged at Willamette Falls Dam in 2012. Data were binned using 10-d intervals based on release dates. Sample sizes for each 10-d interval are listed at top.

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 escapement (Table 11). We expanded the escapement proportions of the tagged fish (*n* = 208) using two ODFW count scenarios: 1) summer steelhead counted during the radio-tagging interval, or 2) the total summer count 1 March – 31 October 2012 .

The highest estimated number (7,660-8,679) of summer steelhead returned to the Santiam River uisng the two scenarios (Table 11). The next highest estimates were to the Middle Fork (3,358-3,804) and McKenzie (3,253-3,686) basins. All point estimates were < 1,000 fish for the Clackamas, Coast Fork, and Fall Creek. As with the winter steelhead expansions, these values assume no error in the total counts at Willamette Falls and that the sampled adults were representative of the run at large.

Table 11. Estimated returns of adult summer steelhead to Willamette River tributaries based on return numbers and percentages of radio-tagged summer steelhead (*n* = 208) and two scenarios of ODFW count data from Willamette Falls Dam in 2012.

			Summer steelhead counted	
			Tag intrval *n* = 21,826	1 Mar-31 Oct *n* = 24,729
Tributary	n	% (95% ci)	Estimate	Estimate
None	60	28.8 (23.1-35.4)	6,296 (5,042-7,726)	7,133 (5,712-8,754)
Clackamas	8	3.8 (2.0-7.4)	839 (437-1,615)	951 (495-1,830)
S. Santiam	50	24.0 (18.7-30.3)	5,238 (4,081-6,635)	5,935 (4,624-7,517)
N. Santiam	23	11.1 (7.5-16.0)	2,422 (1,637-3,492)	2,744 (1,855-3,957)
McKenzie	31	14.9 (10.7-20.4)	3,253 (2,335-4,453)	3,686 (2,646-5,045)
Coast Fork	1	0.5 (0.0-2.7)	105 (17-589)	119 (20-668)
Fall Creek	3	1.4 (0.5-4.2)	315 (109-917)	357 (124-1,039)
Middle Fork	32	15.4 (11.1-20.9)	3,358 (2,423-4,562)	3,804 (2,745-5,168)

Fates of tagged steelhead and overlap with winter steelhead

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

There was evidence for spawning habitat overlap in the South and North Forks of the Santiam River and the Middle Fork Willamette River. We found overlap within the upper and lower reaches of the North Santiam River but found none in the Little North Santiam River (Figure 25). The most overlap we noted within the South Santiam River was near Foster Dam (Figure 26). Within the Middle Fork, overlap extended from the mouth to Dexter Dam (Figure 27). Hatchery summer steelhead are released as smolts at the base of both dams. We found no spatial overlap among winter- and summer-run fish in the Tualatin, Molalla, Yamhill, or Calapooia rivers (Table 12), sites where no hatchery summer steelhead are released. Steelhead from both runs were recorded entering the Clackamas River on the fixed site receiver but their distributions within the tributary were not monitored by mobile tracking.

Table 12. Frequencies of last detections of radio-tagged summer steelhead and the maximum river kilometer reached by radio-tagged winter steelhead .

Tributary	Winter SH frequency	Summer SH frequency	Total
Clackamas	10	8	8
Tualatin	4	0	4
Molalla	23	0	23
Yamhill	7	0	7
South Santiam (SS)	15	32	47
SS – Crabtree Cr.	4	0	4
SS –Thomas Cr.	1	0	1
SS – Wiley Cr.	2	0	2
North Santiam	29	21	50
Little North Santiam	6	0	6
Calapooia	3	0	3
McKenzie	1	21	22
Coast Fork	1	1	2
Fall Creek	5	3	8
Middle Fork	23	22	45
Total	124	108	232

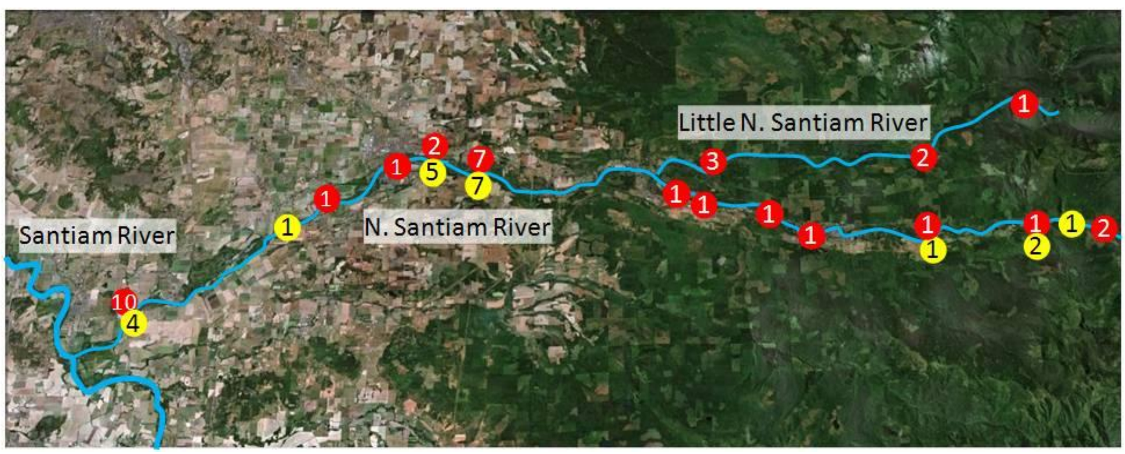


Figure 25. Distribution of maximum river kilometer detections in the North Santiam River for radio-tagged winter steelhead (red circles) and last detections for radio-tagged summer steelhead (yellow circles) in 2012. Numbers indicate number of tagged fish at each site.

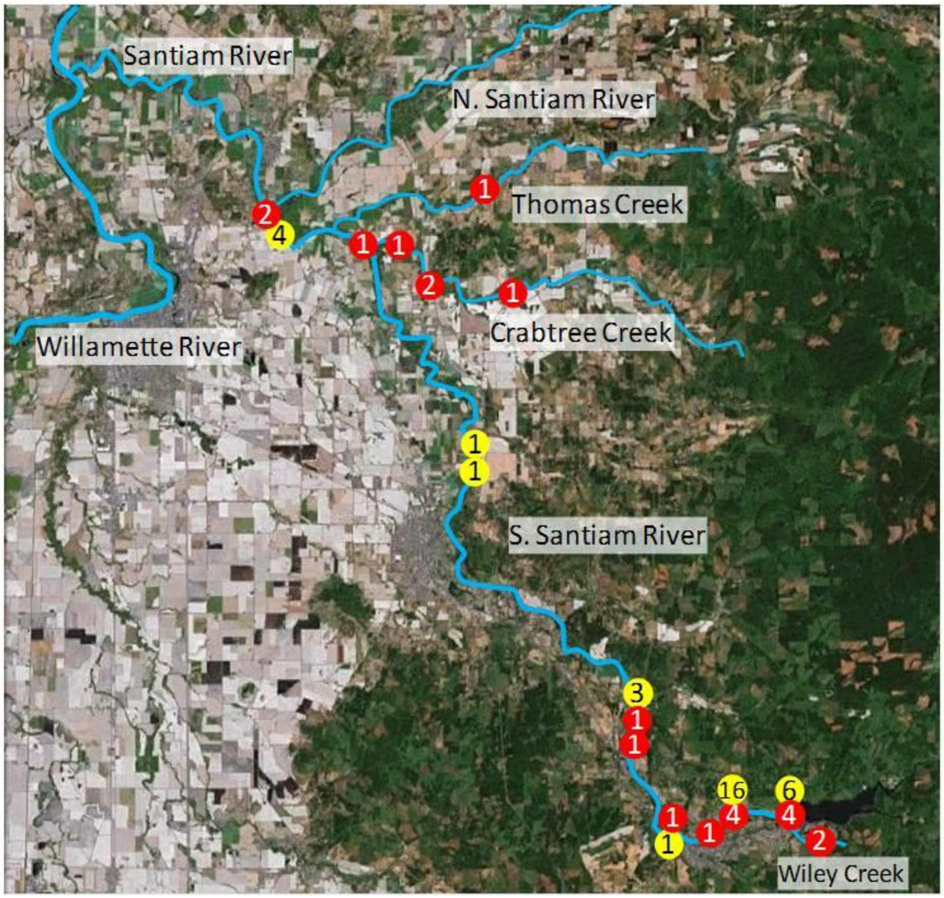


Figure 26. Distribution of maximum river kilometer detections in the South Santiam River for radio-tagged winter steelhead (red circles) and last detections for radio-tagged summer steelhead (yellow circles) in 2012. Numbers indicate number of tagged fish at each site.

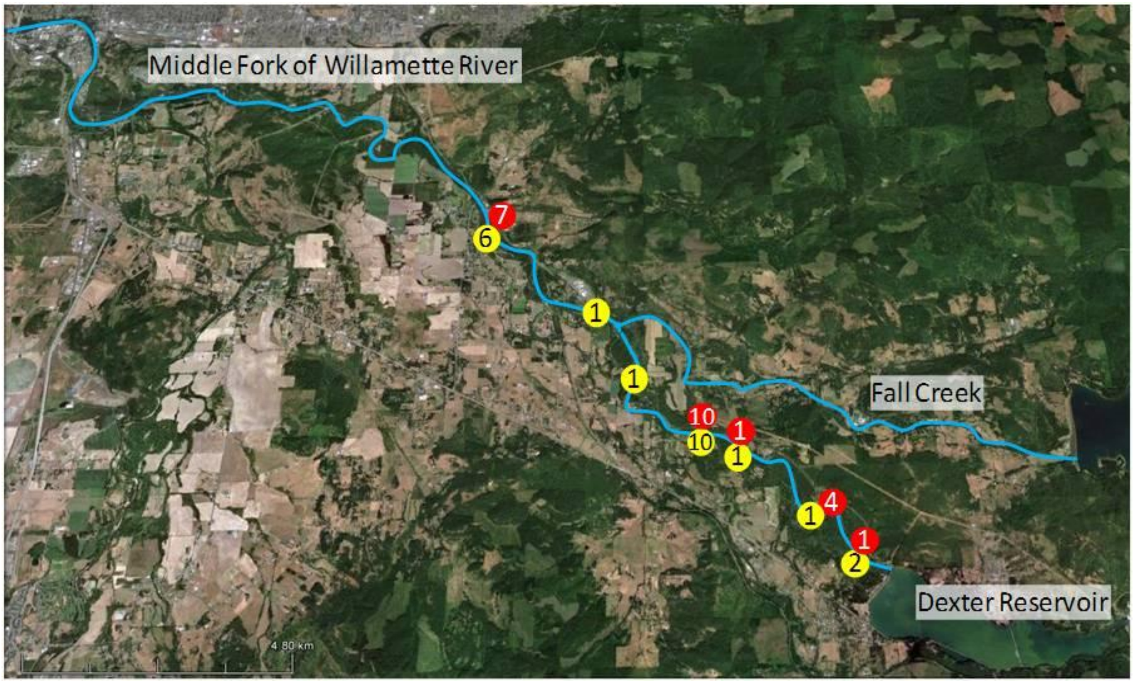


Figure 27. Distribution of maximum river kilometer detections in the Middle Fork Willamette River for radio-tagged winter steelhead (red circles) and last detections for radio-tagged summer steelhead (yellow circles) in 2012. Numbers indicate number of tagged fish at each site.

Behavior and distribution of recycled steelhead

Foster releases - Of the 95 radio-tagged steelhead that were recycled downstream from Foster Dam, 48 (51%) were last detected on a fixed-site receiver or mobile tracked in the Santiam River (Table 13). Four (4%) were reported recaptured by anglers and three (3%) tags were recovered in or near carcasses during spawning ground surveys. The circumstance surrounding the acquisition of one recovered tag provided by ODFW personnel at Foster Dam was unknown. Twenty (21%) steelhead returned to Foster Dam, where they were ponded for broodstock or surplused. Seven (7%) were last detected in the lower main stem Willamette River and 12 (13%) had no radio detections after release. Collectively, 24 steelhead were known to have been collected by anglers or for broodstock, seven were last recorded as moving downstream into the mainstem, and 48 were last recorded in the reach between the Santiam fixed-site and the Foster Dam trap.

Table 13. Distribution of last detections for summer steelhead captured and radio-tagged at Foster Dam and released at Pleasant Valley or Waterloo, OR, in 2012.

Fate	Pleasant Valley release n	Waterloo release n	Total
Tag record only	10	2	12
Lower main stem Williamette R.	6	1	7
Santiam fixed receiver or MBT	31	17	48
Spawning grounds recapture	3	0	3
Angler recapture	2	2	4
Foster Dam return/recapture	17	3	20
Unknown recapture	1	0	1
Total	70	25	95

Dexter releases – Of the 49 radio-tagged summer steelhead released downstream from Dexter Dam, 19 (39%) were last detected in the Middle Fork Willamette River. Eleven (22%) were recaptured, including eight (16%) by anglers and three (6%) by hatchery personnel at Dexter Dam. Fifteen (31%) steelhead were last detected downstream from the Middle Fork Willamette River: six (12%) at the confluence of the Coast Fork and Middle Fork, six (12%) in the upper main stem, one (2%) in the lower main stem, and two (4%) downstream from Willamette Falls Dam. There were no radio detections for four (8%) of the 49 recycled summer steelhead.

Iteroparity rates based on scale analysis

We collected 208 scale samples from summer steelhead radio-tagged at Willamette Falls and 205 were readable for iteroparity analysis. Four of the 205 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 (one at the Middle Fork-Coast Fork confluence and one in the upper main stem).

Results: Spring Chinook salmon

Historic counts and run timing

The annual count of adult spring Chinook salmon passing Willamette Falls Dam in 2012 was 35,899 (Figure 28). This was approximately 2,700 fewer fish than the average count of 38,646 since 1953. The 2012 spring Chinook salmon run at Willamette Falls Dam was the fourth latest-timed run in the last twelve years (Figure 29). This was likely associated with the cold April-June water temperatures and high river discharge compared to ten-year averages. The date of median passage in 2012 was 25 May, compared to medians that ranged from 8 May – 13 June in 2001-2011.

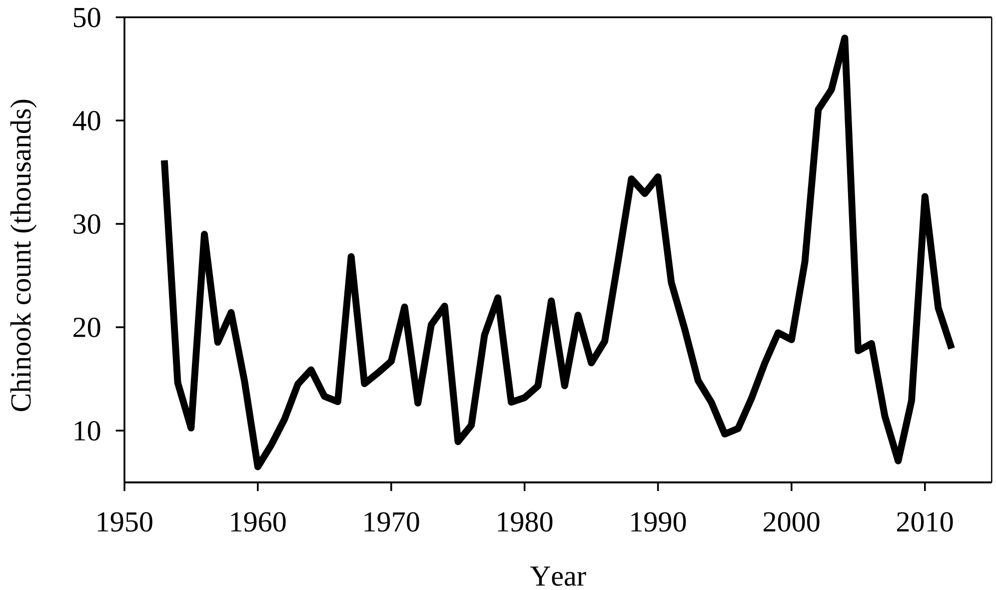


Figure 28. Total annual numbers of adult spring Chinook salmon counted passing Willamette Falls Dam,1953-2012.

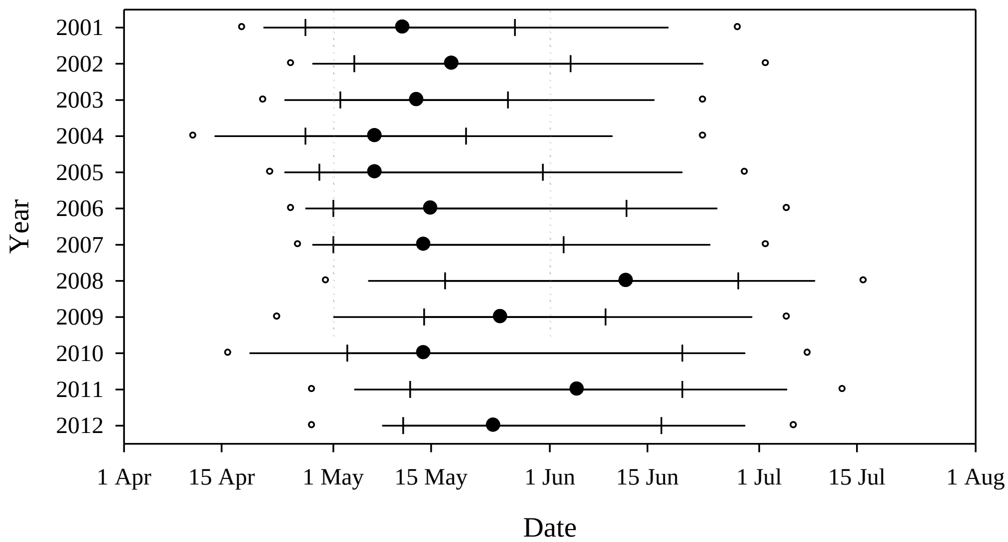


Figure 29. Annual migration timing distributions for spring Chinook salmon counted at Willamette Falls Dam, 2001-2012. Symbols show median (●), quartile (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (○). Data summarized from ODFW daily counts: http://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp

Behavior at Willamette Falls Dam (FRD vs. anesthetic)

Chinook salmon that received the FRD were more likely to exit to the tailrace than fish that were anesthetized (Table 14). In the most direct comparison, 47% of 188 unclipped FRD salmon exited compared to 20% of 152 unclipped anesthetized salmon ($P < 0.001$, χ^2 test). The exit percentages were similar for clipped (45%) and unclipped (47%) FRD treatment groups.

Thirty-nine percent (12/31) of exiting salmon that received the anesthetic treatment subsequently ascended the dam. Smaller percentages (19-35%) of exiting salmon that received the FRD treatment subsequently ascended the dam, although proportions did not differ significantly among handling treatments ($P > 0.19$, χ^2 tests).

Table 14. Numbers of adult Chinook salmon radio-tagged at Willamette Falls Dam in 2012 that exited the dam to the tailrace after release, their adipose fin status, their handling treatments during tagging, and the numbers that exited and then ascended the dam.

Adipose/Trt.	Number released	Number that exited dam (%)	Number that exited and ascended dam (%)
Clipped / FRD	188	85 (45)	30 (35)
Unclipped/ FRD	156	73 (47)	14 (19)
Total FRD	344	158 (46)	44 (28)
Unclipped / AQUI-S®E	152	31 (20)	12 (39)

Main stem residence times and migration rates

The time tagged salmon spent in the main stem Willamette River was directly related to the distance between Willamette Falls Dam and the tributary they ultimately entered (Figure 30). Tagged salmon that returned to the Santiam River spent an average of 14 d in the main stem in 2012, similar to the estimate in 2011. On average, those that returned to the McKenzie River in 2012 spent 22.6 d in the main stem, two days less than those that returned there in 2011. Tagged salmon that returned to the Middle Fork in 2012 spent 23.5 d in the main stem, six fewer than those that returned there in 2011.

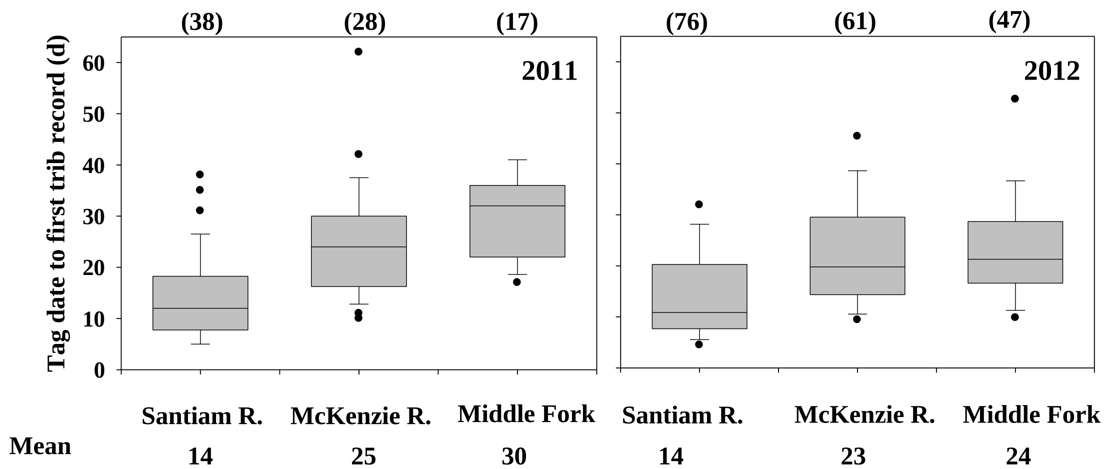


Figure 30. Box plots of radio-tagged spring Chinook salmon passage times (d) from their release at Willamette Falls Dam to first detection in the Santiam, McKenzie, or Middle Fork Willamette rivers in 2011 (left panel) and 2012 (right panel). Box plots show: median (line), quartile (box), 10^{th} and 90^{th} (whisker), and 5^{th} and 95^{th} percentiles. Sample sizes are in parentheses above boxes.

The time tagged salmon spent in different sections of the main stem Willamette River varied with reach length (Figure 31). In both 2012 and 2011, tagged salmon that returned to the Santiam River had the highest mean 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 similar in both years. An exception was in the WL4-WL5 section, where salmon migrated faster in 2012 than in 2011.

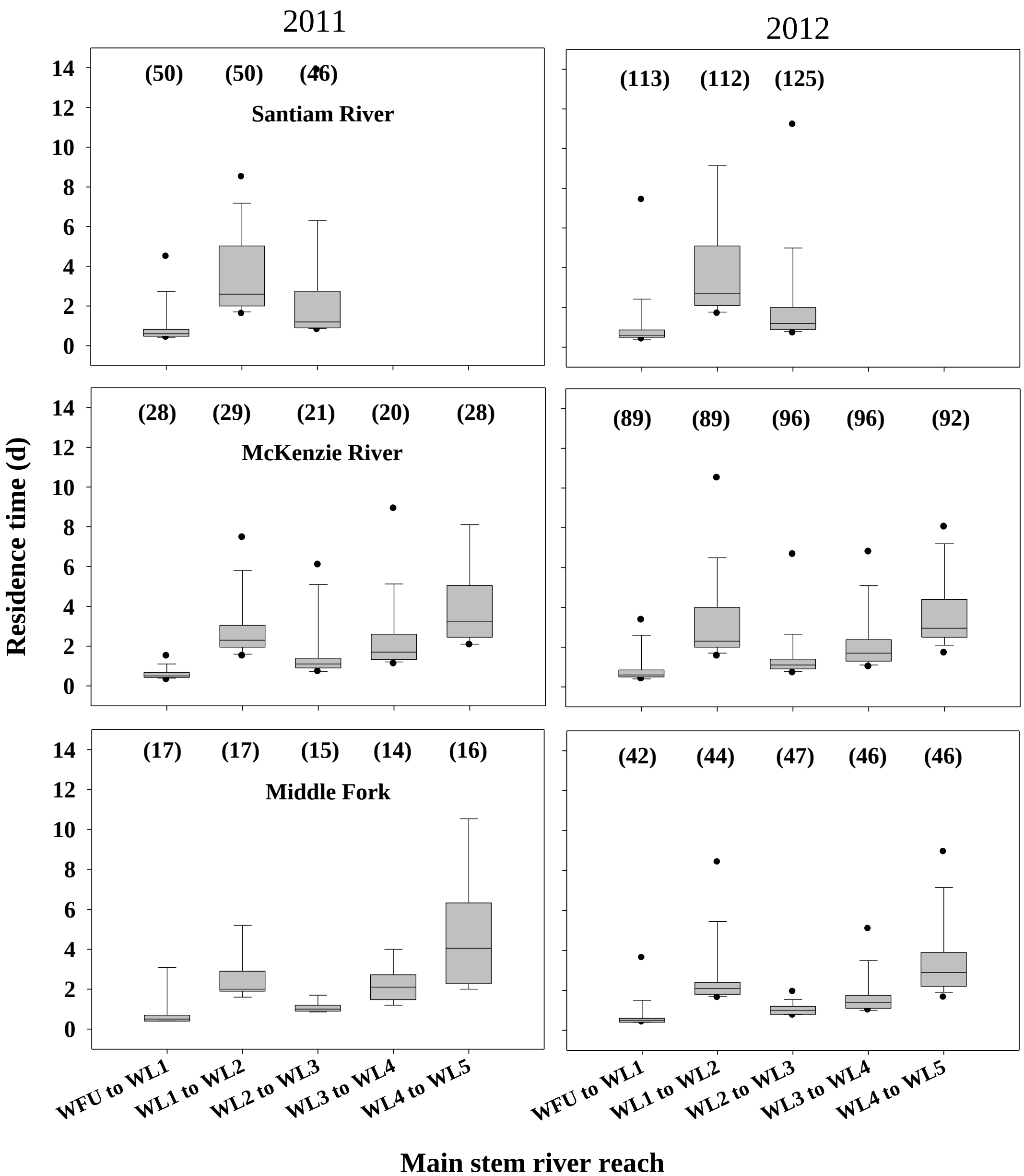


Figure 31. Box plots of times (days) radio-tagged spring Chinook salmon used in reaches of the main stem Willamette River for salmon that returned to the Santiam, McKenzie, and the Middle Fork Willamette rivers in 2011 and 2012. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles. Sample sizes are listed in parentheses above boxes.

