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MIGRATION, SURVIVAL, GROWTH, AND FATE OF HATCHERY JUVENILE CHINOOK SALMON RELEASED ABOVE AND BELOW DAMS IN THE WILLAMETTE RIVER BASIN

Prepared for

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Summary

Spring Chinook salmon *Oncorhynchus tshawytcha* in the Willamette River have decreased throughout the last century to levels warranting listing by the National Marine Fisheries Service as Threatened under the Endangered Species Act. A primary factor in this decline are Willamette Valley Project dams which block access to a substantial portion of historic spawning areas. Transporting (outplanting) adults above dams has led to some spawning success but the impacts of the projects on the ability of juvenile salmon to successfully outmigrate and survive to adulthood are not completely known. To evaluate the effects of Willamette Valley Project dams on downstream passage and adult return of Chinook salmon, we released PIT-tagged juvenile hatchery fish above and below dams on the Middle Fork Willamette and North Santiam rivers. Information gathered from PIT tag detections at Willamette Falls and through other research projects in the Willamette and lower Columbia basins was used to assess differences in survival, movement rate, timing, and growth for juvenile Chinook salmon released above and below dams. Objectives of the work were to 1) estimate the effect that passage through Willamette Valley Project dams and reservoirs has on outmigration success (counts) and rate (distance/time) of juvenile spring Chinook salmon in the North Santiam and Middle Fork Willamette rivers; 2) estimate the effect that passage through dams and reservoirs has on survivorship to adulthood for juvenile spring Chinook salmon in the North Santiam and Middle Fork Willamette rivers; 3) where possible, determine growth rates of recaptured PIT-tagged Chinook salmon and describe differences in growth among release groups by subbasin, and 4) where possible, describe the fate of PIT-tagged fish (e.g., lost to predation, captured in fisheries).

From 2011 to 2013, we released approximately 430,000 PIT-tagged juvenile hatchery spring Chinook salmon in the Middle Fork Willamette and North Santiam rivers. Fish were released into the Middle Fork Willamette River at Hills Creek Reservoir (HCR), Lookout Point (LOP) head of reservoir (HOR), LOP forebay (FB), and Dexter Dam tailrace (TR). In the North Santiam River fish were released at Detroit HOR, Detroit FB, and Minto Dam TR.

We used data from PIT tag detections at Willamette Falls to evaluate juvenile outmigration timing and survival for the different release groups within each year. In total, 2.05% (N=6,251) of the Middle Fork Willamette (MFW) and 3.84% (N=4,792) of the North Santiam (NS) releases were detected at Willamette Falls. Detection proportions for fish released above and below dams differed significantly from expected values with greater detection proportions observed for below dam releases across all years and basins. The magnitude of differences was consistently greater in the MFW than the NS. In the MFW, excluding HCR releases, effect sizes (the percent difference in detections) for below dam versus above dam release comparisons ranged from 60-81% among years from 2011-2013. In the NS, detection proportion effect sizes for below dam versus above dam release comparisons were 15% (2012) and 41% (2013). The discrepancy in effect sizes between basins suggests that the generalized effects of reservoir and dam passage are more serious in the Middle Fork Willamette River than the North Santiam River. The dam passage effect is likely compounded by distance from release to the dam and passage through multiple dams, as evidenced by decreasing detection proportions by release site moving up-river in both basins and the very low detection of HCR fish.

Detections at Willamette Falls were also used to estimate movement rates (km/d post-release) and evaluate possible delay effects from dams and reservoirs. Movement rates were calculated as the distance (km) traveled from release location to detection at the falls, divided by the number of days at large between release and detection. With the exception of the 2011 MFW and 2013 NS FB releases, movement rates for below-dam releases were significantly greater than movement rates for above-dam releases across years and basins, suggesting a dam and reservoir delay effect. The 2011 MFW HOR (6.16 km/d) and 2013 NS FB (1.71 km/d) median movement rates did not significantly differ from the respective TR median movement rates (2011 MFW TR=5.38 km/d; 2013 NS TR=1.49 km/d) in those years. Median movement rates for 2012 and 2013 MFW releases ranged from 0.99-5.82 km/d and 0.97-6.20 km/d, respectively, while median movement rates for NS 2012 and 2013 releases ranged from 7.77-9.48 km/d and 1.39-1.71 km/d, respectively. Outmigration timing patterns were generally similar for MFW releases across years. Initial detections at Willamette Falls occurred in mid to late-June. Excluding the 2011 releases, there appeared to be a reservoir and dam impact on migration timing, with detection peaks at Willamette Falls for TR releases occurring in late July and detections for HOR and FB releases peaking in early August. The 2012 NS release group outmigration patterns were similar to what was observed in the MFW, with early detection peaks and likely dam and reservoir driven delays in outmigration for HOR releases. Initial peak detections for all 2013 NS release groups, however, were not observed until approximately three months after release and notable secondary peaks were evident in all release groups, with the peak timing delayed for the FB and HOR releases.

Recapture and mortality information for fish released in the MFW and NS were reported in the PIT tag information system (PTAGIS). Recaptures occurred during Oregon Department of Fish and Wildlife (ODFW) and U.S. Army Corps of Engineers (USACE) projects in the release basins; ODFW research activities, particularly projects incorporating gillnets, were relatively major contributors to known mortalities of study fish. Recapture and research related mortality data were used to generate growth estimates (mm/d fork length) when length measurements were taken. Growth rates were estimated by dividing change in fork length (FL) between initial tagging length and recapture/mortality length by days at large between tagging and recapture or mortality event. With the exception of MFW HCR 2013 releases, above-dam releases had significantly greater growth rates than fish released below dams across years and basins, suggesting superior growth in the reservoirs. Though not significantly different, the median growth rate for 2013 HCR-released fish appeared to be larger than the median growth rate for the 2013 MFW TR-released fish. A comparison of growth rates was not possible for the 2013 NS releases, as no TR-released fish were recaptured or collected. For MFW 2011 releases, median growth rates ranged from 0.65-0.73 mm/d while MFW 2012 and 2013 median growth rates ranged from 0.31-0.97 mm/d and 0.47-0.90 mm/d, respectively. For the NS releases, 2012 median growth rates ranged from 0.17-0.78 mm/d and 2013 median movement rates ranged from 0.68-0.71 mm/d.

Very few of the fish released for this study have returned as adults (through June 2014), with 11 of the MFW releases and 6 of the NS releases detected in the adult ladder at Willamette Falls. Three of the four adult returns from the 2011 releases were age-4 fish but only 0.03% of the 2011 releases have returned. There have not been enough adult returns to conduct a meaningful analysis of dam and reservoir effects on Chinook salmon survival to adulthood, but to date HOR releases have produced more adult returns (10) than TR releases (7).

Introduction

In 1999, the Upper Willamette River (UWR) spring Chinook salmon *Oncorhynchus tshawytscha* Evolutionarily Significant Unit (ESU) was listed as threatened under the U.S. Endangered Species Act (NMFS 1999), and this status was reaffirmed in 2005 (NMFS 2005). Historically among the most productive populations of the ESU, the Middle Fork Willamette River (MFW) population of spring Chinook salmon has suffered a precipitous decline during the past century, primarily caused by Willamette Valley Project (WVP) dams that blocked adult migrations to historical spawning grounds (Hutchison et al. 1966; NMFS 2008; Keefer et al. 2010). The National Marine Fisheries Service (NMFS) concluded in the 2008 Willamette Project Biological Opinion (BiOp) that the continued operation and maintenance of the WVP would jeopardize the continued existence of UWR Chinook salmon and winter steelhead *O. mykiss* (NMFS 2008). Reasonable and Prudent Alternatives (RPAs) 4.12.2 and 4.12.3 in the BiOp, among others, address downstream fish passage concerns.

Four WVP dams, operated by the U.S. Army Corps of Engineers (USACE), are present in the MFW subbasin (Figure 1). The MFW watershed encompasses 3,509 km^2 and joins the mainstem Willamette River at river kilometer (rkm) 299. Transport and release of adult Chinook salmon into historical MFW spawning grounds above Dexter and Lookout Point (LOP) reservoirs began in 1993 (NMFS 2008). Although these actions were originally intended to provide forage for native bull trout *Salvelinus confluentus* (Johnson and Friesen 2010), the ancillary benefit of augmenting natural production of Chinook salmon in the subbasin soon became a priority (NMFS 2008). Successful spawning above LOP Reservoir was particularly encouraging in light of high pre-spawn mortality and low egg survivorship observed below Dexter Dam (McLaughlin et al. 2008; NMFS 2008; Keefer et al. 2010). However, major challenges accompanied this novel approach towards recovery. For example, high but variable rates of pre-spawn mortality were observed for fish released above LOP Reservoir (Keefer et al. 2010). Perhaps most importantly, direct downstream passage through LOP and Dexter dams is thought to cause unacceptably high levels of juvenile mortality (NMFS 2008).

Similar to LOP and Dexter dams on the MFW, the construction of Detroit and Big Cliff dams (Figure 2) on the North Santiam River (NS) blocked access to an estimated 71% of historic Chinook salmon spawning habitat (Mattson 1948). The NS watershed encompasses 1,980 km^2 and flows into the Willamette River at rkm 174 after joining the South Santiam River. The Oregon Department of Fish and Wildlife (ODFW) began outplanting adult hatchery Chinook salmon above Detroit Dam in 2000 and recent studies confirmed that natural production occurs there (Monzyk et al. 2011; Romer et al. 2012). As with juvenile Chinook that outmigrate from habitats above LOP Reservoir, fish from the upper NS must pass through two WVP reservoirs and dams (Detroit and Big Cliff) before reaching the mainstem Willamette River. Little is known about the risks associated with reservoir and dam passage on the NS. However, research by Normandeau Associates, Inc. (2010) found that passage through the hydroelectric turbines of Detroit Dam resulted in significantly higher mortality for rainbow trout than other at-dam passage routes. Coded-wire tag data demonstrated that juvenile Chinook salmon released into

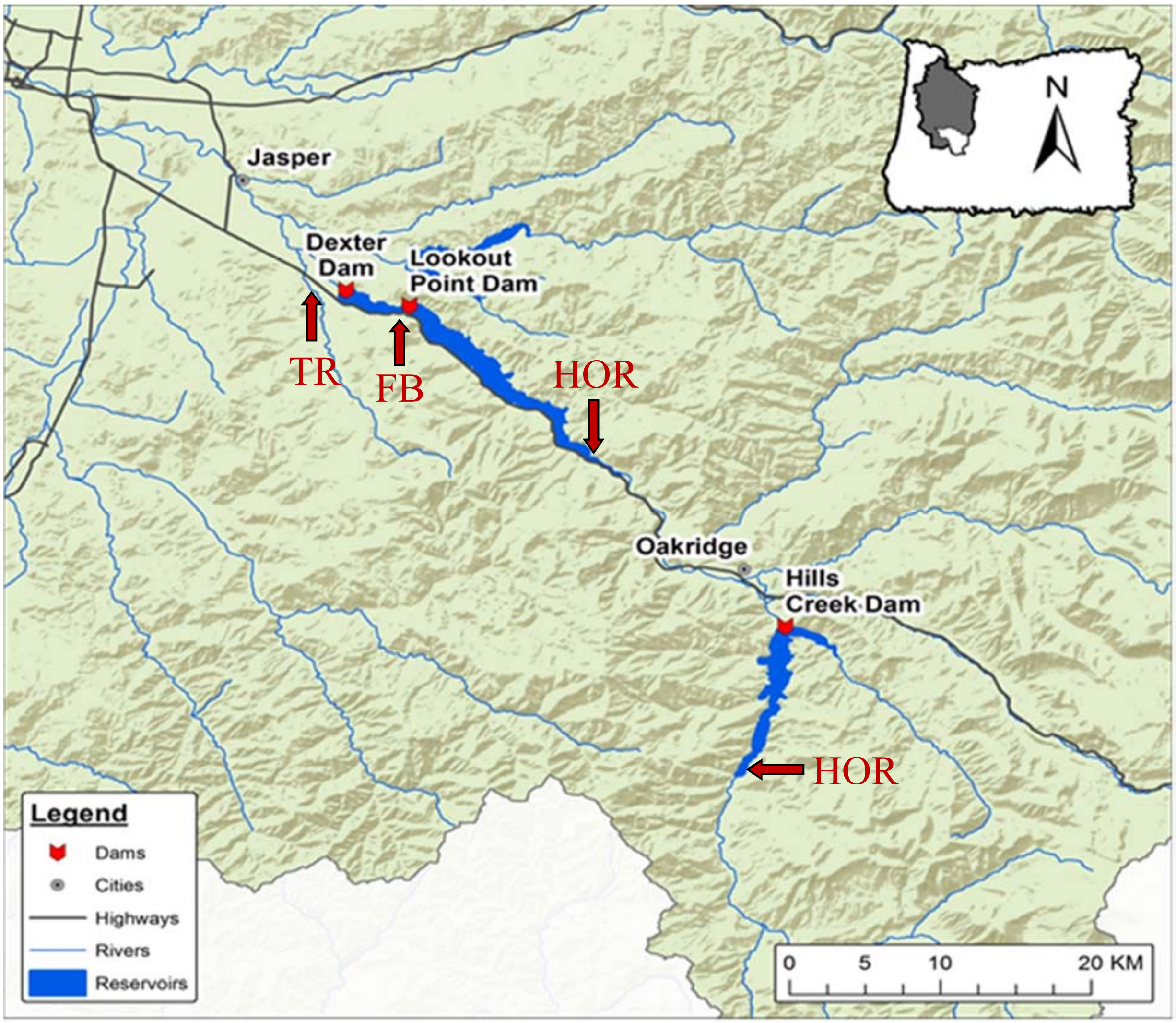

Figure 1. The Middle Fork Willamette River and reservoirs associated with US Army Corps of Engineers-operated dams. Arrows identify juvenile Chinook salmon release locations; HOR=head of reservoir, FB=forebay, and TR=tailrace.

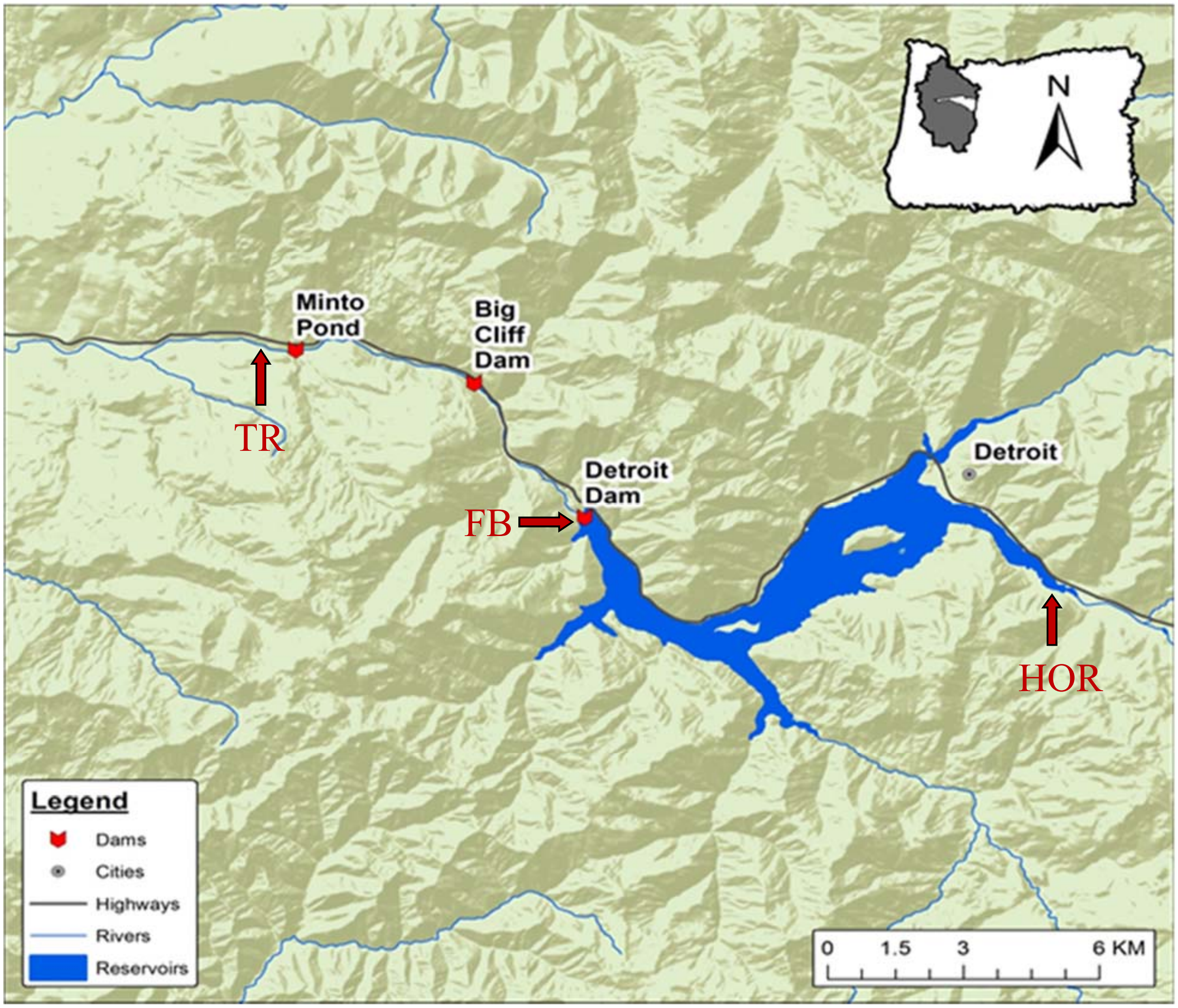

Figure 2. The North Santiam River and reservoirs associated with US Army Corps of Engineers-operated dams. Arrows identify juvenile Chinook salmon release locations; HOR=head of reservoir, FB=forebay, and TR=tailrace.

Detroit Reservoir were generally recovered at lower rates (as adults) than those released below Big Cliff Dam, though direct comparisons were hindered by differences in liberation date and fish size (ODFW, unpublished data).

Although adult collection, transport and release appear to provide a means for re-establishing natural salmon production above WVP dams, the absence of juvenile downstream passage facilities at LOP, Dexter, Hills Creek (HCR), Detroit, and Big Cliff dams represents a potentially serious threat to outmigrating juvenile salmonids in the NS and MFW subbasins (NMFS 2008). Currently, fish must pass through hydroelectric turbines or regulating outlets (Čada 2001; Muir et al. 2001; Ferguson et al. 2006). Spill passage is available at some dams (Detroit, Big Cliff, Lookout Point, and Dexter), though survival through these high-head spillways is also known to be low (e.g., Duncan and Carlson 2011). In addition, known and potential predators of juvenile salmonids including northern pikeminnow *Ptychocheilus oregonensis*, largemouth bass *Micropterus salmoides*, walleye *Sander vitreus*, rainbow trout, and cutthroat trout *O. clarkii* are present in the study area and may represent a substantial risk (Monzyk et al. 2011; Monzyk et al. 2012). Diet samples collected from crappie (*Pomoxis* spp.) in HCR and LOP reservoirs anecdotally suggested high levels of predation on PIT-tagged fish released for this study in 2012. Residualism of Chinook salmon in WVP reservoirs may also disrupt their natural life histories and elevate risks during at-dam passage. Recognizing these potential threats, NMFS (2008) recommended that Action Agencies assess juvenile fish passage through WVP reservoirs (RPA 4.10) and dams (RPA 4.11), as initial steps toward assessing and improving juvenile downstream passage.

One alternative to direct passage through reservoirs and dams is to collect juvenile fish at the head of reservoirs and transport them below dams for release. The effectiveness of such an approach in the Willamette basin, relative to at-dam passage, is unknown. Accordingly, NMFS (2008) recommended that the Action Agencies work to assess the feasibility of collecting juvenile salmonids at the head of WVP reservoirs for subsequent transport and release below dams and "plan, design, build, and evaluate a prototype head-of-reservoir juvenile collection facility above either Lookout Point or Foster reservoir", with these actions being preceded by "feasibility studies" (RPA 4.9). NMFS (2008) further stated that the "Action Agencies will investigate the feasibility of improving downstream fish passage at Lookout Point Dam," beginning "no later than 2012" (RPA 4.12.2) and "investigate the feasibility of improving downstream fish passage at Detroit Dam", beginning "no later than 2015" (RPA 4.12.3). However, collection, transport and downstream release of juvenile salmon can present new risks and challenges. Keefer et al. (2008) provided convincing evidence that when juvenile salmon are subjected to collection and transport, they tend to stray at higher rates during adult spawning migrations. Head-of-reservoir collection and release operations would also likely place juvenile salmonids in highly degraded rearing habitats below dams (NMFS 2008), where mortality might exceed that of reservoir rearing and at-dam passage.

This study was developed to compare the behavior, performance, and survival of hatchery Chinook salmon that pass through USACE reservoirs and dams with those that are released below the dams. These can be used to help quantify project effects and estimate the benefits of passage improvements. Specifically, we will measure and report on the effects that LOP, Dexter, HCR, Detroit, and Big Cliff reservoirs and dams have on juvenile Chinook salmon outmigration behavior and survivorship, as contrasted with unimpeded passage, and determine project impacts (or benefits) on survivorship to adulthood. Results from this research will provide valuable information for assessing the feasibility and development of head-of-reservoir collection and at-dam passage facilities. Accordingly, this research addresses RPA 4.10 (NMFS 2008), which states that, "The Action Agencies will, in coordination with and review by the Services, assess juvenile fish passage through the following Project reservoirs: 1) Cougar, 2) Lookout Point and Dexter, 3) Detroit and Big Cliff, 4) Green Peter and Foster, 5) Fall Creek, 6) Hills Creek". This work also addresses RPA 4.11, as it will "assess passage survival and efficiency through all available downstream routes" of Lookout Point, Dexter, Detroit, and Big Cliff dams. Finally, our research will generate basic information regarding survivorship and outmigration of juvenile Chinook salmon released below WVP dams, thereby providing requisite information for RPA 4.9 (NMFS 2008). Herein we report on fish released from 2011 to 2013 and include detections, recoveries, mortalities, and adult returns reported through June 2014.

Study Objectives

1. Estimate the effect that passage through WVP dams and reservoirs has on outmigration success (counts) and rate (distance/time) by juvenile Chinook salmon in the NS and MFW rivers.

2. Estimate the effect that passage through WVP dams and reservoirs has on survivorship to adulthood for juvenile Chinook salmon in the NS and MFW rivers.

3. Where possible, determine growth rate of recaptured PIT-tagged Chinook salmon and describe differences in growth among release groups (by subbasin). We will also continue to estimate growth rates for PIT-tagged study fish that are recaptured by other researchers.

4. Where possible, describe the fate of PIT-tagged and CWT fish (e.g., lost to predation, captured in fisheries).

Methods

This work was implemented in the MFW and NS subbasins of the UWR. We PIT-tagged juvenile hatchery Chinook salmon and released them above and below WVP dams in both UWR subbasins. We selected tailrace (TR), forebay (FB) and head of reservoir (HOR) release locations to estimate the separate effects from reservoir and at-dam passage on outmigration timing and survivorship. This approach was intended to provide information relevant to alternate downstream passage strategies (i.e., HOR collection, transport and below-dam release vs. volitional passage) for Chinook salmon produced naturally above WVP dams. Specific release locations are provided in Table 1 and indicated in Figures 1 and 2.

Table 1. Release information for juvenile hatchery spring Chinook salmon in the Middle Fork Willamette (MFW) River from 2011 to 2013 and North Santiam (NS) River from 2012 to 2013. Release locations in the MFW were Lookout Point head of reservoir (HOR) and forebay (FB), Dexter tailrace (TR), and Hills Creek Reservoir (HCR), and NS release locations were Detroit HOR and FB, and Minto TR. Tags and marks included adipose fin clip (AD), passive integrated transponder tag (PIT), and coded wire tag (CWT).

Release Site Name	Release Location	Release Date	Release Number	Mark and Tag
		MFW 2011		
Dexter Tailrace	TR	25 May	5,959	PIT
Hampton Boat Ramp	HOR	19 May	5,967	PIT
Hampton Boat Ramp	HOR	19 May	~99,873	CWT
Hampton Boat Ramp	HOR	10 June	~100,800	CWT
		MFW 2012		
Dexter Tailrace	TR	23 May	49,371	AD+PIT
Hampton Boat Ramp	HOR	23 May	49,651	AD+PIT
Hills Creek Reservoir	HCR	23 May	49,330	AD+PIT
		MFW 2013		
Dexter Tailrace	TR	31 May	37,299	AD+PIT
Lookout Point Forebay	FB	31 May	37,310	AD+PIT
Hampton Boat Ramp	HOR	31 May	37,200	AD+PIT
Hills Creek Reservoir	HCR	31 May	33,301	AD+PIT
		NS 2012		
Packsaddle Park	TR	10 August	12,475	CWT+AD+PIT
Packsaddle Park	TR	10 August	~37,525	CWT+AD
Hoover Boat Ramp	HOR	10 August	12,456	CWT+AD+PIT
Hoover Boat Ramp	HOR	10 August	~37,544	CWT+AD
		NS 2013		
Packsaddle Park	TR	27 June	33,299	AD+PIT
Detroit Dam Forebay	FB	27 June	33,246	AD+PIT
Hoover Boat Ramp	HOR	27 June	33,208	AD+PIT

Tagging and Releases

Although our study was designed to provide information relevant to the downstream passage of naturally-produced juvenile salmon, we used sub-yearling, hatchery-origin fish for all releases due to the predictable availability of large numbers of fish. Hatchery- and natural-origin Chinook salmon in our study area are genetically similar (Johnson and Friesen 2014), but differences in their morphology, life history, and behavior are known to exist (Billman et al. 2014). An important assumption of the study is that these hatchery-origin surrogates were adequately similar to natural-origin fish so as to provide inferences about the latter.