The distribution of migration rates (rkm/d) through the main stem Willamette River for radio-tagged Chinook salmon that returned to the Santiam, McKenzie, and Middle Fork Willamette rivers varied with river section (Figure 32). As with both winter and summer steelhead, the speed that Chinook salmon migrated through successive sections generally decreased as fish moved upstream. This pattern was evident in both years.

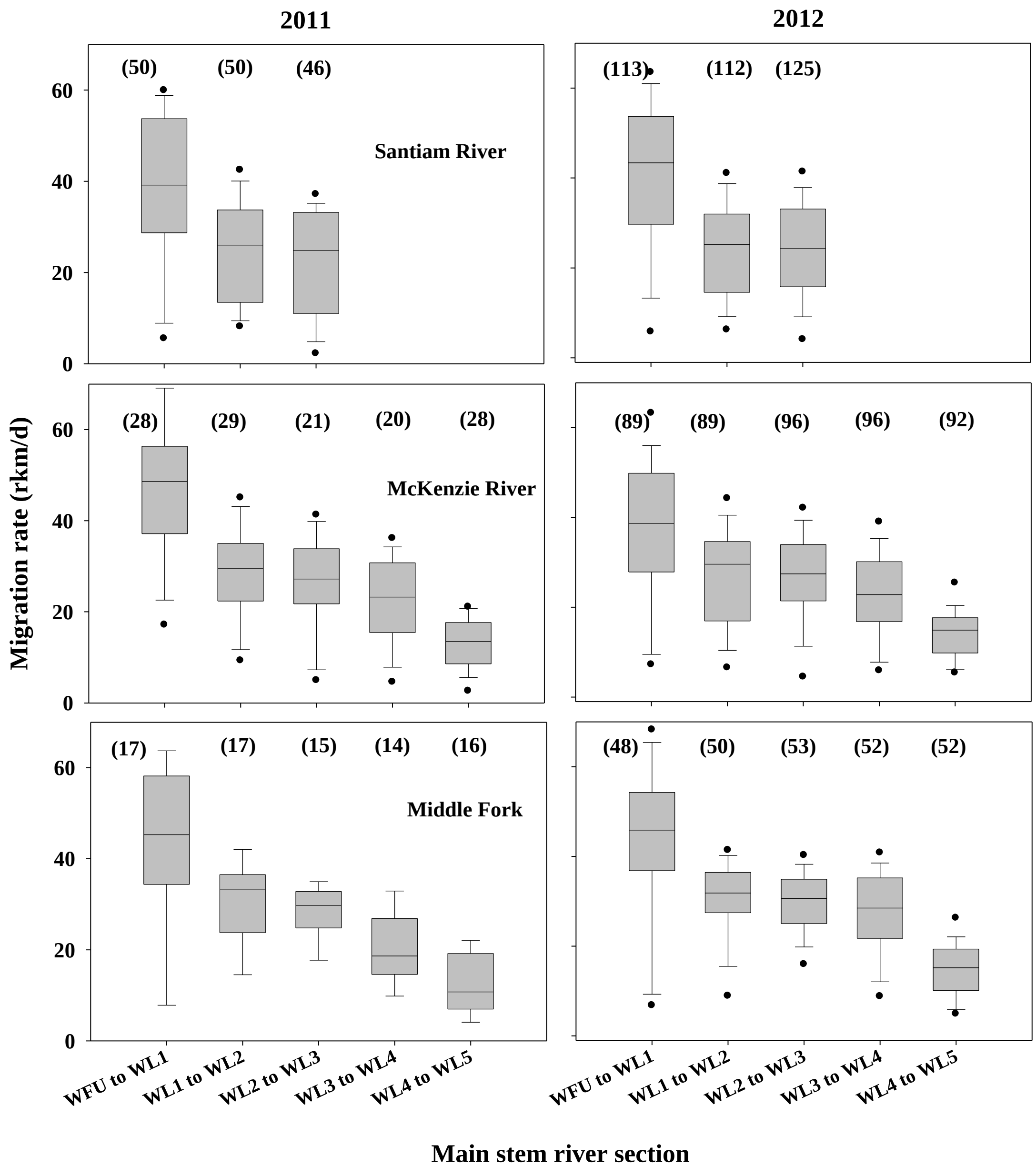


Figure 32. Box plots of rates (rkm/d) radio-tagged spring Chinook salmon used in reaches of the main stem Willamette River for salmon that returned to the Santiam, McKenzie, and the Middle Fork Willamette rivers in 2011 and 2012. Box plots show: median (line), quartile (box), 10th and 90th (whisker), and 5th and 95th percentiles. Sample sizes are listed in parentheses above boxes.

In 2012, the overall mean migration rate within the main stem was 22.9 rkm/d (*s.d.* = 10.3, *n* = 268), very similar to the overall 2011 mean of 22.3 rkm/d (Figure 33). Means for groups of tagged salmon that returned to specific tributaries ranged from 20.1 rkm/d (McKenzie River) to 24.6 rkm/d (Santiam River). The highest variation within a tributary grouping was for salmon last detected in the Santiam River, with rates ranging from 4.8 to 59.1 rkm/d. The distributions of migration rates were similar between years.

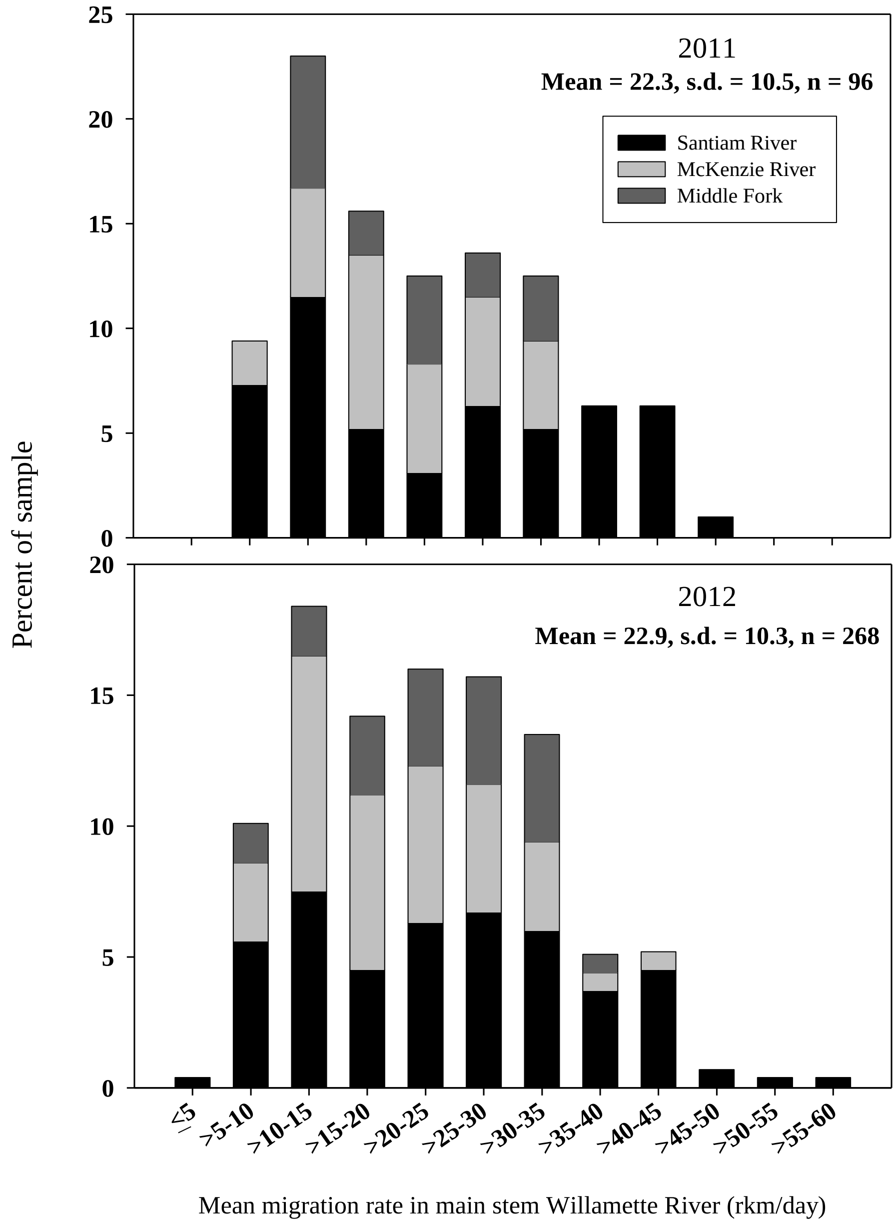


Figure 33. Histogram of radio-tagged Chinook salmon migration rates (rkm/d) within the main stem Willamette River for salmon that escaped to the Santiam, McKenzie, and Middle Fork Willamette rivers in 2011 and 2012.

Migration rates in the main stem reaches were positively correlated with migration date and water temperature and negatively correlated with discharge in 2012. Relationships were generally stronger ($-0.55 < r < 0.55$) than those reported above for winter and summer steelhead, though much of the variation among individuals remained unexplained.

Migration rates of the three major tributary groups also were weakly, positively associated with tag date (Figure 34). The linear regressions for adults returning to the McKenzie River ($r^2 = 0.30$, $P < 0.0001$), Middle Fork ($r^2 = 0.22$, $P < 0.001$), and; and the Santiam River ($r^2 = 0.04$, $P = 0.08$) each indicated faster movement later in the run. The significant relationships for the McKenzie and Middle Fork populations may have resulted from higher river temperatures and lower discharge later in the migration, while the lack of relationship for the Santiam group may have been related to river conditions in the lower reaches that reduced overall migration rate later in the season.

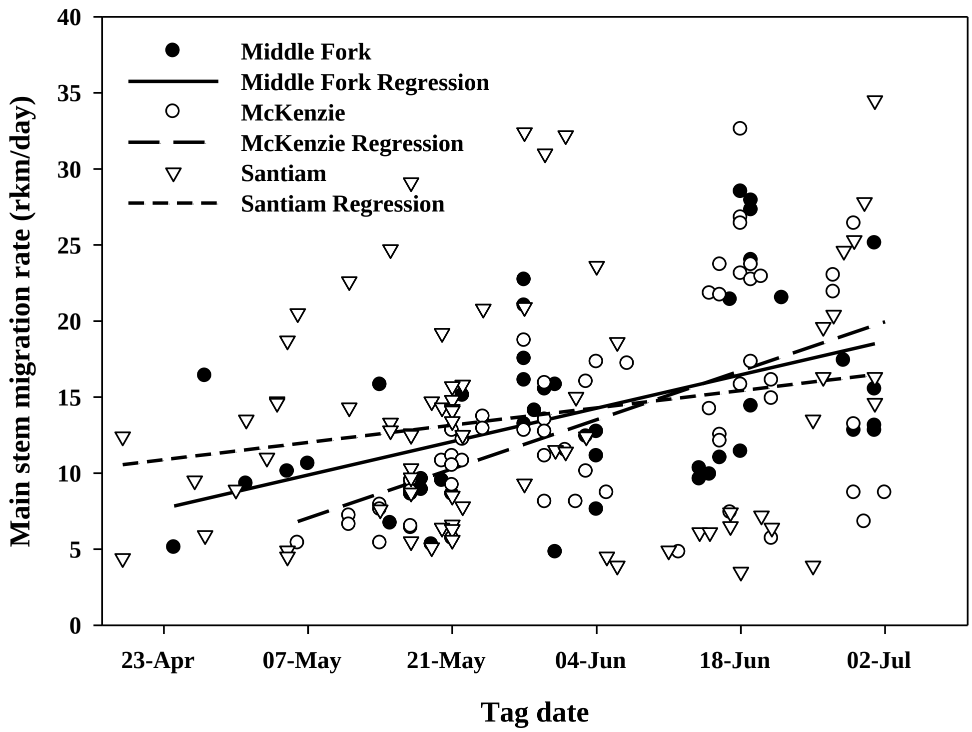


Figure 34. Relationships between radio-tagged Chinook salmon migration rates in the main stem Willamette River and tag date at Willamette Falls Dam in 2012. Lines show separate linear regressions for Middle Fork Willamette, McKenzie, and Santiam River salmon.

Downstream movements, overshoot behavior, and temporary straying

Downstream movements - Approximately ten percent (52/496) of radio-tagged salmon moved downstream in the main stem Willamette River after moving upstream from Willamette Falls Dam (Table 15). Twenty-eight of the 52 had intact adipose fins and 24 had adipose fin clips. There were a total of 23 fallback events at Willamette Falls by 23 unique salmon (4.6%); 11 were ad-clipped salmon and 12 were not. Twenty-two of the 23 fallback fish did not re-ascend the dam, although three of the fallback salmon were last detected entering the Clackamas River. One salmon migrated as far as the Dexter Dam tailrace before initiating downstream movements, but most (15/22) migrated no farther upstream than the WL1 site near Champoeg, OR, before swimming downstream.

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

Overshoot behavior - We differentiated downstream movements of fish that stayed within the main stem from those that moved downstream within the main stem and subsequently entered a tributary downstream from where they started swimming downstream (i.e., tributary overshoot behavior). Eight tagged salmon overshot the tributary to which they eventually escaped (three fin-clipped and five unclipped). One unclipped salmon entered the Santiam River after being detected near Corvallis, OR (WL4). The remaining seven salmon were detected near or upstream from Champoeg, OR (WL1) before entering the Molalla River. One detected near Champoeg, OR, fell back at Willamette Falls Dam, re-ascended the dam, and then entered the Molalla R.

Temporary straying - Nineteen tagged salmon were detected temporarily entering a tributary downstream from a tributary to which they ultimately escaped. Fifteen salmon exited the Willamette Falls fishway after tagging and briefly entered the Clackamas River before ascending the dam. Among the four temporary strays upstream from Willamette Falls, two strayed into the Calapooia River before returning to the McKenzie River or Middle Fork, one strayed into the Lukiamute River before entering the Santiam River, and one strayed into the Yamhill River before returning to the McKenzie River. No radio-tagged salmon were detected on the Tualatin River, Rickreall Creek, Mary's River, the Coast Fork Willamette River, or the Calapooia River receiver sites throughout the study.

Table 15. Numbers of adipose-clipped and unclipped radio-tagged Chinook salmon that moved downstream in the main stem Willamette River in 2012.

Downstream Behavior	Ad-clipped Chinook	Unclipped Chinook	Row sum	Group total
Fallback (no re-ascension)				
DEX to fallback	1		1	22
WL5 to fallback		1	1	
WL4 to fallback	2		2	
WL3 to fallback		1	1	
WL3 to fallback then Clackamas R.		1	1	
WL2 to fallback		1	1	
WL1 to fallback	3	5	8	
WL1 to fallback then Clackamas R.		1	1	
WFU to fallback	3	1	4	
WFU to fallback then Clackamas R.	2		2	
Tributary to main stem				
SST (Santiam R.) to WL2		1	1	9
NS2 (Santiam R.) to WL3	1		1	
NS1 (Santiam R.) to WFU		1	1	
SSF (Santiam R.) to WL2	1		1	
STM (Santiam R.) to WL1		1	1	
MCK to WL5 to McKenzie R.	1		1	
WMF to MFC	2	1	3	
Main stem				
MFC to WL4 then Fall Creek		1	1	13
MFC to WL5	1		1	
WL5 to WL4 then WL5 and MCK		3	3	
WL5 to WL4 then WL5 and WMF		1	1	
WL5 to WL3		1	1	
WL4 to WL3	1		1	
WL4 to WL2	1	1	2	
WL3 to WL1	1		1	
WL3 to WFU	1		1	
WL1 to WFU		1	1	
Overshoot				
WL4 to Santiam R.		1	1	8
WL4 to Mololla R.		1	1	
WL2 to Mololla R.		1	1	
WL1 to Molalla R.	3	1	4	
WL1 to fallback, re-ascend to Molalla R.		1	1	
Column Sum	24	28	52	52

Behavior in tributaries downstream from WVP projects

The time radio-tagged salmon spent within different reaches of their migratory routes varied among groups that migrated to tributary dams that had no adult passage facilities. These included Foster Dam on the South Santiam River, Dexter Dam on the Middle Fork Willamette River, and Cougar Dam on the McKenzie River. Twenty-eight salmon were recaptured at Foster Dam and sixteen had complete radio detection histories. Of the nine tagged salmon recaptured at Dexter Dam, three had complete radio detection histories (i.e., six were not detected on the DEX 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) .

Salmon recaptured at Foster Dam spent an average of 49 days in the Santiam River downstream from the tailrace, whereas those recaptured at Dexter Dam were estimated to have spent an average of approximately one day in the Middle Fork downstream from the Dexter tailrace (Figure 35). Tailrace residency times varied within both groups, with times in the Foster tailrace ranging from <1 to 42 days (*mean* = 10 d; *median* = 6 d) and those in the Dexter tailrace ranging from <1 to 22 days (*mean* = 14 d; *median* = 18). The two tagged salmon with unclipped adipose fins that were recaptured at Dexter Dam spent 19 days in the Dexter Dam tailrace on average, whereas those with clipped adipose fins spent 13 days there on average (Figure 36). Thirteen tagged salmon with unclipped adipose fins were detected on the Cougar Dam tailrace receiver for an average of seven days, and eight were captured in the trap.

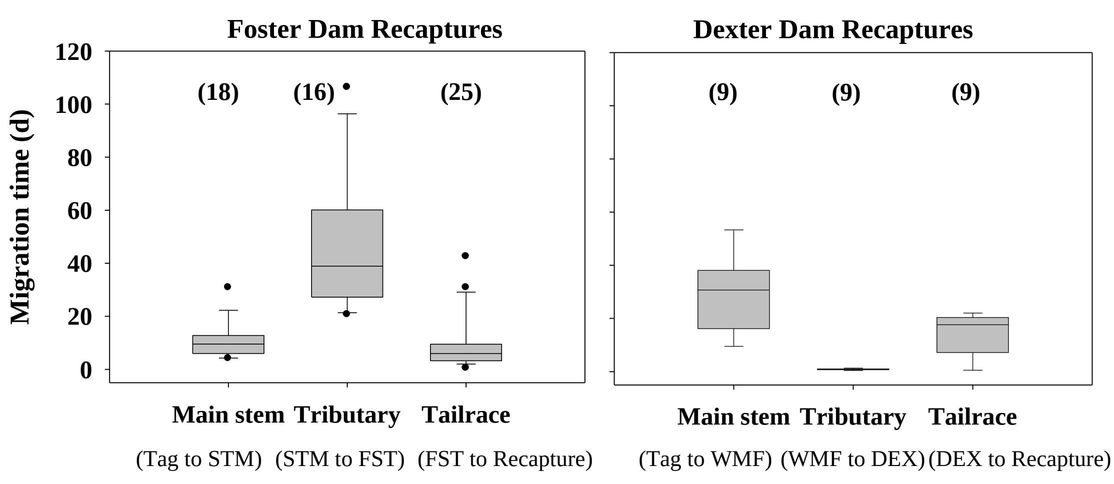


Figure 35. Box plots of times (days) that radio-tagged spring Chinook salmon spent in the main stem Willamette River, a tributary, and in dam tailraces for salmon recaptured at Foster (left panel) and Dexter (right panel) dams in 2012. Box plots show: median (line), quartile (box), 10^{th} and 90^{th} (whisker), and 5^{th} and 95^{th} percentiles (points). Sample sizes are listed in parentheses above box plots in each panel.

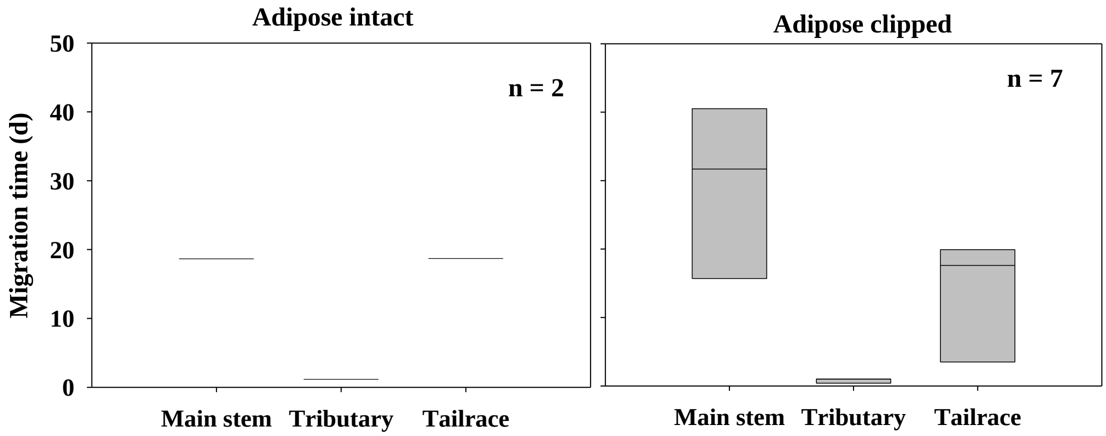


Figure 36. Box plots of times (days) radio-tagged spring Chinook salmon spent in the main stem Willamette River, the Middle Fork Willamette River, and the Dexter Dam tailrace for unclipped (left panel) and clipped (right panel) salmon recaptured at Dexter Dam in 2012. Box plots show: medians (line) and quartiles (box). Sample sizes are listed in the top, right corner of each panel.

Last radio detections and transmitter recoveries

Of the 496 tagged salmon that had no evidence of transmitter loss, 303 (61%) were last recorded or recaptured in Willamette River tributaries and 193 (39%) were last detected at main stem sites either upstream or downstream from Willamette Falls Dam (Figure 37). Five radio-tagged salmon (1.6%) among the 303 salmon last recorded or recaptured in tributaries were reported as recaptured by anglers: two were captured and released in the McKenzie River, two were captured and kept in the Santiam basin, and one was captured and kept downstream from Willamette Falls Dam.

One hundred thirty four (27%) tagged salmon were last recorded (n = 132) or recaptured (n = 2) downstream from Willamette Falls Dam (Figure 38). Of these 134 salmon, 116 (87%) received the FRD treatment. Of the 116 salmon that received the FRD treatment and were last detected downstream from the dam, 57 (49%) were ad-clipped and 59 (51%) were not. Nineteen tagged salmon (4%) were last recorded in the Clackamas River. Fifteen (3%) had no radio detections (n = 2) or their last detections were on the WLL receiver site at the dam (n = 13). Seven fish (2%) were last detected in the Molalla River. Forty four tagged salmon (7%) were last detected on receivers in the main stem, 37 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). One hundred twenty seven radio-tagged salmon (25%) were last detected in the Santiam River, 97 (19%) were in the McKenzie River, and 7 (1%) were in Fall Creek, and 46 (9%) were in the Middle Fork Willamette River.

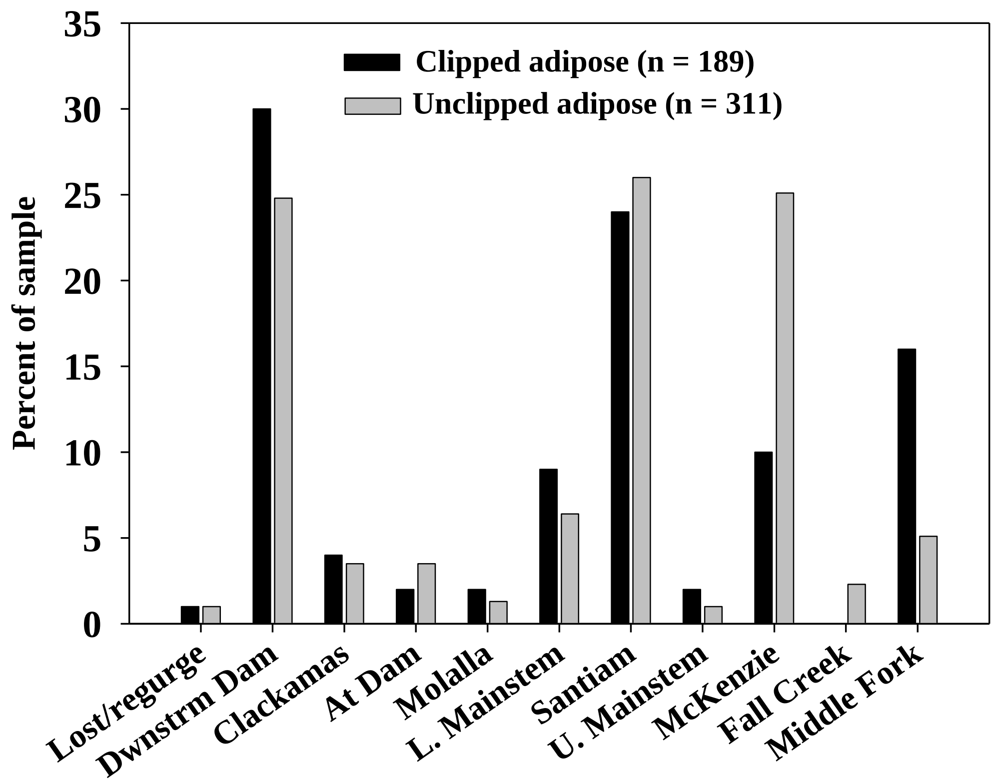


Figure 37. Histogram showing the locations where radio-tagged Chinook salmon were last recorded in the Willamette River basin in 2012. Lost/Regurg. = tags that were regurgitated and recovered after release.

Among the 46 transmitters recovered in the Santiam River, 33 were associated with dams/hatcheries (Foster, Lower Bennett or Upper Bennett dams), two were captured by anglers, four were recovered during spawning ground surveys, and seven were tags found by the public. The distribution of recovered transmitters from the McKenzie River included 21 hatchery returns, two angler recaptures, six tags recovered during spawning ground surveys, and two found tags. In Fall Creek, one tag was recovered at Fall Creek trap and two were found during spawning ground surveys. Fourteen transmitters were recovered in the Middle Fork: eight at Dexter Dam, four during spawning ground surveys and two found tags.