Fish were produced and tagged at the Willamette (MFW releases) and Marion Forks (NS releases) hatcheries. Until they were designated for tagging, fish destined for different release groups were reared in a common environment and treated as regular hatchery production fish; water source, temperature, pond density, feeding regime, and medical treatments were all standardized to the extent possible. Study fish were tagged with PIT tags (Biomark Inc., Boise, ID) in all release years and coded-wire tags (CWTs, Northwest Marine Technology Inc., Shaw Island, WA) for the 2011 MFW and 2012 NS releases. Immediately after being PIT tagged, fish were separated into release groups and held in separate ponds for an additional 10-14 days, again with propagation factors standardized. All fish were adipose (AD) fin clipped to identify them as hatchery origin, except for the MFW releases in 2011, when a labor shortage forced us to release them as unmarked. Protocols and other details of PIT tagging (using 2014 as an example) are described in the Appendix.

Fork length (FL) data for all PIT-tagged fish was collected by Biomark staff during tagging. The minimum size for PIT tagging salmonids is 65 mm FL (see Appendix); the study fish were approximately 25-50% larger than the mean length of naturally-produced spring Chinook salmon in the MFW and NS rivers at time of reservoir entry (Monzyk et al. 2011; Romer et al. 2012). Accordingly, fish released for this study were slightly larger than the same cohort of naturally-produced fish present in the study areas. Prior to release, ODFW personnel collected length data from at least 100 fish from each release group and verified PIT tag codes. All shed tags were collected from the rearing ponds holding study fish. Except for 2011 (MFW) all fish within a subbasin were released on a single day.

Release dates were chosen to follow natural reservoir recruitment and outmigration as closely as possible while also accounting for constraints related to hatchery operations and production. All MFW releases, except for a release of CWT fish in the LOP HOR in 2011, took place in mid-to-late May which was very similar to the timing observed for natural reservoir recruitment (February through June) of Chinook salmon in the MFW (Romer et al. 2012). The NS release dates were variable, with 2012 releases occurring in August and 2013 releases in June which was closer to previously observed reservoir recruitment timing (February through June) in the NS (Romer et al. 2012). Release numbers of fish were also variable between basins and tagging types, but the number released for each group within basins and years was similar (Table 1). Approximately 200,000 fish with CWTs were released in the MFW in 2011, and roughly 75,000 carrying CWTs were released in the NS in 2012, which were the only releases of fish with CWTs for this study. Releases of PIT-tagged fish in the MFW ranged from about 12,000 in the 2011 pilot study to nearly 150,000 in 2012 and 2013, while the number of PIT-tagged fish released in the NS was roughly 25,000 in 2012 and nearly 100,000 in 2013 (Table 1).

Data Collection and Analysis

Release dates and locations for all PIT-tagged fish were uploaded to the PIT tag information system (PTAGIS; http://www.ptagis.org/) shortly after the releases occurred. Subsequent tag detection data was collected at Willamette Falls (PTAGIS site SUJ; Willamette rkm 43) and lower Columbia River (PD7; Columbia rkm 70) fixed interrogation sites, and the NMFS trawl mobile array (TDX) operated near Columbia rkm 75. We also collected data for PIT-tagged fish (i.e. date, fork length, location) encountered during the course of other research and survey activities in the Willamette and lower Columbia basins. In some cases, mortalities from depredation were recorded. We reported all information from PIT tag detections in the field, including recaptures and mortalities, to PTAGIS. For recoveries at Willamette Falls we reported the ratio of detections (e.g., TR:HOR) and the related "effect size;" which can be considered an index of mortality. For a ratio of 2.5:1, for example, the effect size is 1 – (1/2.5); 60% (1 is 60% less than 2.5). We note that, unlike the chi-square tests described below, ratios and effect sizes were not adjusted for differences in release group size, though these were often similar.

We queried the PTAGIS database for information from PIT tag detections of study fish, parsed by subbasin and release year. Data from PIT tag detections at Willamette Falls were used to evaluate juvenile outmigration timing and survival for the different release groups within each year. Pairwise chi-square tests (X^2) for equality of proportions were conducted to determine if observed proportions of fish detected at Willamette Falls were significantly different than equal proportions among release groups within subbasins. Chi-square tests evaluated 2x2 contingency tables of "detect" and "no detect" values for release group pairwise comparisons and incorporated the Yates correction for continuity to address bias associated with small expected cell frequencies.

To evaluate whether tagging size was similar among release groups and whether tagging size was a factor in the likelihood of detection at Willamette Falls, we analyzed initial tagging lengths of all releases and initial tagging lengths of the fish detected at the falls. The distributions of length data were non-normal or lacked homogeneity of variances (or both) across all release groups as indicated by Shapiro-Wilk test results. Therefore, we used non-parametric Mann-Whitney rank sum and Kruskal-Wallis one-way ANOVA on ranks procedures to test for significant differences in initial tagging length, with Dunn's method used for pairwise comparisons.

We plotted the cumulative and daily number of post-release PIT tag detections at Willamette Falls to provide a visual representation of juvenile outmigration success and timing for each release group. Detections at Willamette Falls were also used to estimate movement rates (km/d post-release) and evaluate possible delay effects from dams and reservoirs. Movement rates were calculated as the distance (rkm) traveled from release location to detection at the falls, divided by the number of days at large between release and detection. Shapiro-Wilk test results indicated movement rate data were non-normal or lacked homogeneity of variances (or both) among all release groups and years. We attempted to normalize the movement rate data using transformations (e.g. $\log_e$, $\log_{10}$, arcsin square root, and square root) and outlier removal as suggested by Iglewicz and Hoaglin (1993), but the data could not be normalized and possible outliers were not removed for analysis. Movement rate comparisons among release groups were therefore analyzed using Mann-Whitney rank sum and Kruskal-Wallis one-way ANOVA tests, with Dunn's method used for pairwise comparisons. We also used information from PIT tag detections in the lower Columbia River at PD7 and TWX to estimate movement rates into the lower Columbia River.

We tested for relationships between the number of daily detections and stream discharge, using USGS discharge data (http://waterdata.usgs.gov/nwis) for the Willamette River at Salem (USGS site 14191000), MFW at Jasper (USGS site 14152000), and NS at Mehama (USGS site 14183010). Discharge and daily detection data were non-normal or lacked homogeneity of variances among all release groups and years as indicated by Shapiro-Wilk analysis. Non-parametric Spearman correlation analysis (ρ) was used to assess possible relationships between daily number of detections for each release group and discharge at Salem and other locations. We also plotted daily discharge/spill data (http://www.nwd-wc.usace.army.mil/cgi-bin/dataquery.pl) for LOP, HCR, and Detroit dams to explore relationships between dam operations and outmigration timing.

Recaptures of study fish occurred during ODFW, USACE, and other research efforts. Research activities, particularly ODFW projects incorporating gillnets in reservoirs, were also major contributors to mortalities of study fish. Where recapture mortalities were reported to PTAGIS we subtracted those fish from the at-large groups. Recapture and research-related mortality data were used to generate growth estimates (mm/d, FL) when length measurements were taken. Growth rates were estimated by dividing the change in FL between initial tagging length and recapture/mortality length by days at-large between tagging and recapture or mortality. Shapiro-Wilk test results indicated growth rate data was non-normal or lacked homogeneity of variances among all release groups and years except for 2011 MFW releases. We attempted to normalize the data using a variety of transformations (e.g. $\log_e$, $\log_{10}$, arcsine square root, and square root) and outlier removal as suggested by Iglewicz and Hoaglin (1993), but the data could not be normalized and possible outliers were not removed for analysis. As such, growth rate comparisons among release groups were analyzed using Mann-Whitney rank sum and Kruskal-Wallis one-way ANOVA on ranks tests, with Dunn's method used for pairwise comparisons.

We performed statistical analyses only to compare metrics for releases groups within release years and subbasins, and we used an *a priori* critical value of $\alpha = 0.05$ to determine the significance of all statistical test results. We used SigmaPlot version 12.5 (Systat Software, San Jose, CA) software for all statistical analyses and to construct figures.

Results

Middle Fork Willamette River

Willamette Falls PIT Tag Detections

The median FL of all tagged fish released into the MFW in 2011 was 64 mm (N=11,906), with a median length of 64 mm for fish released in the TR (N=5,955) and 63 mm (N=5,951) for fish released at the HOR (Table 2). The median initial FL of tagged fish detected at Willamette Falls was 64 mm (N=703), with a median FL of 65 mm (N=502) for TR-released fish and 64 mm (N=201) for HOR-released fish detected at the falls (Table 2). Mann-Whitney rank sum test results indicated there was no significant difference (U=45783.50, P=0.053) between initial tagging lengths of TR and HOR fish detected at Willamette Falls.

Of the 11,926 PIT-tagged fish released in the MFW (TR release on 25 May, N=5,959; HOR release on 19 May, N=5,967) in 2011, a total of 704 (503 TR and 201 HOR) were detected at Willamette Falls between 22 June and 12 December 2011 (Figures 3 and 4). The proportion of TR-released fish detected at Willamette Falls (0.084) differed significantly (X^2=137.20, P<0.001) from the proportion of HOR-released fish that were detected (0.034). The ratio of TR to HOR detections was 2.50:1 (Table 3), a 60% effect size. Detections for both release groups increased sharply in the first week of July and peaked near the end of that month, with 95.4% (N=480) of the TR detections and 89.1% (N=179) of the HOR detections recorded by 30 July 2011 (94% of total detections, N=659) (Figures 3 and 4). One TR detection occurred after 31 August 2011, compared to 16 HOR detections after that date (Figures 3 and 4).

The median FL of tagged fish released into the MFW in 2012 was 62 mm (N=147,504), with no difference in median FL among TR, HOR, and HCR-released fish (Table 3). Median initial tagging FL of fish detected at Willamette Falls was 62 mm (N=3,282), with a median FL of 62 mm (N=2,736) for TR-released fish, and 63 mm for HOR (N=531) and HCR (N=15) released fish detected at Willamette Falls (Table 2).

A total of 3,281 (2,747 TR and 534 HOR) of the 99,022 (3.3%; 49,371 TR and 49,651 HOR) fish released on 23 May 2012 in the MFW (excluding HCR-released fish) were detected at Willamette Falls, with the earliest detection recorded on 17 June 2012 and the last on 9 May 2013 (Figures 3 and 4). As for 2011 MFW releases, the proportion of TR-released fish detected at the falls (0.056) was larger than the proportion of HOR-released fish detected at the falls (0.011) and differed significantly (X^2=1555.38, P<0.001) from equal proportions. In this year, the ratio of detections for TR and HOR releases was 5.14:1 (Table 3), an 80% effect size. Detections of both groups peaked near the end of the first week of August with 92.0% of all detections occurring by 8 August 2012 (TR=95.5%, N=2,623; HOR= 74.2%, N=396) (Figures 3 and 4). From 1 November 2012 to the last detection on 9 May 2013, 14 TR and 13 HOR detections were recorded (Figures 3 and 4).

Only 0.03% (N=15) of the fish from the 2012 HCR release group (N=49,330) were detected at Willamette Falls (Figures 3 and 4). Six detections were recorded between 16 November 2012 (first detection approximately five months after first detections of TR and HOR-

Table 2. Fork length (FL) at tagging information for all juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette (MFW) River from 2011 to 2013 and North Santiam (NS) River from 2012 to 2013, and for MFW and NS released fish detected at Willamette Falls. Release locations in the MFW were Lookout Point head of reservoir (HOR) and forebay (FB), Dexter tailrace (TR), and Hills Creek Reservoir (HCR), and NS release locations were Detroit HOR and FB, and Minto TR.

Release Location	Released FL (mm)					Detected FL (mm)				
	N	Mean	SE	Median	Range	N	Mean	SE	Median	Range
					MFW 2011					
Total	11,906	64.0	0.03	64	77-55	703	64.8	0.10	64	75-56
TR	5,955	64.4	0.04	64	77-55	502	65.0	0.13	65	75-56
HOR	5,951	63.7	0.04	63	74-55	201	64.4	0.18	64	73-56
					MFW 2012					
Total	147,504	61.9	0.01	62	110-46	3,282	62.5	0.06	62	80-52
TR	49,211	61.6	0.02	62	80-49	2,736	62.3	0.06	62	80-52
HOR	49,341	62.1	0.02	62	110-46	531	63.1	0.14	63	74-54
HCR	48,952	62.0	0.02	62	106-47	15	63.2	0.68	63	71-60
					MFW 2013					
Total	145,105	67.8	0.01	68	158-52	2,266	68.5	0.08	69	82-55
TR	37,144	68.0	0.02	68	82-52	1,358	69.0	0.11	69	79-55
FB	37,149	67.8	0.02	68	86-54	499	68.1	0.18	68	82-57
HOR	37,017	67.6	0.02	62	158-53	397	68.0	0.20	68	78-55
HCR	33,169	68.0	0.02	68	147-54	12	67.8	1.32	67	78-63
					NS 2012					
Total	24,786	90.4	0.04	91	121-63	1,923	92.0	0.14	92	117-64
TR	12,409	90.6	0.06	91	117-63	1,036	93.0	0.19	93	117-73
HOR	12,377	90.2	0.06	90	121-63	887	90.8	0.19	91	108-64
					NS 2013					
Total	99,298	68.7	0.01	69	210-55	2,869	69.3	0.07	69	84-57
TR	33,191	68.8	0.02	69	210-52	1,218	69.6	0.11	70	84-58
FB	33,003	68.9	0.02	69	181-50	926	69.2	0.13	70	84-58
HOR	33,104	68.5	0.02	68	86-56	725	68.9	0.14	69	81-59

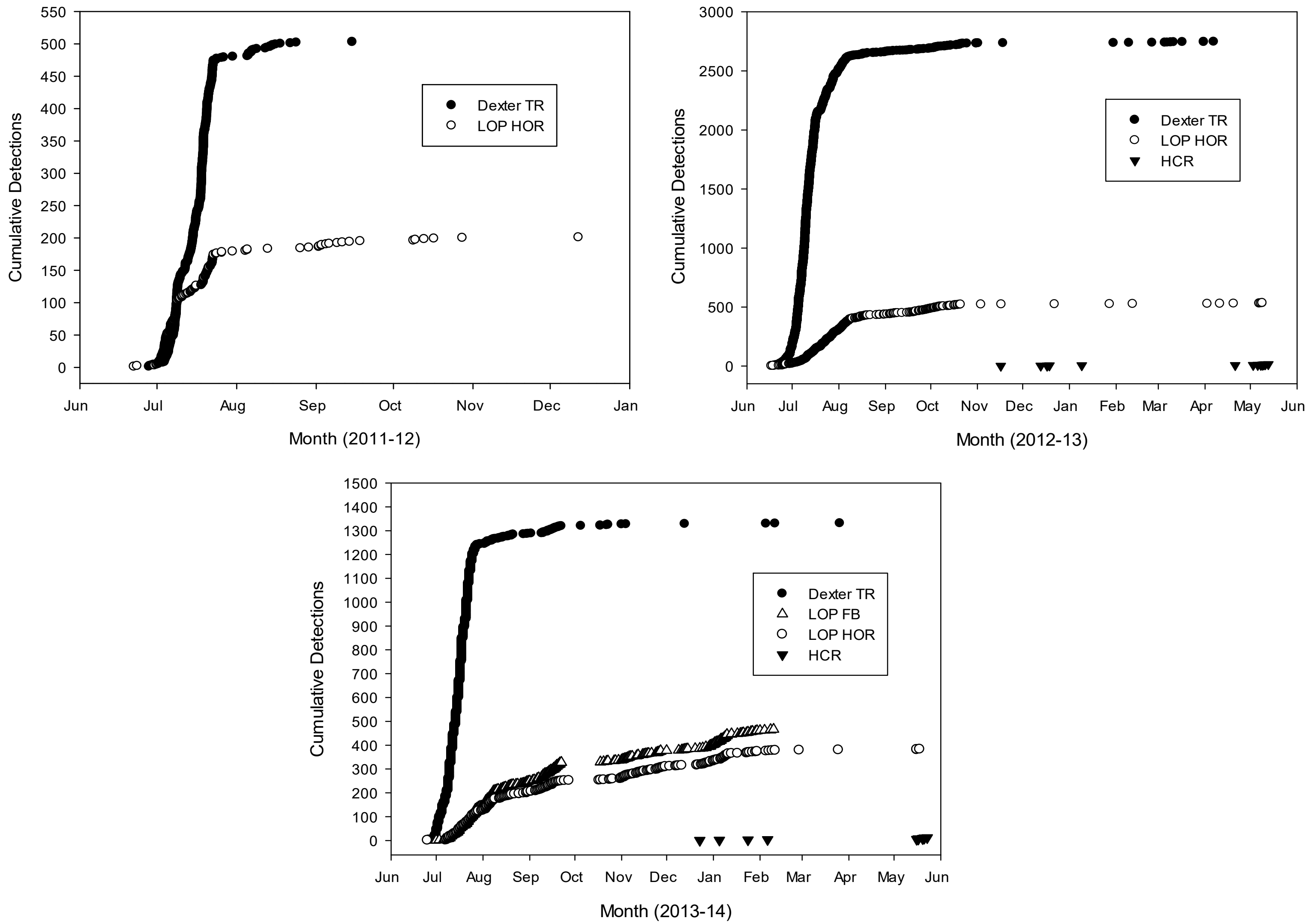

Figure 3. Cumulative detections at Willamette Falls of PIT-tagged juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette River. Release locations were Lookout Point (LOP) head of reservoir (HOR) and forebay (FB), Dexter tailrace (TR), and Hills Creek Reservoir (HCR). Release dates in 2011 were 25 May for TR and 19 May for HOR, 25 May for all release locations in 2012, and 31 May for all release locations in 2013. Note scale differences on X and Y axes.

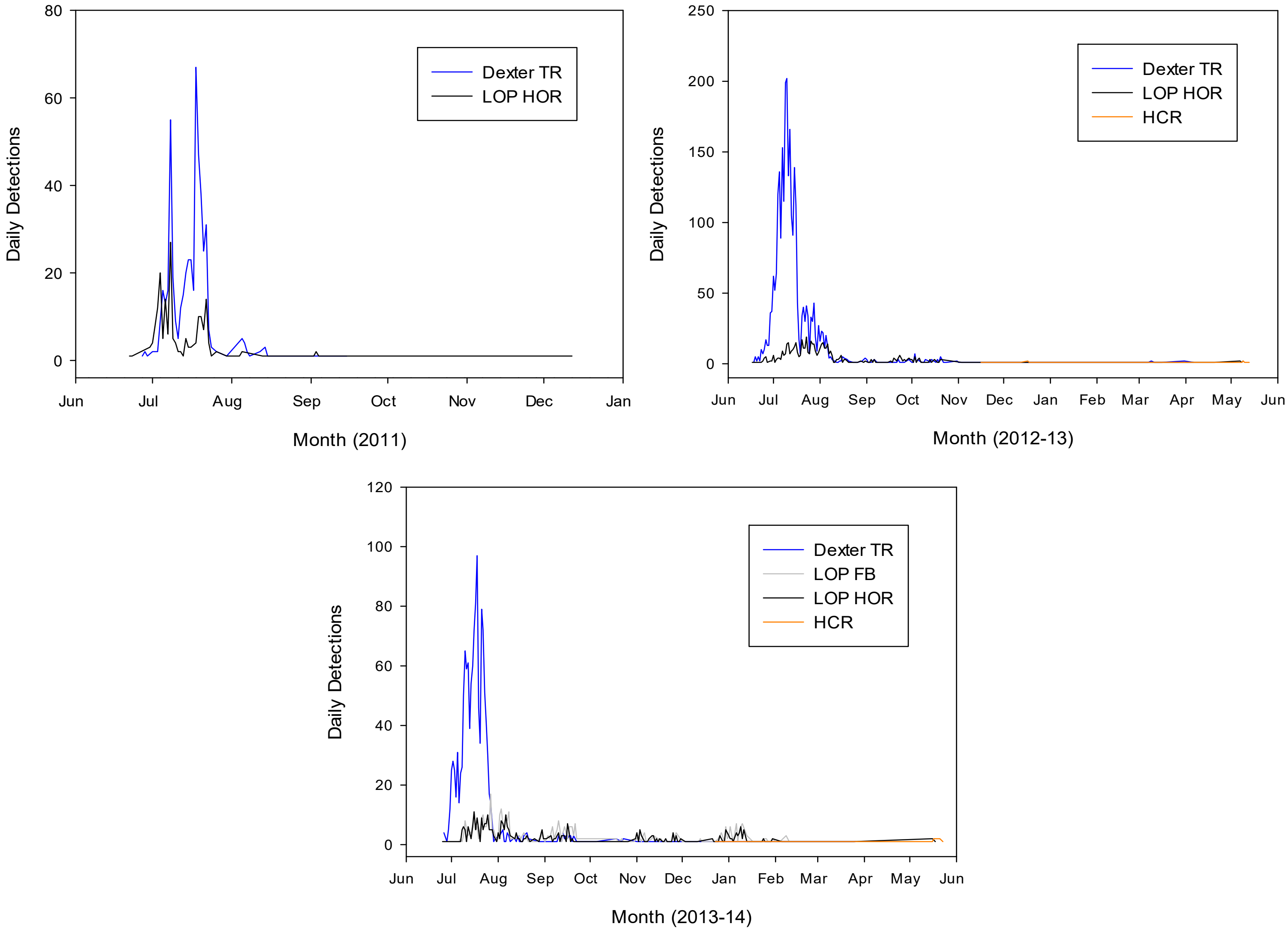

Figure 4. Daily detections at Willamette Falls of PIT-tagged juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette River. Release locations were Lookout Point (LOP) head of reservoir (HOR) and forebay (FB), Dexter tailrace (TR), and Hills Creek Reservoir (HCR). Release dates in 2011 were 25 May for TR and 19 May for HOR, 25 May for all release locations in 2012, and 31 May for all release locations in 2013. Note scale differences on X and Y axes.

released fish) and 9 January 2013, with the remainder of the detections occurring between 21 April and 13 May 2013, about one year after release (Figures 3 and 4). The ratios of 2012 MFW TR and HOR detections to HCR detections were 183.13:1 and 35.60:1, respectively. Both detection proportions for TR (X^2=2775.76, P<0.001) and HOR (X^2=488.11, P<0.001) releases differed significantly from the detection proportion of HCR ($3.0x10^{-4}$) released fish (Table 3).

Median FL of the 145,105 tagged fish released into the MFW in 2013 was 68 mm overall, and 68 mm for all four groups, including the TR (N=37,144), FB (N=37,149), HCR (N=33,169) and HOR (N=37,017) releases (Table 2). Among those detected at Willamette Falls, median initial tagging lengths were 69 mm (N=2,266), with a median length of 69 mm (N=1,358) for TR-released fish, 68 mm for FB (N=499) and HOR (N=397) released fish, and 67 mm (N=12) for HCR-released fish (Table 2). Kruskal-Wallis one-way ANOVA on ranks test results indicated significant differences (H=27.71, P<0.001; Dunn's method was not able to distinguish significant comparisons) among tagging lengths of fish detected at the falls.

For 2013 releases, 2,260 (1,361 TR, 499 FB, and 400 HOR) of the 111,809 (2.0% of total; 37,299 TR, 37,310 FB, and 37,200 HOR) fish released on 31 May 2013 in the MFW (excluding HCR-released fish) were detected at Willamette Falls, with the earliest detection occurring on 25 June 2013 and the last detection recorded on 18 May 2014 (Figures 3 and 4). From 22 September 2013 to 17 October 2013 the antenna at Willamette Falls in the north fish bypass malfunctioned resulting in 30 TR, 32 FB, and 17 HOR detections without accurate date-time stamps that could not be represented in the cumulative detection graphs (a few fish were detected in Turbine 13 which had a functional antenna). As in previous years, the observed proportions of TR (0.036), FB (0.013), and HOR (0.011) released fish detected at the falls were all significantly different than equal proportions (TR/FB: X^2=40785.00, P<0.001; TR/HOR: X^2=530.58, P<0.001; FB/HOR: X^2=10.27, P=0.001). The ratios of TR to FB, TR to HOR, and FB to HOR detections were 2.73:1, 3.40:1, and 1.25:1, respectively (Table 3). The effect size between TR and HOR releases was 71%. Detections of TR-released fish peaked near the end of July with 91.3% (N=1,243) of the detections occurring by 30 July 2013 (Figures 3 and 4). Detections of FB and HOR-released fish followed similar trajectories, initially peaking in mid-August with 223 FB (44.7%) and 185 HOR (46.3%) detections by 15 August 2013 (Figures 3 and 4). Whereas only three 2013 TR-released fish were detected at Willamette Falls in 2014, approximately 13% of FB (N=65) and HOR (N=51) released fish were detected (Figures 3 and 4).

Among the 33,301 fish released in HCR on 31 May 2013, only 12 (0.04%) were detected at Willamette Falls (Figures 3 and 4). Four were detected between 23 December 2013 (the first approximately six months after first detections of other MFW-released fish) and 6 February 2014, with the remainder of the detections occurring between 16 May and 23 May 2014, about one year after release (Figures 3 and 4). The ratio of 2013 MFW TR detections to HCR detections was 113.42:1, while the ratios of FB to HCR and HOR to HCR detections were 41.58:1 and 33.33:1, respectively. Detection proportions for TR, FB, and HOR-released fish were all significantly different (TR/HCR: X^2=1202.35, P<0.001; FB/HCR: X^2=413.90, P<0.001; HOR/HCR: X^2=326.66, P<0.001) from the proportion of HCR ($3.6x10^{-4}$) released fish detected at Willamette Falls (Table 3).