Salmon last detected in the upper main stem had the latest mean tag date among groups and the seven salmon last detected in Fall Creek had the earliest (Table 16). The fifteen salmon last detected at Willamette Falls Dam were the longest and heaviest on average. Mean fatmeter readings among fate groups ranged from 6.5 to 8.9%.

Table 16. Sample sizes, adipose fin clip status, mean tag date, mean fork length, mean weight, and mean fatmeter readings for radio-tagged adult Chinook salmon by final detection site within the Willamette River in 2012.

Fate	*n*	# Ad-clipped (y/n)	Mean tag date	Mean fork length (cm)	Mean weight (kg)	Mean fatmeter (%)
Lost/regurge.	4	1/3	7 Jun	80.6	7.0	7.4
Downstream from Dam	134	57/77	31 May	76.4	5.9	7.7
Clackamas River	19	8/11	3 Jun	76.8	5.8	6.5
Willamette Falls Dam	15	4/11	6 Jun	80.8	7.3	8.9
Molalla River	7	3/4	3 Jun	74.0	5.4	7.6
Lower main stem[1]	37	17/20	6 Jun	79.7	6.9	7.0
S. Santiam River	83	37/46	1 Jun	76.4	6.0	7.3
N. Santiam River	44	9/35	1 Jun	79.3	6.7	7.3
Upper main stem[2]	7	4/3	11 Jun	69.8	4.4	6.8
McKenzie River	97	19/78	29 May	77.2	5.9	7.5
Fall Creek	7	0/7	3 May	75.1	5.2	8.5
Middle Fork Willamette River	46	16/30	2 Jun	72.6	5.1	6.8

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

Chinook salmon that were anesthetized were far more likely to escape to tributaries than those that received the FRD treatment. Among unclipped salmon, 82% of 152 anesthetized fish returned to tributaries versus 47% of 156 fish that used the FRD ($P <$ 0.0001, χ^2 Test). Escapement was 56% for the 189 clipped salmon, all of which used the FRD.

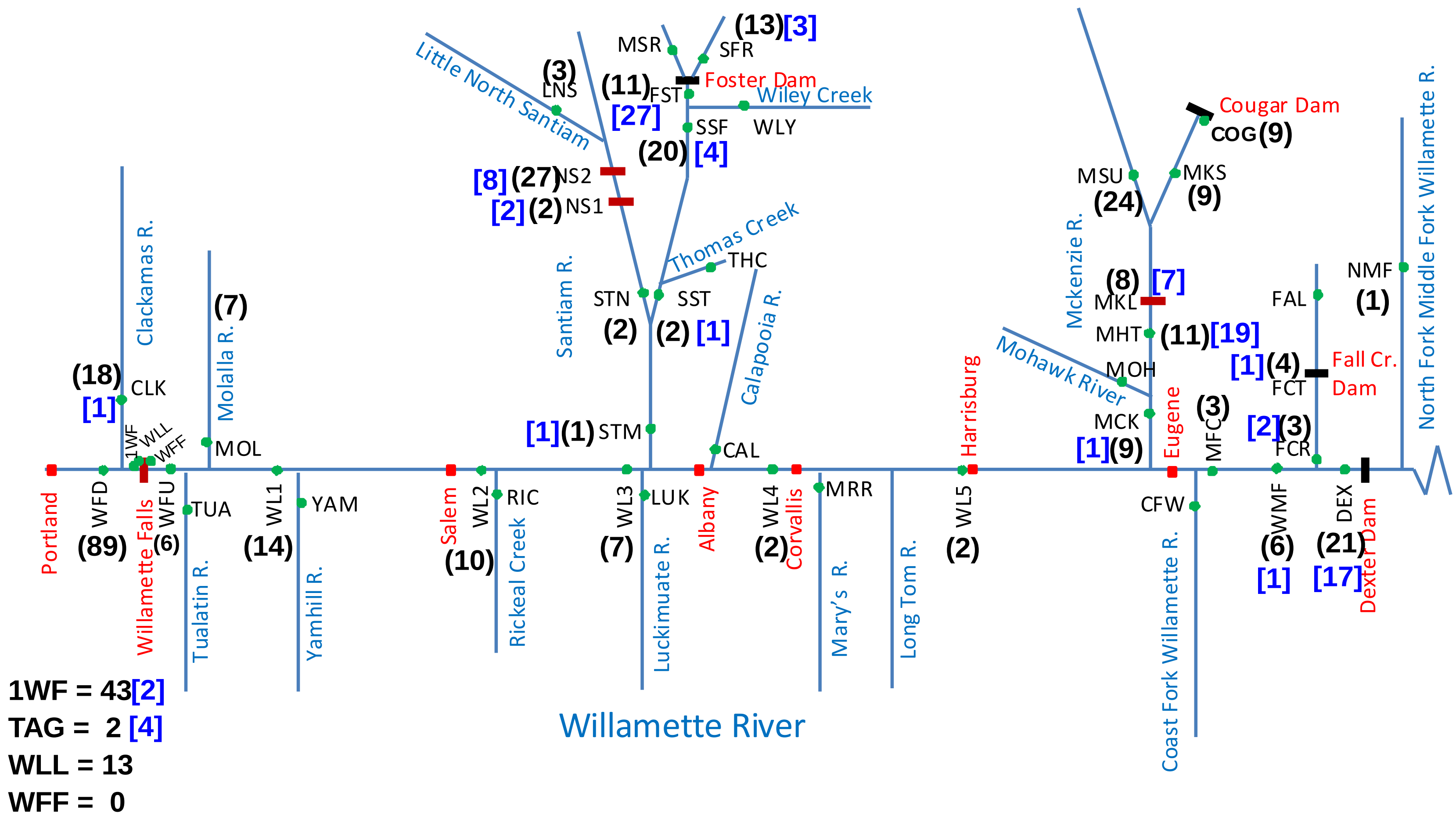


Figure 38. Sites where adult Chinook salmon radio-tagged and released at Willamette Falls Dam were last detected (black font and parentheses) or where they were recaptured (blue font and brackets). Green dots represent radio receiver sites, red blocks (dams) are passable structures and black blocks are impassable. Locations in red text are landmarks for reference.

No covariates were statistically significant ($P > 0.05$) in the escapement model for fin-clipped Chinook salmon (Table 17). The model included tag date, fork length, weight, and Fatmeter value; there was no handling treatment term because all fish were in the FRD. In the model for unclipped Chinook salmon, FRD fish and later-timed migrants were less likely to escape to tributaries

Table 17. Results of separate logistic regression models of escapement to tributaries by unclipped (left) and fin-clipped Chinook salmon (right) radio-tagged at Willamette Falls Dam in 2012. The handling treatment was FRD or anesthesia.

	Unclipped salmon (n = 305)		Fin-clipped salmon (n = 185)	
	χ^2	P	χ^2	P
Tag date	4.0	0.039	0.0	0.936
Fork length	0.4	0.508	0.2	0.631
Weight	0.1	0.709	0.0	0.997
Fatmeter	0.9	0.348	2.7	0.103
Handling treatment	33.5	<0.001	n/a	n/a

Run Composition

Run composition for the 106 fin-clipped Chinook salmon last recorded in tributaries showed that the two largest return groups (i.e., Santiam and Middle Fork) were represented in all of the 10-day tagging intervals (Figure 39). Fin-clipped salmon that returned to the McKenzie River were present in eight of the 10-day blocks. The small percentage of clipped salmon that returned to the Molalla River passed Willamette Falls Dam intermittently throughout the run whereas those that returned to the Clackamas River did so in the middle and later portions of the run. The mean tag date for each population was: 30 May (Santiam), 1 June (Molalla), 3 June (Middle Fork), 5 June (McKenzie), and 14 June (Clackamas).

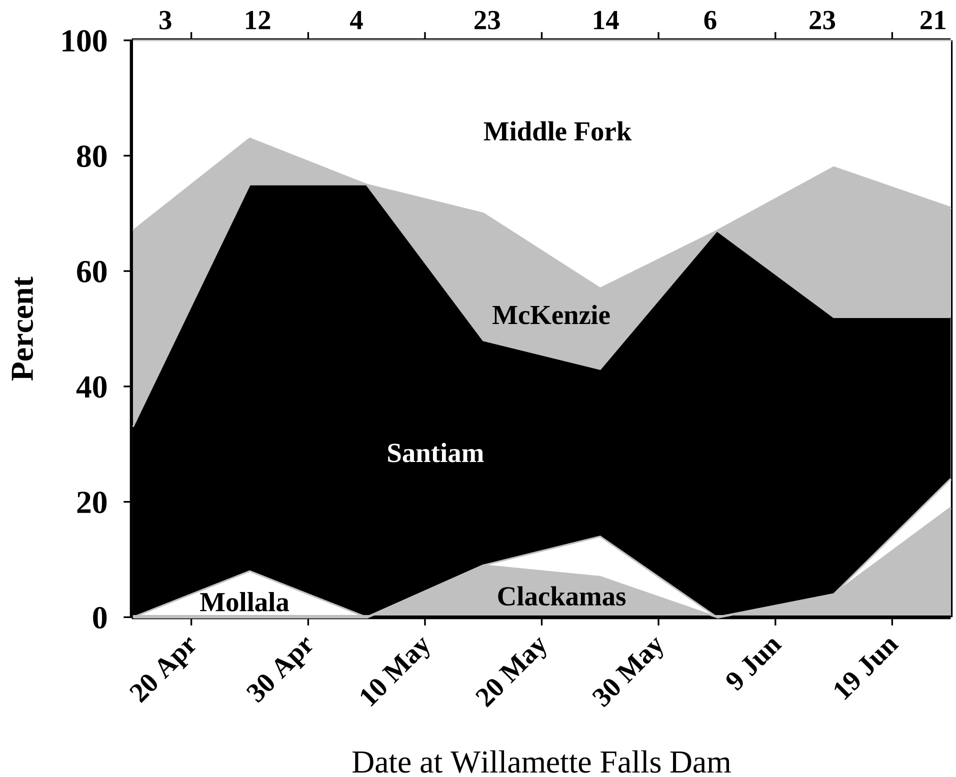


Figure 39. Composition of 106 ‘escaped’, fin-clipped Chinook salmon at Willamette Falls Dam in 2012 using 10-d intervals based on release dates of radio-tagged fish. Sample sizes for each 10-d interval are listed at top.

Run composition for the 197 unclipped salmon last recorded in tributaries was characterized by the two largest return groups (i.e., Santiam and McKenzie rivers) making up 57-100% of all the returns within each 10-day tagging interval (Figure 40). Unclipped salmon that returned to Fall Creek passed Willamette Falls in the first three 10-day blocks only and those that returned to the Middle Fork were present in small percentages in five of the eight 10-day blocks. Unclipped salmon that returned to the Molalla and Clackamas rivers were absent from the early part of the run but small percentages intermittently passed Willamette Falls Dam after early May. The mean tag date for each population was: 29 April (Fall Creek), 25 May (Clackamas), 27 May (McKenzie), 29 May (Middle Fork), 2 June (Santiam), and 5 June (Molalla).

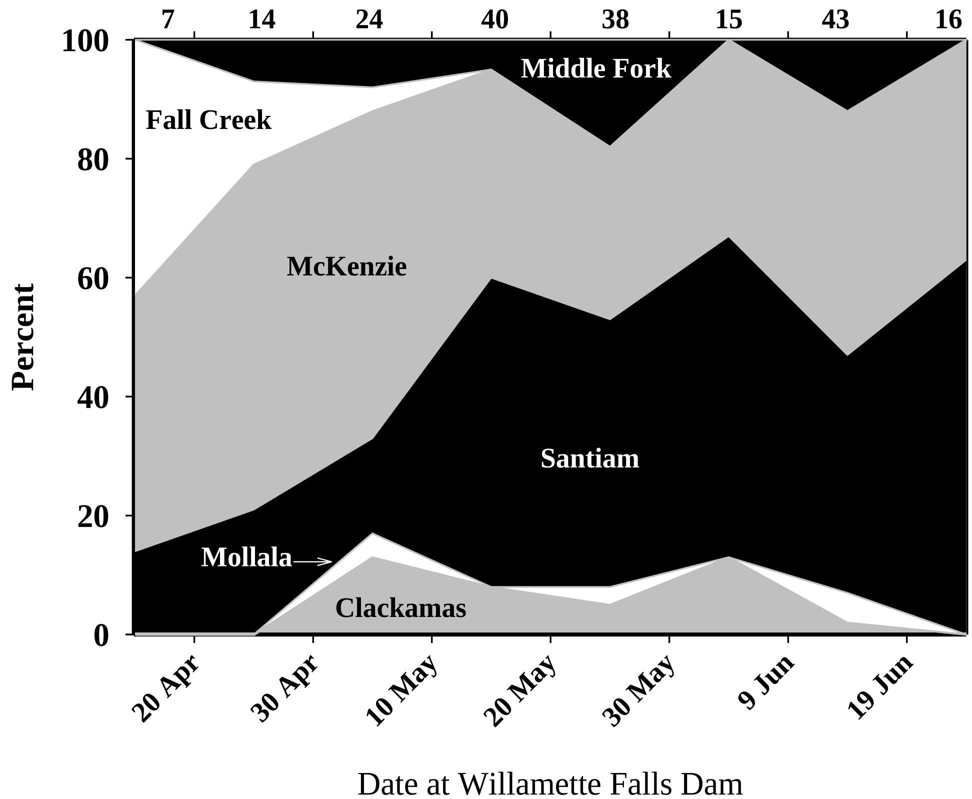


Figure 40. Composition of 197 'escaped', unclipped Chinook salmon at Willamette Falls Dam in 2012 using 10-d intervals based on release dates of radio-tagged fish.

Estimated returns by sub-basin

We estimated the number of Chinook salmon returning to tributaries using: 1) the percentage of the count past Willamette Falls Dam that was fin-clipped (76.8%) and unclipped (23.2%), 2) the percentage of each radio-tagged fate group that was clipped (*n* = 188) and unclipped (*n* = 308), and 3) two count scenarios: a) Chinook salmon counted during the radio-tagging interval (16 April – 2 July), or b) the total annual count (21 February – 15 August). Estimated returns to tributaries were likely biased low because of the high percentage of tagged salmon that received the FRD treatment and did not escape to a tributary. For comparison, we therefore also estimated escapement to tributaries for unclipped salmon using only data derived from anesthetized salmon (Table 18 at bottom).

The tributary to which the highest estimated return of Chinook salmon was the Santiam River, based on the return percentages of 496 radio-tagged salmon (Table 18). Point estimates of adult returns to the Santiam River ranged from 6,172 to 6,993 ad-clipped individuals and from 2,004 to 2,270 unclipped individuals. Point estimates for the Middle Fork ranged from 4,025-4,561 fin-clipped fish and 396-448 unclipped fish. Estimates for the McKenzie River ranged were 2,549-2,888 fin-clipped fish and 1,930-2,186 unclipped fish (Table 18).

Table 18. Estimated returns of adult Chinook salmon to Willamette River tributaries based on return numbers and percentages of 496 radio-tagged salmon (*n* = 188 fin-clipped and 308 unclipped) and two scenarios of ODFW count data from Willamette Falls Dam in 2012. Percentages were weighted by the ODFW-reported proportions of fin-clipped (76.8%) and unclipped (23.2%) salmon passing Willamette Falls Dam. (Note: given the handling effect associated with Chinook salmon restraint, the fin-clipped and unclipped, all estimates of escapement were likely underestimates; for comparison, the shaded cells show estimates based on unclipped, anesthetized fish only.)

			Fin-clipped Chinook count	
			Tag interval	Annual
			n = 25,226	*n* = 28,580
Tributary	*n*[1]	% (95% ci)	Estimate	Estimate
None	82	43.6 (36.7-50.8)	11,003 (9,258-12,815)	12,466 (10,489-14,519)
Clackamas	8	4.3 (2.2-8.2)	1,073 (555-2,069)	1,216 (629-2,344)
Molalla	3	1.6 (0.6-4.6)	403 (151-1,160)	456 (171-1,315)
S. Santiam	37	19.7 (14.6-26.0)	4,965 (3,683-6,559)	5,625 (4,173-7,431)
N. Santiam	9	4.8 (2.5-8.9)	1,207 (631-2,245)	1,368 (714-2,544)
McKenzie	19	10.1 (6.6-15.3)	2,549 (1,665-3,860)	2,888 (1,886-4,373)
Fall Creek	-	-	-	-
Middle Fork	30	16.0 (11.4-21.9)	4,025 (2,876-5,524)	4,561 (3,258-6,259)

			Unclipped Chinook count	
			Tag interval	Annual
			n = 7,621	*n* = 8,633
Tributary	*n*[2]	% (95% ci)	Estimate	Estimate
None	111	36.0 (30.9-41.5)	2,747 (2,355-3,163)	3,111 (2,668-3,583)
Clackamas	11	3.6 (2.0-6.3)	272 (152-480)	308 (173-544)
Molalla	4	1.3 (0.5-3.3)	99 (38-251)	112 (43-285)
S. Santiam	46	14.9 (11.4-19.4)	1,138 (869-1,479)	1,289 (984-1,675)
N. Santiam	35	11.4 (8.3-15.4)	866 (632-1,174)	981 (716-1,330)
McKenzie	78	25.3 (20.8-30.5)	1,930 (1,585-2,324)	2,186 (1,796-2,633)
Fall Creek	7	2.3 (1.1-4.6)	173 (84-351)	196 (95-397)
Middle Fork	16	5.2 (3.2-8.3)	396 (244-633)	448 (276-717)

			Unclipped Chinook count	
			Tag interval	Annual
			n = 7,621	*n* = 8,633
Tributary	*n*[3]	% (95% ci)	Estimate	Estimate
None	28	18.4 (13.1-25.3)	1,402 (998-1,928)	1,588 (1,131-2,184)
Clackamas	4	2.6 (1.0-6.6)	198 (76-503)	224 (86-570)
Molalla	4	2.6 (1.0-6.6)	198 (76-503)	224 (86-570)
S. Santiam	27	17.8 (12.5-24.6)	1,354 (953-1,876)	1,533 (1,079-2,125)
N. Santiam	21	13.8 (9.2-20.2)	1,052 (703-1,539)	1,193 (796-1,744)
McKenzie	50	32.9 (25.9-40.7)	2,507 (1,974-3,102)	2,840 (2,236-3,514)
Fall Creek	4	2.6 (1.0-6.6)	198 (76-503)	224 (86-570)
Middle Fork	14	9.2 (5.6-15.3)	701 (427-1,166)	794 (483-1,321)

[1] includes restrained and anesthetized Chinook salmon
[2] includes restrained and anesthetized Chinook salmon
[3] includes anesthetized Chinook salmon only

Fates of tagged salmon with intact adipose fins

Of the 311 tagged salmon in 2012 with an intact adipose fin, 25% were last detected downstream from Willamette Falls Dam, 26% were last detected in the Santiam River, and 25% were last recorded in the McKenzie River (Figure 41). The percentage of salmon last detected downstream from the dam in 2012 (24.8%) was more than four times higher than in the small sample (n = 38) in 2011 (5.2%).

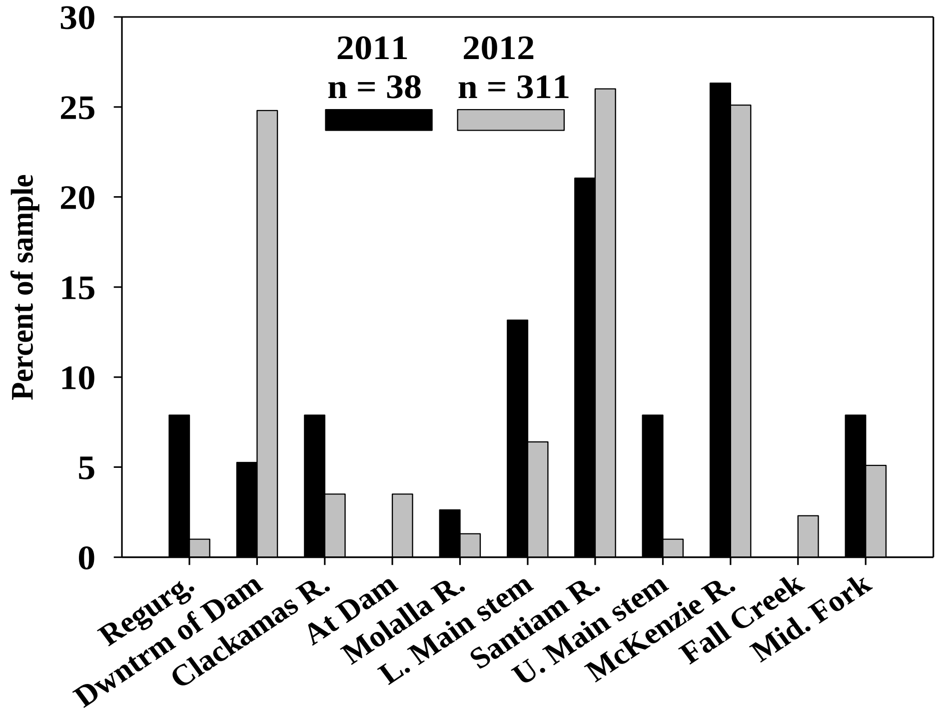


Figure 41. Histograms showing where unclipped, radio-tagged spring Chinook salmon were last recorded in 2011 and 2012.

The high percentage of unclipped, radio-tagged Chinook salmon last detected downstream from Willamette Falls Dam in 2012 was likely due to the FRD handling treatment (Figure 42). Thirty-eight percent of unclipped salmon that received the FRD treatment were last detected downstream from the dam compared to 12% for anesthetized unclipped salmon. Conversely, 8-14% more anesthetized salmon were last detected in the Santiam, McKenzie, and Middle Fork drainages than salmon that received the FRD treatment.

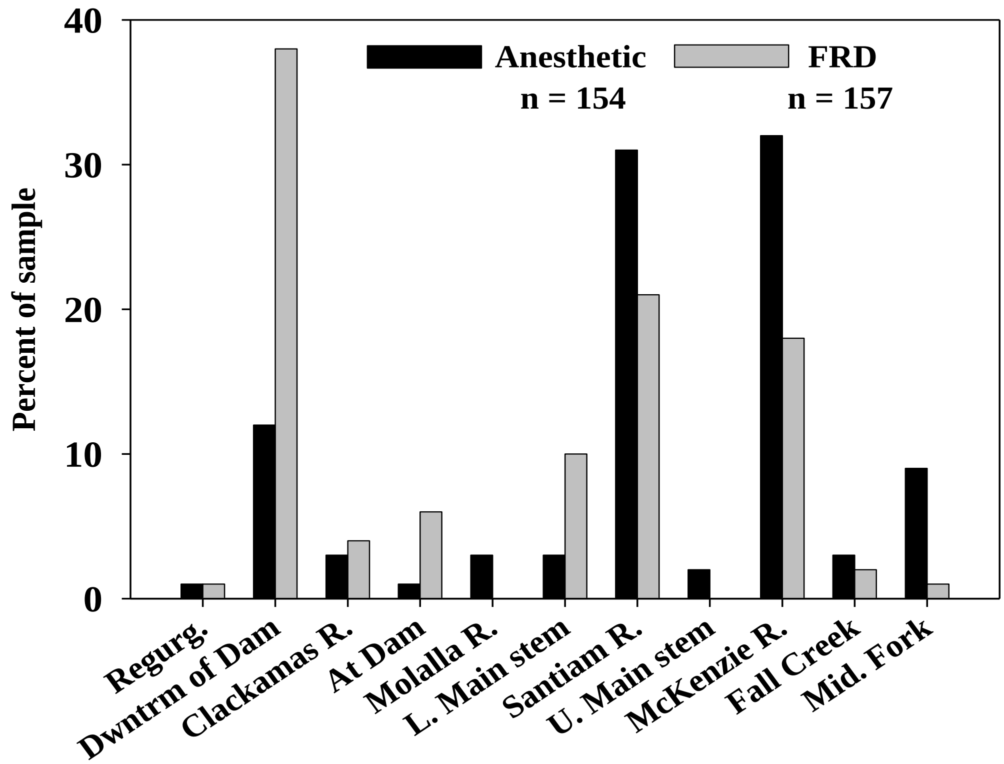


Figure 42. Histograms showing where all unclipped, radio-tagged spring Chinook salmon that received the anesthetic (black bars) or fish restraint device handling (FRD) treatment (grey bars) were last recorded in 2012.

Fates of tagged salmon with clipped adipose fins

All 189 of the adipose-clipped salmon radio-tagged in 2012 received the FRD treatment. Of these, 30% were last detected downstream from Willamette Falls Dam, 24% were last detected in the Santiam River, and 16% were last recorded in the Middle Fork (Figure 43). The percentage of salmon last detected downstream from the dam in 2012 (30%) was almost twice as high as in 2011(17%) when FRD treatments were also applied to clipped adults. Approximately 38% of the clipped salmon were last recorded in the Santiam River in 2011 compared to 24% in 2012.

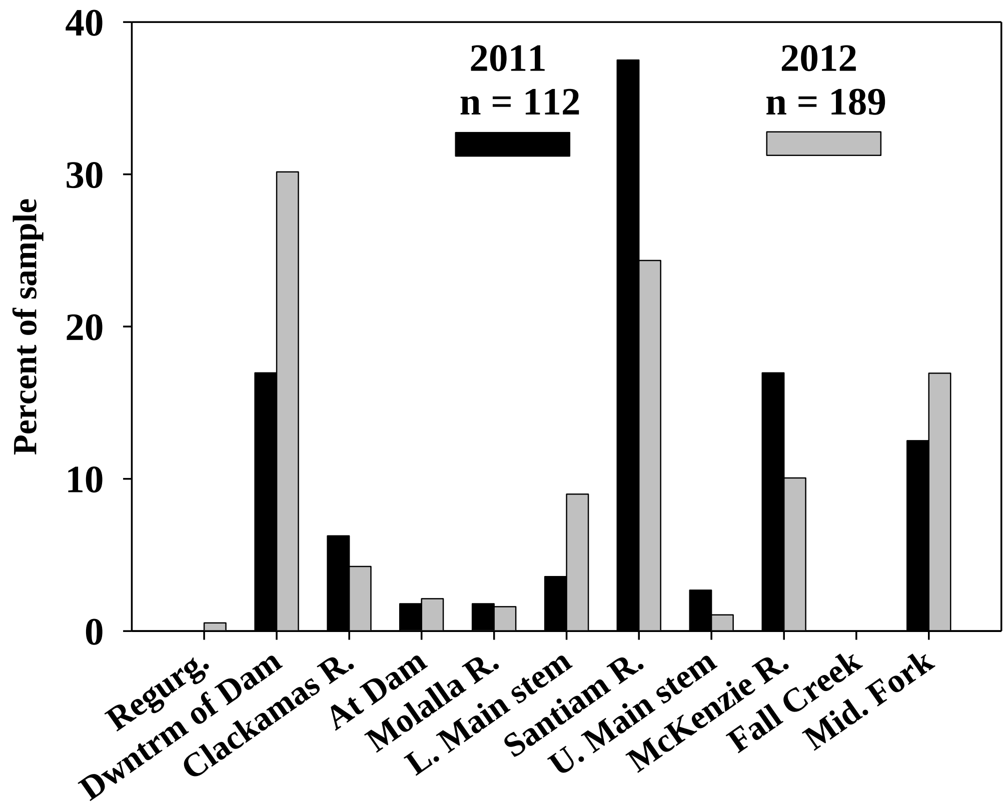


Figure 43. Histograms showing where adipose fin-clipped, radio-tagged spring Chinook salmon were last recorded in 2011 and 2012.

Temperature histories of individual salmon

There were 25 temperature logger recoveries from the 99 salmon outfitted with radio transmitters and loggers in 2012. Of the 25, 24 (96%) had retrievable data, including loggers of fish recovered in the Santiam River (n = 13), the McKenzie River (n = 6), and the Middle Fork Willamette River (n = 4). One of the Middle Fork fish was recovered from Youngs Creek, a tributary to Hills Creek Reservoir. The final temperature logger with data was recovered from a regurgitated transmitter found in Fishway 1 at Willamette Falls Dam; these data were excluded.

The recovered loggers were from salmon tagged from early June through early July in the 2012 run (Figure 44). Earlier-timed migrants were not tagged with temperature loggers in 2012, in contrast to in 2011. Consequently, the maximum temperatures salmon experienced in 2012 were higher, on average, than those recorded in 2011 (Figure 45). In terms of absolute maximums, the highest temperature recorded was 22.0 °C in 2011 and was 22.1 °C in 2012, reflecting similar annual maxima in the main stem Willamette River.

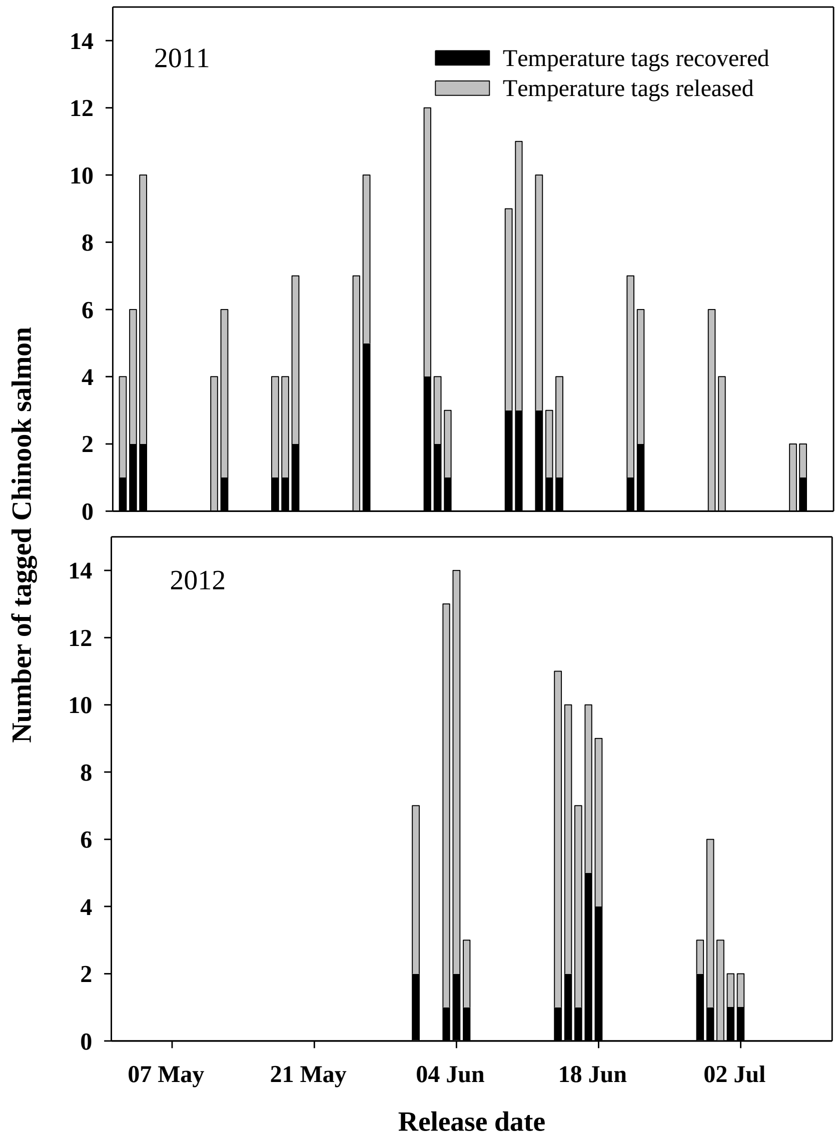


Figure 44. Histograms showing the dates that Chinook salmon were released in 2011 and 2012. Gray portion of bars are for fish that had unrecovered loggers; black portions of bars are for fish whose temperature loggers were recovered.

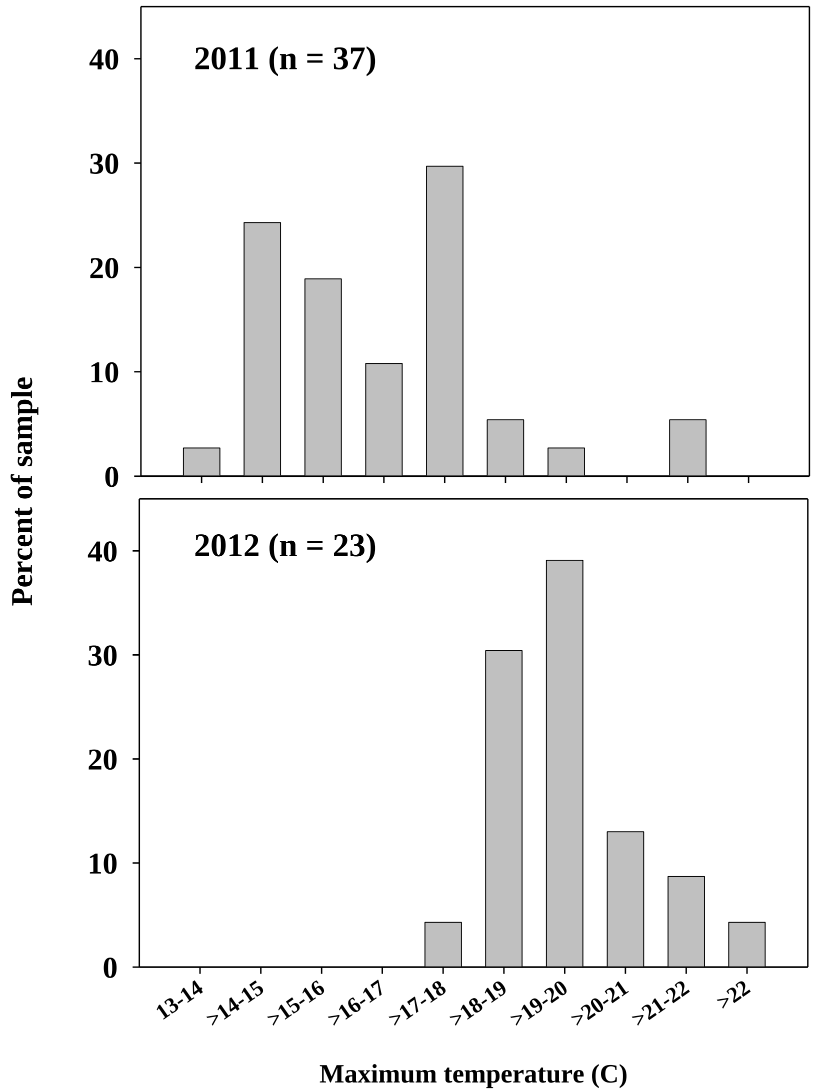


Figure 45. Histograms showing the maximum temperatures recorded on temperature loggers recovered from tagged Chinook salmon released at Willamette Falls Dam in 2011 and 2012. Note that salmon were tagged with temperature loggers only later in the run in 2012.

Temperature data from ten USGS sites were used to help evaluate water temperatures Chinook salmon encountered during migration in 2012 (Figure 46). The four main stem Willamette River sites (Portland, Newburg, Albany, Harrisburg) showed that mean daily water temperatures were warmer at the downstream sites and cooler at the upstream sites on any given day. The main stem temperatures also showed several notable warming-cooling fluctuations in June and early July, as did the Jefferson site on the lower Santiam River. In contrast, the Middle Fork sites (Jasper, Dexter), McKenzie site (Vida), and South Santiam site (Foster), showed lower day-to-day temperature fluctuations, reflecting the ameliorating effects of reservoir water releases from upstream dams (Figure 47). The three tributary sites closest to dams (Foster, Vida, Dexter) showed similar seasonal patterns in 2011 and 2012, with peak temperatures in August or early September (Figure 45). An exception occurred at the Dexter site in 2011, when there was a rapid rise in mean temperature from 12°C on 12 July to 17.2°C on 17-20 July. Dexter Dam and Reservoir serve as a reregulating project for Lookout Point Dam and reservoir, which is located about three miles upstream from Dexter. The discharge water from Lookout Point pool directly enters the Dexter pool and often moves downstream with little mixing before it passes Dexter Dam. Warm water (17-19 °C) occupied the upper 20 feet of Lookout Point Dam forebay in mid-July 2011 when there was sustained spillway discharge at Lookout Point from 11 to 22 July 2011 (D. Garletts, USACE, pers. comm.). There was no similar thermal spike in 2012.

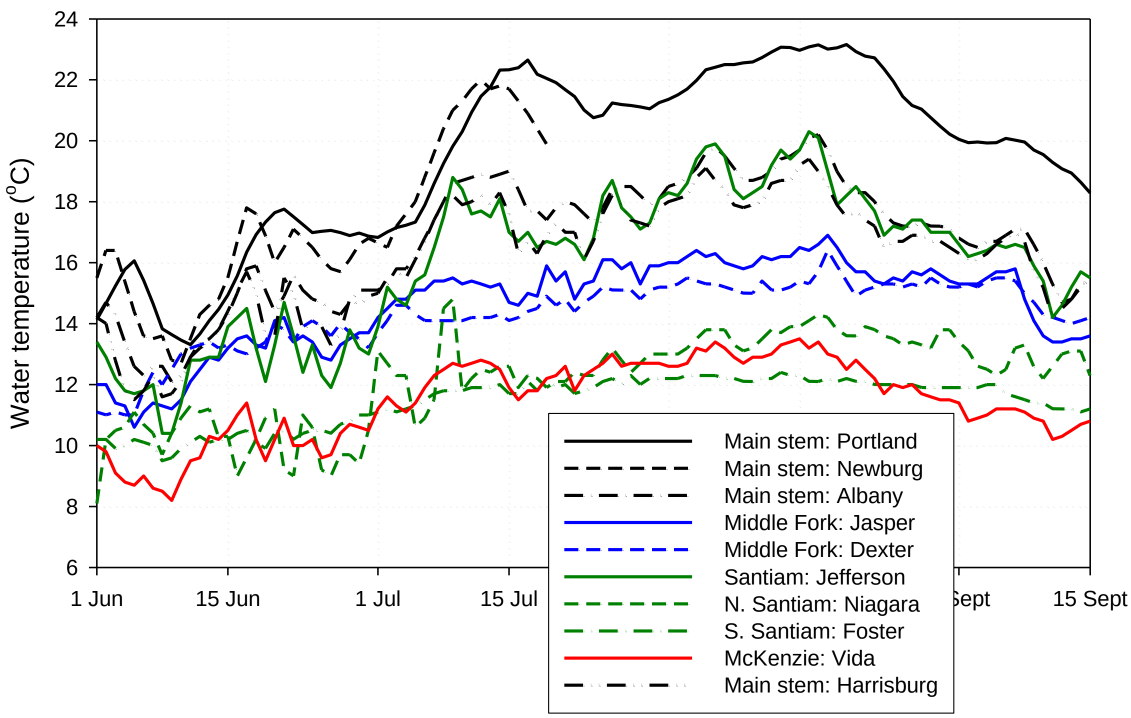


Figure 46. Mean daily water temperatures (°C) recorded at USGS gauge sites in the main stem Willamette, Middle Fork Willamette, Santiam, and McKenzie rivers during the spring Chinook salmon migration in 2012.

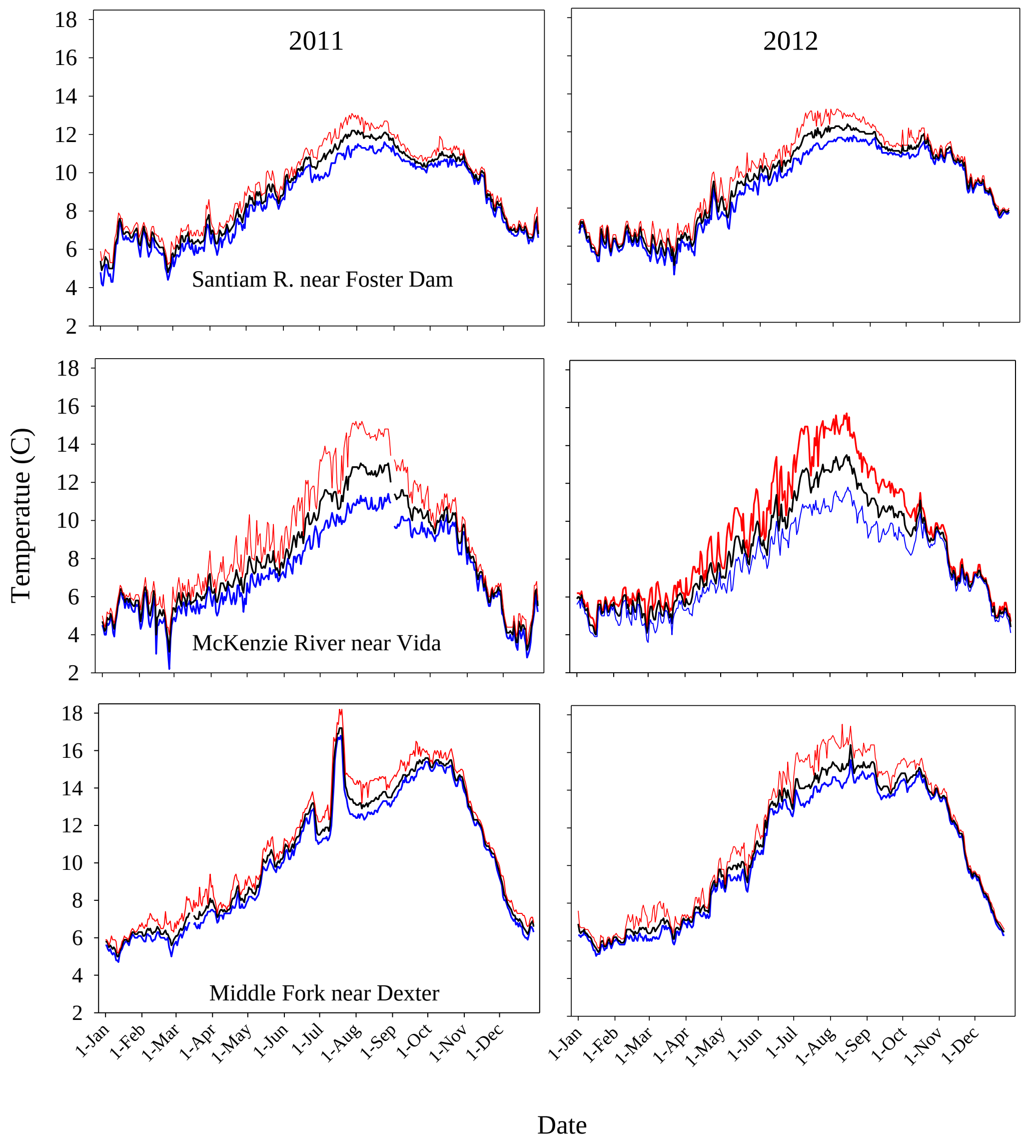


Figure 47. Minimum (blue line), mean (black line), and maximum (red line) daily water temperatures recorded at USGS gauge stations near Foster, Vida, and Dexter, OR in 2011 and 2012. Data were collected from http://ida.water.usgs.gov/.

Thermal histories for individual salmon showed that fish experienced a wide range of water temperatures from ~8 to ~21 °C (Figure 48). The highest temperatures encountered were typically in the main stem Willamette River or in the lower reaches of the Santiam River. Sharply lower temperatures were encountered when salmon entered some tributaries, especially the South Santiam and Middle Fork.

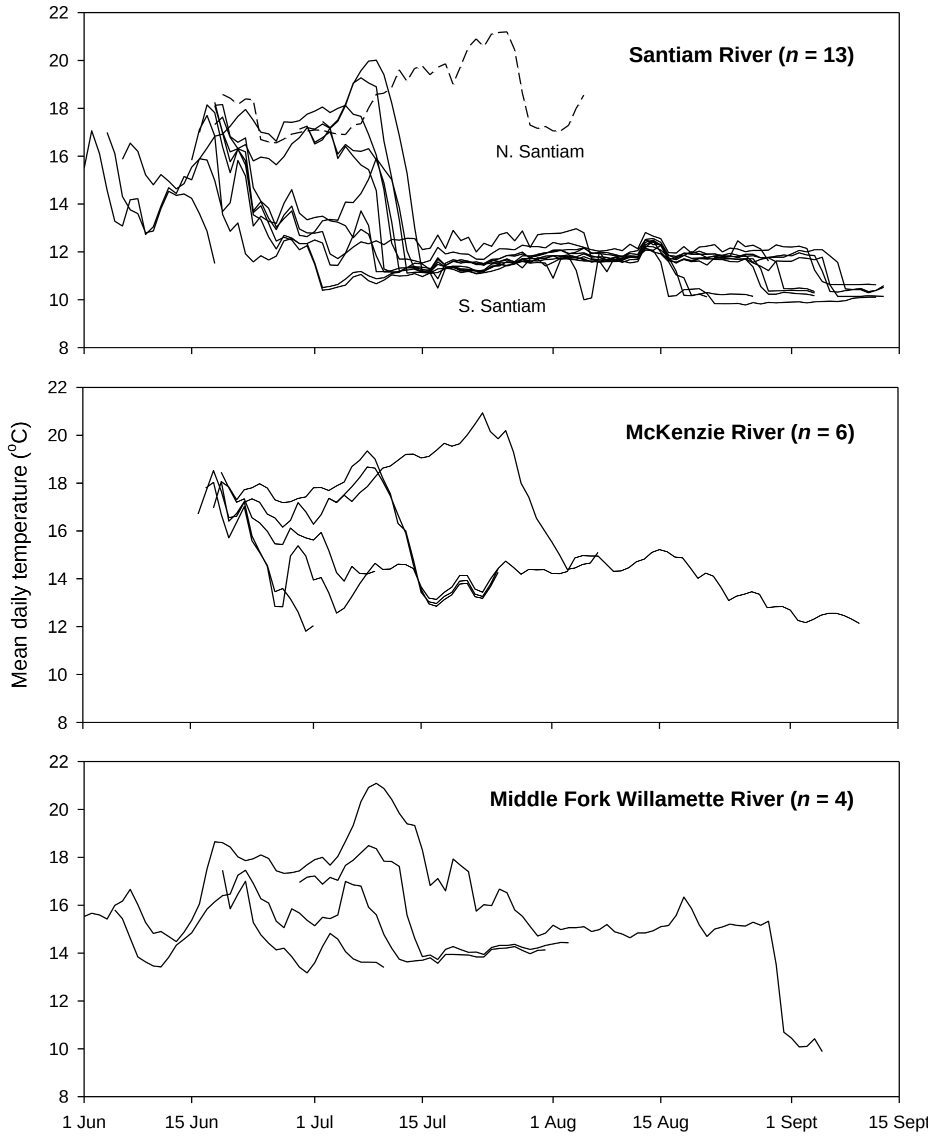


Figure 48. Mean daily temperatures (°C) of 23 radio-tagged Chinook salmon that had archival temperature loggers recovered in 2012. The three panels are for fish recaptured in the Santiam, McKenzie, and Middle Fork Willamette rivers. Each line represents an individual fish (Appendix A includes all individual thermal histories, matched to radiotelemetry detections).

The mean arrival date at the mouth of the Santiam River for all tagged salmon detected there was 10 June 2012 ($n = 82$) and the mean arrival date for the temperature logger sample was 16 June 2011 ($n = 7$, a subset of the 82 above). Generally, the highest temperatures encountered by tagged salmon recovered in the Santiam River were experienced while they were in the main stem Willamette River. Similarly, those recovered in the McKenzie River and in the Middle Fork experienced warmer temperatures in the main stem Willamette River than in the tributaries. The result for the 2012 Middle Fork fish was different than in 2011, when fish were exposed to higher water temperatures in the Dexter tailrace than in the main stem river downstream.

Internal fish temperatures recorded on the loggers were positively associated with USGS water temperatures in most study reaches (Figures 49 and 50). In regressions between mean daily fish temperatures and mean daily USGS temperature, r^2 values ranged from 0.81 (reach = WFU to WL1) to 0.99 (reaches WL2 to WL3 and WL3 to WL4). The USGS site at Albany site had the best fit data in most main stem reaches (note: data were missing from the Newburg site). In the tributary reaches, regressions generally had lower r^2 values, but there was also lower variability in water temperatures among fish and among dates. Temperature logger data from reaches in the lower Santiam and South Santiam had the lowest correlations with the available USGS data (at Foster). The low association in these reaches was related to the longer distances between fish locations and the USGS site and some longitudinal heterogeneity in the migration reach (particularly true between the junction of the North and South Santiam rivers and Foster Dam).

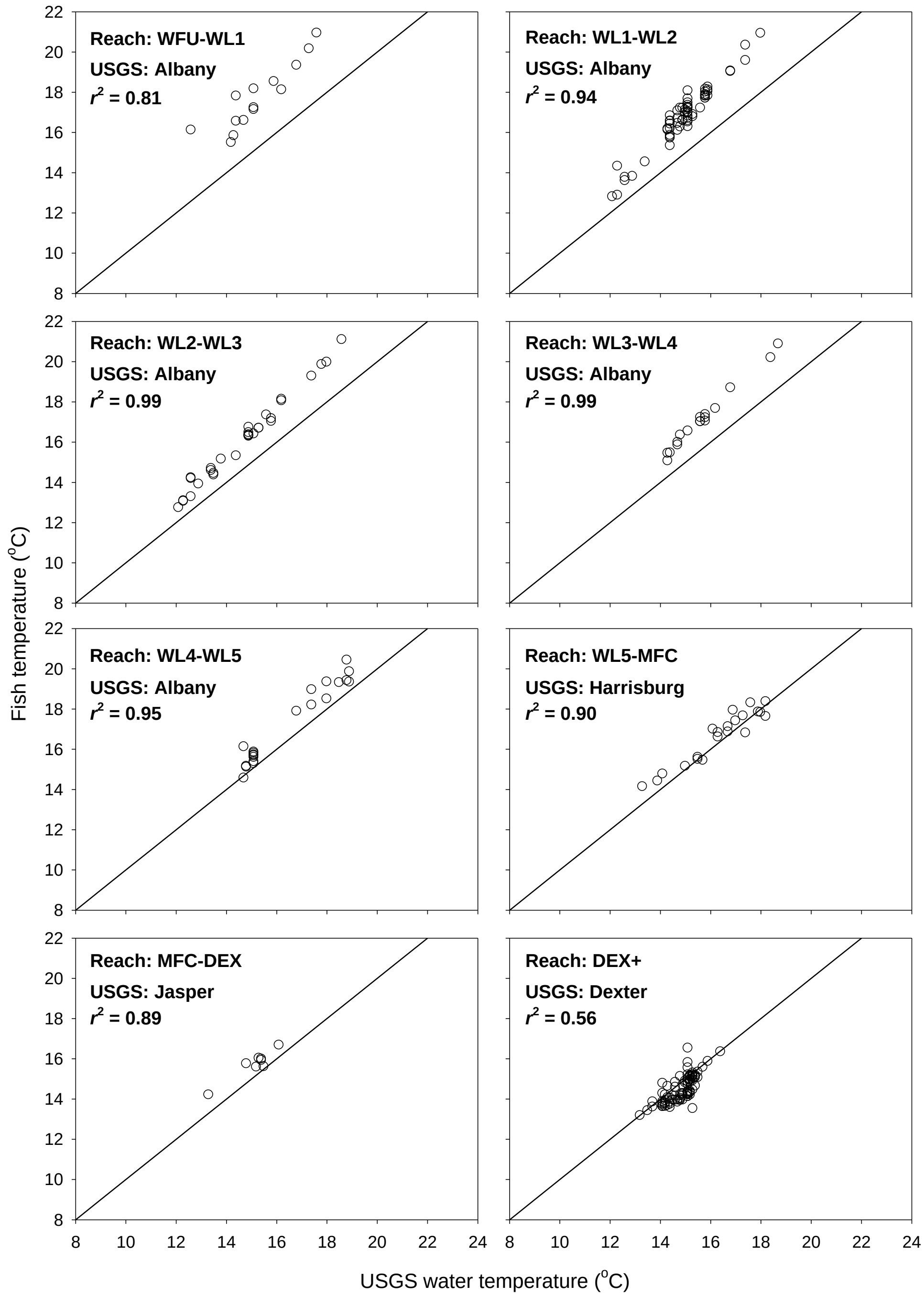


Figure 49. Relationships between mean daily water temperature (°C) at USGS gauging stations and mean daily Chinook salmon temperatures (°C) retrieved from archival tags. Data are organized by river reach, with fish assigned to individual reaches based on the radiotelemetry detections. Each datapoint represents a single fish-day. Antenna sites bracketed reaches: WFU, WL1, WL2, WL3, WL4 and WL5 were in the main stem; MFC and DEX were in the Middle Fork. (See Table 1 for site details.)