Table 3. Proportions of juvenile hatchery spring Chinook salmon detected at Willamette Falls from 2011-13 Middle Fork Willamette Dexter tailrace (TR), Lookout Point head of reservoir (HOR) and forebay (FB), and Hills Creek Reservoir (HCR) releases. Proportions within the same release year that do not share the same letter differed significantly (X^2, P<0.05).

	Release Location			
Release Year	TR	FB	HOR	HCR
2011	0.084^{A}	--	0.034^{B}	--
2012	0.056^{A}	--	0.011^{B}	$3.0x10^{-4\ C}$
2013	0.036^{A}	0.013^{B}	0.011^{C}	$3.6x10^{-4\ D}$

A number of fish released in the MFW during this study were detected in the lower Columbia River by the PD7 antenna and TWX trawl-towed array. In conjunction with data from Willamette Falls, those detections were used to develop estimates of juvenile detection efficiency at the falls. For 2012 releases, 35 TR, 3 HOR, and 1 HCR-released fish were detected in the lower Columbia River (all but one were detected by the towed array) and of those fish, 16 (14 TR, 2 HOR) were also detected at Willamette Falls (41.0% overall). Seventeen fish from the 2013 releases (12 TR, 2 FB, 2 HOR, 1 HCR) were detected in the lower Columbia River (13 of the 17 detections occurred at TWX) of which 11 TR and 1 FB-released fish were also detected at Willamette Falls (70.6% overall).

Numerous tags were also collected at East Sand Island in the lower Columbia River (PTAGIS site code ESANIS, rkm 8), likely as a consequence of avian predation. For 2011 releases, 13 (7 TR, 6 HOR) fish/tags were collected at ESANIS of which 3 TR and 3 HOR tags were also detected at Willamette Falls (46.2% overall). Forty six fish/tags from the 2012 releases (41 TR, 5 HOR) were collected at ESANIS with 47.8% (19 TR and 3 HOR) of those tags also detected at Willamette Falls. A total of 22 (12 TR, 8 FB, 1 HOR, 1 HCR) fish/tags from the 2013 releases were collected at ESANIS of which 7 TR, 5 FB, and 1 HOR tags were also detected at the falls (59.1% overall).

Movement rates

The median travel time from date of release to detection at Willamette Falls for the 2011 MFW PIT-tagged Chinook salmon was 52 d (N=704) with median travel times of 53 d (N=503) and 50 d (N=201) for TR and HOR-released fish, respectively (Table 4). The overall median movement rate for fish released in the MFW in 2011 was 5.48 km/d (N=704). Movement rates of TR (median=5.38 km/d, N=503) and HOR (median=6.16 km/d, N=201) released fish detected

Table 4. Travel time (days) and movement rate (km/day) as determined from PIT tag detections at Willamette Falls of juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette (MFW) River from 2011 to 2013 and North Santiam (NS) River from 2012 to 2013. Release locations in the MFW were Lookout Point head of reservoir (HOR) and forebay (FB), Dexter tailrace (TR), and Hills Creek Reservoir (HCR), and NS release locations were Detroit HOR and FB, and Minto TR.

Release Location	Travel Time (d)					Movement rate (km/d)				
	N	Mean	SE	Median	Range	N	Mean	SE	Median	Range
MFW 2011										
Total	704	54.2	0.56	52	207-33	704	5.6	0.04	5.5	9.1-1.5
TR	503	52.0	0.38	53	113-33	503	5.6	0.04	5.4	8.6-2.5
HOR	201	59.7	1.67	50	207-34	201	5.6	0.09	6.2	9.1-1.5
MFW 2012										
Total*	3,288	57.5	0.51	50	351-25	3,288	5.6	0.02	5.7	12.3-0.9
TR	2,754	53.7	0.44	49	318-26	2,754	5.7	0.02	5.8	11.0-0.9
HOR	534	77.4	1.94	66	351-25	534	4.8	0.07	4.7	12.3-0.9
HCR	16	295.4	18.09	347	355-177	16	1.2	0.09	1.0	1.9-1.0
MFW 2013										
Total*	2,181	72.6	1.15	51	352-25	2,181	5.3	0.04	5.7	12.3-0.9
TR	1,331	48.5	0.51	46	299-26	1,331	6.3	0.04	6.2	11.0-1.0
FB	467	108.8	3.01	81	255-30	467	3.7	0.09	3.6	9.7-1.1
HOR	383	112.0	3.56	81	352-25	383	3.9	0.11	3.8	12.3-0.9
HCR	12	311.8	18.01	351	357-206	12	1.2	0.08	1.0	1.7-1.0
NS 2012										
Total	1,940	78.5	1.84	47	334-14	1,940	8.8	0.11	8.4	27.1-1.2
TR	1,045	64.0	2.00	40	260-14	1,045	10.2	0.18	9.5	27.1-1.5
HOR	895	95.5	3.13	52	334-19	895	7.2	0.12	7.8	21.3-1.2
NS 2013										
Total	2,482	159.6	1.59	155	347-16	2,482	1.9	0.03	1.5	13.5-0.7
TR	1,000	144.5	2.24	146	299-16	1,000	2.1	0.05	1.5	13.5-0.7
FB	802	154.1	2.87	133	347-24	802	2.0	0.04	1.7	9.5-0.7
HOR	680	188.5	3.13	173	347-27	680	1.6	0.04	1.4	8.9-0.7

*Does not include HCR-released fish

at Willamette Falls were not significantly different (Mann-Whitney rank sum; U=47765.00, P=0.252) (Figure 5, Table 5).

Excluding the HCR release group, the median travel time from date of release to detection at Willamette Falls for the 2012 MFW releases was 50 d (N=3,288) with median travel times of 49 d (N=2,754) and 66 d (N=534) for TR and HOR-released fish, respectively (Table 4). The overall median movement rate for fish released into the MFW in 2012, excluding the HCR group, was 5.70 km/d (N=3,288). Movement rates of TR-released fish (median=5.82 km/d, N=2,754) were significantly greater (Mann-Whitney rank sum: U=426306.00, P<0.001) than

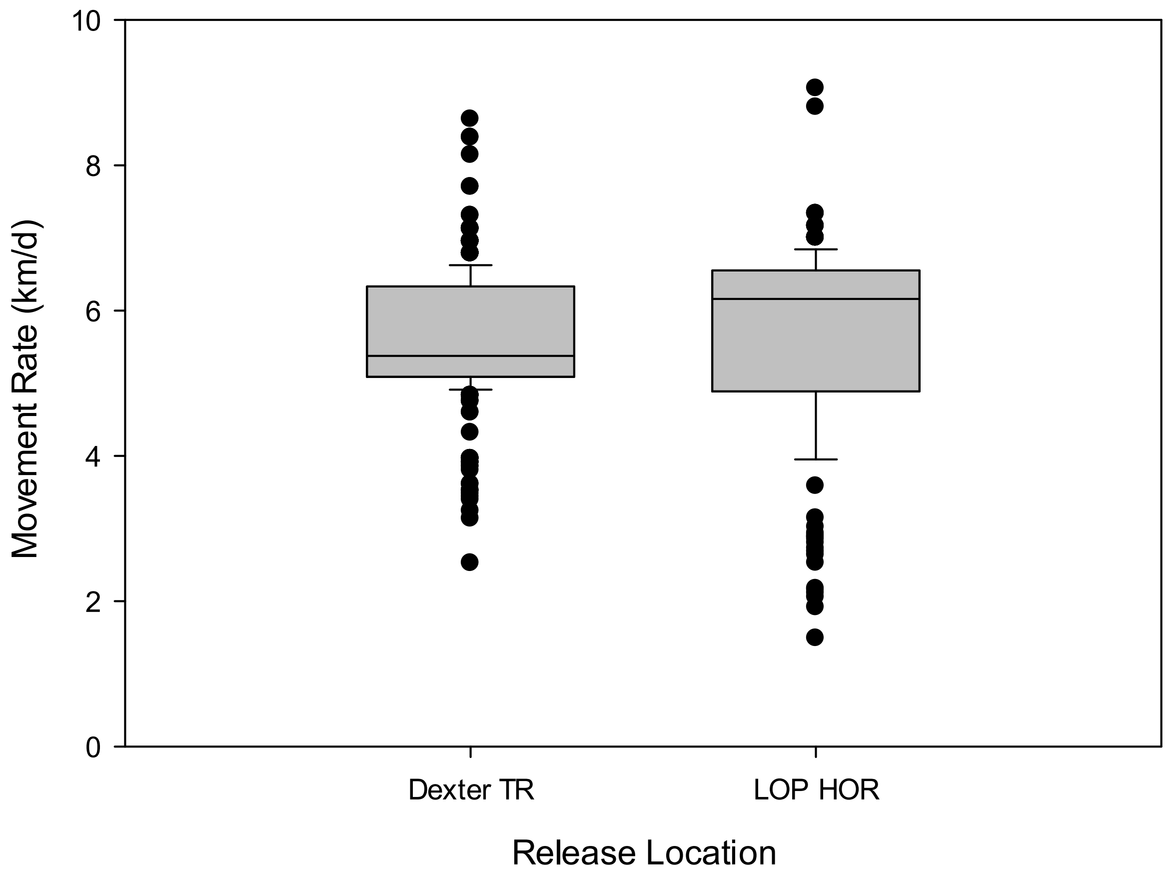

Figure 5. Movement rates as determined from PIT tag detections at Willamette Falls of juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette River on 25 May 2011 at Dexter tailrace (TR) and 19 May 2011 at Lookout Point (LOP) head of reservoir (HOR).

Table 5. Median movement rates (km/day) of juvenile hatchery spring Chinook salmon detected at Willamette Falls from 2011-13 Middle Fork Willamette Dexter tailrace (TR), Lookout Point head of reservoir (HOR) and forebay (FB), and Hills Creek Reservoir (HCR) releases. Median movement rates within the same release year that do not share the same letter differed significantly (Mann-Whitney rank sum and Kruskal-Wallis one-way analysis of variance on ranks, *P*<0.05).

	Release Location			
Release Year	TR	FB	HOR	HCR
2011	5.38^{A}	--	6.16^{A}	--
2012	5.82^{A}	--	4.70^{B}	0.99^{C}
2013	6.20^{A}	3.58^{B}	3.80^{C}	0.97^{D}

movement rates of HOR (median=4.70 km/d, N=534) released fish (Figure 6, Table 5). The 16 HCR fish detected at Willamette Falls had the greatest median travel time (347 d) and slowest median movement rate (0.99 km/d) among all 2012 release groups (H=281.79, $P<0.001$, Dunn's method $P<0.05$) (Table 5).

Excluding the HCR group, the median travel time from release to detection at Willamette Falls for the 2013 MFW released fish was 51 d (N=2,181) with median travel times of 46 d (N=1,331) for TR-released fish and 81 d for FB (N=467) and HOR (N=383) releases (Table 4). The overall median movement rate for fish released into the MFW in 2013, excluding HCR-released fish, was 5.70 km/d (N=2,181), with median movement rates of 6.20 km/d (N=1,331), 3.58 km/d (N=467), and 3.80 km/d (N=383) for TR, FB, and HOR-released fish, respectively (Figure 7, Table 5). Movement rates for the 2013 released fish differed significantly (Kruskal-Wallis one-way ANOVA on ranks; H=723.68, $P<0.001$, Dunn's method $P<0.05$) among all release groups (Table 5). The 12 HCR-released fish detected at Willamette Falls had the greatest median travel time (351 d) and slowest median movement rate (0.97 km/d) among all release groups in 2013 (H=749.66, $P<0.001$, Dunn's method $P<0.05$) (Table 5).

Additional Detections - Movement rates

Fish detections at PD7 and TWX in the lower Columbia River provided supplementary information about fish movement rates below Willamette Falls and through the lower Columbia River. Fish released in the MFW in 2012 that were detected in the lower Columbia River (excluding an HCR detection) traveled at a median overall rate of 8.24 km/d (N=38, median travel time=51 d) (Table 6). For 2012 MFW TR-released fish, median movement rate to detection in the lower Columbia River was 8.16 km/d (N=35, median travel time=51 d), while HOR-released fish had a median movement rate of 8.61 km/d (N=3, median travel time=51 d) (Table 6). One 2012 HCR-released fish was detected in the lower Columbia River and it traveled at a rate of 1.34 km/d (352 d). A total of 16 fish from the 2012 releases detected in the lower Columbia River were also detected at Willamette Falls and those fish had a median overall movement rate of 5.94 km/d (median travel time=48 d) to the falls and a median overall movement rate of 43.67 km/d (median travel time=3 d) from the falls to detection in the lower Columbia River (Table 7). For TR-released fish that were also detected at Willamette Falls, median movement rate to the falls was 5.94 km/d (N=14, median travel time=48 d) while median movement rate below the falls to lower Columbia River detection was 38.2 km/d (N=14, median travel time=4 d) (Table 7). For HOR fish that were also detected at Willamette Falls, median movement rate to the falls was 6.01 km/d (N=2, median travel time=52 d) while median movement rate below the falls to lower Columbia River detection was 43.67 km/d (N=2, median travel time=3 d) (Table 7).

Fish released in the MFW in 2013 that were detected in the lower Columbia River (excluding an HCR detection) traveled at a median overall rate of 8.47 km/d (N = 16, median travel time = 50 d). For 2013 MFW TR-released fish, median movement rate to detection in the lower Columbia River was 8.76 km/d (N=12, median travel time=48 d) while FB and HOR-released fish had median movement rates of 6.23 km/d (N=2, median travel time=88 d) and 3.69 km/d (N=2, median travel time=121 d), respectively (Table 6). One 2013 HCR-released fish was detected in the lower Columbia River and it traveled at a rate of 1.35 km/d (351 d). A total of 14

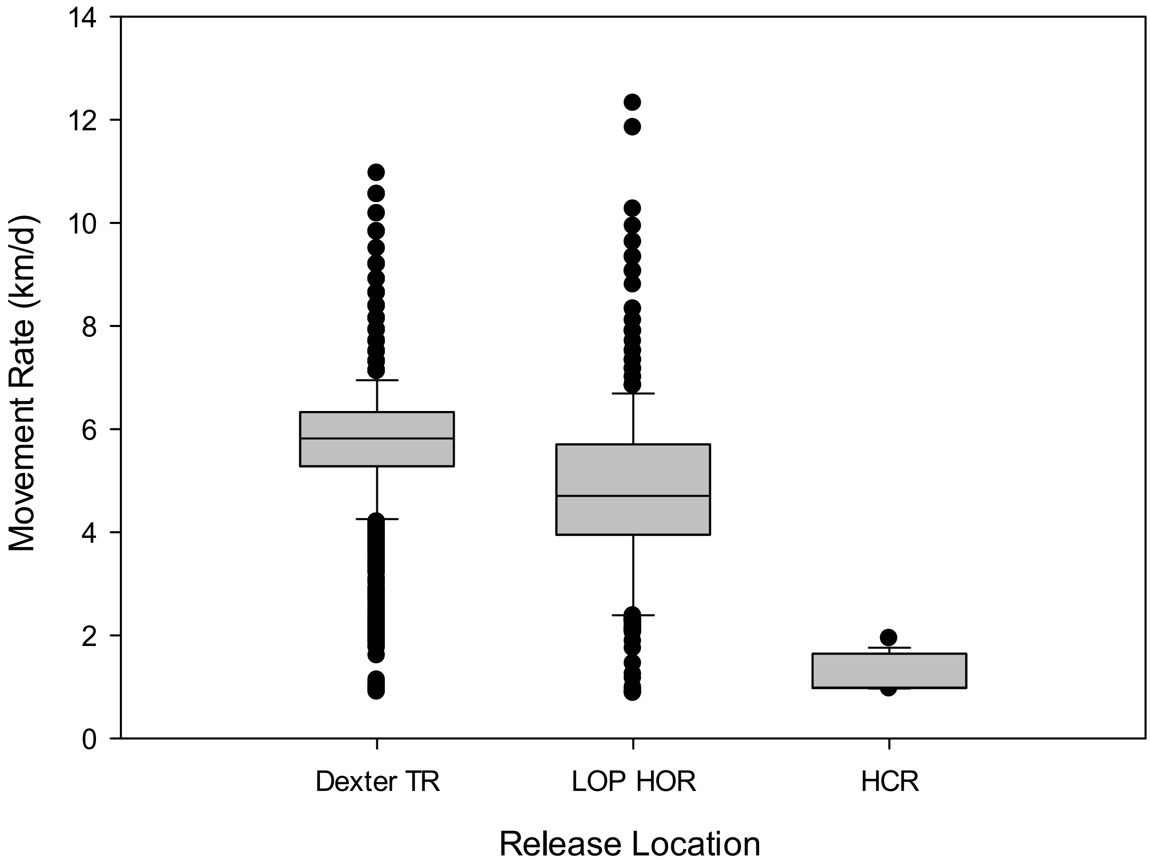

Figure 6. Movement rates as determined from PIT tag detections at Willamette Falls of juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette River on 23 May 2012 at Dexter tailrace (TR), Lookout Point (LOP) head of reservoir (HOR), and Hills Creek Reservoir (HCR).

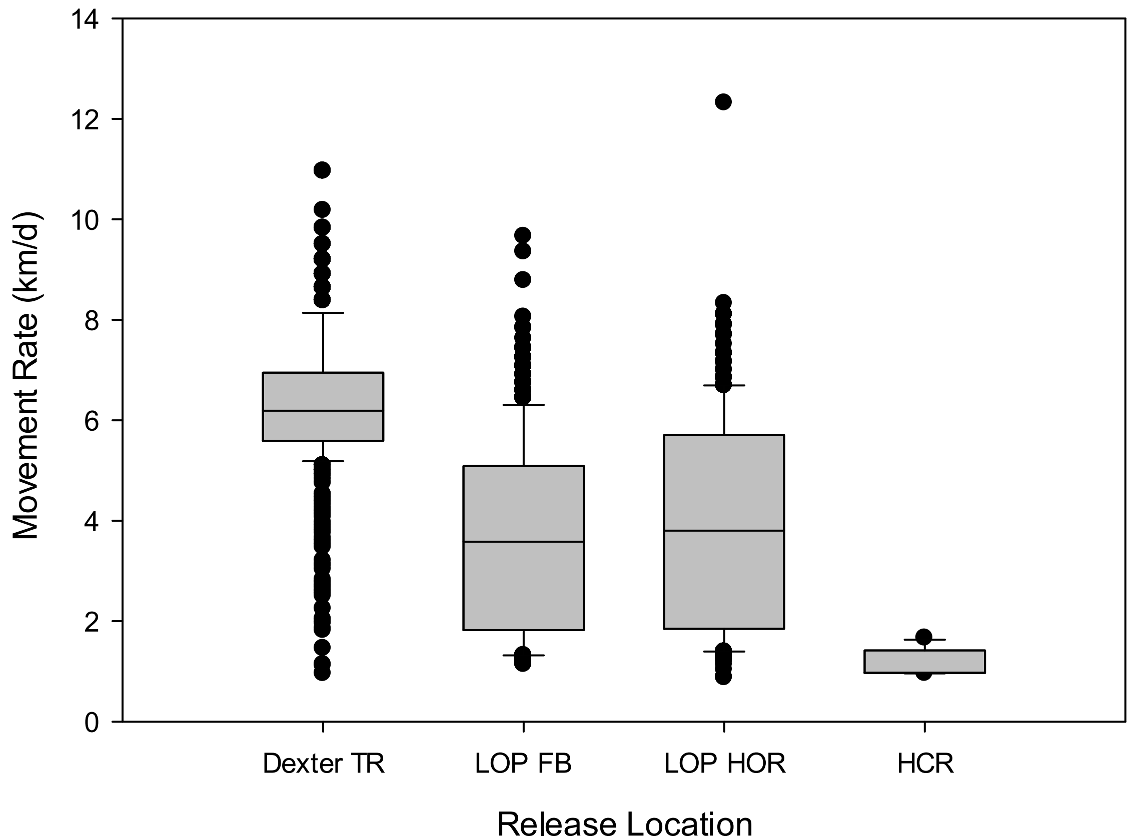

Figure 7. Movement rates as determined from PIT tag detections at Willamette Falls of juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette River on 31 May 2013 at Dexter tailrace (TR), Lookout Point (LOP) head of reservoir (HOR) and forebay (FB), and Hills Creek Reservoir (HCR).

Table 6. Travel time and movement rate as determined from PIT tag detections at a PIT tag antenna at rkm 70 (PD7) and an experimental towed array detection trawl project conducted by NMFS at approximately rkm 75 (TWX) in the lower Columbia River of juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette (MFW) and North Santiam (NS) Rivers from 2012 to 2013. Release locations in the MFW were Lookout Point head of reservoir (HOR) and forebay (FB), and Dexter tailrace (TR), and Hills Creek Reservoir (HCR), and NS release locations were Detroit HOR and FB, and Minto TR.

	Travel Time (d)					Movement rate (km/d)				
Release Location	N	Mean	SE	Median	Range	N	Mean	SE	Median	Range
					MFW 2012					
Total*	38	58.2	6.67	51	302-36	38	8.0	0.24	8.2	11.6-1.4
TR	35	58.8	7.24	51	302-36	35	8.0	0.26	8.2	11.6-1.4
HOR	3	52.0	3.22	51	58-47	3	8.5	0.51	8.6	9.3-7.6
					MFW 2013					
Total*	16	62.2	7.77	50	130-35	16	7.8	0.58	8.5	11.9-3.3
TR	12	48.2	1.54	48	55-35	12	8.8	0.34	8.8	11.9-7.6
FB	2	87.5	41.50	88	129-46	2	6.2	2.93	6.2	9.2-3.3
HOR	2	121.0	9.00	121	130-112	2	3.7	0.27	3.7	4.0-3.4
					NS 2012					
Total	22	281.4	3.37	287	297-238	22	1.3	0.01	1.3	1.5-1.3
TR	3	246.3	6.44	242	259-238	3	1.4	0.03	1.4	1.5-1.4
HOR	19	286.9	1.47	287	297-278	19	1.3	0.01	1.3	1.4-1.3
					NS 2013					
Total	33	268.7	13.91	302	328-79	33	1.7	0.19	1.2	4.4-1.1
TR	9	240.6	30.69	278	304-79	9	1.9	0.47	1.3	4.4-1.1
FB	13	254.0	26.02	302	325-85	13	1.8	0.34	1.2	4.3-1.1
HOR	11	309.1	5.25	309	328-264	11	1.2	0.02	1.2	1.4-1.1

*Does not include HCR-released fish

Table 7. Movement rate to Willamette Falls and from the falls to detection in the lower Columbia River as determined from PIT tag detections at Willamette Falls, a PIT tag antenna at rkm 70 (PD7), and an experimental towed array detection trawl project conducted by NMFS at approximately rkm 75 (TWX) in the lower Columbia River of juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette (MFW) and North Santiam (NS) rivers from 2012 to 2013. Release locations in the MFW were Lookout Point head of reservoir (HOR) and forebay (FB), Dexter tailrace (TR), and Hills Creek Reservoir (HCR), and NS release locations were Detroit HOR and FB, and Minto TR.

	Movement rate to Falls (km/d)						Movement rate Falls to Columbia (km/d)					
Release Location	N	Mean	SE	Median	Range	Median Days	N	Mean	SE	Median	Range	Median Days
						MFW 2012						
Total	16	5.8	0.17	5.4	6.6-4.6	48	16	37.8	1.86	32.8	43.7-21.8	3
TR	14	5.8	0.19	5.9	6.6-4.6	48	14	37.0	2.03	38.2	43.7-21.8	4
HOR	2	6.0	0.41	6.0	6.4-5.6	52	2	43.7	0.00	--	--	3
						MFW 2013						
Total[1]	12	6.7	0.29	6.7	9.2-5.5	43	12	28.6	2.17	29.5	43.7-16.4	5
TR	11	6.7	0.32	6.6	9.2-5.5	43	11	28.2	2.34	26.2	43.7-16.4	5
						NS 2012						
HOR	3	0.9	0.02	0.9	0.9-0.8	276	3	40.0	3.64	43.7	43.7-32.8	3
						NS 2013						
Total[2]	7	1.7	0.40	1.1	2.9-0.7	198	7	26.6	8.58	27.2	65.5-1.3	5
TR	3	1.7	0.63	1.1	2.9-1.0	198	3	10.2	8.49	2.2	27.2-1.3	61
FB	3	2.1	0.70	2.8	2.9-0.7	82	3	37.4	14.24	27.2	65.5-19.4	5

[1] a single FB observation was included in the total
[2] a single HOR observation was included in the total

fish from the 2013 releases detected in the lower Columbia River were also detected at Willamette Falls and those fish had a median overall movement rate of 6.71 km/d (N=14, median travel time=43 d) to the falls and a median overall movement rate of 29.48 km/d (N=14, median travel time=5 d) from the falls to detection in the lower Columbia River (Table 7). For TR-released fish that were also detected at Willamette Falls, median movement rate to the falls was 6.63 km/d (N=11, median travel time = 43 d) while median movement rate below the falls to lower Columbia River detection was 26.2 km/d (N=11, median travel time=5 d)(Table 7). The one FB-released fish that was detected at Willamette Falls and in the lower Columbia River traveled at a rate of 6.9 km/d (42 d) to the falls and 32.75 km/d (4 d) below the falls until it was detected in the lower Columbia River (Table 7).