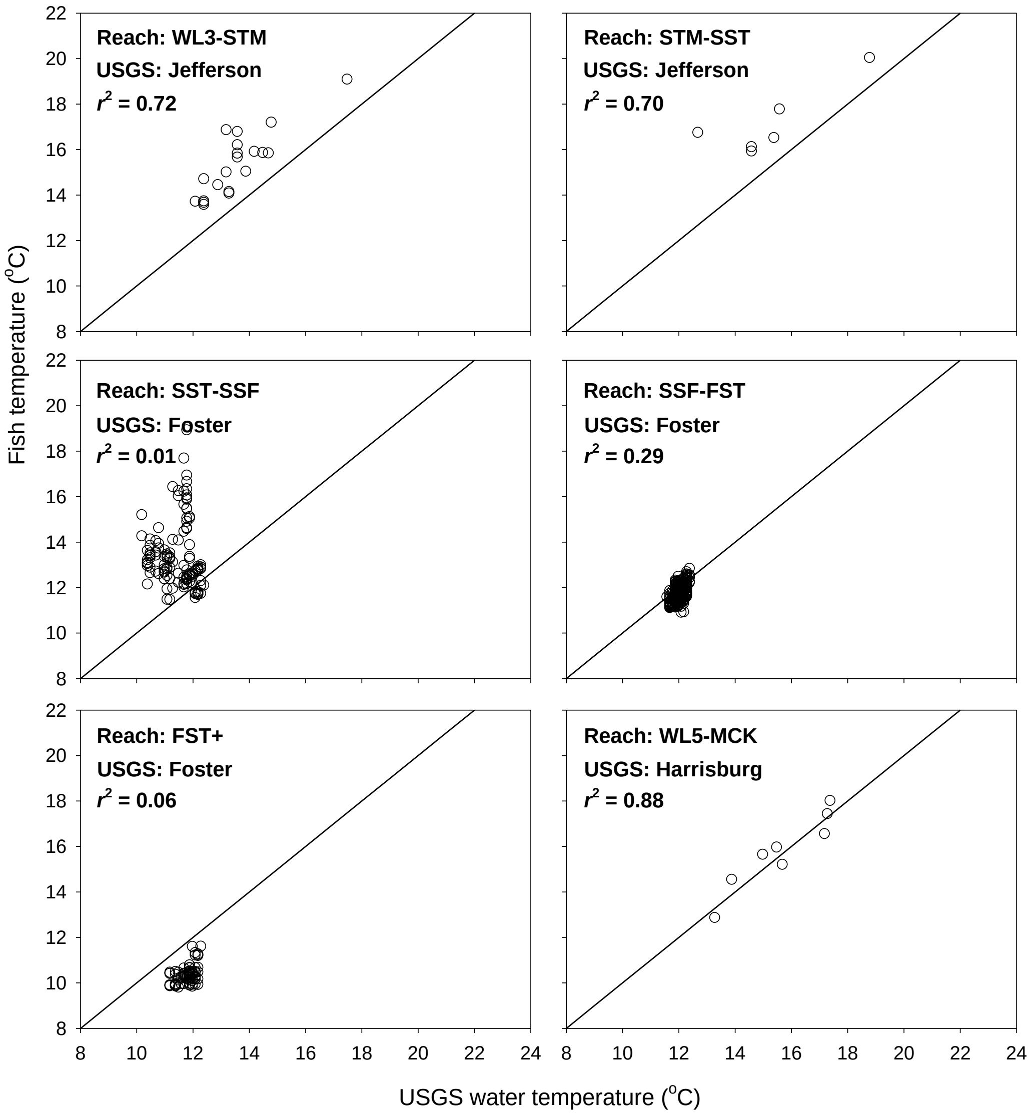


Figure 50. Relationships between mean daily water temperature (°C) at USGS gauging stations and mean daily Chinook salmon temperatures (°C) retrieved from archival tags. Data are organized by river reach, with fish assigned to individual reaches based on the radiotelemetry detections. Each datapoint represents a single fish-day. Antenna sites bracketed reaches: WL3 and WL5 were in the main stem; STM, SST, SSF, and FST were in the Santiam River, and MCK was in the McKenzie River. (See Table 1 for site details.)

The regression relationships in Figures 51 and 52 were used to develop a preliminary predictive model of Chinook salmon temperature exposure between Willamette Falls and adult collection sites. To build the model, we calculated mean daily temperatures from each of the recovered temperature loggers and used the radiotelemetry data to assign each of the temperature logger fish to a single migration reach for each day. We then identified the highest correlations between the mean daily temperature data in each reach (from temperature loggers) with nearby USGS sites. The resulting linear relationships were used to estimate fish temperature exposures that could be compared to actual thermal histories from the temperature loggers.

Predicted values developed from both the 2011 and the 2012 relationships approximated actual thermal histories in most cases (examples in Figure 49). Fits were particularly good along the main stem migration corridor, where there were strong associations between fish temperatures and river temperatures. The availability of multiple USGS sites improved the spatial resolution in both years. The largest deviations from the recorded temperatures occurred in the Santiam River between the confluence with the Willamette River and the Foster Dam site. It was often difficult to assess exactly where fish were located in this migration section (i.e., up or downstream from receiver sites) and there was a substantial temperature differential between lower reaches in the Santiam system and the USGS site at Foster.

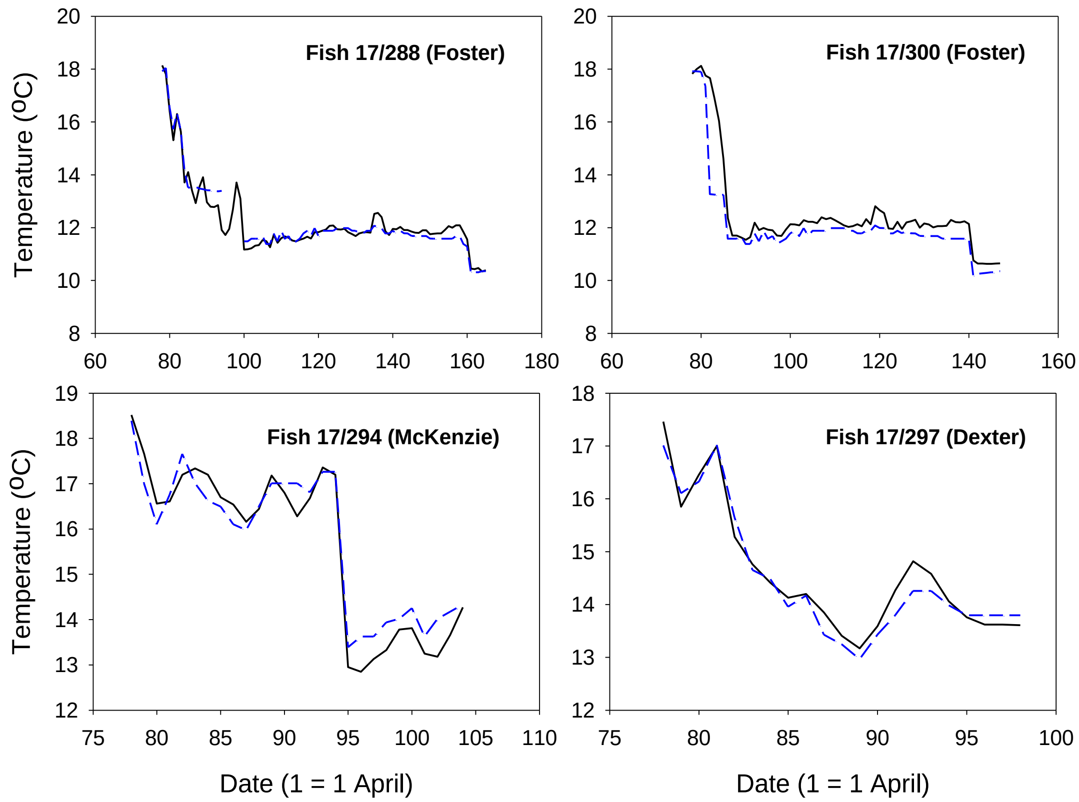


Figure 51. Examples of 2012 Chinook salmon thermal histories as recorded by temperature loggers (solid black lines) and as predicted (dashed blue lines) using a reach-specific model based on the relationships between USGS temperature data and temperature logger data for all recovered fish.

We further used the 2012 logger data and predicted temperatures to estimate degree day accumulations in the tagged salmon. There was generally high agreement between the actual and modeled degree day accumulation rates (i.e., degree days per day) (Figure 50). In the small 2012 sample, it was evident that degree day accumulation rates were highest for Chinook salmon that returned to the McKenzie and Middle Fork rivers.

Accumulation rates were lower for salmon that were collected at Foster Dam, reflecting the often extended residence times in the relatively cool water downstream from the project.

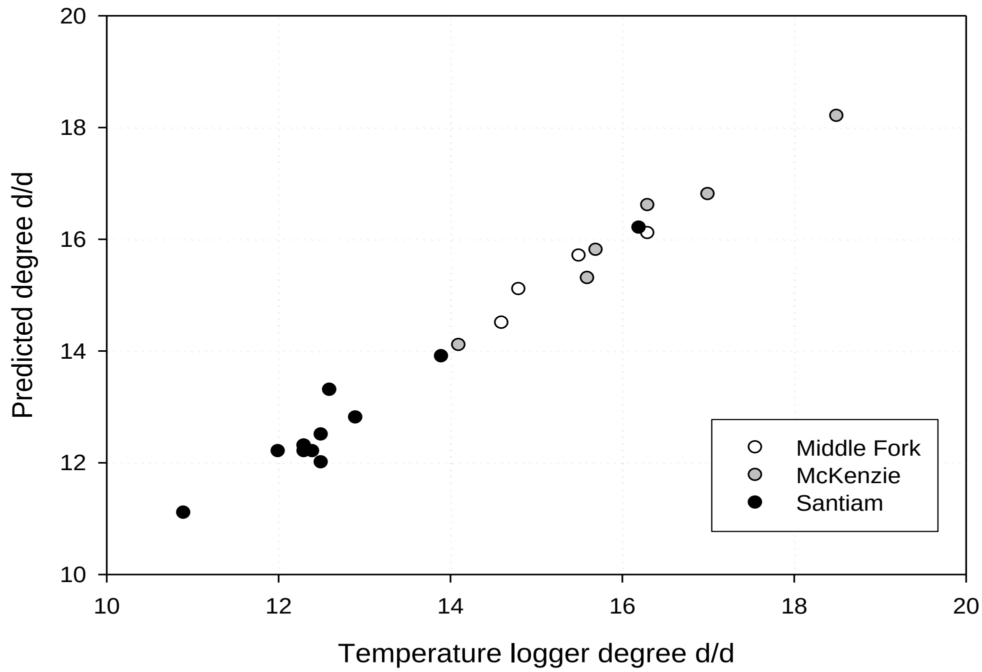


Figure 52. Relationship between the 2012 rate of degree day accumulation (degree d/d) by Chinook salmon as recorded by temperature loggers and as predicted using a reach-specific model based on the relationships between USGS temperature data and temperature logger data for all recovered fish. Different symbol colors indicate different recovery tributaries.

Discussion

In this study, we collected information on run composition, run timing, and migration behaviors of adult winter and summer steelhead and spring Chinook salmon during migration in the Willamette River basin. We also experimentally evaluated the effects of two alternative tagging procedures on subsequent migration behavior. Based on our previous experience collecting and radio-tagging adult Chinook salmon (e.g., Keefer et al. 2005; Jepson et al. 2010) and summer steelhead (e.g., Keefer et al. 2009) we think it is likely that most of the tagged fish in the 2012 Willamette River study behaved similarly to untagged fish. An important exception, however, was that Chinook salmon tagged in the FRD handling treatment were more likely to exit to the Willamette Falls tailrace after tagging and were less likely to escape to monitored tributaries. The apparent negative handling effect of the FRD was species-specific for spring Chinook salmon, with no evidence of a treatment effect in winter steelhead. We were not able to rigorously evaluate treatment effects in summer steelhead due to restrictions on tagging, but the point estimate for FRD-tagged summer steelhead was nearly identical to that for both treatments in winter steelhead. The FRD results in 2012 were similar to what we reported for Chinook salmon radio-tagged in 2011 (Jepson et al. 2012), and suggest that anesthesia rather than fish restraint should be used when possible. AQUI-S®E has been approved for use in non-production (e.g., hatchery and aquaculture) setting such as these studies, and our work in 2013 will use AQUI-S®E for all tagging conducted at Willamette Falls.

Winter Steelhead

There are no previous basin-wide tagging studies of adult winter steelhead in the Willamette River basin (see review by Keefer and Caudill 2010). Therefore, the 2012 results provide important baseline information 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 fish, and basic migration behaviors.

After adjusting for known transmitter loss, 83% of 169 radio-tagged winter steelhead escaped to Willamette River tributaries, based on maximum upstream detection sites. The remaining fish were last detected downstream from Willamette Falls Dam (12%), at the dam (<1%), or in the lower (4%) or upper (2%) 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 would be ~17%. It is more likely, however, that the 17% 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 the 84 fish (50% of the total sample of 169) 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 56 steelhead (33% of 169) that entered tributaries but did not kelt 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 model of winter steelhead escapement, only tag date was a statistically significant predictor of success. Later migrants were more likely to reach monitored tributaries than early migrants, but the mechanism behind this result was unclear. It is possible that later-timed fish had more directed migration because they were active closer to the spawning period. Alternately, fish that arrived early may have been more vulnerable to unreported harvest, catch-and-release handling, or transmitter loss or failure. 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-one of the ‘unsuccessful’ tagged winter steelhead in 2012 were last detected downstream from Willamette Falls. This may indicate that there was a negative handling or tagging effect, a high rate of unreported harvest downstream from the dam, or overshoot behaviors by steelhead whose natal sites were downstream from Willamette Falls. We found that similar percentages of anesthetized winter steelhead exited the fishway after release compared to restrained steelhead (16% versus 18%). This suggests that handling treatment was not an important factor, but it does not rule out an overall handling effect. The harvest of winter-run adipose-intact steelhead was prohibited in most portions of the Willamette basin in 2012 (ODFW 2012), which reduced the likelihood that winter steelhead last detected downstream from the dam were captured and killed before they could have been detected at fixed stations or during mobile tracking. Based on a query of the PTAGIS database in December 2012, no radio-tagged (and PIT-tagged) winter steelhead were detected on any PIT antenna sites in the Columbia River basin other than the one at Willamette Falls Dam, suggesting downstream movements were not associated with subsequent migration up the Columbia River above Bonneville Dam.

Winter steelhead migration rates have been estimated using fish counts at Willamette Falls 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. They also moved more slowly through successive sections of the main stem Willamette River, perhaps because the upstream reaches are higher gradient than downstream reaches. It is also possible that some other biological factors (e.g., searching behavior, prespawn holding or staging) or environmental effects (e.g., lower water temperature in upstream reaches) explain this behavior. This pattern of slower rates in upstream reaches was also observed in radio-tagged summer steelhead and Chinook salmon in this study, suggesting a common cause.

The run timing of the aggregate native winter steelhead population is later than that of the introduced Big Creek stock and they are separated by ODFW using a fixed date threshold in early February at Willamette Falls. We could not differentiate these two groups at the time of tagging and the degree to which their migration timing overlaps is not known (Keefer and Caudill 2010). Interestingly, the Big Creek hatchery releases ended in 1997 and Johnson et al. (2013) suggest there is no introgression of the Big Creek stock into the native winter steelhead genome (Johnson et al. 2013), though the latter study was based on an opportunistic sampling design. The timing of the 2012 winter steelhead run as a whole was early in 2012 but we are not aware of any reported analyses of the factors that affect inter-annual variability in migration timing at Willamette Falls. 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. Generally, we found that early-run fish were a well-mixed combination from lower basin populations (i.e., Clackamas, Tualatin, Molalla, and Yamhill rivers). Mid-basin populations (i.e., Santiam and Calapooia rivers) were intermediately-timed and upper basin populations (i.e., McKenzie, Coast Fork and Middle Fork Willamette rivers, and Fall Creek) tended to be relatively late-timed in 2012. 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), though such introduction. The modest separation among populations may provide some management opportunity, but we caution against drawing strong conclusions from a single study year. Future analyses of adult composition at Willamette Falls using a combination of telemetry and GSI assignments (including the 2013 run-year) should reduce the above uncertainties.

We observed considerable kelting behaviors in the radio-tagged sample. About 60% of the winter steelhead that entered tributaries moved downstream during the presumed post-spawn period. Many of the kelts were detected below Willamette Falls. 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 (8.5%). Both estimates imply high (~83%; ~10 successful repeat spawners / 60 kelts) inter-spawn mortality rates in these populations, but this estimate contains considerable uncertainty.

Summer Steelhead

As with winter steelhead, the 2012 summer steelhead study provided some of the first basin-wide information on the distribution, behavior, and fate of summer-run fish. The tagged sample was available for harvest (supporting recreational fisheries is a primary management objective for this population) and hence almost all fish received the FRD treatment. Again, we note that equal percentages of summer and winter steelhead in the FRD samples exited the Willamette Falls fishway to the tailrace after release (18%).

Overall, 71% of radio-tagged summer steelhead were last detected in Willamette River tributaries. The remaining fish were last detected downstream from the Willamette Falls Dam (8%), at the dam (2%), or in the lower (8%) or upper (11%) main stem. In contrast to the winter run fish, summer steelhead tagged in 2012 would have spawned in 2013. 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 in spring 2013. 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 summer-run fish. We were unable to implement a tag reward program during 2012 due to concerns of encouraging angling take so reported rates of harvest were likely biased low. If we assumed that all tagged steelhead not detected in a tributary were harvested or died before spawning, then the maximum *en route* main stem mortality was 29%. 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. 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. Migration speeds were weakly correlated with river environmental conditions, with faster passage associated with warmer temperatures and lower discharge. We found little evidence of thermoregulatory behavior.

The run timing and run composition data collected in 2012 indicated that there is high potential for summer steelhead to overlap spatially and temporally with winter steelhead. Generally, the three most abundant summer-run groups (i.e., Santiam, McKenzie, and Middle Fork) were present throughout the nominal summer-run period at Willamette Falls. Final detections of many summer-run fish indicated direct spatial overlap with the maximum upstream detections of tagged winter steelhead in the South and North Forks of the 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 congregate due to the lack of upstream passage. Although we had limited monitoring effort in the Clackamas River, tagged steelhead from both the summer- and winter-run entered the Clackamas River, and the two populations are known to inter-breed in this sub-basin (Kostow et al. 2003; Kostow and Zhou 2006). The recent genetic study by Johnson et al. (2013) also indicated winter-summer hybridization in the McKenzie and Santiam sub-basins. Importantly, we could not directly assess summer-winter temporal overlap on spawning grounds, because the two groups spawned in different years (i.e., 2012 summer steelhead spawned in spring 2013 and the 2012 winter steelhead spawned in spring 2012). Nevertheless, it has been estimated that 10-30% of all summer steelhead passing Willamette Falls spawn naturally (NMFS 2000; Johnson et al. 2013) and the 2012 radiotelemetry data strongly 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).

A more thorough investigation of overlap between summer- and winter-run steelhead will require additional information on harvest rates. Somewhat surprisingly, only five of the 208 (2.8%) summer steelhead radio-tagged at Willamette Falls were reported harvested by anglers. The absence of a reward program for recovered transmitters may have resulted in a low reporting rate. Reward programs, better angler education, and integration with creel surveys are recommended for future tagging studies and we are implementing a reward program for summer (but not winter) steelhead during 2013.

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

Chinook salmon

2012 was the second study year that spring Chinook salmon were radio-tagged at Willamette Falls Dam, but there were some important differences between 2011 and 2012 protocols. First, the 2012 sample included a disproportionate number of unclipped 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 AQUI-S®E. As noted above, anesthetized salmon were less likely to exit the Willamette Falls fishway to the tailrace and were substantially more likely to escape to upriver tributaries than were fish tagged using the FRD. The negative effect of the FRD should be kept in mind when interpreting study results.

After adjusting for known transmitter loss, 61% of 496 radio-tagged salmon escaped to Willamette River tributaries (fin-clipped and unclipped samples combined and restrained and anesthetized sample combined). The remaining fish were last detected downstream from the dam (27%), at the dam (3%), or in the lower (7%) or upper (1%) main stem. Assuming that all tagged salmon last detected outside a tributary died before spawning, the maximum prespawn mortality estimate was 39% in 2012. This was higher than our estimate of 26% in 2011 (Jepson et al. 2012). Estimates in both 2011 and 2012 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 in 1989-1992. We note that our tributary escapement estimate for unclipped, anesthetized salmon was 81.6%, and this may be considered a potential ‘best-case’ scenario. The ‘worst-case’ was 43.6% for fin-clipped, restrained salmon.

The high percentage of tagged salmon last detected downstream from Willamette Falls in 2012 was primarily associated with salmon that received the FRD handing treatment. The percentages of fish last detected downstream from the dam in the three tagging treatments were: 38% (unclipped, FRD), 30% (clipped, FRD), and 12% (unclipped, anesthetic). While some downstream fish movement following tagging is common (Bernard et al. 1999; Mäkinen et al. 2000), the rates we observed in 2012 were at the high end of the reported range and the apparent short-term effect of the FRD treatment (exit from the ladder to the tailrace) was also associated with last detection below the Falls. Potential mechanisms include long-term effects on behavior, additional exposure to unreported harvest in the fishery downstream from the dam and predation by the California sea lions (*Zalophus californianus*). Final detection below the dam could also have been associated with overshoot behaviors by fish whose natal sites were downstream from Willamette Falls (e.g., Schreck et al. 1994; Keefer et al. 2008c), though it is unclear why this mechanism would differentially affect FRD-treated adults. Notably, 22 of 23 (96%) of the salmon that were recorded falling back at the dam did not reascend, indicating that potential injury or mortality may have resulted from this behavior (e.g., Keefer et al. 2005). Regardless, the fate of the fish last recorded downstream was largely unknown: two were reported as being harvested, none entered the Clackamas River, and none were detected at Columbia River PIT tag interrogation sites.

Migration rates and main stem behaviors

Chinook salmon migrated through the main stem faster as water temperature and date increased. This was consistent with the steelhead results and the Chinook behaviors reported in Schreck et al. (1994), who found that late-run Willamette River Chinook salmon tended to migrate at a relatively rapid pace in contrast to 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 2012 (median = 22.9 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).

The 10% of tagged salmon with downstream movements in the main stem in 2012 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 tagged salmon of hatchery origin that migrated to the Dexter Dam tailrace in 2012 before swimming downstream and falling back at Willamette Falls, 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). Similarly, we observed little temporary straying into non-natal tributaries by tagged salmon in 2012, perhaps because the relatively cool main stem conditions reduced the need for the use of thermal refuges. We also note that hatchery Chinook released into the Molalla River as smolts are from fish spawned, reared, and trucked from South Santiam Hatchery. This may partially explain the overshoot behavior observed by some fish that returned to the Molalla River.

Adult salmon spent two to more than six weeks in the main stem before reaching tributaries and time spent in the mainstem was longer for upstream populations. Longer transit times may be an important factor affecting migration success and prespawn mortality in Willamette River Chinook salmon, particularly in warm years. In 2012, main stem water temperatures reported from USGS sites were typically higher than in the tributaries. Additionally, several main stem reaches are negatively impacted by habitat alteration associated with urbanization, and there are many sources of point and nonpoint contaminants from agricultural, industrial, and residential sources entering the main stem. We have also hypothesized that adult salmon may be exposed to bacterial, fungal, and eukaryotic pathogens and parasites during migration through the main stem (Schreck et al. 2012). Each of these factors potentially affects prespawn mortality rates. We have observed higher disease burdens in adults that died prior to spawning and in adults that migrated to tributary collection sites compared to those collected at Willamette Falls and then held in cool disease-free water at the OSU Fish Performance and Genetics Laboratory. Collectively, the results suggest that some pathogens are acquired during upstream migration and/or upstream migration contributes to the expression of disease.

In our logistic regression models, later-timed salmon were less likely to escape to tributaries. This finding was consistent with a potential interaction between exposure to higher water temperatures in the main stem, disease expression, and/or a carry-over effect of condition on run timing whereby relatively poor condition fish pass the Falls later. The interactions among river environmental conditions (especially temperature), exposure duration (migration rate and distance), disease status at river entry, exposure to disease during migration, and other impacts such as toxins exposure are likely to be complex and variable from year to year. Cool conditions in 2012 may have resulted in lower than average *en route* and prespawn mortality. We expect that mortality will be higher in warmer years, as has been observed in the Middle Fork outplanting studies (Keefer et al. 2010; Mann et al. 2011; Naughton et al. 2012).

We observed no relationship between estimated initial lipid content and fate of adult fish, suggesting energetic reserves at river entry were sufficient to fuel upstream migration to tributaries in 2012. The metabolic costs of migration increase at higher temperatures, particularly at temperatures thought to be physiologically stressful to salmon (e.g,. >18° C; Richter and Kolmes 2005). Several adults experienced temperatures above this threshold and exposure times for those that did were extended (1-3 weeks) in some cases. Alternately, estimation error associated with the fatmeter may have prevented detection of an effect. We note that values reported here are based on the manufacturer's algorithm and that concurrent evaluations in tributary populations suggest the analytical precision of the fatmeter can be useful for estimating relative, but not absolute, lipid levels for individual adults (Naughton et al. *in prep.*). Regardless, the effects of energy limitation are expected to be greatest in warm years (Mann et al. 2011) and we hypothesize that if there was an undetected effect of lipid reserves on migration success in 2012, the effect was small.