Stream Discharge and Willamette Falls Daily Detections

Spearman correlation analysis for 2011 MFW daily detections at Willamette Falls and Willamette River discharge at Salem showed a statistically significant positive relationship for

TR (ρ=0.35, *P*=0.001, N=86) and no correlation (ρ= -0.11, *P*=0.16, N=174) for HOR daily detections with Willamette discharge, though graphs of daily detections for both release groups appear to show negative relationships with discharge (overall correlation: ρ= -0.024, *P*=0.70, N=260) (Figure 8). For 2012 released fish, analyses indicated significant negative relationships for TR (ρ= -0.66, *P*<0.001, N=294) and HOR (ρ= -0.68, *P*<0.001, N=296) daily detections with Willamette discharge, and a non-significant positive relationship for HCR (ρ=0.11, *P*=0.06, N=331) daily detections with Willamette discharge (overall correlation: ρ= -0.48, *P*<0.001, N=921) (Figure 8). Daily detections at Willamette Falls of 2013 TR (ρ= -0.64, *P*<0.001, N=275), FB (ρ= -0.53, *P*<0.001, N=231), and HOR (ρ= -0.56, *P*<0.001, N=328) released fish were all significantly negatively correlated with Willamette discharge at Salem, while HCR (ρ=0.02, *P*=0.75, N=333) detections were, again, not significantly correlated with Willamette discharge (overall correlation: ρ= -0.46, *P*<0.001, N=1,167) (Figure 8).

Spearman correlation analysis for daily detections at Willamette Falls of 2011 release groups and MFW discharge at Jasper indicated a significant negative relationship for HOR (ρ= -0.16, *P*=0.04, N=174) and non-significant relationship for TR (ρ= -0.13, *P*=0.25, N=86) released fish with MFW discharge (overall correlation: ρ= -0.18, *P*=0.004, N=260) (Figure 9). For 2012 released fish, daily detections for TR (ρ= -0.34, *P*<0.001, N=294) and HOR (ρ= -0.26, *P*<0.001, N=327) releases showed significant negative relationships with MFW discharge, while HCR daily detections were significantly positively correlated (ρ=0.19, *P*<0.001, N=331) with MFW discharge (overall correlation: ρ= -0.19, *P*<0.001, N=952) (Figure 9). Daily detections for fish released in the TR (ρ= -0.44, *P*<0.001, N=275), FB (ρ= -0.21, *P*=0.002, N=231), and HOR (ρ= -0.33, *P*<0.001, N=328) in 2013 showed significant negative relationships with MFW discharge while HCR detections were not significantly correlated (ρ= -0.03, *P*=0.64, N=333) with MFW discharge (overall correlation: ρ= -0.29, *P*<0.001, N=1167) (Figure 9).

Analysis of USACE LOP and HCR discharge and spill data showed multiple periods of increased discharge and spill shortly after PIT-tagged fish were released into the MFW. These dam operations could have helped facilitate movement of fish through the reservoirs and dams. Following the MFW fish releases in May of 2011, 2012, and 2013, LOP discharge and spill levels of 2,000 to 6,000 cfs were recorded in June and July, with continued spill occurring into August of 2012 and 2013 (Figure 10). Periods of increased discharge and spill also occurred in HCR in June and July, with levels reaching 500 to 2,000 cfs (Figure 11).

Mortalities

Mortalities of MFW released fish were attributed to predation (avian and piscine) and various research activities (e.g., netting and trapping) that occurred in the Middle Fork and mainstem Willamette rivers. A total of 19 fish released in the MFW in 2011 were collected as mortalities, with 8 mortalities reported for TR-released fish and 11 for HOR-released fish (Table 8). The first mortality for 2011 releases was recorded on 6 June 2011, approximately three weeks after release, and the last on 8 November 2012, about 1.5 years after release. All reported predation of 2011 released fish was attributed to birds (N=14); the remainder (N=5) were from research activities (Table 8).

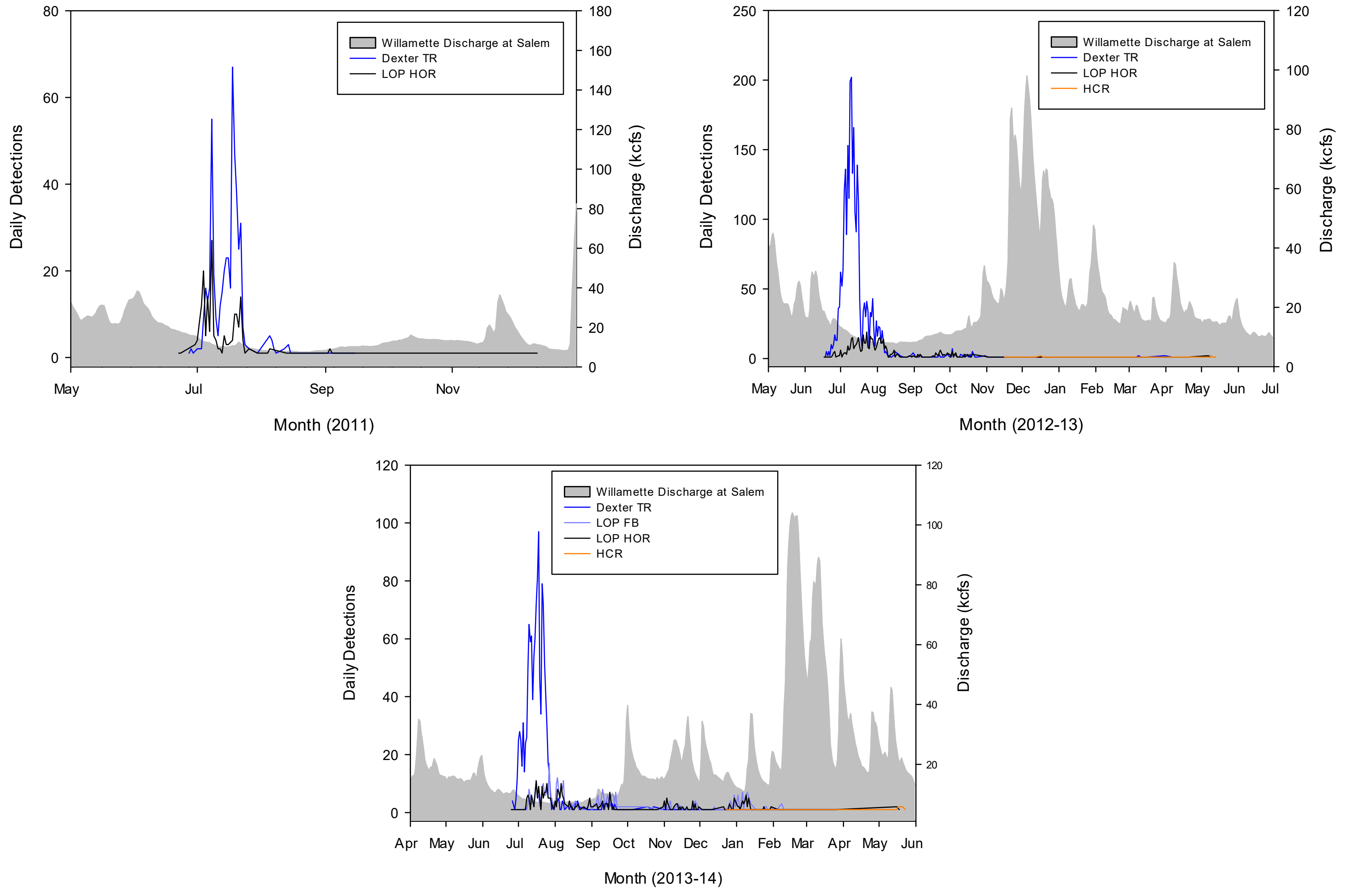

Figure 8. Daily detections at Willamette Falls of PIT-tagged juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette River and Willamette River discharge (kcfs) at Salem (USGS, http://waterdata.usgs.gov/nwis). Release locations were Lookout Point (LOP) head of reservoir (HOR) and forebay (FB), Dexter tailrace (TR), and Hills Creek Reservoir (HCR). Release dates in 2011 were 25 May for TR and 19 May for HOR, 25 May for all release locations in 2012, and 31 May for all release locations in 2013. Note scale differences on X and Y axes.

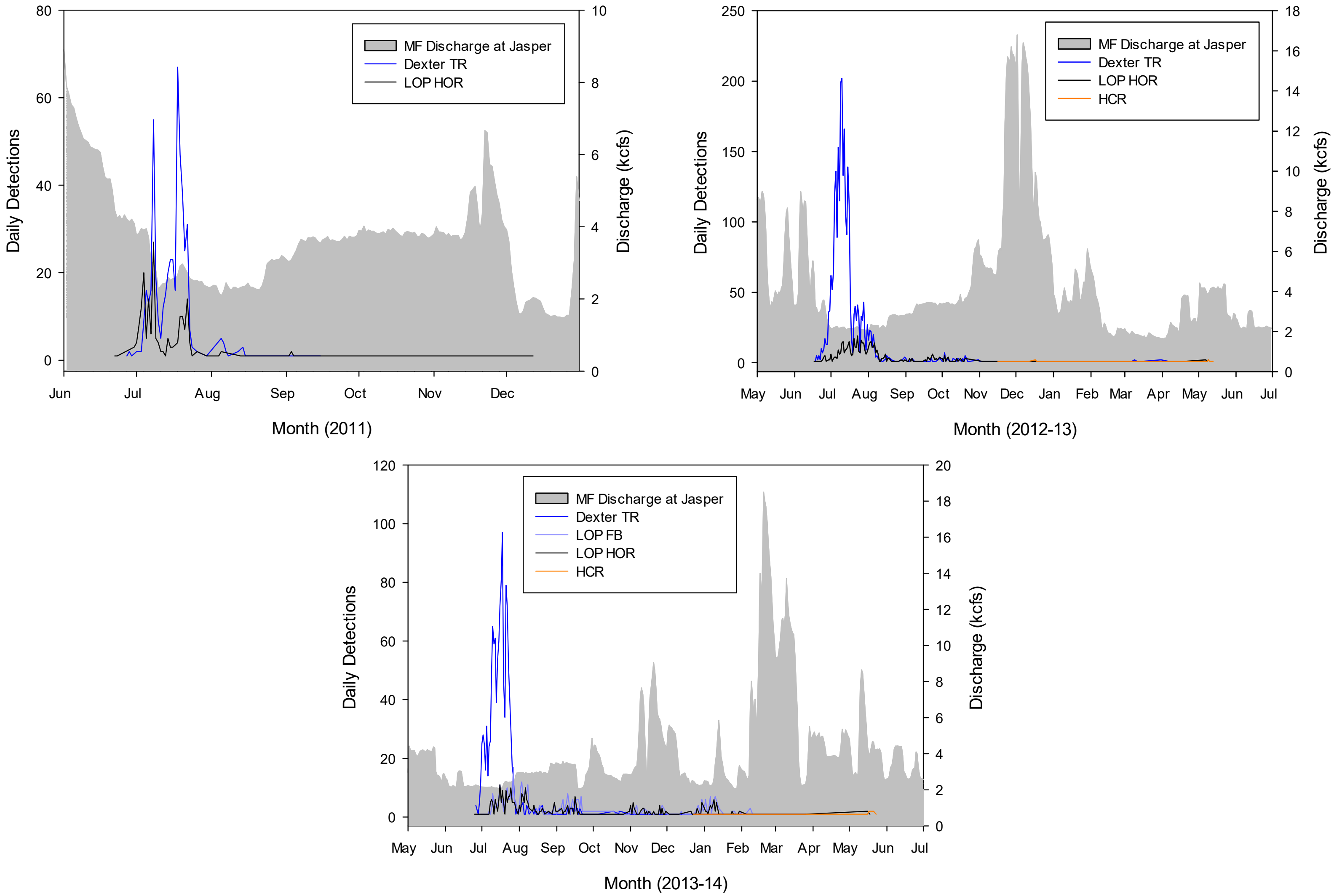

Figure 9. Daily detections at Willamette Falls of PIT-tagged juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette (MFW) River and MFW discharge (kcfs) at Jasper (USGS, http://waterdata.usgs.gov/nwis). Release locations were Lookout Point (LOP) head of reservoir (HOR) and forebay (FB), Dexter tailrace (TR), and Hills Creek Reservoir (HCR). Release dates in 2011 were 25 May for TR and 19 May for HOR, 25 May for all release locations in 2012, and 31 May for all release locations in 2013. Note scale differences on X and Y axes.

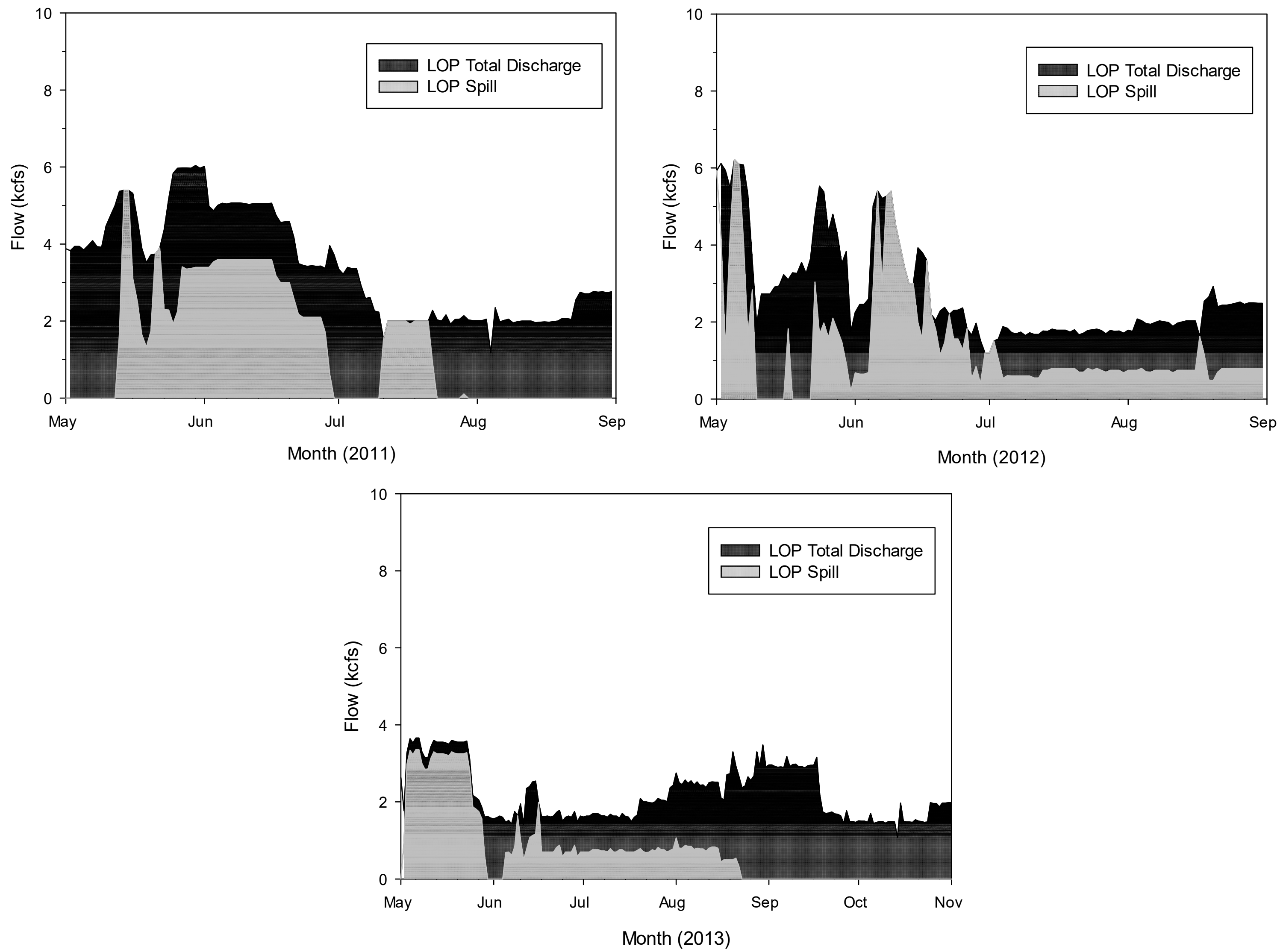

Figure 10. Discharge and spill (kcfs) information for Lookout Point (LOP) Dam in the Middle Fork Willamette (MFW) River (US Army Corps of Engineers, http://www.nwd-wc.usace.army.mil/cgi-bin/dataquery.pl). Releases of juvenile hatchery spring Chinook salmon in the MFW took place on the 19 May and 25 May 2011, on 25 May 2012, and on 31 May 2013. Note scale difference on the X-axis.

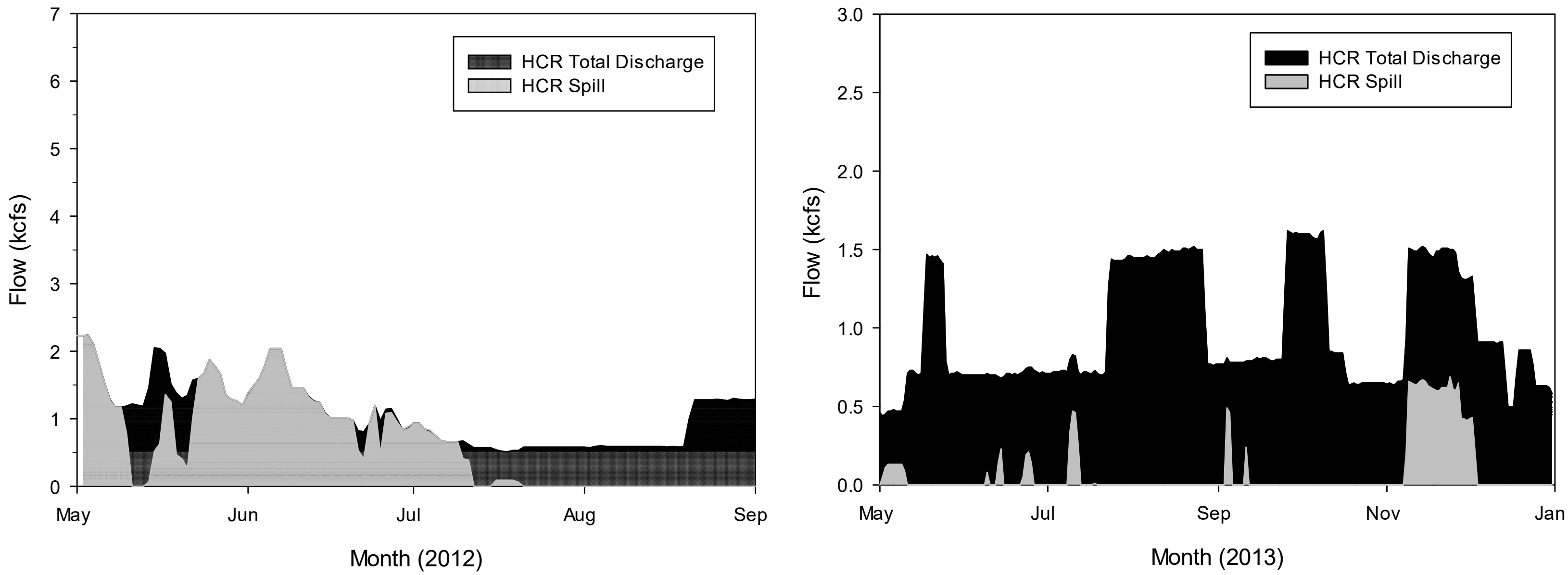

Figure 11. Discharge and spill (kcfs) information for Hills Creek (HCR) Dam in the Middle Fork Willamette (MFW) River (US Army Corps of Engineers, http://www.nwd-wc.usace.army.mil/cgi-bin/dataquery.pl). Releases of juvenile hatchery spring Chinook salmon in the MFW took place on 25 May 2012 and 31 May 2013. Note scale differences on the X and Y axes.

Table 8. Mortality information for juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette (MFW) River from 2011 to 2013 and North Santiam (NS) River from 2012 to 2013. Release locations in the MFW were Lookout Point head of reservoir (HOR) and forebay (FB), Dexter tailrace (TR), and Hills Creek Reservoir (HCR), and NS release locations were Detroit HOR and FB, and Minto TR. Mortalities occurred from ODFW (gillnet, box trap, screw trap, e-fishing, juvenile bypass, and beach seine) and US Army Corps of Engineers (screw trap) research activities as well as avian and piscine predation. Predatory fish species include walleye (WAL, *Sander vitreus*), largemouth bass (LMB, *Micropterus salmoides*), northern pike minnow (NPM, *Ptychocheilus oregonensis*), white crappie (WCR, *Pomoxis annularis*), black crappie (BCR, *Pomoxis nigromaculatus*), cutthroat trout (CT, *Oncorhynchus clarki*), and rainbow trout (RBT, *Oncorhynchus mykiss*).

	Predation								Research					
Release Location	Avian	WAL	LMB	NPM	WCR	BCR	CT	RBT	Gillnet	Box Trap	Screw Trap	E-fish	Beach Seine	Juv Bypass
									MFW 2011					
Total	14	0	0	0	0	0	0	0	3	1	1	0	0	0
TR	8	0	0	0	0	0	0	0	0	0	0	0	0	0
HOR	6	0	0	0	0	0	0	0	3	1	1	0	0	0
									MFW 2012					
Total	46	1	7	3	120	2	1	2	210	2	35	9	1	0
TR	41	0	0	0	0	0	1	0	0	0	0	0	1	0
HOR	5	1	7	3	35	2	0	0	201	2	13	9	0	0
HCR	0	0	0	0	85	0	0	2	9	0	22	0	0	0
									MFW 2013					
Total	35	9	1	8	25	0	0	0	583	19	25	0	0	0
TR	12	0	0	0	0	0	0	0	1	0	0	0	0	0
FB	14	4	1	2	0	0	0	0	311	9	2	0	0	0
HOR	8	5	0	6	25	0	0	0	262	10	2	0	0	0
HCR	1	0	0	0	0	0	0	0	9	0	21	0	0	0
									NS 2012					
Total	30	0	0	0	0	0	0	0	106	0	2	0	0	2
TR	15	0	0	0	0	0	0	0	0	0	0	0	0	2
HOR	15	0	0	0	0	0	0	0	106	0	2	0	0	0
									NS 2013					
Total	10	0	0	0	0	0	0	0	473	0	36	0	0	0
TR	4	0	0	0	0	0	0	0	0	0	0	0	0	0
FB	3	0	0	0	0	0	0	0	275	0	18	0	0	0
HOR	3	0	0	0	0	0	0	0	198	0	18	0	0	0

Among the 2012 release group, 439 fish were collected as mortalities with 43 mortalities reported for TR-released fish, 278 for HOR-released fish, and 118 for HCR-released fish. The first mortality was recorded 24 May 2012, one day after release, and the last on 13 December 2013, more than 1.5 years after release. White crappie (WCR) *Pomoxis annularis* and birds were the greatest reported cause of predation mortality, accounting for 166 of 182 (91%) recorded predation mortalities (Table 8). A number of WCR sampled in LOP and HCR reservoirs were found to have multiple PIT tags in their stomachs, with one fish containing 13. For research-related mortalities, gillnet (reservoir) and screw trap (river) operations were responsible for 95%

(N=245) of reported mortalities (Table 8). Of the 439 reported mortalities, 51 (12%) were noted as having copepods.

Tags from 705 fish released in the MFW in 2013 were collected from mortalities, with 13 mortalities reported for TR-released fish, 343 for FB-released fish, 318 for HOR-released fish, and 31 for HCR-released fish (Table 8). The first mortality was recorded 4 June 2013, about 4 days after release, and the final mortality was reported 14 August 2014, more than a year after release. Birds and WCR had the greatest predatory impact on 2013 released fish, accounting for 60 of 78 mortalities (77%) attributed to predation (Table 8). Similar to observations for 2012 releases, a number of WCR were found to have multiple PIT tags from 2013 releases in their stomachs. For research-related mortalities, gillnetting took the greatest toll on 2013-released fish, with 583 of the 627 research-related mortalities (93%) attributed to this activity (Table 8). Of the 705 reported mortalities, 141 (20%) were noted as having copepods.

Recaptures and Growth Rates

A number of fish released in the MFW for this study were recaptured during various projects in the Middle Fork and mainstem Willamette rivers and their data were reported to PTAGIS. Recaptures of 2011 released fish totaled 22, with 11 each from the TR and HOR release groups (Table 9). The first recapture was collected on 14 June 2011 and the final recapture occurred on 5 January 2012. The median growth rate (mm/d FL) for recaptures and mortalities (collected during research projects) of fish released in 2011 was 0.71 mm/d (N=24) with a median of 64 days at large (Table 10). Growth rates differed significantly between release groups (T= -2.21, P=0.04) (Table 11), with median growth rates of 0.65 mm/d (N=11, median days at large=68) and 0.73 mm/d (N=13, median days at large=52) for TR and HOR-released fish, respectively (Figure 12, Table 10). One HOR recapture with a growth rate of 11.8 mm/d was omitted from analysis as an apparent outlier.

A total of 184 recaptures were recorded for fish released in the MFW in 2012, including 80 TR-released fish, 92 HOR-released fish, and 12 HCR-released fish (Table 9). Recaptures of 2012 MFW-released fish were reported between 24 May 2012 and 1 May 2013. The median growth rate for recaptures and mortalities (collected during research projects) of fish released in 2012 was 0.78 mm/d (N=438) with a median of 77 days at large (Table 10). Growth rates differed significantly among release groups (Kruskal-Wallis one-way ANOVA on ranks; H=89.39, P<0.001) and HOR-released fish had a significantly greater median growth rate (0.97 mm/d, median days at large=77, N=316) than TR-released fish (0.31 mm/d, median days at large=41, N=81) (Figure 13, Table 10). The median growth rate for HCR-released fish (0.64 mm/d, median days at large=199, N=41) was significantly different from the median growth rate for TR releases but not HOR releases (Table 11).

For 2013 fish released in the MFW, 80 were recaptured, including 8 TR, 12 FB, 3 HOR, and 57 HCR-released fish (Table 9). All recaptures were reported during 3 June 2013 to 30 December 2013. The median growth rate for recaptures and mortalities (collected during research projects) of fish released in 2013 was 0.88 mm/d (N=693) with a median of 103 days at large (Table 10). Median growth rates were significantly different among release groups (Kruskal-Wallis one-way ANOVA on ranks; H=172.51, P<0.001); HOR-released fish again had

Table 9. Recapture information for juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette (MFW) River from 2011 to 2013 and North Santiam (NS) River from 2012 to 2013. Release locations in the MFW were Lookout Point head of reservoir (HOR) and forebay (FB), Dexter tailrace (TR), and Hills Creek Reservoir (HCR), and NS release locations were Detroit HOR and FB, and Minto TR. Recaptures were recorded during ODFW (gillnet, box trap, screw trap, e-fishing, and beach seine) and US Army Corps of Engineers (screw trap) research activities.

Release Location	Gillnet	Box Trap	Screw Trap	E-fish	Beach Seine	Juv Bypass
			MFW 2011			
Total	0	6	3	0	13	0
TR	0	0	0	0	11	0
HOR	0	6	3	0	2	0
			MFW 2012			
Total	2	15	41	46	79	1
TR	0	0	0	0	79	1
HOR	2	15	29	46	0	0
HCR	0	0	12	0	0	0
			MFW 2013			
Total	0	3	66	0	8	3
TR	0	0	0	0	8	0
FB	0	1	9	0	0	2
HOR	0	2	0	0	0	1
HCR	0	0	57	0	0	0
			NS 2012			
Total	0	0	1	0	0	7
TR	0	0	0	0	0	7
HOR	0	0	1	0	0	0
			NS 2013			
Total	0	0	146	0	0	7
FB	0	0	82	0	0	1
HOR	0	0	64	0	0	6

Table 10. Days at large and growth rate (mm/day, FL) as determined from recaptures and research-related mortalities of PIT-tagged juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette (MFW) River from 2011 to 2013 and North Santiam (NS) River from 2012 to 2013. Release locations in the MFW were Lookout Point head of reservoir (HOR) and forebay (FB), Dexter tailrace (TR), and Hills Creek Reservoir (HCR), and NS release locations were Detroit HOR and FB, and Minto TR.

Release Location	Days at Large					Growth Rate (FL, mm/d)				
	N	Mean	SE	Median	Range	N	Mean	SE	Median	Range
MFW 2011										
Total	24	68.6	8.20	64	247-42	24	0.71	0.03	0.71	1.03-0.47
TR	11	66.0	2.11	68	76-49	11	0.64	0.04	0.65	0.80-0.47
HOR	13	70.8	15.30	52	247-42	13	0.76	0.04	0.73	1.03-0.60
MFW 2012										
Total	438	85.3	2.88	77	363-21	438	0.70	0.02	0.78	1.23- -0.25
TR	81	46.3	3.75	41	314-28	81	0.36	0.03	0.31	0.80- -0.04
HOR	316	81.7	2.93	77	363-21	316	0.79	0.02	0.97	1.23- -0.25
HCR	41	190.4	6.46	202	363-141	41	0.72	0.02	0.69	1.10-0.50
MFW 2013										
Total	693	120.4	1.91	103	432-25	693	0.84	0.01	0.88	1.15- -0.08
TR	9	55.1	5.68	51	99-38	9	0.50	0.09	0.47	1.10-0.20
FB	332	115.4	2.51	102	432-32	332	0.87	0.01	0.89	1.09-0
HOR	273	114.2	2.44	103	207-31	273	0.88	0.01	0.90	1.15-0.07
HCR	79	170.3	7.56	199	236-25	79	0.59	0.02	0.64	1.00- -0.08
NS 2012										
Total	116	94.8	5.03	83	286-21	116	0.72	0.02	0.76	1.06-0.11
TR	9	225.4	2.35	226	239-216	9	0.20	0.02	0.17	0.33-0.13
HOR	107	83.8	3.87	82	286-21	107	0.76	0.02	0.78	1.06-0.11
NS 2013										
Total	655	131.0	2.04	127	318-25	655	0.69	0.01	0.70	1.16-0.08
FB	372	121.6	2.66	106	317-25	372	0.70	0.01	0.71	1.16-0.08
HOR	283	143.3	3.04	137	318-28	283	0.68	0.01	0.68	1.03-0.25

Table 11. Median growth rates (mm/day, FL) of juvenile hatchery spring Chinook salmon recaptures and research-related mortalities from 2011-13 Middle Fork Willamette Dexter tailrace (TR), Lookout Point head of reservoir (HOR) and forebay (FB), and Hills Creek Reservoir (HCR) releases. Median growth rates within the same release year that do not share the same letter differed significantly (Mann-Whitney rank sum and Kruskal-Wallis one-way analysis of variance on ranks, $P<0.05$).

	Release Location			
Release Year	TR	FB	HOR	HCR
2011	0.65^{A}	--	0.73^{B}	--
2012	0.31^{A}	--	0.97^{B}	0.69^{B}
2013	0.47^{A}	0.89^{B}	0.90^{B}	0.64^{A}

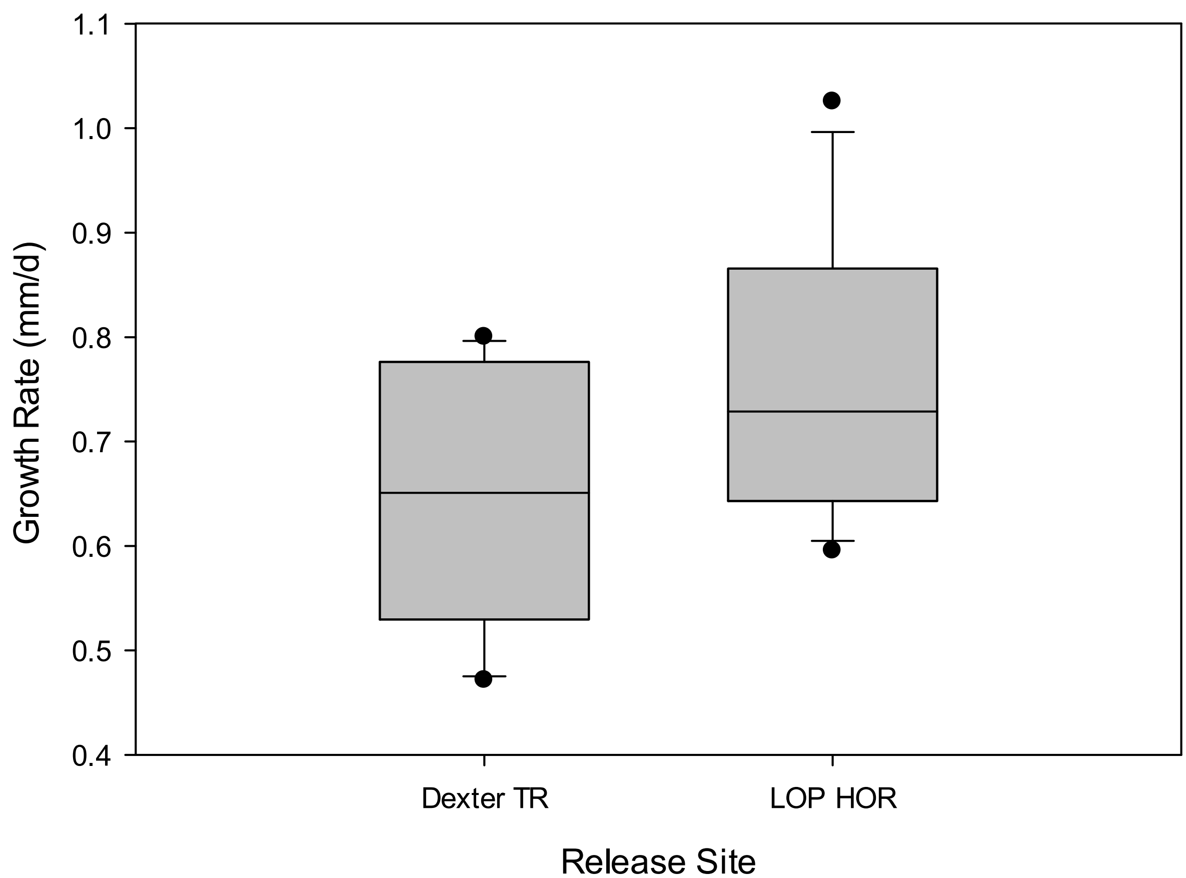

Figure 12. Growth rates as determined from recaptures and research-related mortalities of PIT-tagged juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette River on 25 May 2011 at Dexter tailrace (TR) and 19 May 2011 at Lookout Point (LOP) head of reservoir (HOR).

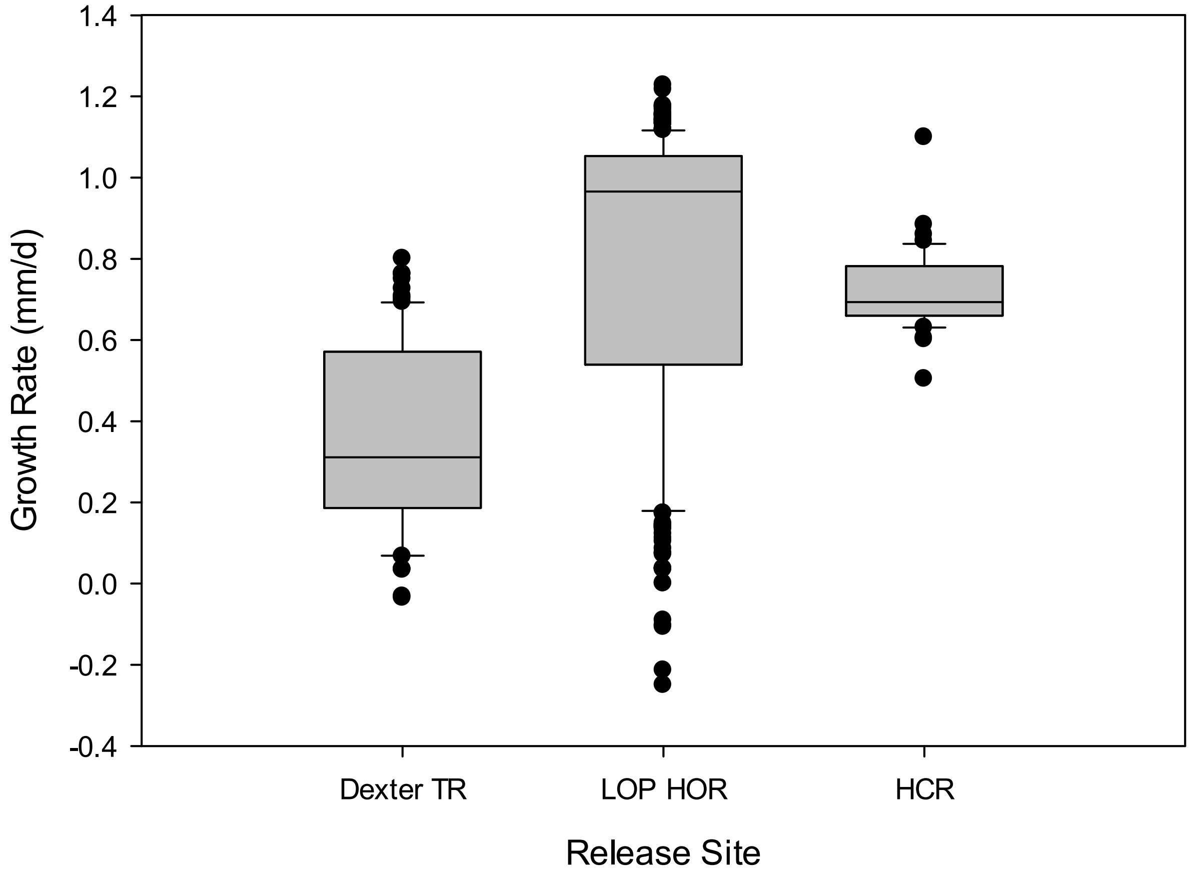

Figure 13. Growth rates as determined from recaptures and research-related mortalities of PIT-tagged juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette River on 23 May 2013 at Dexter tailrace (TR), Lookout Point (LOP) head of reservoir (HOR), and Hills Creek Reservoir (HCR).

the greatest median growth rate (0.90 mm/d, median days at large=103, N=273) compared to TR (median=0.47 mm/d, median days at large=51, N=9) and HCR (median=0.64 mm/d, median days at large=199, N=79) releases (Figure 14, Table 10). Growth rates for HOR and FB (median=0.89 mm/d, median days at large=102, N=332) and TR and HCR releases were not significantly different (Dunn's method; P>0.05), but differences for all other comparisons were statistically significant (Table 11).

Survival to Adulthood

Four of the PIT-tagged Chinook salmon released in 2011 were detected at Willamette Falls as returning adults. One fish was detected on 22 April 2013, indicating it returned as an age-3 jack. The other three returned between 2 May 2014 and 14 May 2014 as age-4 adults (mean 1,082 days at large, SE=1.76). Two of the adult returns, including the fish that was detected in 2013, were released in Dexter TR and two were released in LOP HOR. Only one of the returning adults detected at Willamette Falls was also detected at the falls during outmigration. The HOR-released fish was first detected as a juvenile at the falls on 2 July 2011,

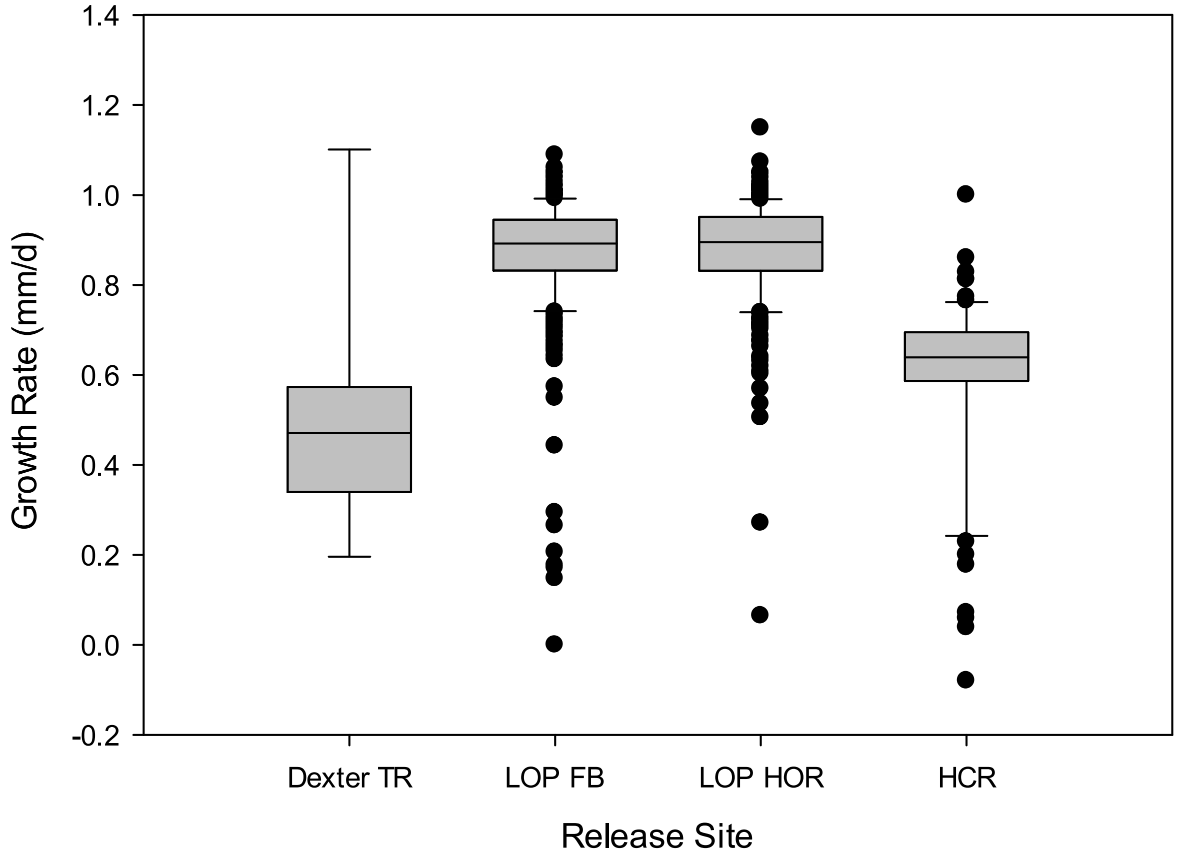

Figure 14. Growth rates (mm/day) as determined from recaptures and research-related mortalities of PIT-tagged juvenile hatchery spring Chinook salmon released in the Middle Fork Willamette River on 31 May 2013 at Dexter tailrace (TR), Lookout Point (LOP) head of reservoir (HOR) and forebay (FB), and Hills Creek Reservoir (HCR).

then again on 2 May 2014 as a returning adult (1,016 days between detections). A query of the Regional Mark Information System (RMIS, http://www.rmpc.org) indicated that 16 of the nearly 200,000 CWT-tagged fish released at the LOP HOR were recovered as adults. Of the 16 recoveries, 13 were collected at hatcheries while the other three were from an Alaska rockfish commercial fishery, Columbia/Willamette freshwater sport harvest, and a lower Columbia River test-net fishery.

For the 2012 releases in the MFW, seven fish were detected as returning age-3 jacks at Willamette Falls in 2014. These were detected at the falls between 28 April 2014 and 28 May 2014 (average of 719 days at large; SE=3.97). Five were from HOR releases and two originated from the Dexter TR release (no HCR-released fish have been detected as returning adults). Only one of the adults detected at Willamette Falls was also detected during outmigration. This TR-released fish was detected at the falls as a juvenile on 25 June 2012, then as an adult on 17 May 2014 (691 days between detections).

North Santiam River

Willamette Falls PIT Tag Detections

The median FL of tagged fish released into the NS in 2012 was 91 mm (N=24,786), with a median length of 91 mm for fish released in the TR (N=12,409) and 90 mm (N=12,377) for fish released in the HOR (Table 2). The median initial tagging FL of fish detected at Willamette Falls was 92 mm (N=1,923), with a median length of 93 mm (N=1,036) for TR-released fish and 91 mm (N=887) for HOR-released fish (Table 2).

Of the 24,931 (12,475 TR and 12,456 HOR**)** PIT-tagged fish released in the NS on 10 August 2012, 1,940 (7.8%; 1,045 TR and 895 HOR) were detected at Willamette Falls between 24 August 2012 and 10 July 2013 (Figure 15). The proportion of TR-released fish detected at the falls (0.084) was larger than the proportion of HOR-released fish (0.072) and differed significantly (X^2=11.99, P<0.001) from equal proportions. The ratio of TR to HOR detections was 1.17:1 (Table 12), an effect size of 15%. Cumulative detections plateaued in mid-October for both release groups, followed by a secondary outmigration in the subsequent spring and summer (Figure 15). Prior to 1 February 2013, 917 TR detections were recorded (87.8% of 2012 TR detections) with only 39 more (3.7% of 2012 TR detections) occurring between 23 October 2012 and 31 January 2013 (Figures 15 and 16). From 1 February to the last detection on 27 April 2013, an additional 128 tags were detected (12.3% of 2012 TR detections) at Willamette Falls. This pattern was similar for HOR detections, except for the secondary peak, which occurred later. There were 737 detections (82.4% of 2012 HOR detections) between 29 August 2012 and 31 April 2013. An additional 158 detections (17.7% of 2012 HOR detections) occurred from 1 May 2013 to the last detection on 10 July 2013 (Figures 15 and 16).

The median FL of tagged fish released into the NS in 2013 was 69 mm (N=99,298) with a median length of 69 mm for fish released in the TR (N=33,191) and the FB (N=33,003), and 68 mm (N=33,104) for fish released in the HOR (Table 2). Median tagging FL of fish detected at Willamette Falls was 69 mm (N=2,869), with a median length of 70 mm for TR (N=1,218) and FB (N=926) releases, and 69 mm (N=725) for HOR-released fish detected at Willamette Falls (Table 2). Median initial tagging lengths of TR-released fish were significantly larger (Kruskal-Wallis one-way ANOVA on ranks; H= 10.42, P=0.005; Dunn's method P<0.05) than initial tagging lengths of HOR detections, but initial tagging lengths of fish detected at Willamette Falls did not differ significantly among the other release groups.

A total of 2,887 (1,222 TR, 937 FB, 728 HOR) of the 99,753 (2.9%; 33,299 TR, 33,246 FB, 33,208 HOR) PIT-tagged fish released in the NS on 27 June 2013 were detected at Willamette Falls. The first detection of 2013 NS releases was recorded on 13 July 2013 and the last occurred on 9 June 2014 (Figure 15). From 22 September 2013 until 17 October 2013 the antenna at Willamette Falls in the north fish bypass malfunctioned resulting in 222 TR, 135 FB, and 48 HOR detections without accurate date-time stamps, and thus could not be represented in the cumulative detection graphs (a few were detected in Turbine 13 which had a functional antenna). The proportions of TR (0.037), FB (0.028), and HOR (0.022) released fish detected at the falls were all significantly different from equal proportions (TR/FB: X^2=37.86, P<0.001; TR/HOR: X^2=127.60, P<0.001; FB/HOR: X^2=26.92, P<0.001) with detection ratios of 1.30:1,

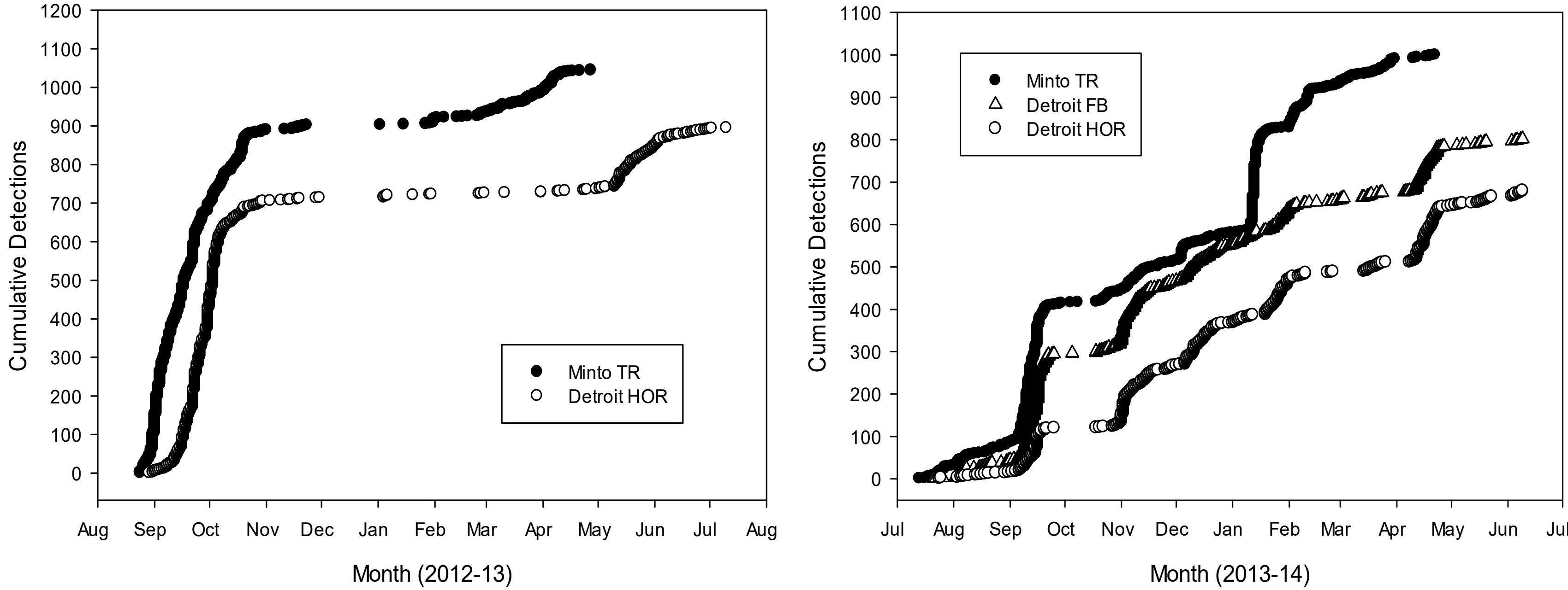

Figure 15. Cumulative detections at Willamette Falls of PIT-tagged juvenile hatchery spring Chinook salmon released into the North Santiam River. Release locations were Detroit head of reservoir (HOR) and forebay (FB), and Minto tailrace (TR), and release dates were 10 August 2012 and 27 June 2013. Note scale differences on the X and Y axes.

Table 12. Proportions of juvenile hatchery spring Chinook salmon detected at Willamette Falls from 2012-13 North Santiam Minto tailrace (TR) and Detroit head of reservoir (HOR) and forebay (FB). Proportions within the same release year that do not share the same letter differed significantly (X^2, $P<0.05$).