Tributary and tailrace behaviors

Chinook salmon that returned to Dexter Dam to the Middle Fork Willamette River spent one day to six weeks holding in the tailrace prior to collection. Data recovered from temperature loggers indicated that the fish held in water that was ~14-16°C in the Dexter tailrace, consistent with the temperatures recorded by the USGS sites at Jasper and Dexter. These temperatures were substantially lower than those encountered by some tagged Chinook salmon in 2011 (Jepson et al. 2012). Nonetheless, long holding periods in the Dexter tailrace suggest that some salmon potentially accumulate high numbers of degree days in this river section. We also note that salmon returning to the Middle Fork have the longest travel distances of any population and may already be thermally stressed when they arrive. We have hypothesized that the combination of long holding periods, high salmon density, and high angler pressure below Dexter Dam is stressful for salmon and contributes to the high prespawn mortality in outplanted fish from this location. Alternative operations at the Dexter Dam Trap that collected adults shortly after arrival could potentially reduce stress in this population. However, transport from the Dexter trap and conditions at outplant sites are also potentially stressful, and there are tradeoffs between the various trap-and-outplant scenarios being considered.

Run timing and composition

The moderately late timing of the 2012 spring Chinook salmon run was consistent with relatively cool river temperatures and high discharge. The latest-timed run in the last decade was in 2008 and it was associated with cold April-June water temperatures. Conversely, early-timed runs in 2001, 2004, and 2005 were associated with warm March water temperatures and/or low spring discharge. This pattern has been well documented for Columbia River spring Chinook salmon (Keefer et al. 2008a; Anderson and Beer 2009), and appears to be a result of both large-scale winter and spring weather patterns, ocean environment, and estuary and river conditions.

There has generally been little information on spring Chinook salmon run composition at Willamette Falls so the data collected in 2011 and 2012 represent steps forward in understanding relative population abundance through the migration season, particularly 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. Those that returned to the Molalla River were relatively early-timed and those that returned to the Clackamas River were late-timed in 2012. Run composition of the 'wild' sample was characterized by the two largest return groups (Santiam and McKenzie rivers) making up 57-100% 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 requiring greater time in the mainstem to reach upstream tributaries. It is also possible that past differences in hatchery selection, the distribution of wild versus hatchery-produced adults, or inter-basin straying rates may affect the timing of migration through the migration corridor. Such relationships have not been well described for the Willamette River populations.

Temperature exposure histories

The below-average Willamette River water temperatures in 2011 and 2012 limited possible inferences about the relationship between main stem thermal experience and prespawn mortality in this study. The temperature logger-tagged salmon with the highest maximum temperature exposure in 2012 was a fish that escaped to the North Santiam River, but its highest temperatures (>21 °C) were recorded in the main stem near Willamette Falls in late July. Its last radio detections were near Upper Bennett Dam in early August and it was recovered in late August. Unfortunately, the circumstances surrounding the recapture event were not known. Specifically, we do not know whether the fish was alive or dead, or whether gametes were present at the time of recapture.

Reconstructed temperature exposure histories for other salmon in the logger-tagged sample indicated that the highest temperatures most fish experienced were in main stem reaches. That said, many fish also accumulated large numbers of degree days during the long prespawn holding period in tributaries. In the small sample of recovered loggers, degree day accumulation rates (degree d/d) were higher – on average – for Middle Fork and McKenzie River salmon than for those recovered at Foster Dam on the South Santiam River. We think it is likely that short-term exposure to stressful water temperatures may have different effects on adult Chinook salmon than the accumulation of degree days at cool to moderate temperatures. It is also possible that spatial and temporal components of exposure to elevated temperatures may be an important predictor of negative effects (i.e., exposure early in migration may have a different impact than exposure closer during the spawning period). These relationships are not well understood, and are a continuing part of this research project.

The predictive models of temperature exposure that we have developed using USGS data paired with radiotelemetry detections show promise for recreating thermal histories for salmon without temperature loggers. The good fit of the modeled temperatures to the logger temperatures in both 2011 and 2012 indicated that the approach may be useful in future years. The predictions were especially good in the main stem reaches. However, the temperature logger-USGS temperature relationships differed in 2011 and 2012 (i.e., regression slopes were not identical), and therefore a universal model that could be applied in any year will require refinement. Data from additional salmon with loggers, and data collected across a broader range of temperature conditions will help improve this approach.

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.

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.

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. I inferring the relative oceanic distribution of salmon from patterns of age-specific arrival timing. Transactions of the American Fisheries Society 142:556-567.

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.

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.

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.

Investigational New Animal Drug (INAD). 2011. Study protocol for a compassionate aquaculture investigational new animal drug exemption for AQUI-S®E 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.

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 (*O. mykiss*): variability among sympatric populations. Canadian Journal of Fisheries and Aquatic Sciences 66: 1734-1747.

Keefer, M. L., and C. C. Caudill. 2010. 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. 2010. Prespawn mortality in adult spring Chinook salmon outplanted above barrier dams. Ecology of Freshwater Fish 19:361-372.

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.

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.

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. 2012. Migration behavior and spawning success of spring Chinook salmon in Fall Creek and the North Fork Middle Fork Willamette River: relationships among fate, fish condition, and environmental factors, 2011. Technical Report 2012-2, University of Idaho, Moscow.

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.

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.

Oregon Department of Fish and Wildlife (ODFW). 2012. 2012 Oregon sport fishing regulations.

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.

Schreck, C .B., M. Kent, S. Benda, J. Unrein, R. Chitwood, C.C. Caudill, and G. Naughton. 2012. Prespawn mortality in spring Chinook salmon in the upper Willamette River: potential causes. USACE 2011 Willamette Basin Fisheries Science Review, Corvallis, OR.

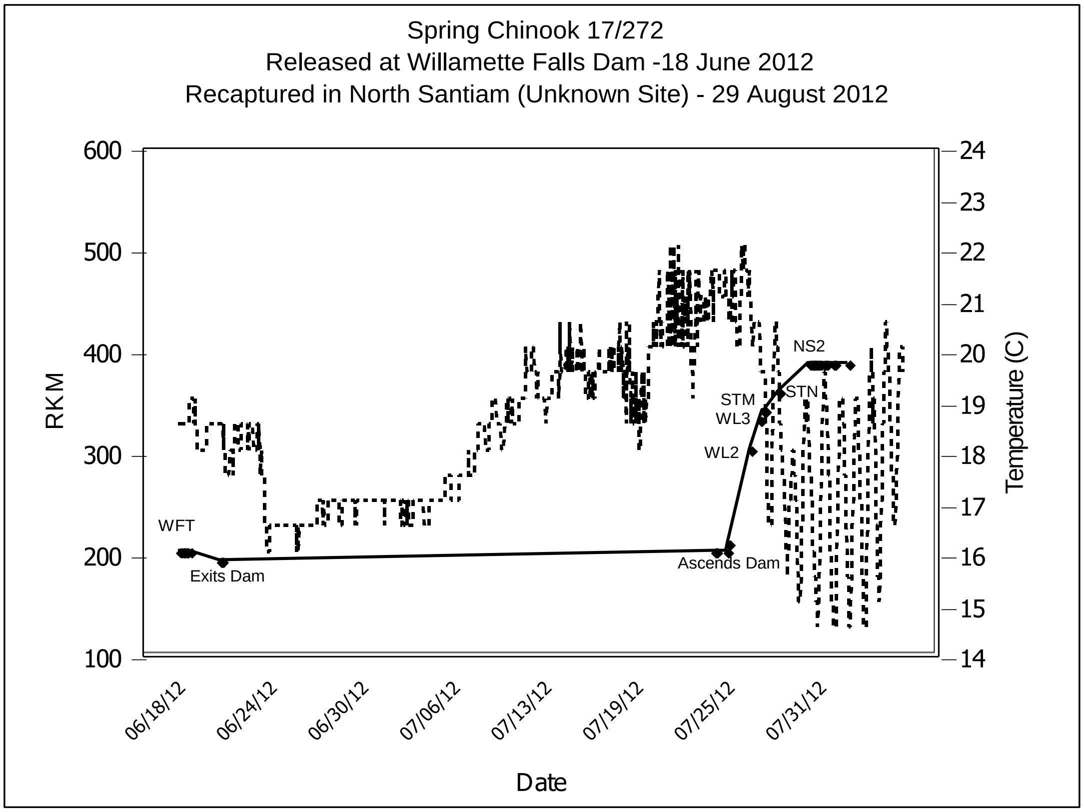
Schroeder, R. K, K. R. Kenaston, and L. K. McLaughlling. 2007. Spring Chinook salmon in the Willamette and Sandy Rivers. ODFW, Portland, OR.

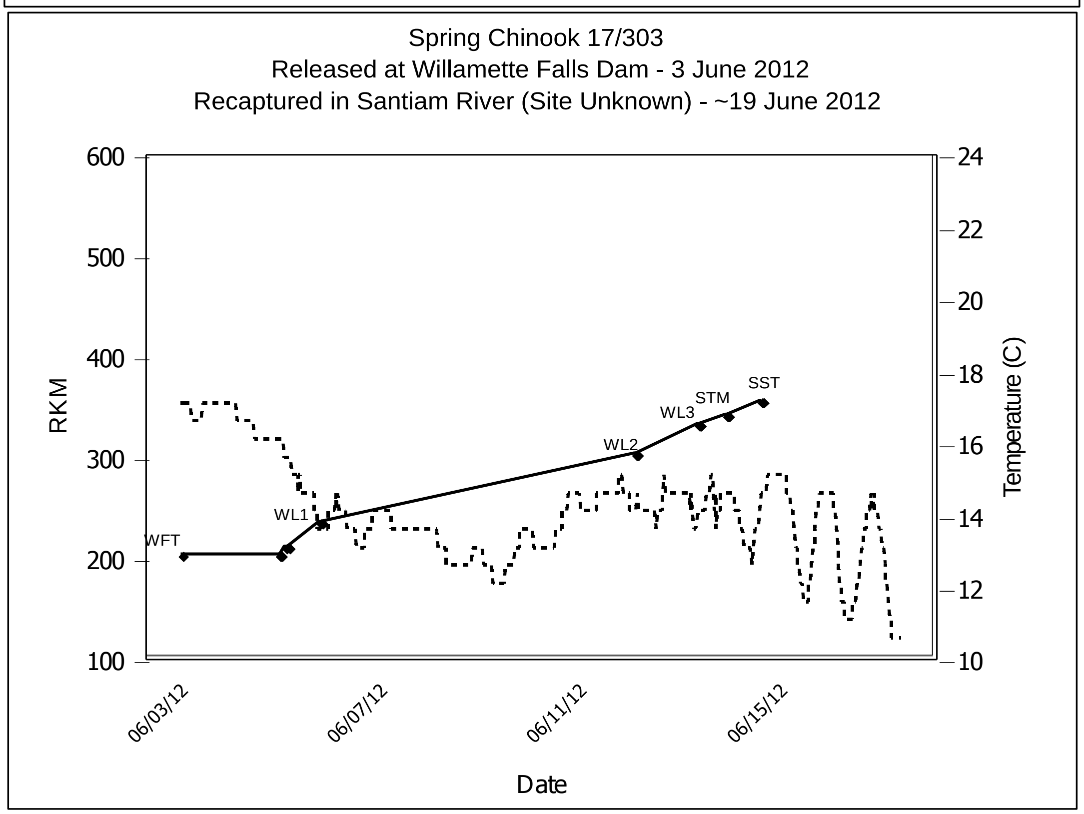
Thomson, R. E., and R. A. S. Hourston. 2011. A matter of timing: the role of ocean conditions in the initiation of spawning migration by late-run Fraser River sockeye salmon (*Oncorhynchus nerka*). Fisheries Oceanography 20:47-6

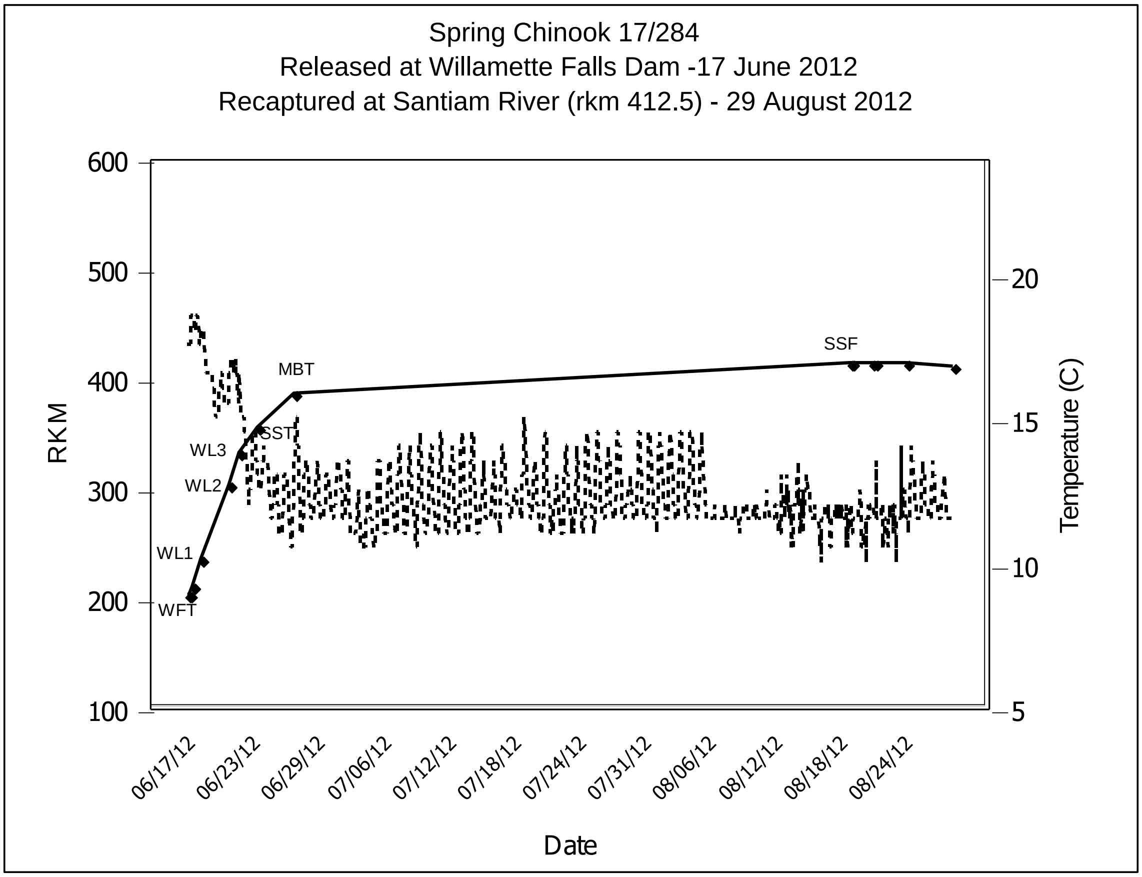
Tinus, C. A., and T. A. Friesen. 2010. Summer and winter steelhead in the Upper Willamette Basin: current knowledge, data needs, and recommendations. Technical report to U.S. Army Corps of Engineers. ODFW, Corvallis, OR.

Appendix

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


Spring Chinook 17/272
Released at Willamette Falls Dam -18 June 2012
Recaptured in North Santiam (Unknown Site) - 29 August 2012
RKM
Temperature (C)
Date
WFT
Exits Dam
Ascends Dam
WL2
WL3
STM
STN
NS2
06/18/12
06/24/12
06/30/12
07/06/12
07/13/12
07/19/12
07/25/12
07/31/12


Spring Chinook 17/303
Released at Willamette Falls Dam - 3 June 2012
Recaptured in Santiam River (Site Unknown) - ~19 June 2012
RKM
Temperature (C)
Date
WFT
WL1
WL2
WL3
STM
SST
06/03/12
06/07/12
06/11/12
06/15/12


Spring Chinook 17/284
Released at Willamette Falls Dam -17 June 2012
Recaptured at Santiam River (rkm 412.5) - 29 August 2012
RKM
Temperature (C)
Date
WFT
WL1
WL2
WL3
SST
MBT
SSF
600
500
400
300
200
100
20
15
10
5
06/17/12
06/23/12
06/29/12
07/06/12
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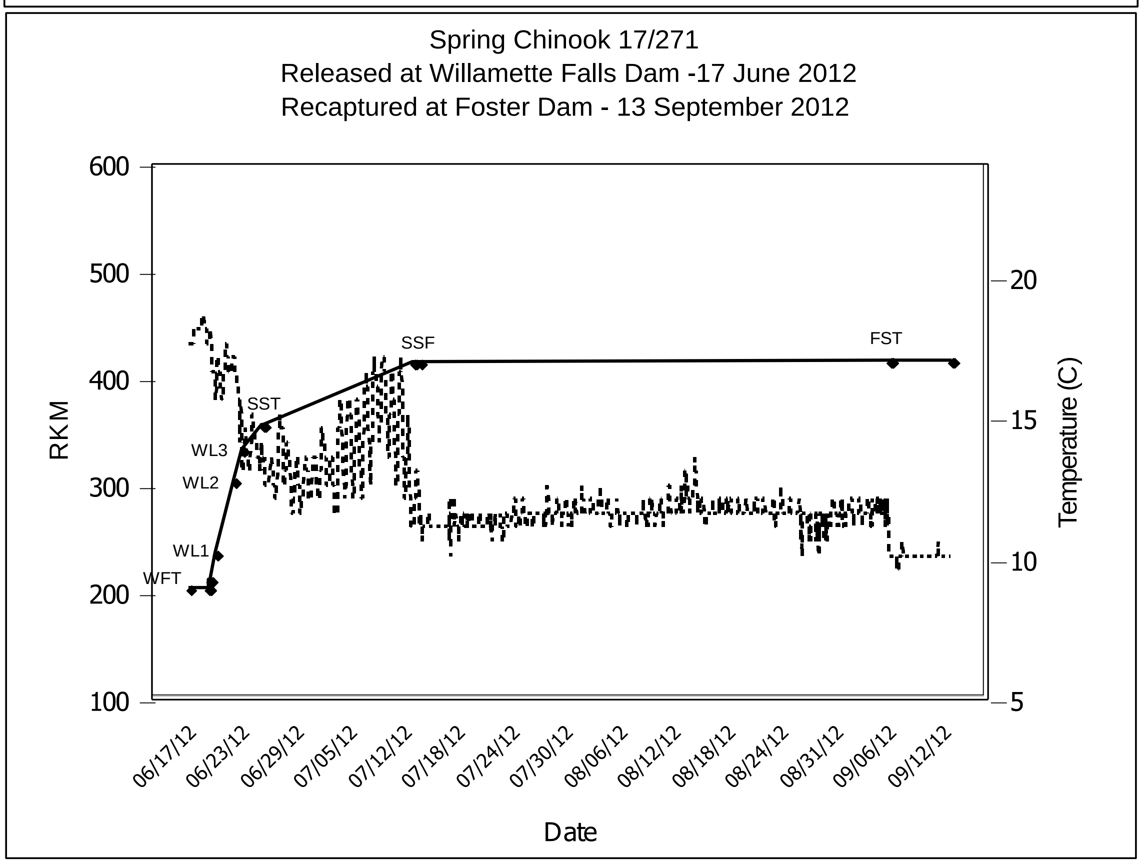
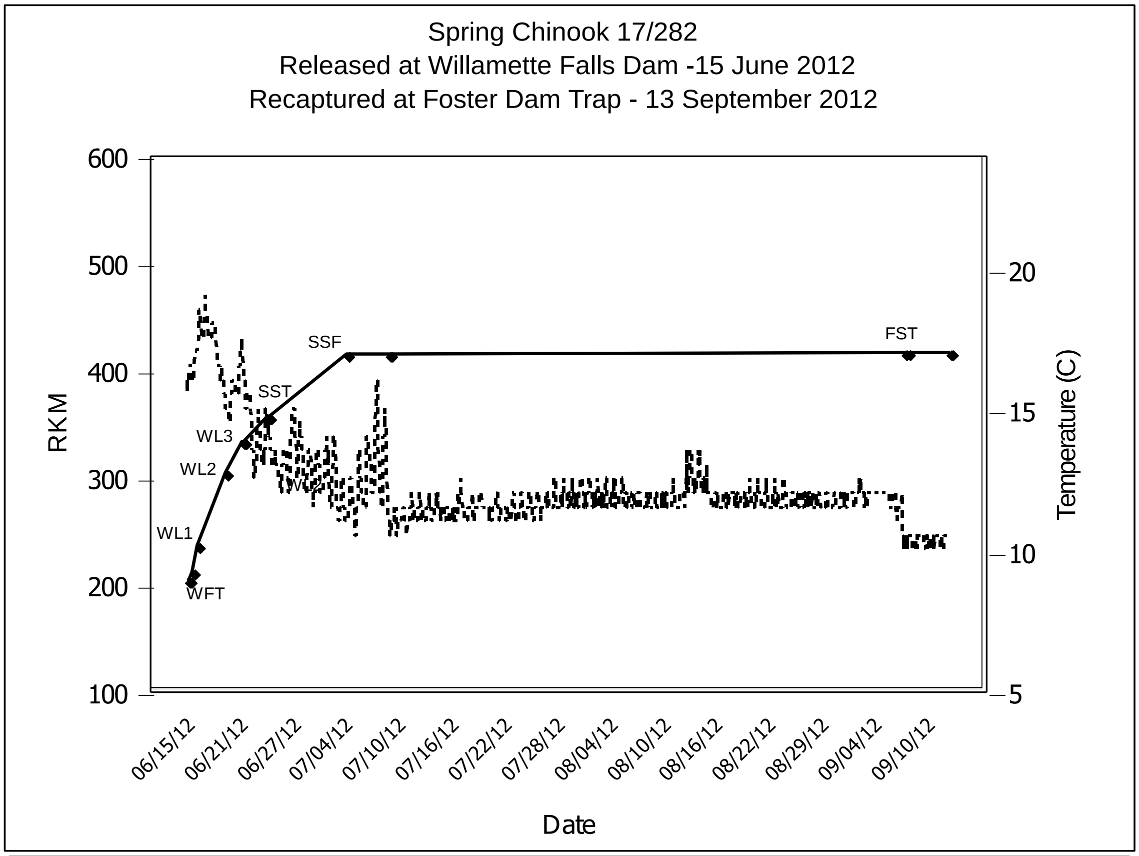
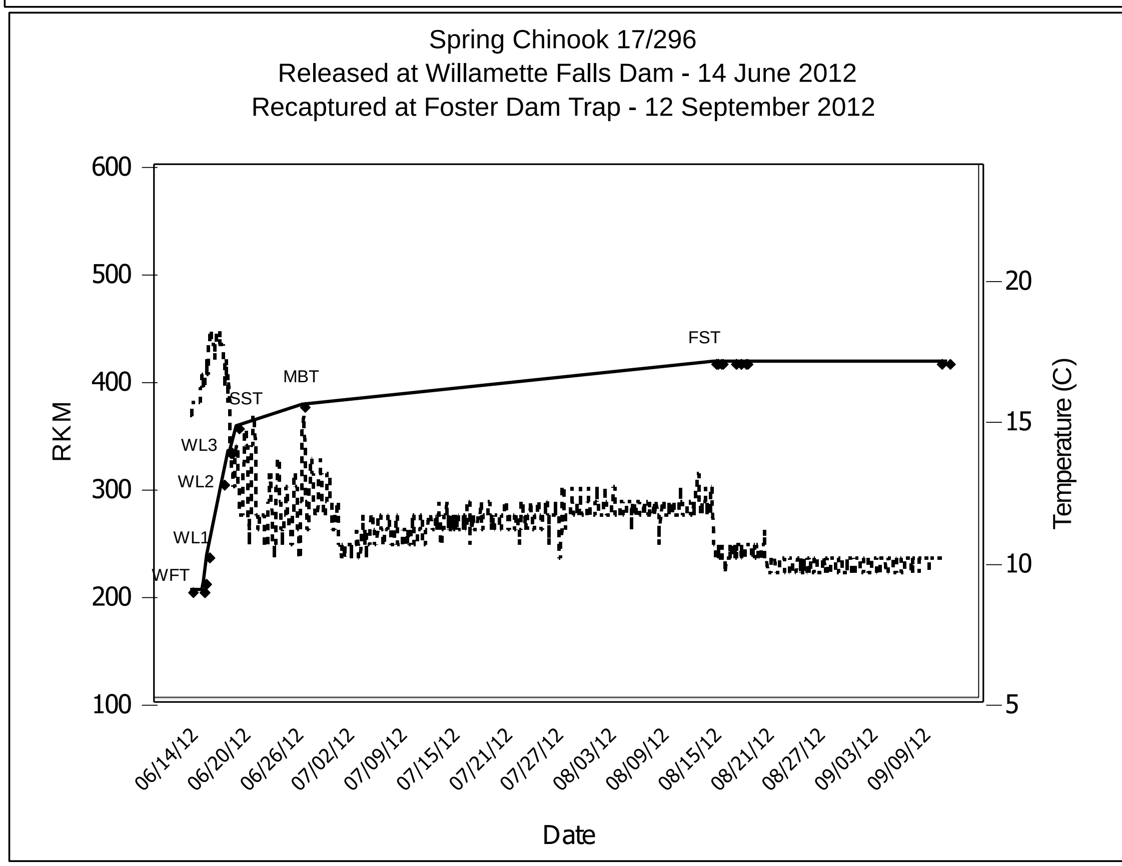
07/24/12
07/31/12
08/06/12
08/12/12
08/18/12
08/24/12