	Release Location		
Release Year	TR	FB	HOR
2012	0.084^{A}	--	0.072^{B}
2013	0.037^{A}	0.028^{B}	0.022^{C}

1.68:1, 1.29:1 for TR to FB, TR to HOR, and FB to HOR, respectively (Table 12). The effect size between TR and HOR releases was 41%. Daily detections peaked multiple times for each release group in 2013 and 2014 (Figure 16). For TR-released fish, detections initially peaked by mid-October with a cumulative 639 (52.3% of 2013 TR detections) detections between 13 July 2013 and 17 October 2013, which then increased in January by 419 detections (34.3% of 2013 TR detections) between 1 January 2014 and 22 March 2014 (Figure 15). Detection patterns of FB and HOR-released fish were similar, with 432 FB (46.1% of 2013 FB detections) and 168 HOR (23.1% of 2013 HOR detections) detections by 17 October 2013. Additional peaks in daily counts were detected in mid-November and late April with 151 FB (16.1% of 2013 FB detections) and 135 HOR detections (18.5% of 2013 HOR detections) between 25 October 2013 and 25 November 2013. An additional 109 FB (11.6% of 2013 FB detections) and 132 HOR (18.1% of 2013 HOR detections) detections were recorded between 1 April 2014 and 30 April 2014 (Figure 15).

A number of fish released in the NS during this study were detected in the lower Columbia River by the PD7 fixed antenna and TWX trawl array. For 2012 releases, 3 TR and 19 HOR-released fish were detected in the lower Columbia River (all but 1 were detected by the towed array) of which 3 HOR-released fish were also detected at Willamette Falls (13.6% of PD7 and TWX detections). Thirty-three fish (9 TR, 13 FB, 11 HOR) from 2013 releases were detected in the lower Columbia River (23 of the 33 detections occurred at TWX) with 21.2% (3 TR, 3 FB, 1 HOR) of those fish also detected at the falls. Numerous tags were also collected at East Sand Island in the lower Columbia River (ESANIS; rkm 8) likely as a consequence of avian predation. Thirty fish/tags (15 TR, 15 HOR) from 2012 NS releases were collected at ESANIS, of which 6 TR and 5 HOR (36.7%) released fish were also detected at Willamette Falls. For 2013 NS releases, 4 TR, 3 FB, and 3 HOR fish/tags were collected at ESANIS with 60% (3 TR, 2 FB, and 1 HOR) of those fish/tags also detected at Willamette Falls.

Movement rates

The median travel time from release to Willamette Falls for the 2012 NS PIT-tagged fish was 47 d (N=1,940) with median travel times of 40 d (N=1,045) and 52 d (N=895) for TR and HOR-released fish, respectively (Table 4). The median movement rate of 2012 NS

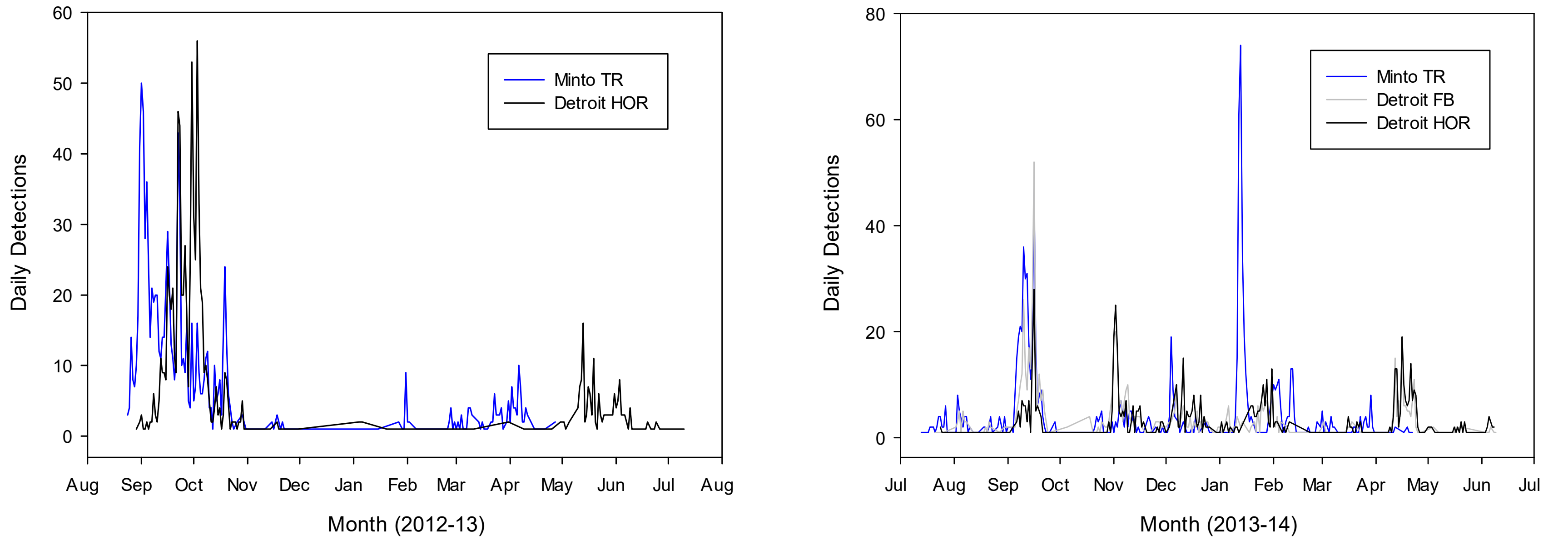

Figure 16. Daily detections at Willamette Falls of PIT-tagged juvenile spring Chinook salmon released in the North Santiam River. Release locations were Detroit head of reservoir (HOR) and forebay (FB), and Minto tailrace (TR), and release dates were 10 August 2012 and 27 June 2013. Note scale differences on the X and Y axes.

releases was 8.84 km/d, and TR-released fish traveled significantly faster (Mann-Whitney rank sum: U=320085.00, $P<0.001$) (median=9.48 km/d, N=1,045) than HOR-released fish (median=7.77 km/d, N=895) (Figure 17, Table 13).

For 2013 NS releases, median travel time from release to Willamette Falls was 155 d (N=2,482) with median travel times of 146 d (N=1,000), 133 d (N=802), and 173 d (N=680) for TR, FB, and HOR-released fish, respectively (Table 4). The median movement rate for 2013 NS releases was 1.49 km/d (N=2,482), with TR (median=1.49 km/d, N=1,000) and FB (median=1.71 km/d, N=802) releases showing significantly greater (Kruskal-Wallis one-way ANOVA on ranks; H=28.84, $P<0.001$, Dunn's method $P<0.05$) movement rates than HOR releases (median=1.39km/d, N=680)(Figure 18, Table 13). Movement rates for fish detected at Willamette Falls did not significantly differ among other release groups (Table 13).

Additional Detections - Movement rates

Additional fish detections at PD7 and TWX in the lower Columbia River provided supplementary information about fish movement rates below Willamette Falls and through the lower Columbia River. Fish released in the NS in 2012 that were detected in the lower Columbia River traveled at a median overall rate of 1.30 km/d (N=22, median travel time=287 d). For 2012 NS TR-released fish, the median movement rate to detection in the lower Columbia River was 1.43 km/d (N=3, median travel time=242 d) while HOR-released fish had a median movement rate of 1.30 km/d (N=19, median travel time=287 d) (Table 6). For HOR fish that were also detected at Willamette Falls, median movement rate to the falls was 0.87 km/d (N=3, median travel time=276 d) while median movement rate below the falls to lower Columbia River detection was 43.67 km/d (N=3, median travel time=3 d) (Table 7).

Fish released in the NS in 2013 that were detected in the lower Columbia River traveled at a median overall rate of 1.20 km/d (N=33, median travel time=302 d). For 2013 NS TR-released fish, median movement rate to detection in the lower Columbia River was 1.27 km/d (N=9, median travel time=278 d), while FB and HOR-released fish had median movement rates of 1.19 km/d (N=13, median travel time=302 d) and 1.21 km/d (N=11, median travel time= 309 d), respectively (Table 6). A total of 7 fish from the 2013 releases detected in the lower Columbia River were also detected at Willamette Falls and those fish had a median overall movement rate of 1.09 km/d (median travel time=198 d) to the falls and a median overall movement rate of 27.20 km/d (median travel time=5 d) from the falls to detection in the lower Columbia River. For TR-released fish that were also detected at Willamette Falls, median movement rate to the falls was 1.09 km/d (N=3, median travel time=198 d) while median movement rate below the falls to lower Columbia River detection was 2.23 km/d (N=3, median travel time=61 d) (Table 7). The 3 FB-released fish that were detected both at Willamette Falls and in the lower Columbia River traveled at a median rate of 2.78 km/d (median travel time= 82 d) to the falls and 27.20 km/d (median travel time=5 d) below the falls until detection in the lower Columbia River. One 2013 HOR-released fish traveled at a rate of 0.80 km/d (301 d) to the falls and 43.7 km/d (3 d) from the falls to detection in the lower Columbia River.

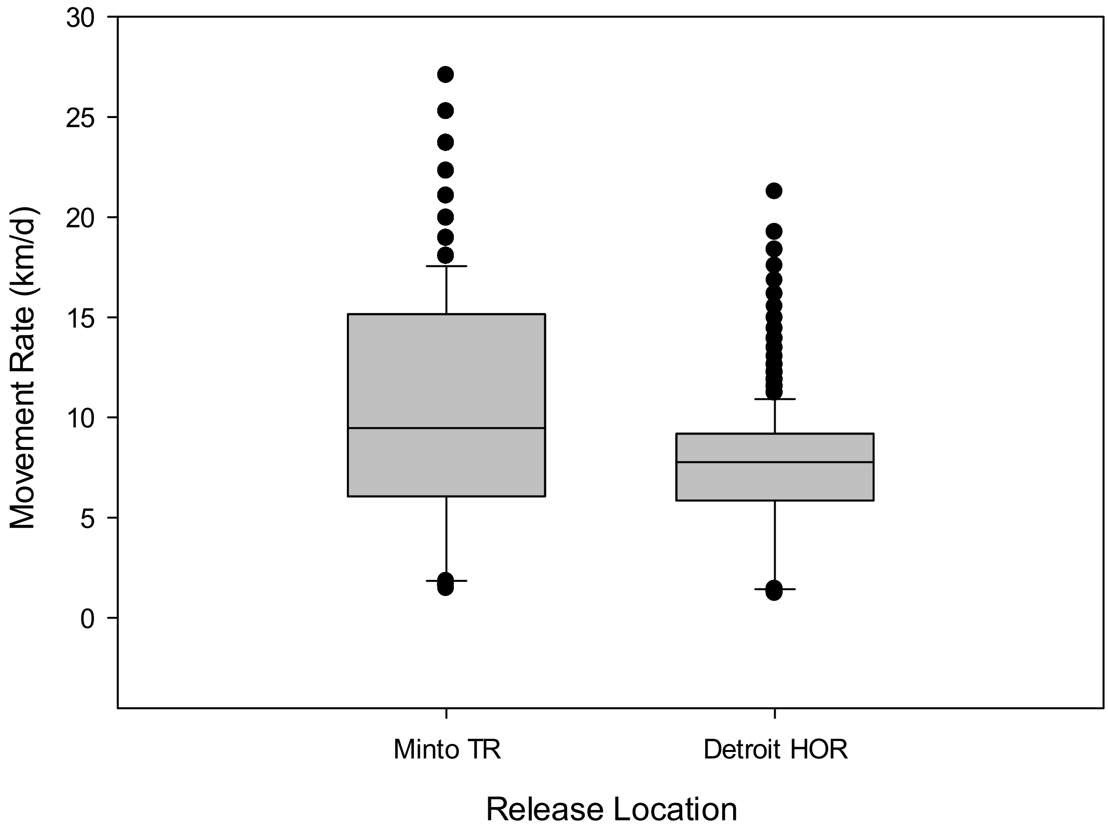

Figure 17. Movement rates as determined from PIT tag detections at Willamette Falls of juvenile hatchery spring Chinook salmon released in the North Santiam River on 10 August 2012 at Minto tailrace (TR) and Detroit head of reservoir (HOR).

Table 13. Median movement rates (km/day) of juvenile hatchery spring Chinook salmon detected at Willamette Falls from 2012-13 North Santiam Minto tailrace (TR), and Detroit head of reservoir (HOR) and forebay (FB) releases. Median movement rates within the same release year that do not share the same letter differed significantly (Mann-Whitney rank sum and Kruskal-Wallis one-way analysis of variance on ranks, *P*<0.05).

	Release Location		
Release Year	TR	FB	HOR
2012	9.48^{A}	--	7.77^{B}
2013	1.49^{A}	1.71^{A}	1.39^{B}

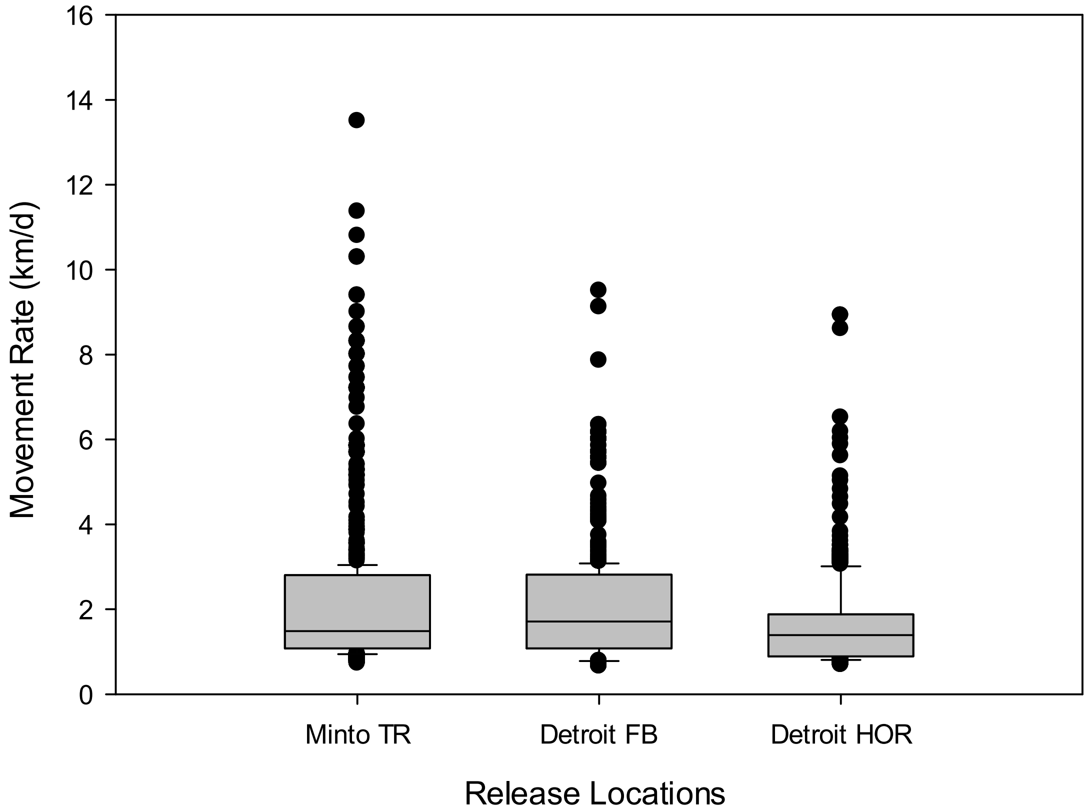

Figure 18. Movement rates as determined from PIT tag detections at Willamette Falls of juvenile hatchery spring Chinook salmon released in the North Santiam River on 27 June 2013 at Minto tailrace (TR) and Detroit head of reservoir (HOR) and forebay (FB).

Stream Discharge and Willamette Falls Daily Detections

Spearman correlation analysis for 2012 NS daily detections at Willamette Falls and Willamette River discharge at Salem indicated significant negative relationships for TR (ρ= -0.67, P<0.001, N=247) and HOR (ρ= -0.50, P<0.001, N=321) daily detections with Willamette discharge (overall correlation: ρ= -0.55, P<0.001, N=568) (Figure 19). For 2013 released fish, Spearman correlation analysis indicated a significant negative relationships for FB (ρ= -0.14, P=0.001, N=329) daily detections and Willamette discharge, and non-significant negative relationships for TR (ρ= -0.14, P=0.58, N=278) and HOR (ρ= -0.06, P=0.26, N=332) daily detections with Willamette discharge (overall correlation: ρ= -0.08, P<0.01, N=939) (Figure 19).

Spearman correlation analysis for daily detections at Willamette Falls of 2012 releases and NS discharge at Mehama indicated significant negative relationships for TR (ρ= -0.57, P<0.001, N=247) and HOR (ρ= -0.33, P<0.001, N=321) daily detections with NS discharge (overall correlation: ρ= -0.42, P<0.001, N=568) (Figure 20). For 2013 released fish, daily detections for TR (ρ= -0.04, P=0.52, N=284), FB (ρ= -0.10, P=0.07, N=332), and HOR (ρ=

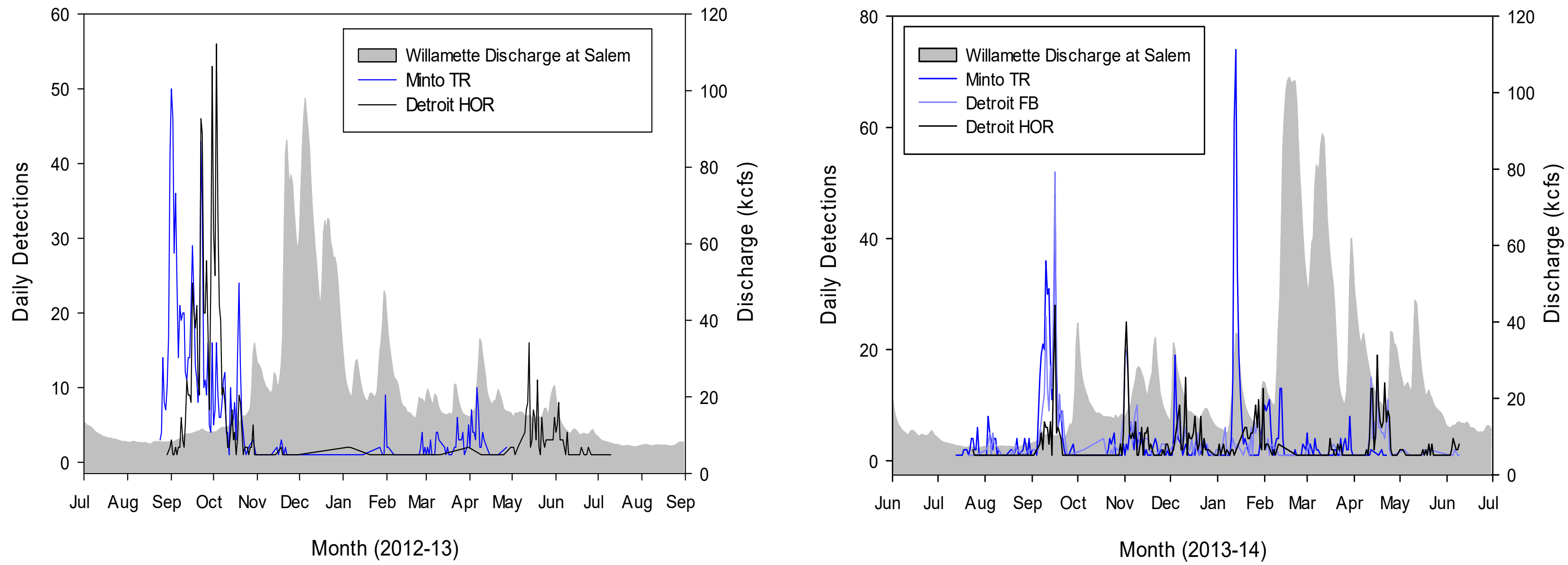

Figure 19. Daily detections at Willamette Falls of PIT-tagged juvenile spring Chinook salmon released in the North Santiam River and Willamette River discharge (kcfs) at Salem (USGS, http://waterdata.usgs.gov/nwis). Release locations were Detroit head of reservoir (HOR) and forebay (FB), and Minto tailrace (TR), and release dates were 10 August 2012 and 27 June 2013. Note scale differences on the X and Y axes.

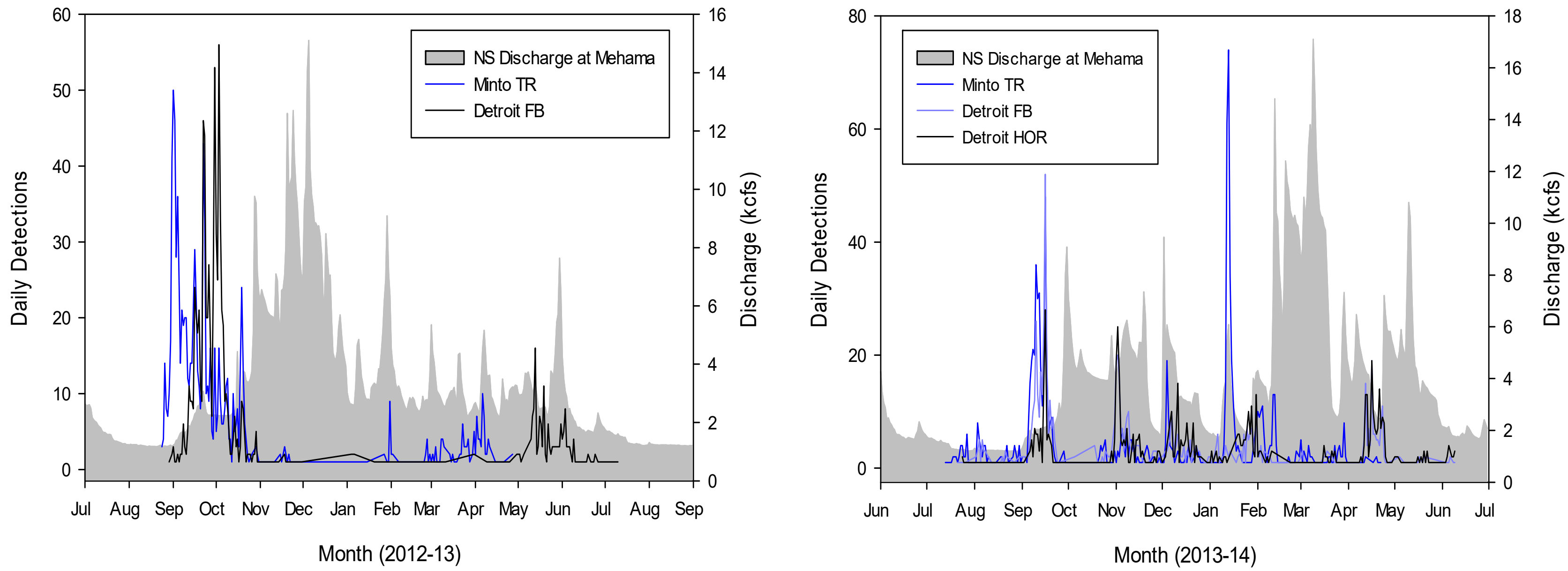

Figure 20. Daily detections at Willamette Falls of PIT-tagged juvenile spring Chinook salmon released in the North Santiam (NS) River and NS discharge (kcfs) at Mehama (USGS, http://waterdata.usgs.gov/nwis). Release locations were Detroit head of reservoir (HOR) and forebay (FB), and Minto tailrace (TR), and release dates were 10 August 2012 and 27 June 2013. Note scale differences on the X and Y axes.

-0.08, *P*=0.18, N=332) released fish showed non-significant negative relationships with NS discharge (overall correlation: ρ= -0.07, *P*=0.07, N=948) (Figure 20).

Analysis of USACE Detroit Dam discharge and spill data showed multiple periods of increased discharge and spill shortly after NS releases that could have helped facilitate movement of fish through the reservoir and dam (Figure 21). Following the NS releases in August of 2012 and June 2013, Detroit discharge and spill levels of 500 to 2,500 cfs were recorded from August into September, with continued spill into mid-September for both years (Figure 21).

Mortalities

Mortalities of NS released fish attributed to predation (avian and piscine) and various research activities taking place in the NS and Willamette mainstem (e.g., netting and trapping activities) were reported throughout the duration of the study. For 2012 NS releases, 140 fish were reported as mortalities with 17 reported for TR-released fish and 123 for HOR-released fish (Table 8). The first mortality for 2012 releases was recorded 16 August 2012 approximately one week after release, and the final mortality was reported 13 December 2013 approximately 16 months after release. All reported predation of 2012 released fish was attributed to birds (N=30), while gillnets were the leading cause of reported mortalities (N=106) related to research (Table 8). Of the 140 reported mortalities, parasitic copepods were noted on 81 fish (58%).

A total of 519 fish released in the NS in 2013 were collected as mortalities with 4 mortalities reported for TR-released fish, 296 for FB-released fish, and 219 for HOR-released fish (Table 8). The first mortality of 2013 releases was recorded on 16 July 2013 approximately 3 weeks after release, and the final mortality was reported 26 April 2014 roughly 43 weeks after release. As was the case for 2012 releases, birds (N=10) and gillnets (N=473) were the major contributors to reported mortalities of 2013 NS releases (Table 8). Of the 519 reported mortalities for 2013 released fish, 298 (57%) were noted as having copepods.

Recaptures and Growth Rates

A number of fish released in the NS for this project have been recaptured during various projects in the NS and mainstem Willamette River and reported to PTAGIS. Recaptures of 2012 released fish totaled 8, with all but one coming from TR-released fish (Table 9). The initial recapture of 2012 releases was collected on 5 November 2012 and the final recapture occurred on 22 March 2013. The median growth rate (mm/d FL) for recaptures and mortalities (collected during research projects) of fish released in 2012 was 0.76 mm/d (N=116), with a median of 83 days at large (Table 10). Median growth rates differed significantly between release groups (Mann-Whitney rank sum test=10.00, *P*<0.001), with HOR-released fish having significantly greater growth rates (median=0.78 mm/d, median days at large=82, N=107) than TR (median=0.17 mm/d, median days at large=226, N=9) released fish (Figure 22, Table 14).

A total of 153 recaptures were recorded for fish released in the NS in 2013 with 82 from FB-released fish and 70 from HOR-released fish (Table 9). The first recapture of 2013 released fish occurred on 8 July 2013 and the final recapture was collected 24 April 2014. The median

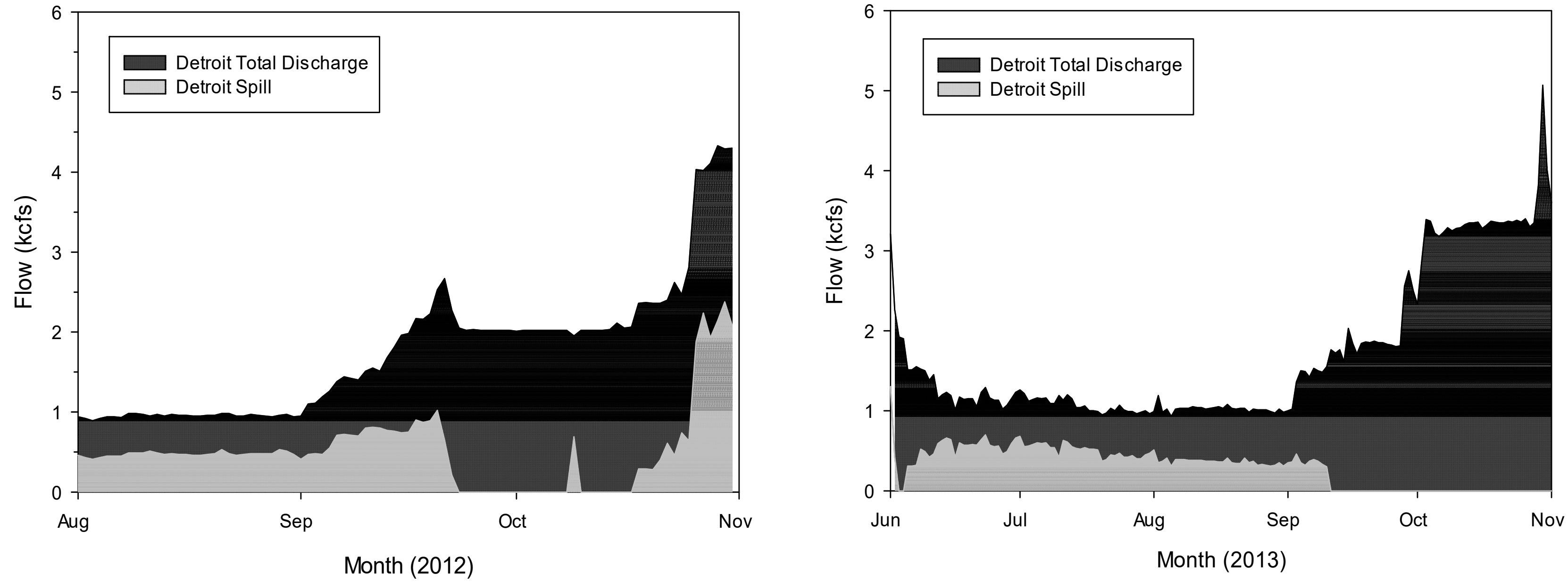

Figure 21. Discharge and spill (kcfs) information for Detroit Dam in the North Santiam (NS) River (US Army Corps of Engineers, http://www.nwd-wc.usace.army.mil/cgi-bin/dataquery.pl). Releases of juvenile spring Chinook salmon in the NS took place on the 10 August 2012 and 27 June 2013. Note scale difference on the X axis.

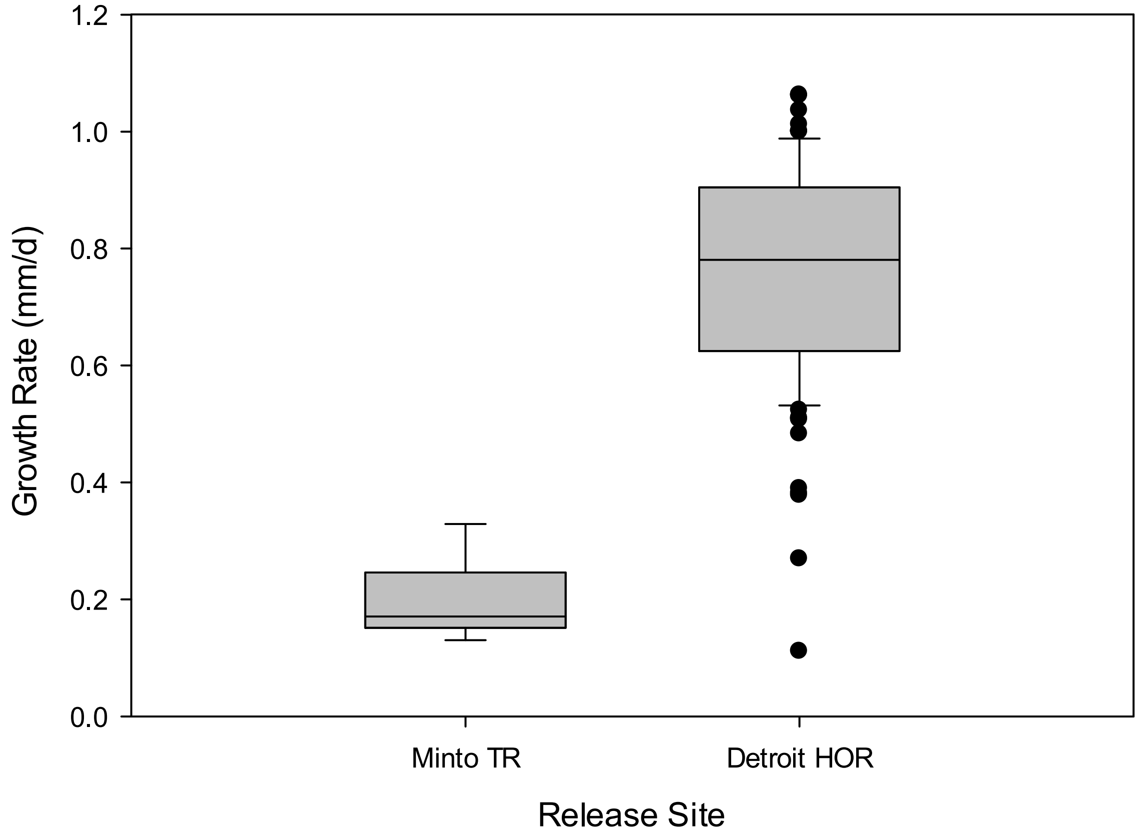

Figure 22. Growth rates as determined from recaptures and research-related mortalities of PIT-tagged juvenile hatchery spring Chinook salmon released in the North Santiam River on 10 August 2012 at the Minto tailrace (TR) and Detroit head of reservoir (HOR).

Table 14. Median growth rates (mm/day, FL) of juvenile hatchery spring Chinook salmon recaptures and research-related mortalities from 2012-13 North Santiam Minto tailrace (TR), and Detroit forebay (FB) and head of reservoir (HOR) releases. Median growth rates within the same release year that do not share the same letter differed significantly (Mann-Whitney rank sum and Kruskal-Wallis one-way analysis of variance on ranks, $P<0.05$).

	Release Location		
Release Year	TR	FB	HOR
2012	0.17^{A}	n/a	0.78^{B}
2013	--	0.71^{A}	0.68^{B}

growth rate for recaptures and mortalities (collected during research projects) of fish released in 2013 was 0.70 mm/d (N=655) with a median of 127 days at large (Table 10). Median growth rates differed significantly (Mann-Whitney rank sum test: U=47399.00, *P*=0.029) between release groups (there were no recaptures or research mortalities from TR-released fish), as growth rates for FB-released fish (median=0.71 mm/d, median days at large=106, N=372) were significantly greater than those of HOR-released fish (median=0.68 mm/d, median days at large=137, N=283) (Figure 23, Table 14).

Survival to Adulthood

Six of the NS 2012 released fish have been detected in the adult ladder at Willamette Falls. One fish released in the TR on 10 August 2012 at 103 mm FL was detected in the adult ladder on 25 February 2013 (200 d after release), indicating it was likely an early-returning precocial male. The other five fish with a mean initial tagging length of 92 mm FL returned between 31 May 2014 and 30 July 2014 as age-3 jacks (average of 692 days at large, SE=10.86). Three of the returners, including the fish that was detected in 2013, were released in Minto TR and three were released in Detroit HOR. Two of the returning adults were detected at Willamette Falls as adults and during outmigration. Both fish were initially released at the HOR, with one detected at the falls on 4 October 2012 and 31 May 2014 (604 d between detections) and the other detected on 26 September 2012 and 26 June 2014 (638 d between detections). A query of RMIS indicated that none of the roughly 75,000 CWT-tagged Chinook salmon released in the Minto TR and Detroit HOR have been recovered.

Discussion

With 6,251 of the MFW and 4,792 of the NS releases detected at Willamette Falls, a substantial amount of data was available to make inferences regarding outmigration survival and movement rates of the study fish. As expected, observed proportions of fish detected at Willamette Falls for each release group across release years and basins differed significantly from equal proportions, with TR release groups consistently having the greatest detection rates. Our results indicate an effect of direct reservoir and dam passage on juvenile Chinook salmon survival which is likely compounded by distance from release to the dam and passage through multiple dams, as evidenced from decreasing detection proportions by release site moving up-river in both basins. The detection of only 27 of 82,631 HCR-released fish at Willamette Falls is a particularly compelling example of the possible compounding impacts on juvenile salmonid survival from passing through multiple reservoirs and dams. Though detection proportions were not large for any of the release groups, detection proportions of MFW TR releases were approximately 2.5 to 183 times greater than the other MFW release group proportions. Differences in detection proportions for NS releases were less than those observed for MFW releases with TR proportions 1.2 to 1.3 times greater than other NS release groups. This discrepancy in effect sizes between basins suggests that the generalized effect of reservoir and dam passage is more substantial in the MFW than the NS. However, differences in fish release size and timing, distance to detection at Willamette Falls, and other factors may limit these between-basin inferences.

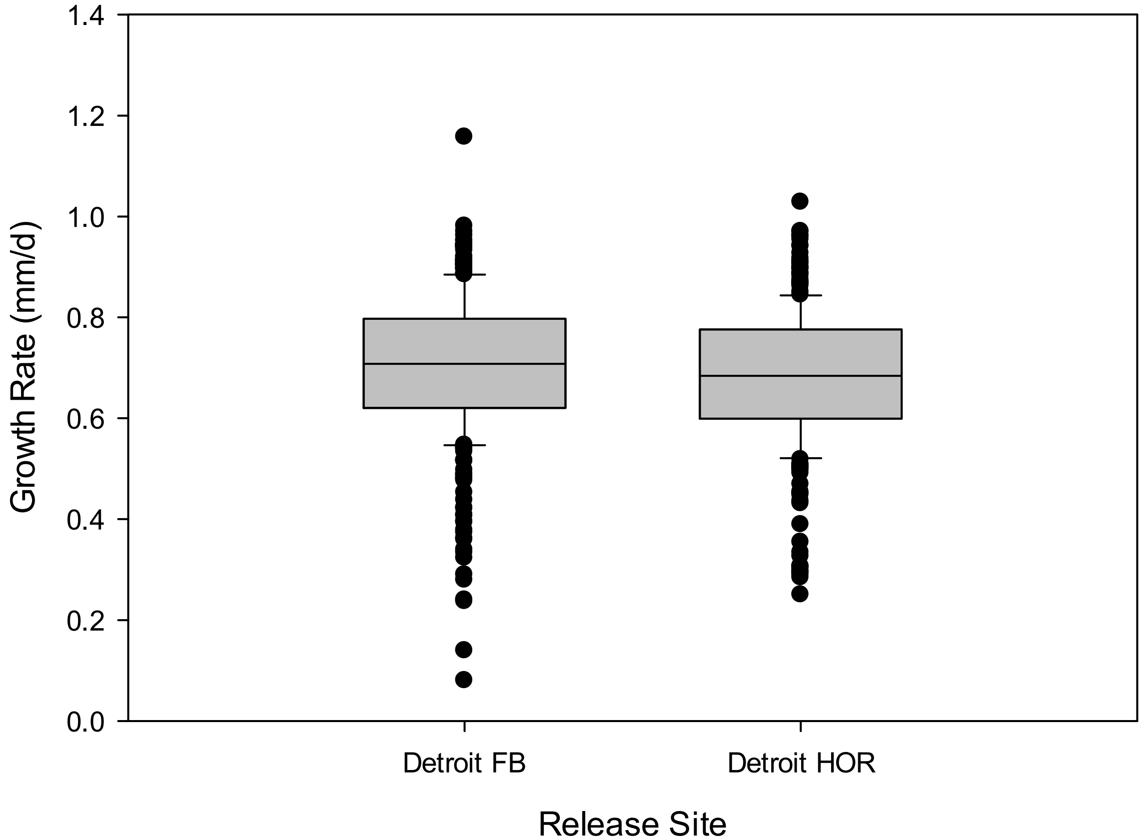

Figure 23. Growth rates (mm/day) as determined from recaptures and research-related mortalities of PIT-tagged juvenile hatchery spring Chinook salmon released in the North Santiam River on 27 June 2013 at the Detroit forebay (FB) and head of reservoir (HOR).

Numerous studies within (Ziller 2002; Duncan and Carlson 2011; Keefer et al. 2012; Keefer et al. 2013; Beeman and Adams 2015) and outside (Mathur et al. 1996; Muir et al. 2001; Ferguson et al. 2006) the Willamette basin have examined the impacts of direct dam passage on outmigrating juvenile salmonid survival, with results indicating likely dam passage effects. Beeman and Adams (2015) estimated low probabilities of passage for spring Chinook salmon and summer steelhead surrogates at Detroit Dam; about 1 in 10 during spring and 1 in 100 during the fall, despite high probabilities of fish reaching the forebay and dam. Tests conducted at Detroit Dam in 2009 to assess spillway, regulating outlet, and turbine passage demonstrated extremely high impacts to both "sensor fish" and live rainbow trout tagged and released at the same time and locations; the authors concluded that none of the passage routes were safe for juvenile passage (Duncan and Carlson 2010). Ziller (2002) estimated mortality rates of 12% for Chinook salmon passing through the LOP turbines and 59% and 32% for passage through HCR turbines and regulating outlets, respectively. In the NS, Ziller (2002) estimated mortality rates of 58-65% for juvenile Chinook salmon passing through both Detroit and Big Cliff dams. Though not directly comparable, our results indirectly support this previous work, indicating outmigrating juvenile salmon in the upper MFW and NS basins experience substantial survival impacts from reservoir and dam passage.

Our estimates of juvenile survival and effect size were likely affected by variable detection efficiency at Willamette Falls. Juvenile salmonids approaching the falls are known to have a low entrainment rate into the north fish bypass that may vary substantially with river discharge. The relationship between discharge and entrainment rate is not precisely known and therefore it was not possible to accurately estimate the total number of fish from a given release that pass Willamette Falls (only the number of fish detected in the north fish bypass is known). This could lead to inaccurate estimates of counts among different release groups from a particular basin and year if they passed under different river conditions. Schroeder et al. (2016) recently provided an expansion factor that may help correct this problem; we plan to apply the expansion to our data retrospectively in future versions of this report (we provide additional recommendations below). The adult fish bypass has 100% detection efficiency (except during maintenance or power outages); juvenile-to-adult survival estimates to Willamette Falls will not be affected by variations in river flow.

Other biases in juvenile detection and survival estimates were possible, most associated with differences in release sites and procedures. The forebay release sites in particular were generally warmer at the surface and considerably deeper than the head-of-reservoir or tailrace sites. Some sites were up to 40 km apart (HCR vs. LOP TR), resulting in greater truck transport time prior to release. For purposes of this study we assumed additional mortality was not imparted by any of these factors. While we lacked the resources to test this assumption (e.g., by recapturing and holding fish from each release to assess delayed mortality), observations during and shortly (hours to days) after the releases suggested there was little immediate post-release mortality. In several cases where we could watch the fish for extended periods (Detroit FB and LOP HOR), we observed schooling and feeding behavior of the study fish immediately after they were released. The consistent patterns observed among basins and years leads us to believe that any biases, if they exist, are of constant magnitude and direction (see Figures 3 and 15).

Uncertainties associated with the fate of released fish in our study also created difficulties in making definitive determinations about reservoir and dam effects on outmigrating juvenile Chinook salmon. Willamette Falls is a substantial distance from release locations in the MFW and NS, and no specific efforts were made to collect fish between the release sites and the falls. It is possible that an unknown number of the fish released above dams passed through the dams unharmed only to succumb to predation or other stressors later during downstream migration in the MFW, NS, or Willamette rivers. Those non-detects would be assumed mortalities from reservoir and dam passage for our analysis which could inflate perceived effect sizes. The TR releases would also probably experience similar downstream effects, but it is important to recognize that the detection proportions used to evaluate reservoir and dam impacts on juvenile Chinook salmon survival are indices that likely include mortality not related to dam and reservoir passage.

Except for 2012 NS releases, median FLs of fish used for this study were similar across basins and years with median release group values from 62-69 mm. Chinook salmon released in the NS in 2012 had a median FL of 91 mm which was substantially larger than the median FLs of the other releases. Median release sizes were larger than those of naturally-produced subyearling Chinook salmon entering MFW and NS reservoirs, with most fish entering reservoirs in spring as fry <40 mm (Romer et al. 2012; Romer et al. 2013; Monzyk et al. 2014). Monzyk et al. (2014) observed markedly greater average sizes (>54 mm) of fish sampled in LOP reservoir in May and June which was around the time of our MFW releases, but average sizes of those captured in Detroit reservoir in June were still approximately 20-40 mm less than the median FLs of our NS releases. Various studies have examined the impacts of greater juvenile sizes on a variety of life history characteristics such as movement rates and timing (Beckman et al. 1998; Friesen et al. 2007), adult return timing (Scheuerell 2005), and dam passage mortality (Keefer et al. 2012) with results indicating faster juvenile outmigration rates, earlier outmigration and adult return timing, and greater risk of dam passage mortality for larger juveniles. However, the size of juvenile Chinook salmon considered to be "large" is often different from study to study, making it difficult to compare previous findings to our results. Initial tagging lengths of study fish detected at Willamette Falls were examined to check for a "release size" effect on the likelihood of detection at the falls, but for the most part median tagging lengths of fish detected at the falls did not differ from median initial tagging lengths of all released fish by release group, basin, and year. The 2012 NS median tagging FL was 22 mm greater than the 2013 NS median tagging FL and the total percentage of 2012 NS releases detected at Willamette Falls appeared to be 5% greater than the total percentage of 2013 NS detections, possibly indicating a positive relationship between larger tagging sizes and outmigration survival for NS Chinook salmon. However, the fact that 2012 releases took place approximately 1.5 months later than the 2013 releases diminishes meaningful comparisons.

With the exception of 2011 MFW and 2013 NS FB releases, movement rates for the TR release groups were greater than those of the other release groups across basins and years, possibly signifying a dam and reservoir effect on juvenile migration in the MFW and NS basins. For the 2011 MFW and 2013 NS TR and FB releases, movement rates were not significantly different from one another indicating no statistical difference in rates for those release groups. Venditti et al. (2000) found that median movement rates of juvenile Chinook salmon in the Snake River decreased from 25 km/d to 1 km/d as fish moved from HORs to FBs, but Beeman (2014) observed that it was common for juvenile Chinook salmon to move repeatedly back and forth from the head of Cougar Reservoir to the dam outlet, making it difficult to get an accurate idea of movement rates through reservoirs. Movement rates observed in our study, even for TR releases, are markedly slower than those that have been reported in other research. Evaluations by Giorgi et al. (1997) and Bell (1991) indicated juvenile Chinook salmon move downstream in the Columbia River at rates from 21-38 km/d but differences in dam operation procedures and stream characteristics make it likely that movement rates in the Columbia would be quicker than in the Willamette. Friesen et al. (2007) observed movement rates of 12.4 km/d for hatchery juvenile Chinook salmon in the lower Willamette River, and Schroeder et al. (2008) reported movement rates from 10-13 km/d for naturally-produced fish tagged below WVP dams in the NS and 15-31 km/d for naturally-produced fish tagged in the UWR below WVP dams. Though slower than what has been reported for outmigrating Columbia River Chinook salmon, the Willamette River movement rates are still substantially faster than what was observed in our study across all release groups, years, and basins. Differences in study design and fish size may account for the discrepancies in movement rates, as Friesen et al. (2007) also found a positive relationship between larger juvenile sizes and greater movement rates which may help to explain why the median movement rate of the 2012 NS releases appeared to be 3-6 km/d greater than median movement rates observed across all other release groups and years. Interestingly, movement rates below Willamette Falls for fish released in our study appeared to be much greater than observed movement rates to the falls, with median movement rates by release year ranging from 27.2-43.7 km/d. This observation falls in line with results from Dawley et al. (1986) who found juvenile Chinook salmon movement rates in excess of 59 km/d in the Columbia estuary, and Schroeder et al. (2008) also found greater mean movement rates for fish that were detected in the Columbia River as compared to those that were detected only at Willamette Falls.

Outmigration timing patterns were generally similar for MFW releases across years. Initial detections at Willamette Falls occurred in mid to late-June for all release years. Excluding the 2011 releases, there appeared to be a reservoir and dam impact on migration timing with detection peaks at Willamette Falls for TR releases occurring in late July and detections for HOR and FB releases peaking in early August. The HCR-released fish showed substantial delays in migration as initial Willamette Falls detections did not occur until 6-7 months after release. The movement of MFW releases through the dams in this study happened earlier than what was observed by Keefer et al. (2012), who found most juvenile Chinook salmon in the MFW entered the reservoirs from February-June and passed dams from November-February when water levels were lower and discharge was high. Romer et al. (2012 and 2013) also observed peak juvenile emigration into LOP reservoir to be from February-June and peak collection below Dexter dam from November-February with some recoveries in February and April as well, though historically non-typical spill related to consistency across years for paired releases in the early summer months during their research resulted in an increased number of fish captured below the dam in May and June. A combination of spill, increasing water temperature, and fish size likely lead to the swift movement of a large number of our study fish out of LOP reservoir and the Dexter TR downstream to Willamette Falls. Additional detections of MFW releases occurred after the initial peaks but in much lower numbers, with additional detections by release group similar except for the 2013 FB and HOR releases which were more numerous than the TR additional detections. Friesen (2007) found that the total outmigration period for hatchery and unmarked juvenile Chinook salmon in the Willamette River was surprisingly long, with fish present in the lower river (below Willamette Falls) in 34 of 35 months sampled, though Schroeder et al. (2008) postulated that few fish migrate in the Willamette River after mid-July due to non-optimal mainstem water temperatures.

Migratory patterns of the 2013 NS releases were particularly interesting as the migration timing across the release groups differed from the other NS and MFW releases. The 2012 NS release group outmigration patterns were similar to what was observed in the MFW with early detection peaks and likely dam and reservoir driven delays in outmigration for HOR releases. Initial peak detections for all 2013 NS release groups, however, were not observed until approximately three months after release and fairly profound secondary peaks were evident in all release groups with the peak timing delayed for the FB and HOR releases. Though not as large as the 2013 releases, there were perceived secondary peaks in the 2012 NS releases as well and the HOR release group again showed a delay in migration timing which may be an indication of study fish following different migratory life history patterns (movers and stayers). Romer et al. (2012 and 2013) collected juvenile Chinook salmon below Detroit Dam from August-September which is similar to what was observed in our study, but they stated that most of the juvenile collection below Detroit Dam occurred in November. The timing of tagging and release may strongly influence outmigration timing and survival; Schroeder et al. (2008) discovered that Chinook salmon tagged in the NS in May to mid-June tended to arrive earlier at Willamette Falls than those tagged in mid-June to early July. They suggest that their data support the theory that subyearlings tagged in the late spring or early summer are actively outmigrating while fish tagged later in the summer are likely rearing through the summer in the Willamette River or lower reaches of tributaries before emigration in the winter or following spring. The NS releases in this study occurred later than the MFW releases, and it is possible that due to the later release dates more of the NS study fish delayed migration and moved downstream later in winter and spring.

Stream discharge has often been cited as an important factor driving fish migration (Čada et al. 1997). In general, daily detections at Willamette Falls for our study were significantly negatively correlated with Willamette and respective basin discharge. Berggren and Filardo (1993) found migration time estimates of yearling and subyearling Chinook salmon released in the Columbia River to be inversely correlated with average system flows in most cases, and it is possible that our study fish sought slow-water refuge during high water events and continued their migrations as water levels subsided. However, anecdotal evidence from fish detected in the Columbia during our study suggests juvenile PIT tag detection efficiencies at Willamette Falls were low (as expected), which in part may be due to fish passing over the falls in periods of higher discharge, as opposed to through the detector arrays in the fish bypass (Royer et al. 2001). Substantial numbers of study fish may have passed over the falls during high water events throughout our project and, with many studies showing positive correlations between stream discharge and movement rate for juvenile Chinook salmon (Raymond 1968; Čada et al. 1997; Friesen et al. 2007), our correlation results should be interpreted cautiously.