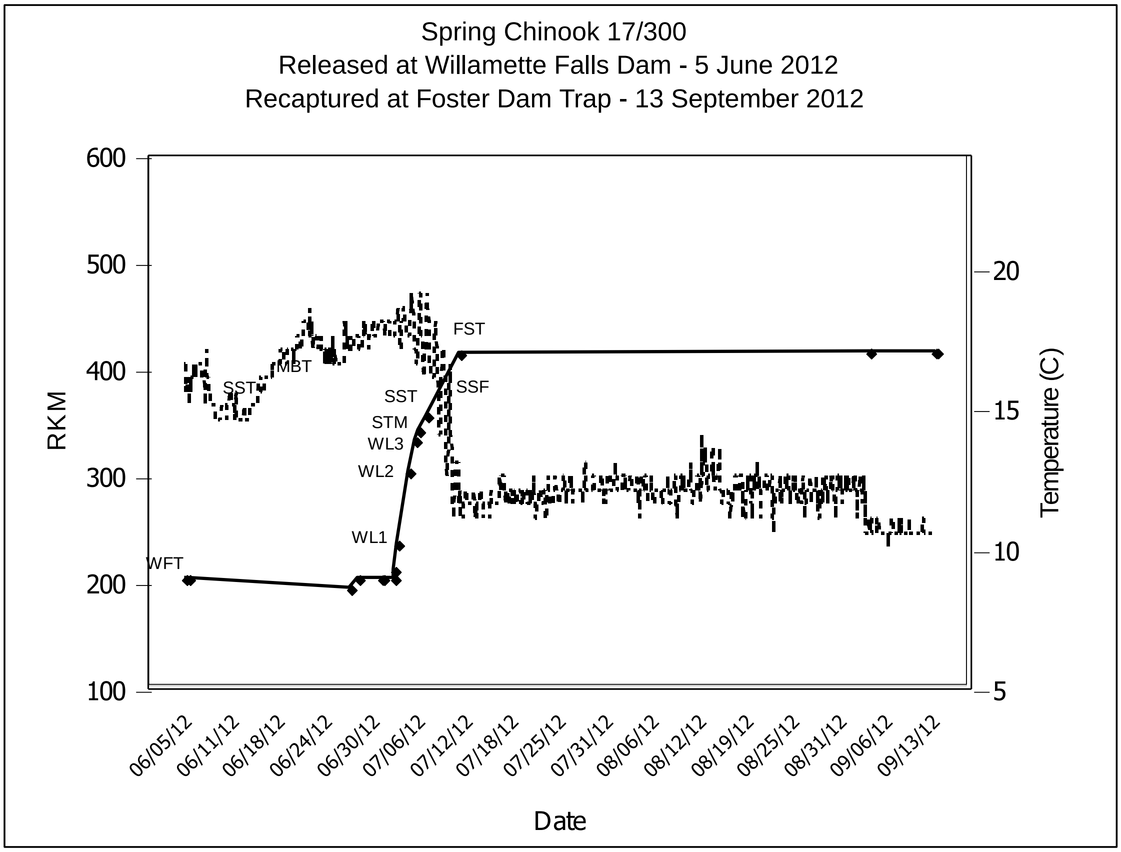

Spring Chinook 17/271
Released at Willamette Falls Dam -17 June 2012
Recaptured at Foster Dam - 13 September 2012
RKM
Temperature (C)
Date
WFT
WL1
WL2
WL3
SST
SSF
FST
600
500
400
300
200
100
20
15
10
5
06/17/12
06/23/12
06/29/12
07/05/12
07/12/12
07/18/12
07/24/12
07/30/12
08/06/12
08/12/12
08/18/12
08/24/12
08/31/12
09/06/12
09/12/12

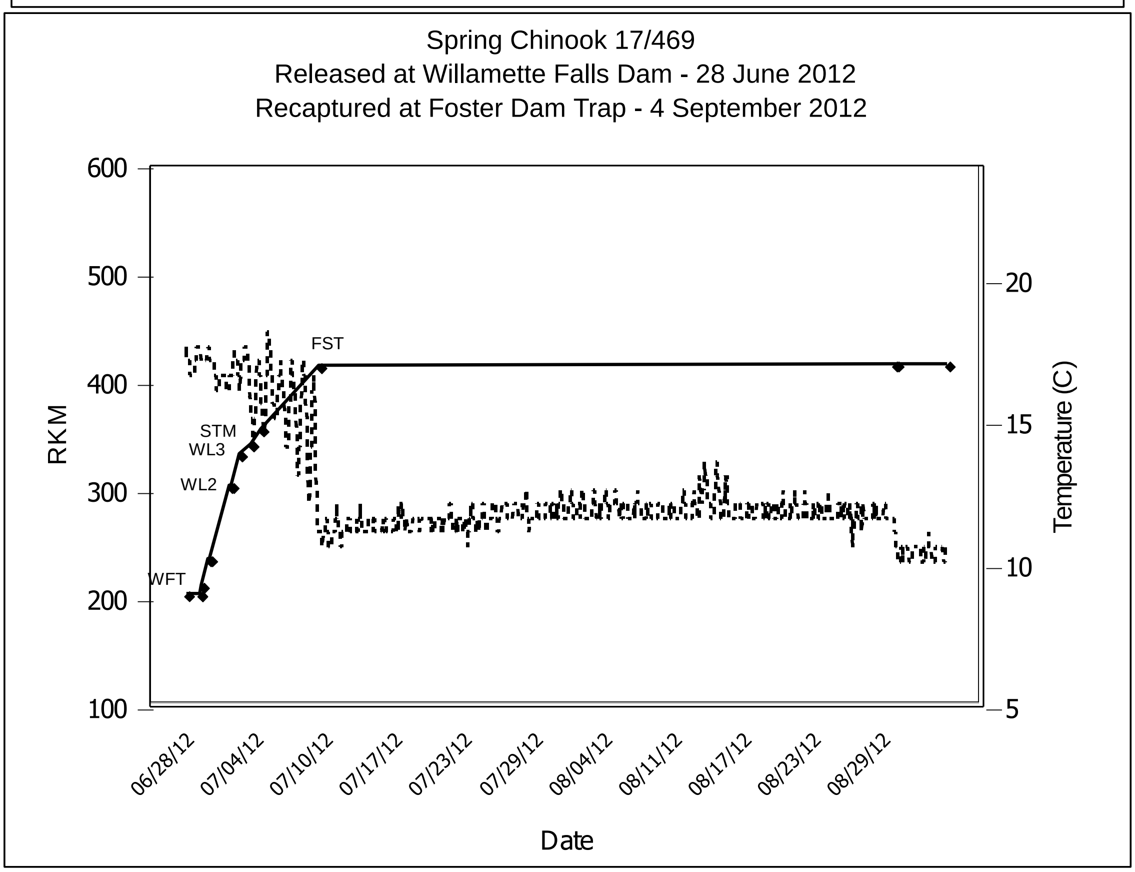


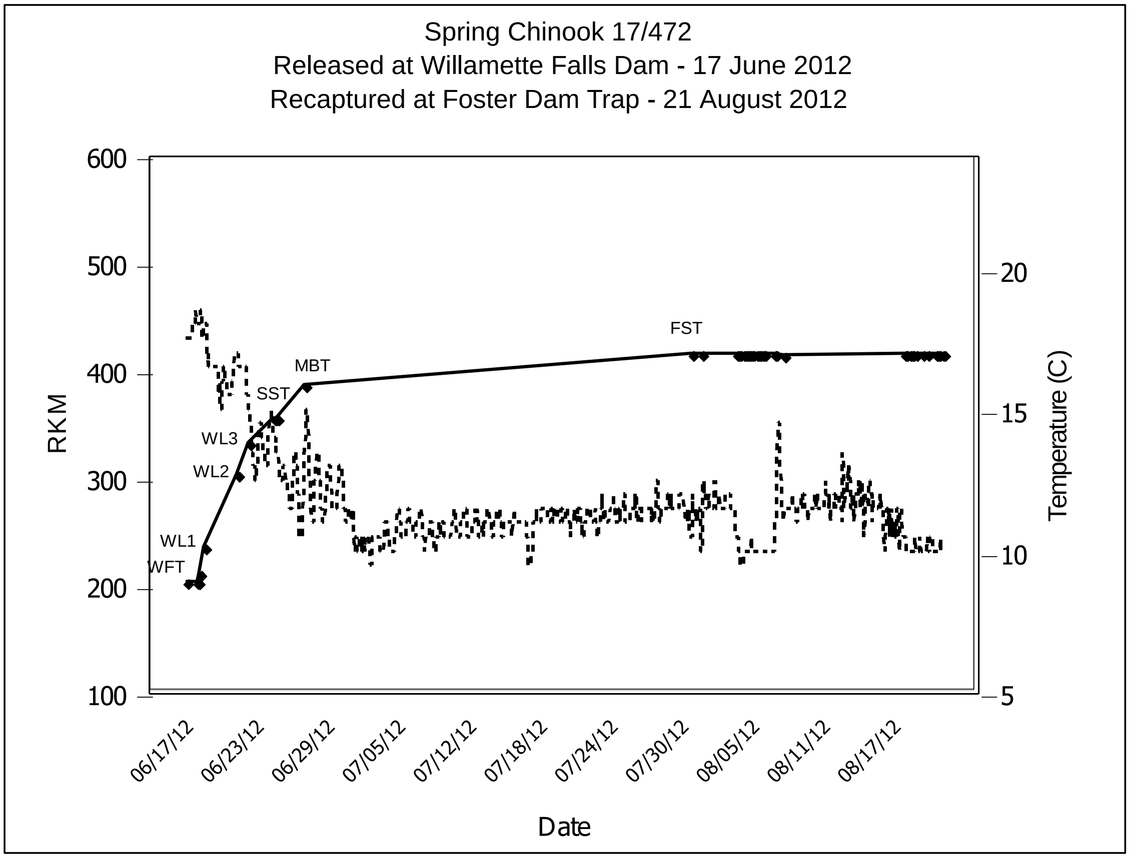
Spring Chinook 17/282
Released at Willamette Falls Dam -15 June 2012
Recaptured at Foster Dam Trap - 13 September 2012



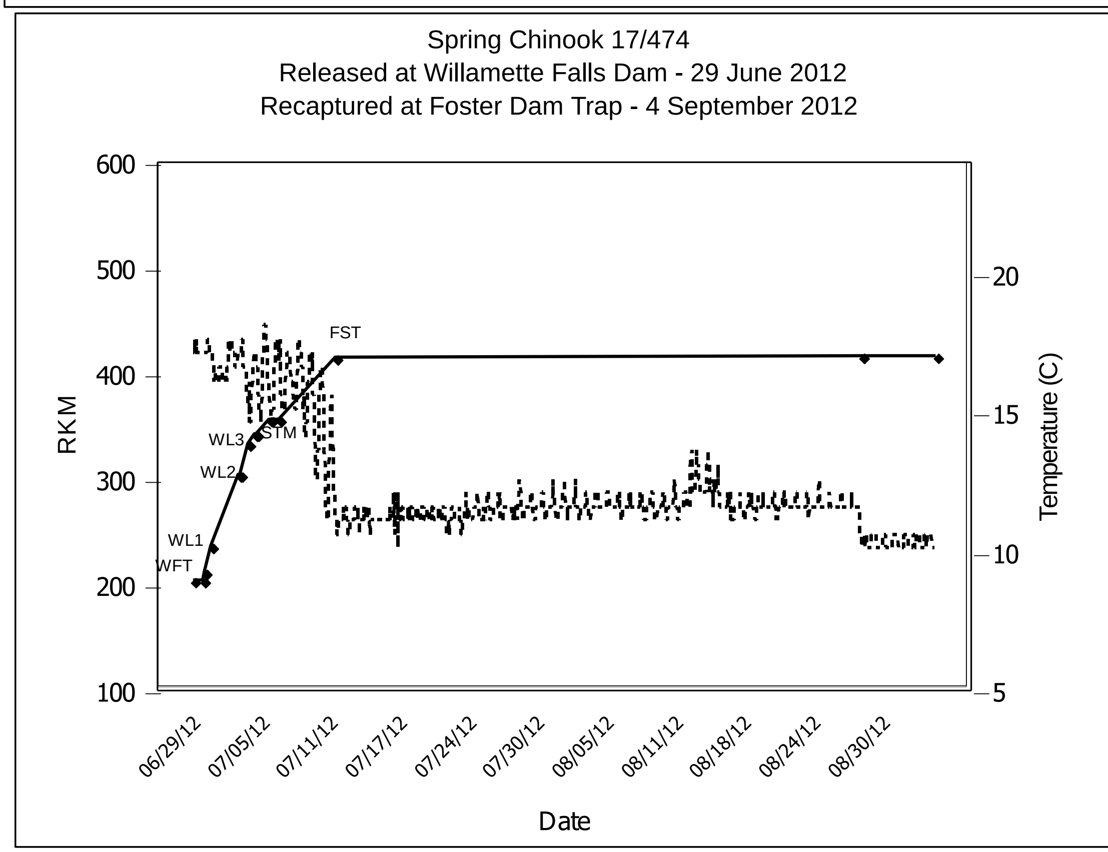
Spring Chinook 17/296
Released at Willamette Falls Dam - 14 June 2012
Recaptured at Foster Dam Trap - 12 September 2012


Spring Chinook 17/300
Released at Willamette Falls Dam - 5 June 2012
Recaptured at Foster Dam Trap - 13 September 2012
RKM
Temperature (C)
Date
600
500
400
300
200
100
20
15
10
5
06/05/12
06/11/12
06/18/12
06/24/12
06/30/12
07/06/12
07/12/12
07/18/12
07/25/12
07/31/12
08/06/12
08/12/12
08/19/12
08/25/12
08/31/12
09/06/12
09/13/12
WFT
SST
MBT
SST
STM
WL3
WL2
WL1
FST
SSF

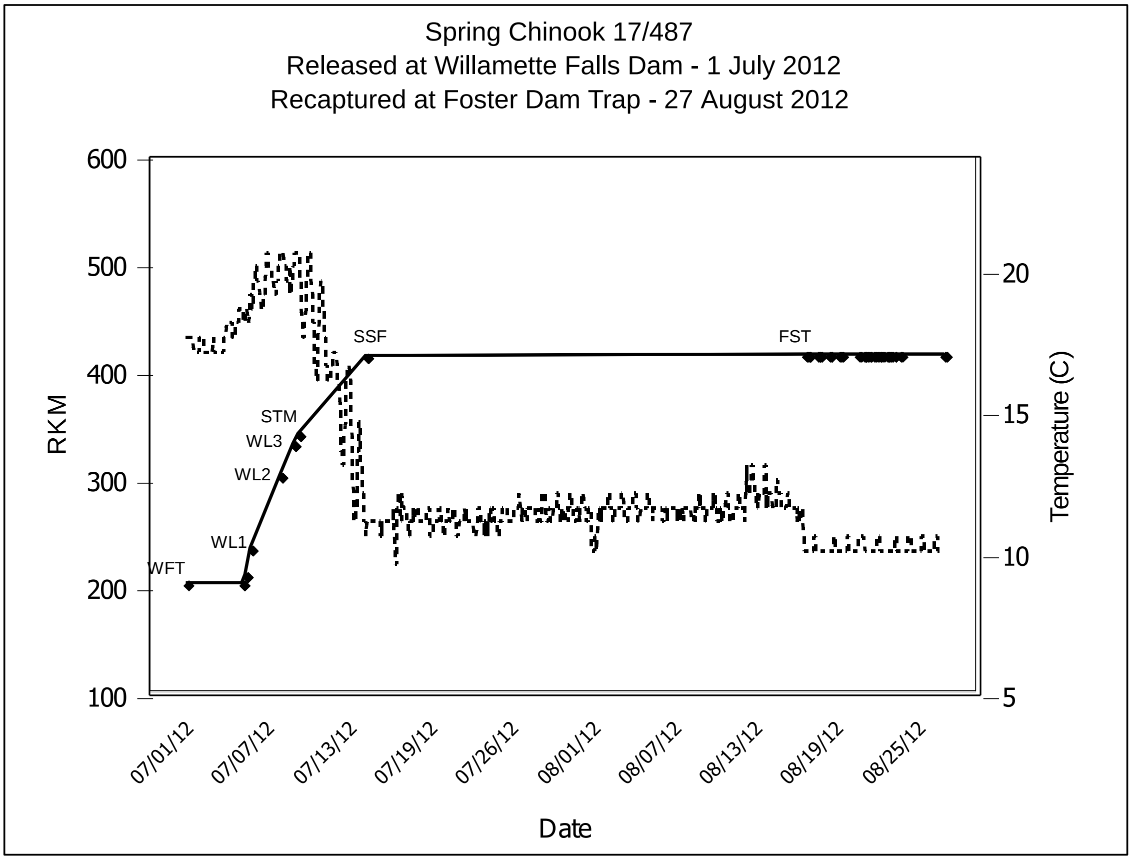

Spring Chinook 17/469
Released at Willamette Falls Dam - 28 June 2012
Recaptured at Foster Dam Trap - 4 September 2012
RKM
Temperature (C)
Date
600
500
400
300
200
100
20
15
10
5
06/28/12
07/04/12
07/10/12
07/17/12
07/23/12
07/29/12
08/04/12
08/11/12
08/17/12
08/23/12
08/29/12
WFT
WL2
WL3
STM
FST

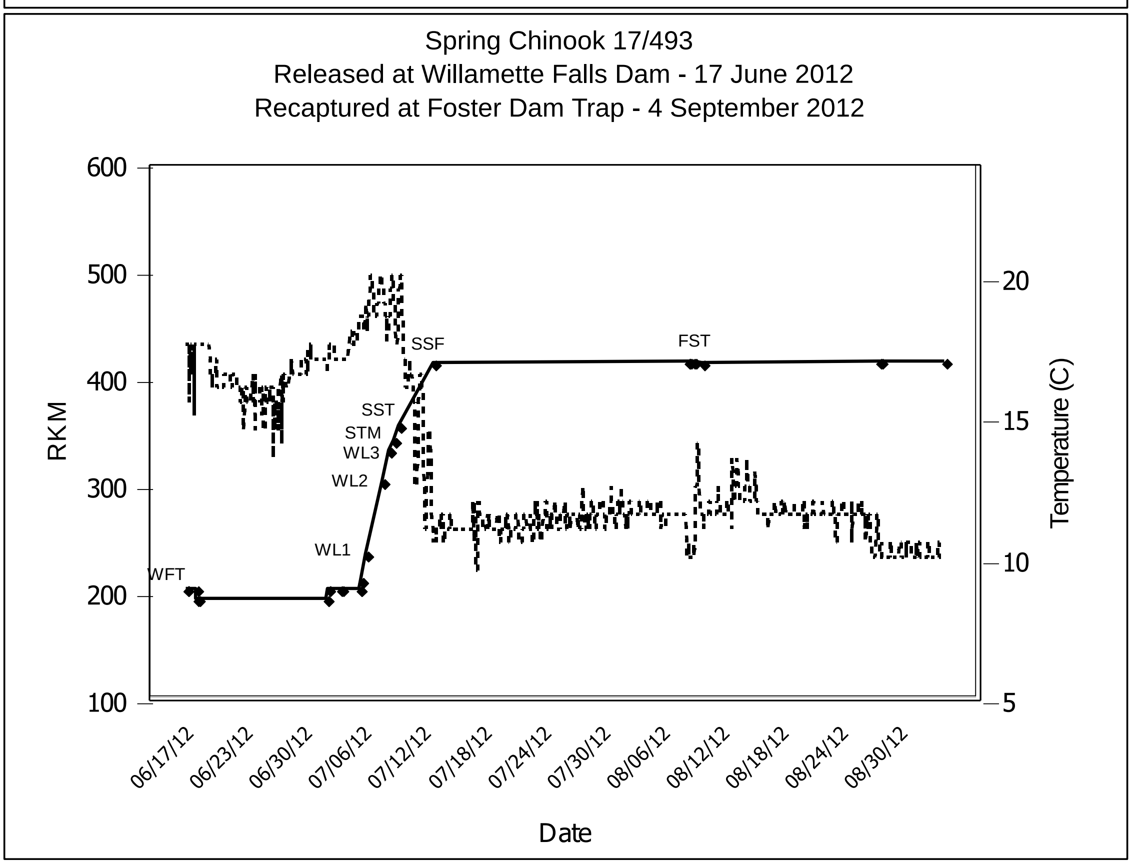


Spring Chinook 17/472
Released at Willamette Falls Dam - 17 June 2012
Recaptured at Foster Dam Trap - 21 August 2012
RKM
Temperature (C)
Date
WFT
WL1
WL2
WL3
SST
MBT
FST
600
500
400
300
200
100
20
15
10
5
06/17/12
06/23/12
06/29/12
07/05/12
07/12/12
07/18/12
07/24/12
07/30/12
08/05/12
08/11/12
08/17/12



Spring Chinook 17/474
Released at Willamette Falls Dam - 29 June 2012
Recaptured at Foster Dam Trap - 4 September 2012
RKM
Temperature (C)
Date
WFT
WL1
WL2
WL3
STM
FST
600
500
400
300
200
100
20
15
10
5
06/29/12
07/05/12
07/11/12
07/17/12
07/24/12
07/30/12
08/05/12
08/11/12
08/18/12
08/24/12
08/30/12


Spring Chinook 17/487
Released at Willamette Falls Dam - 1 July 2012
Recaptured at Foster Dam Trap - 27 August 2012
600
500
400
300
200
100
RKM
20
15
10
5
Temperature (C)
WFT
WL1
WL2
WL3
STM
SSF
FST
07/01/12
07/07/12
07/13/12
07/19/12
07/26/12
08/01/12
08/07/12
08/13/12
08/19/12
08/25/12
Date


Spring Chinook 17/493
Released at Willamette Falls Dam - 17 June 2012
Recaptured at Foster Dam Trap - 4 September 2012
600
500
400
300
200
100
RKM
20
15
10
5
Temperature (C)
WFT
WL1
WL2
WL3
STM
SST
SSF
FST
06/17/12
06/23/12
06/30/12
07/06/12
07/12/12
07/18/12
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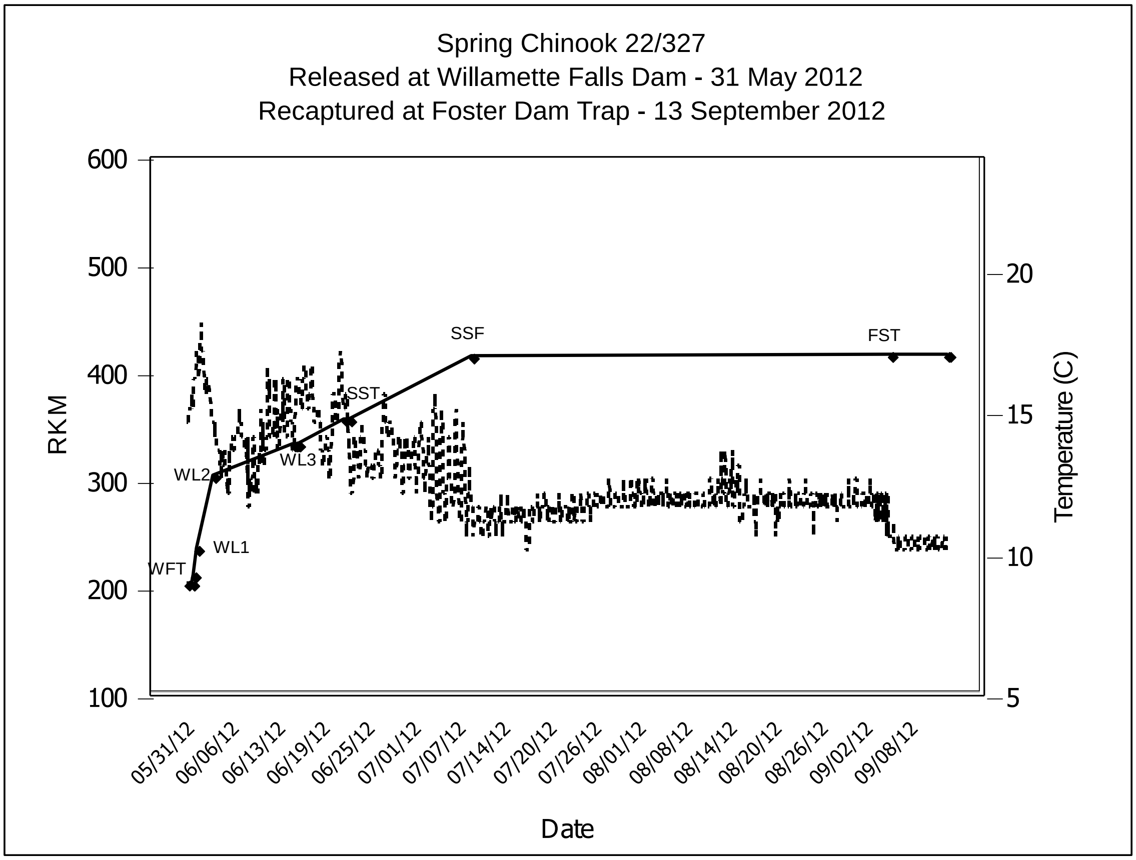
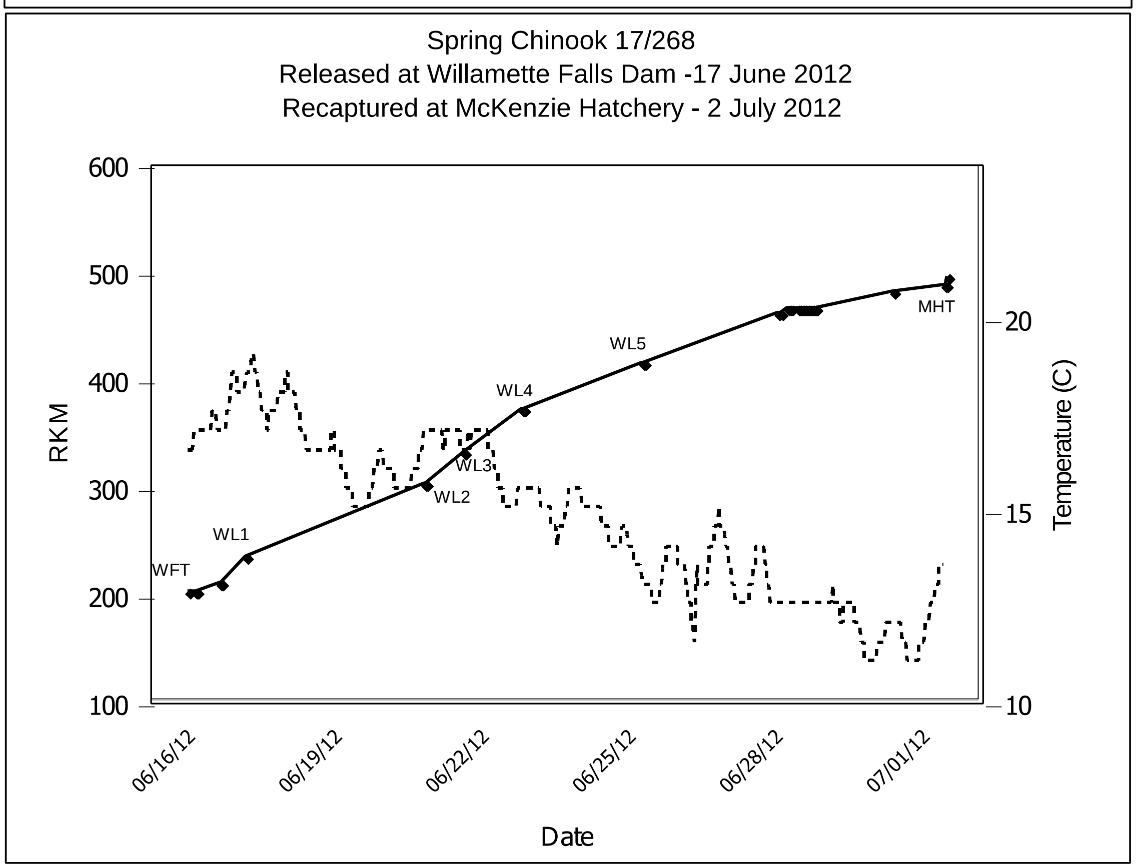
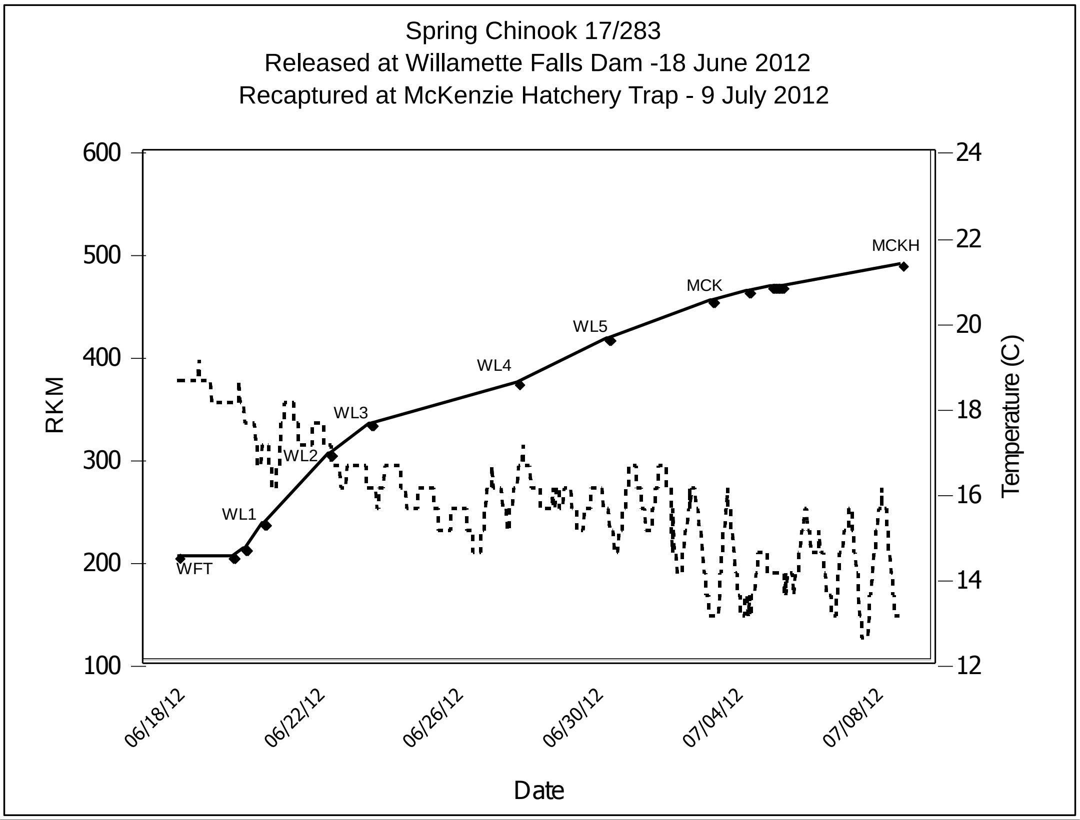
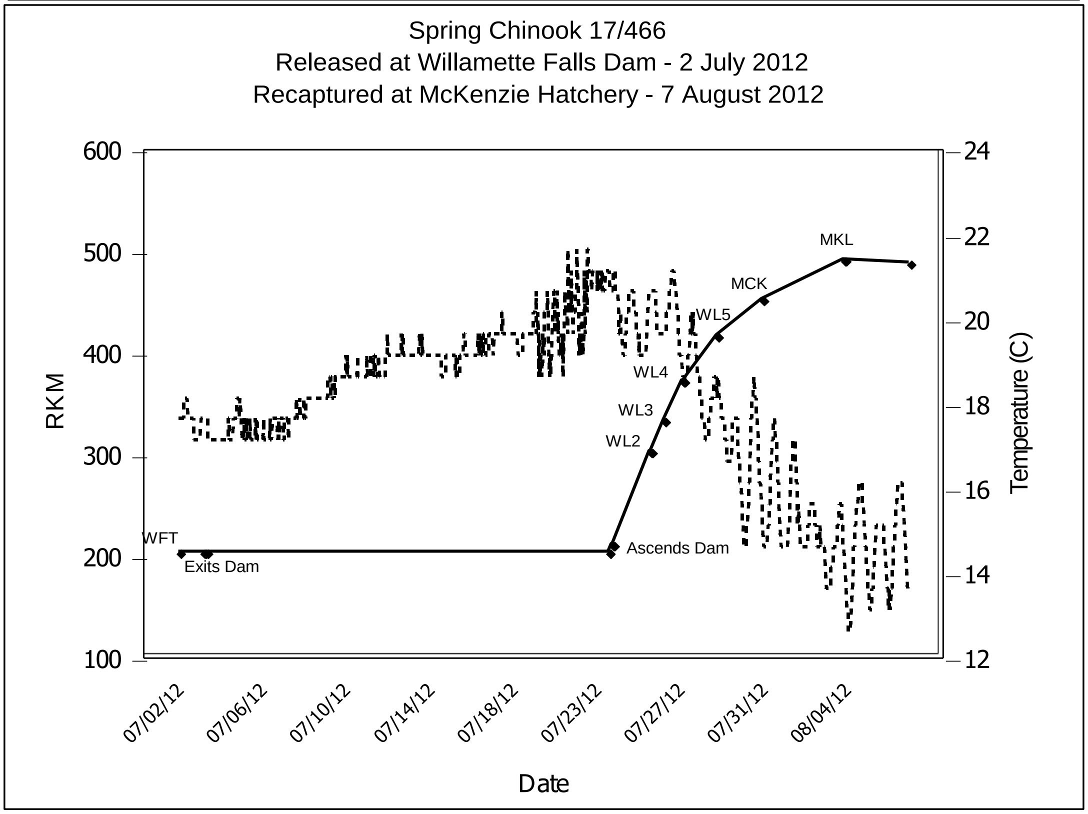
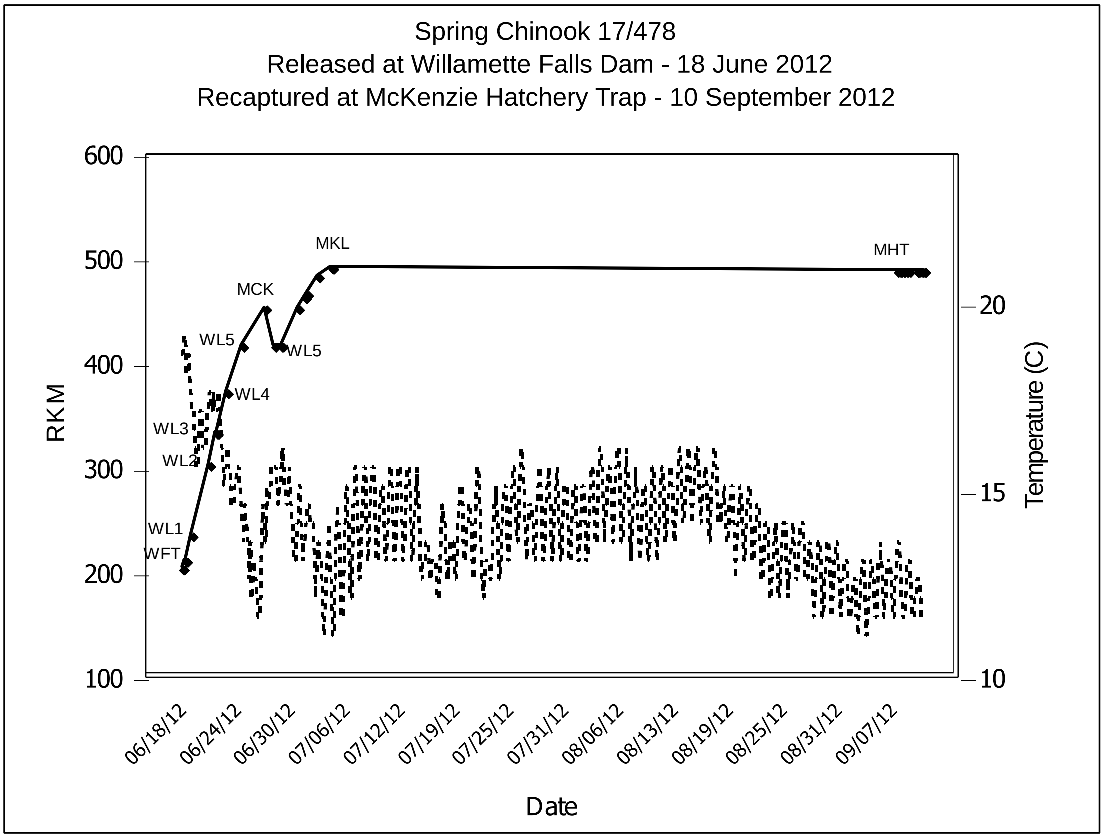
07/30/12
08/06/12
08/12/12
08/18/12
08/24/12
08/30/12
Date


Spring Chinook 22/327
Released at Willamette Falls Dam - 31 May 2012
Recaptured at Foster Dam Trap - 13 September 2012
RKM
Temperature (C)
Date
WFT
WL1
WL2
WL3
SST
SSF
FST
05/31/12
06/06/12
06/13/12
06/19/12
06/25/12
07/01/12
07/07/12
07/14/12
07/20/12
07/26/12
08/01/12
08/08/12
08/14/12
08/20/12
08/26/12
09/02/12
09/08/12


Spring Chinook 17/268
Released at Willamette Falls Dam -17 June 2012
Recaptured at McKenzie Hatchery - 2 July 2012
RKM
Temperature (C)
Date
WFT
WL1
WL2
WL3
WL4
WL5
MHT
06/16/12
06/19/12
06/22/12
06/25/12
06/28/12
07/01/12


Spring Chinook 17/283
Released at Willamette Falls Dam -18 June 2012
Recaptured at McKenzie Hatchery Trap - 9 July 2012
RKM
Temperature (C)
Date
WFT
WL1
WL2
WL3
WL4
WL5
MCK
MCKH
600
500
400
300
200
100
24
22
20
18
16
14
12
06/18/12
06/22/12
06/26/12
06/30/12
07/04/12
07/08/12


Spring Chinook 17/466
Released at Willamette Falls Dam - 2 July 2012
Recaptured at McKenzie Hatchery - 7 August 2012
RKM
Temperature (C)
Date
WFT
Exits Dam
Ascends Dam
WL2
WL3
WL4
WL5
MCK
MKL
600
500
400
300
200
100
24
22
20
18
16
14
12
07/02/12
07/06/12
07/10/12
07/14/12
07/18/12
07/23/12
07/27/12
07/31/12
08/04/12


Spring Chinook 17/478
Released at Willamette Falls Dam - 18 June 2012
Recaptured at McKenzie Hatchery Trap - 10 September 2012
RKM
Temperature (C)
Date
600
500
400
300
200
100
20
15
10
MKL
MHT
MCK
WL5
WL5
WL4
WL3
WL2
WL1
WFT
06/18/12
06/24/12
06/30/12
07/06/12
07/12/12
07/19/12
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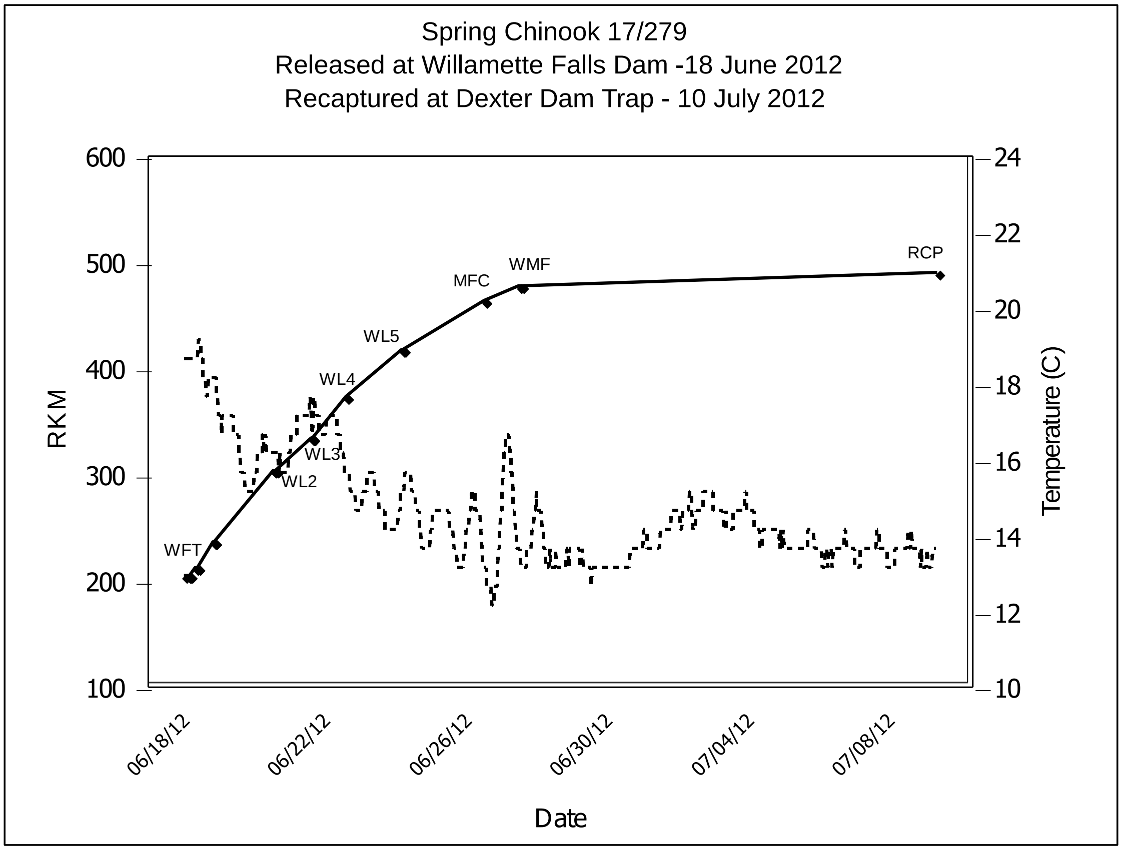
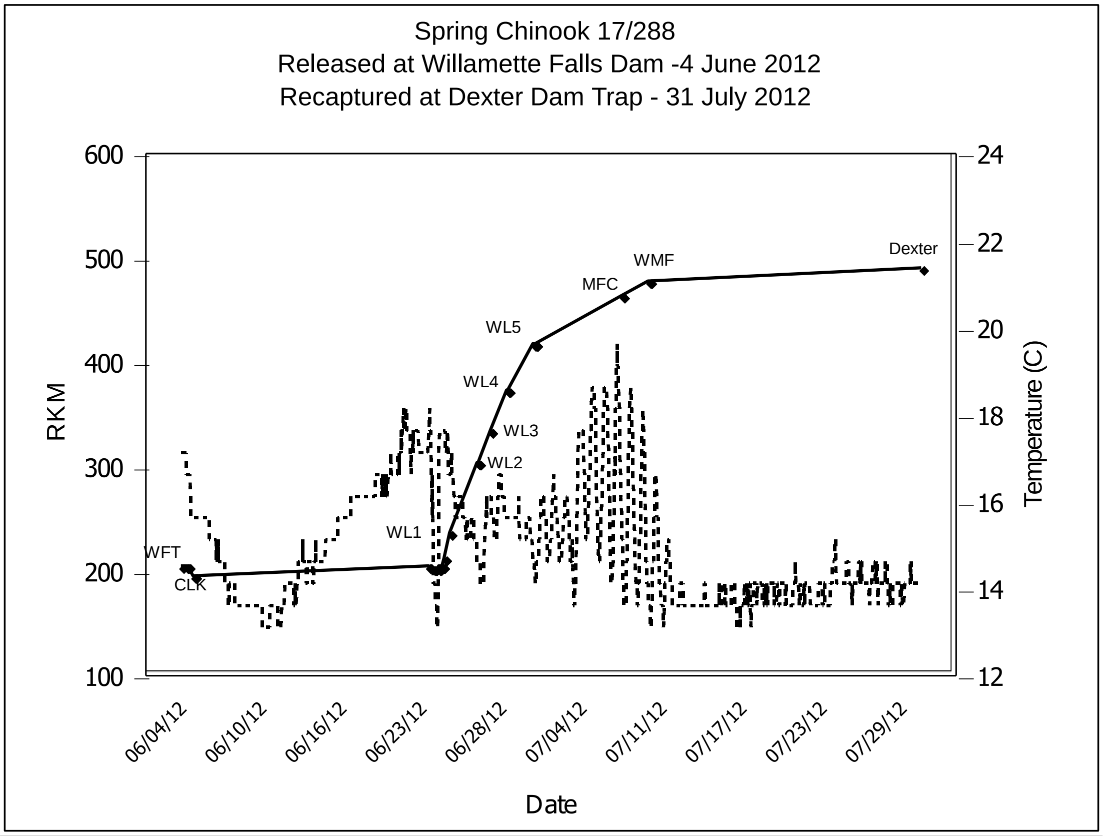
08/31/12
09/07/12


Spring Chinook 17/279
Released at Willamette Falls Dam -18 June 2012
Recaptured at Dexter Dam Trap - 10 July 2012
RKM
Temperature (C)
Date
600
500
400
300
200
100
24
22
20
18
16
14
12
10
RCP
WMF
MFC
WL5
WL4
WL3
WL2
WFT
06/18/12
06/22/12
06/26/12
06/30/12
07/04/12
07/08/12


Spring Chinook 17/288
Released at Willamette Falls Dam -4 June 2012
Recaptured at Dexter Dam Trap - 31 July 2012
RKM
Temperature (C)
Date
WFT
CLK
WL1
WL2
WL3
WL4
WL5
MFC
WMF
Dexter
06/04/12
06/10/12
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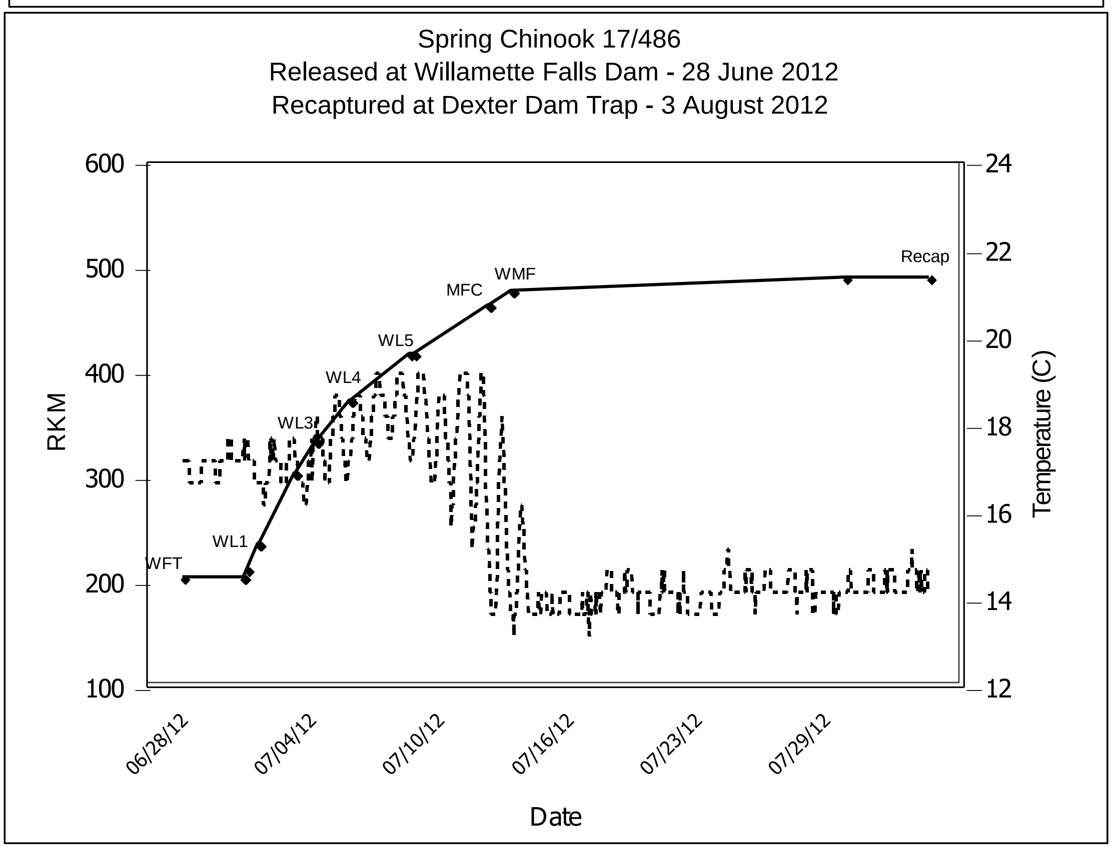
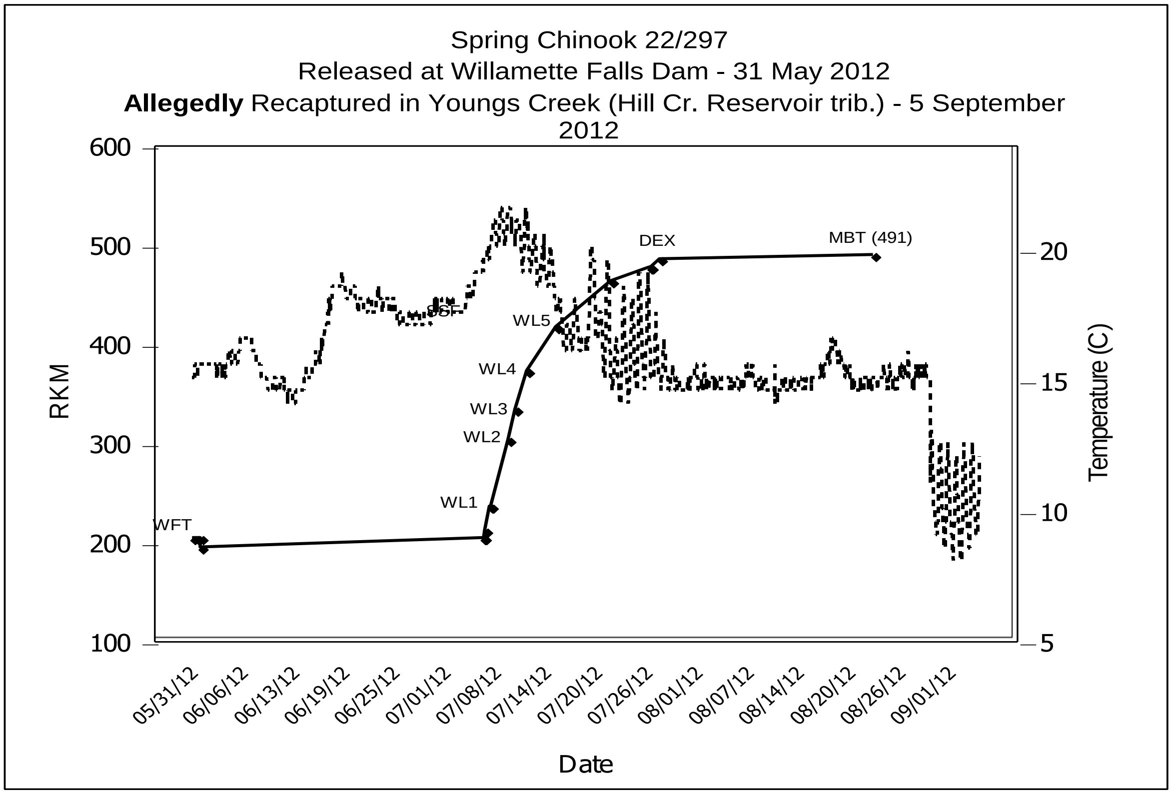
07/17/12
07/23/12
07/29/12


Spring Chinook 17/486
Released at Willamette Falls Dam - 28 June 2012
Recaptured at Dexter Dam Trap - 3 August 2012
RKM
Temperature (C)
Date
WFT
WL1
WL3
WL4
WL5
MFC
WMF
Recap
06/28/12
07/04/12
07/10/12
07/16/12
07/23/12
07/29/12


Spring Chinook 22/297
Released at Willamette Falls Dam - 31 May 2012
Allegedly Recaptured in Youngs Creek (Hill Cr. Reservoir trib.) - 5 September 2012
RKM
Temperature (C)
Date
WFT
WL1
WL2
WL3
WL4
WL5
DEX
MBT (491)
600
500
400
300
200
100
20
15
10
5
05/31/12
06/06/12
06/13/12
06/19/12
06/25/12
07/01/12
07/08/12
07/14/12
07/20/12
07/26/12
08/01/12
08/07/12
08/14/12
08/20/12
08/26/12
09/01/12