A majority of mortalities observed for our study fish came from research projects taking place in the MFW and NS basins, with 83% of the reported mortalities attributed to research activities across years and basins. Research related mortalities only accounted for a very small fraction of the fish that were not detected at Willamette Falls, however. Avian and piscine predation likely took a marked toll on the study fish as well. Avian predators were responsible for 43% of observed mortalities attributed to predation and a majority of those mortalities occurred in the Columbia estuary. Substantial piscine predation in the MFW reservoirs was observed; WCR in particular appeared to prey heavily on study fish. Dissection of 15 WCR from HCR on a single day in June 2012 yielded 61 paired release PIT tags, with 13 of those tags coming from one crappie. A number of additional piscine predators such as NPM, WAL, LMB, and RBT inhabit MFW reservoirs and have relatively unknown impacts on juvenile salmonids. Monzyk et al. (2014) estimated that >100,000 juvenile Chinook salmon are consumed by NPM each spring in LOP reservoir, and also concluded that piscine predation impacts in LOP reservoir are likely greater than what would be expected in Detroit reservoir due to a greater number of predatory species. Predatory impacts may be an important component of the apparent dam and reservoir effect on Chinook salmon survival observed in our study, and potentially greater piscine predation in the MFW reservoirs may partially explain why the dam and reservoir effect size appears to be much greater for the MFW releases as compared to what was observed for the NS releases. The liberation of thousands of juvenile fish at each release site during a single day may have led to greater predation levels than would normally be expected for naturally-produced salmon recruiting to the reservoirs, but results from this study indicate that piscine predation may be a factor limiting juvenile salmon survival in MFW reservoirs.

An apparent dam and reservoir effect on growth was evident in our study as reservoir released fish had significantly greater growth rates than TR-released fish across years and basins. Though not significantly different the median growth rate for 2013 HCR-released fish appeared to be larger than the median growth rate for the 2013 MFW TR-released fish, and a comparison of growth rates was not possible for the 2013 NS releases as none of the 2013 TR-released fish were recaptured or collected during research activities. Greater growth for Chinook salmon rearing in MFW and NS reservoirs was also observed by Monzyk et al. (2014) as subyearlings rearing in reservoirs were 45-117 mm larger than other cohort members rearing in streams, with greater primary and secondary productivity and water temperatures conducive to maximum growth cited as the likely reasons for increased growth in the reservoir rearing fish. Growth rates for HOR releases in our study appeared to be similar to those reported by Monzyk et al. (2014) who observed growth rates of 0.71-0.97 mm/d for juvenile Chinook salmon rearing in LOP reservoir and 0.73-0.84 mm/d for those rearing in Detroit Reservoir. Conner and Burge (2003) and Conner et al. (2001) reported slightly greater juvenile Chinook salmon growth rates of 1.0-1.3 mm/d than what we observed in our study. Interestingly, growth rates for 2013 LOP HOR and FB releases were also significantly greater than growth rates for HCR-released fish which may be a reflection of better conditions for growth in LOP reservoir. Monzyk et al. (2013) reported a trend of greater growth rates in lower elevation reservoirs corresponding with warmer water temperatures, and though the elevation difference between LOP reservoir and HCR is not substantial, warmer water temperatures in LOP reservoir may have been optimal for growth. In general, growth rates for the TR releases also appeared to be similar to those previously reported for naturally-produced juvenile Chinook salmon collected below WVPs in the Willamette basin, as Schroeder et al. (2008) observed average growth rates of 0.13-0.62 mm/d in the UWR and 0.35-0.65 mm/d in the NS. The median growth rate for the 2012 NS TR-released fish was quite low, possibly due to non-ideal rearing water temperatures stemming from the late release timing.

Very few of the fish released for this study have returned as adults, with 11 of the MFW releases and 6 of the NS releases detected in the adult ladder at Willamette Falls. Johnson and Friesen (2013) found that most Chinook salmon returning to the UWR are age-4 and age-5 adults, which likely means that the majority of our adult returns will be recorded in the next few years as a bulk of our study releases occurred in 2012 and 2013. Three of the four adult returns from the 2011 releases were age-4 fish but only 0.03% of the 2011 releases have returned as adults. The release size of fish in our study may influence adult return timing and numbers as Scheuerell (2005) found that Chinook salmon tagged at smaller sizes (< 78 mm) were more likely to return as age-5 adults and Tipping (2011) reported that larger size at tagging for juvenile Chinook salmon (73-115 mm) produced more jacks and led to a higher rate of adult returns than smaller size at tagging (66-93 mm) in the Columbia River. With median FLs by release group ranging from 62-69 mm (excluding 2012 NS releases) in our study, a substantial number of our study fish may return as age-5 adults. There have not been enough adult returns to make conclusions regarding dam and reservoir effects on survival to adulthood, but to date HOR releases have produced more adult returns than TR releases.

Conclusions and Future Directions

Results from our study suggest WVP dams and reservoirs impact juvenile Chinook salmon survival, movement rate and timing, and growth in the MFW and NS basins. Mortality stemming from direct passage of reservoir released fish through dam turbines or spill may partially explain the significantly smaller Willamette Falls detection proportions for reservoir released fish as compared to TR releases. Issues related to direct dam passage are likely compounded for fish passing through multiple dams as evidenced by the small number of detections of HCR-released fish at Willamette Falls. The dam and reservoir effect on juvenile survival appeared to be more profound in the MFW, suggesting that downstream passage through WVPs on the NS may be less of a concern than in the MFW. Piscine predation in MFW reservoirs likely contributed to the observed discrepancy in dam and reservoir effects on juvenile Chinook salmon survival between basins, as the number and size of predators in MFW reservoirs are known to be larger than in Detroit Reservoir and mortalities related to predation were only observed for MFW releases. The lentic reservoir environment appeared to affect movement rates and timing, with reservoir releases generally having significantly slower movement rates and later Willamette Falls detection peaks than those observed for TR releases. Though migration timing was delayed, prolonged reservoir rearing likely contributed to the significantly greater growth rates for a majority of our HOR releases as compared to TR releases. Additional adult returns are needed to more completely evaluate possible dam and reservoir impacts on study fish and the utility of trapping outmigrating juvenile salmon and transporting them below WVP dams.

We repeated the MFW and NS releases in 2014, with about 33,000 PIT-tagged juvenile Chinook salmon released at LOP HOR and FB, Dexter Dam TR, Detroit HOR and FB, and Minto TR. The HCR release was eliminated as a cost-savings measure; as reported here, very few of these fish (released in 2012 and 2013) were subsequently detected or recovered. Initial results from the 2014 releases will be available in early 2015. In addition, on 14 November 2014 we released the first groups of PIT-tagged winter steelhead in the NS; approximately 6,000 each at Detroit HOR (Mongold State Park) and below Minto Dam (Packsaddle Park). We expect to have reportable results on steelhead detections and associated metrics in mid-2015.

Per discussions with the USACE, fisheries managers, and other researchers, in 2015 we plan to (1) repeat releases of PIT-tagged Chinook salmon in the NS as implemented in 2013 and 2014; (2) increase releases of PIT-tagged winter steelhead in the NS to about 14,000 fish per group, and (3) eliminate releases in the MFW. The elimination of the MFW releases will serve to standardize the number of years fish were released in each subbasin (four) and may be revisited in the future if substantial operational changes to improve fish passage (e.g., drawdown, late refill, additional spill) are realized. We also recommended conducting research to estimate the entrainment rate of PIT-tagged fish to the Willamette Falls north fish bypass relative to river discharge, which could provide retrospective estimates of the total number of fish from each release group that successfully reached Willamette Falls, thereby improving juvenile survival estimates. This could be done by applying our data to the expansion factor calculated by Schroeder et al. (2016), conducting additional test releases under a variety of river flows, or a combination thereof. Installing a second antenna array in the north fish bypass, which would improve efficiency estimates, is also under consideration. A decision has yet to be made whether to fund and implement these activities.

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APPENDIX: Biomark Tagging Report, 2014

PIT-TAG JUVENILE SPRING CHINOOK AND WINTER STEELHEAD AT WILLAMETTE AND MARION FORKS HATCHERIES, 2014

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INTRODUCTION

The National Marine Fisheries Service (NMFS) Biological Opinion (BiOp) (2008) requires improved juvenile fish passage by providing either head-of-reservoir collection and transport systems or improved juvenile passage at Willamette Project dams. NMFS BiOp also requires improving flows and water temperatures below Willamette Project dams. There is a paucity of data available on outmigration behavior and survival of spring Chinook salmon rearing above and below Willamette Valley projects. Monitoring marked juvenile spring Chinook salmon (*Oncorhynchus tshawytscha)* can help inform survival and migration timing within and below Willamette Project Reservoirs. Information can be used to better understand the life history of juvenile Chinook salmon, and inform decisions regarding juvenile passage and survival at Willamette Project dams.

In May of 2011, Biomark PIT-tagged approximately 12,000 hatchery juvenile spring Chinook salmon at Willamette Hatchery as a pilot project. In May and July of 2012, Biomark PIT-tagged approximately 175,000 hatchery juvenile spring Chinook at Willamette and Marion Forks Hatchery (150,000 and 25,000, respectively). In 2013, Biomark PIT-tagged approximately 150,000 spring Chinook at Willamette Hatchery and 100,000 spring Chinook at Marion Forks Hatchery.

METHODS

All tagging was conducted in a self-contained tagging trailer positioned near the raceway holding the fish to be tagged. Water for the trailer was pumped from a raceway or pond nearest the trailer. This water was also used to chill the re-circulating anesthetic water within the tagging trailer. Variation in water temperature between the holding facility and the anesthetic water was maintained at less than 0.5 °C difference.

Biomark followed the PIT-tagging protocols mandated by the U.S. Army Corps of Engineers (USACE), Portland District (CENWP) using the body cavity tagging techniques similar to those described in Prentice et al. (1990). Fish were tagged with 12.5mm 134.2 kHz ISO PIT tags (SST tags) using preloaded 12-gauge hypodermic needles (Biomark Pre-loaded needle BIO12.BPL) fitted onto an injection device (Biomark implant gun MK-25). All fish were tagged with single-use needles to reduce the chance of disease transmission, injuries caused by dull needles, and reduce the number personnel required for the project.

Anesthetic water was changed every two hours. An un-buffered anesthetic (MS-222) was used.

The Biomark tagging crew consisted of 6-8 taggers and 3-4 data collectors (data collectors interrogate each tagged fish, measure fork length and note external signs of disease). The data collectors also tagged fish, as time allowed.

No obviously diseased or injured fish were tagged, including, but not limited to, BKD and pinheads. An attempt was made to only tag fish ≥ 60 mm fork length (FL). Potential anomalous conditions were recorded for each fish that was tagged (i.e., bleeding, dropped, deep tag insertion). All tagged fish were returned to a holding trough or circular ponds via a 3-inch PVC pipe. All undersized fish and fish rejected for physical conditions were returned untagged to the raceway of origin.

At the time of tagging the tag code, fork length, fish condition and treatment group were stored using PITTAG3 software [Pacific States Marine Fisheries Commission (PSMFC)]. PIT tag codes were used only one time. During tagging operations any shed tags found in the trough, along with tags removed from mortalities, were scanned into a file and this data was used to "dot–out" tag codes in the tagging files. The tags were then implanted into new fish with the appropriate information recorded.

Tagging files were consolidated and submitted to PTAGIS regional database after tagging. Copies of the data files were also provided to the ODFW technical lead Tom Friesen.

Task 1 – PIT tag 140,000 spring Chinook salmon at Willamette Hatchery

The objective at Willamette Hatchery was to PIT tag 140,000-hatchery juvenile subyearling Chinook salmon beginning in early May 2014. Biomark tagged up to 20,000 fish per day until the task was completed.

The fish to be tagged were taken from a circular tank within the hatchery building. After tagging, the fish were returned to a circular tank inside the hatchery building. When the number of tagged fish in a circular tank reached approximately 17,500, the pipe was moved to another tank. At release, two groups of approximately 17,500 fish were released at each of four release sites.

Task 2 – PIT tag 120,000 spring Chinook salmon at Marion Forks Hatchery

The objective at Marion Forks Hatchery was to PIT tag 120,000-hatchery juvenile subyearling Chinook salmon beginning in late June 2014. Biomark tagged approximately 20,000 fish per day for six days.

The fish to be tagged were held in four circular ponds (C8-C11). After tagging, the fish were returned to five circular ponds (C1-C5). Three ponds were to have 33,333 tagged fish (C3, C4 and C5) while two ponds were to have 10,000 tagged fish in each (C1 and C2).

Task 3 – PIT tag 14,000 winter steelhead at Marion Forks Hatchery

The objective at Marion Forks Hatchery was to tag 14,000-hatchery juvenile winter steelhead beginning in late June 2014. Biomark tagged the total required fish in one day to complete the task.

The fish to be tagged were held in one circular pond (C7). Half of the tagged fish (n = 7,000) were put into a separate circular pond (C6) and the other half (n = 7,000) were placed back into the original circular pond (C7).

RESULTS

The primary goals of this project to PIT tag approximately 140,000 juvenile subyearling Chinook salmon at Willamette Hatchery, approximately 120,000 juvenile subyearling Chinook salmon at Marion Forks Hatchery and approximately 14,000 juvenile winter steelhead at Marion Forks Hatchery were met.

Task 1 – PIT tag 140,000 juvenile subyearling Chinook salmon at Willamette Hatchery

Biomark implanted PIT tags into a total of 139,979 juvenile subyearling Chinook salmon at Willamette Hatchery between 07 May and 15 May 2014 (Table 1). Lengths were recorded for 99.7% of the tagged fish (Table 2). A total of seven tag codes present in the clip files, but not detected during tagging, were removed from the tagging database because the tags were broken (n = 5) or non-functional (n = 2). A total of 20,103 fish were rejected prior to tagging because they were less than 60 mm FL (n = 19,659) or they had obvious signs of disease or injury (n = 444). A total of 160,082 fish were handled during the tagging process (Table 1).

A total of 5,315 (3.80%) combined mortality and shed tags were collected for Task 1 (Table 1). A total of 133 (0.10%) combined mortality and shed tag codes collected during tagging were dotted-out of the original file and the tags were re-implanted into fish in the same group. A total of 5,182 (3.70%) tags were collected by ODFW personnel after the tagging project (Table 1). The 5,182 tags were not recorded as being either a "mortality" or "shed" when they were collected. All of the tags collected after the tagging project ended were dotted-out and given both a mortality ("M") and shed tag ("L") conditional comment in the tagging files

Task 2 – PIT tag 120,000 juvenile subyearling Chinook salmon at Marion Forks Hatchery

Biomark implanted PIT tags into a total of 120,699 juvenile subyearling Chinook salmon at Marion Forks Hatchery between 24 June and 29 June 2014 (Table 3). Lengths were recorded for 99.63% of the tagged fish (Table 4). A total of 1,835 fish were rejected prior to tagging because they were less than 60 mm FL (n = 1,541) or they had obvious signs of disease or injury (n = 294). A total of 122,534 fish were handled during the tagging process (Table 3).

A total of 302 (0.25%) combined mortality and shed tags were recovered. Of those a total of 81 tags were collected during tagging (74 of those tags were re-implanted into fish) and 221 were collected after tagging and prior to release by hatchery personnel (Table 3).

Task 3 – PIT tag 14,000 juvenile winter steelhead at Marion Forks Hatchery

Biomark implanted PIT tags into a total of 13,210 juvenile winter steelhead at Marion Forks Hatchery on 23 June 2014 (Table 3). Lengths were recorded for 99.6% of the tagged fish (Table

5). A total of two tag codes present in the clip files, but not detected during tagging, were removed from the tagging database because the tags were non-functional.

A total of 49 fish were rejected prior to tagging because they were less than 60 mm FL (n = 26) or they had obvious signs of disease or injury (n = 23). A total of 13,259 fish were handled during the tagging process (Table 5).

A total of 106 (0.8%) combined mortality and shed tags were collected for Task 3. During tagging a total of 7 tags were collected (no tags were re-used) and a total of 99 tags were recovered after tagging and prior to release by hatchery personnel (Table 3).

DISCUSSION

Task 1 – PIT tag 140,000 juvenile subyearling Chinook salmon at Willamette Hatchery

Fish quality at Willamette Hatchery was good. The length frequency histogram indicated a narrow length range for tagged fish (

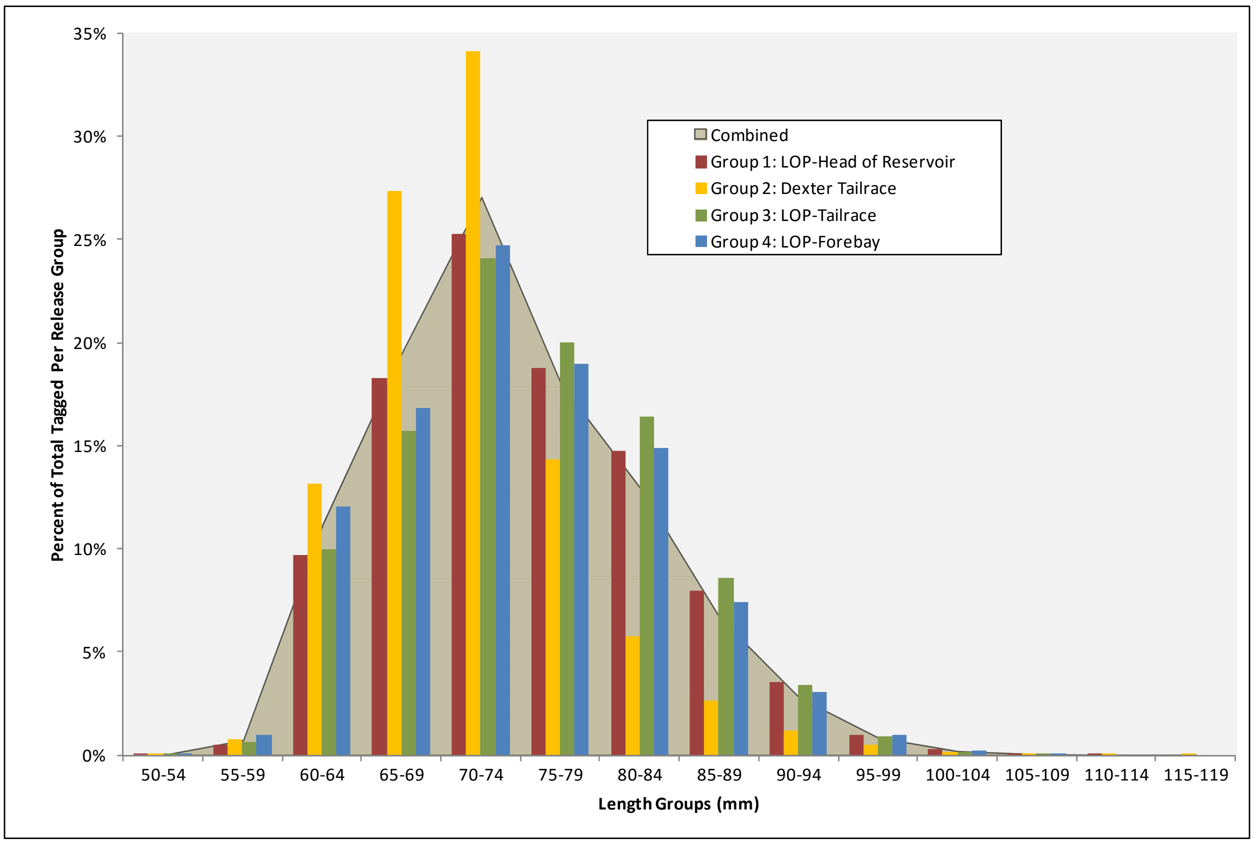

Figure 1). A relatively large number of fish were rejected due to being undersize (n = 19,659, 12.28%). A total of 3,075 fish with a fork length less than 60mm were tagged (2.19% of total fish tagged). Most of those fish had fork lengths in the 55-59mm range (n=3,030, 2.16%) with fewer fish in the 50-54mm range (n=45, .03%). The average fork length of the tagged fish was

73.9mm. A relatively small number of fish were rejected because of obvious signs of disease or deformities/injuries (n = 444, 0.28%).

The combined mortality and tag shedding rate for Task 1 was 3.70%. This rate was higher than what has been observed in the past. The main cause of this high mortality was due to the handling of the fish a short time after completing the PIT-tagging. Allowing the fish the full 14 recommended days to recover before handling would greatly decrease this high mortality rate. The new circular tanks with screen covers that were installed at the hatchery in 2014 greatly reduced the stress on the fish, and allowed for a much more gentle water flow. This greatly reduced the tag shedding rate and the overall mortality rate while tagging 0.10% (Table 1) in the 2014. The average length of 73.9mm (Table 2) was a much better average length for safely tagging. However, due to sorting out fish smaller than 65mm fork length there were not enough fish in the circular tanks to meet the Task 1 tagging goal. ODFW personnel had to collect and high-grade additional fish so that Biomark could complete the required tagging goal.

Task 2 – PIT tag 120,000 juvenile subyearling Chinook salmon at Marion Forks Hatchery

The Chinook salmon quality at Marion Forks Hatchery was very good. The majority of fish tagged (80.7%) had a fork length between 70mm and 84mm (

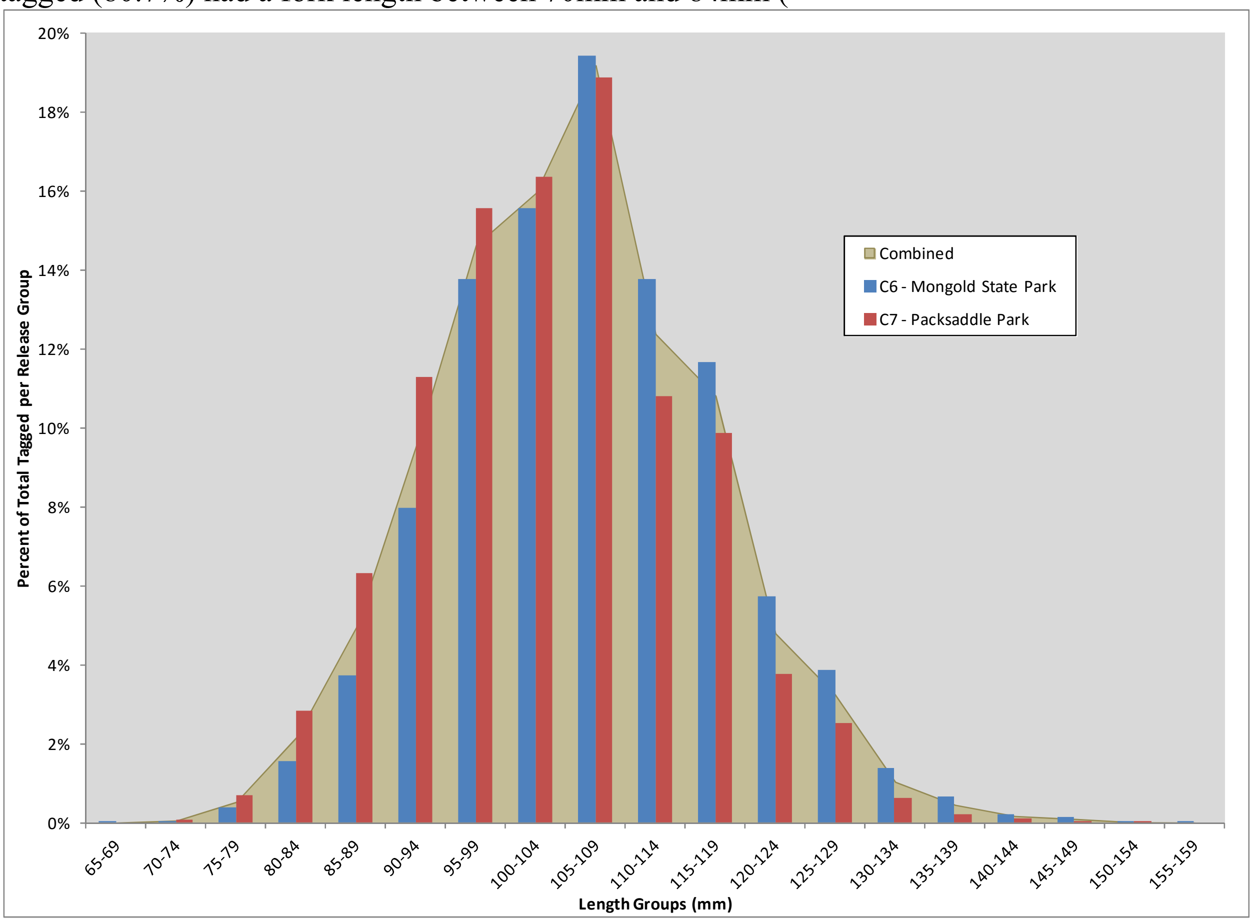

Figure 3). A relatively small number of fish were rejected due to being undersize (n = 1,541, 1.26%). Few fish were rejected because of obvious signs of disease or deformities (n = 294, 0.24%).

The observed mortality/shedding rate was low (n = 302, 0.25%). While this rate is higher than what has been observed in the past it is still an acceptable level of mortality/shedding.

Task 3 – PIT tag 14,000 juvenile winter steelhead at Marion Forks Hatchery

The quality of the winter steelhead at Marion Forks Hatchery was good. A majority of the fish (86.9%) had a fork length between 90mm and 124mm (Figure 3). A very small number of fish were rejected due to being undersize (n = 26, 0.2%). Few fish were rejected because of obvious signs of disease or deformities (n = 23, 0.17%).

The number of mortality/shed tags collected was higher than what we would like to see (n = 106, 0.8%). While tagging at Marion Forks Hatchery we collected a total of 7 steelhead mortalities. A majority of the mortality/shed tags were collected after tagging (n = 99, 94.4%). These numbers indicate that the mortality was directly tagging related, but the PIT tagging may still be one factor contributing to the overall mortality rate.

RECOMMENDATIONS

Biomark recommends changes should be made in four areas of the tagging protocol:

1. Fish Size. The Columbia Basin recommends PIT tagging fish 65 mm fork length or greater to avoid elevated mortality, tag shedding and tag related behavior or survival issues.
    a. We recommend that additional fish be reared to the recommended size to assure that the tagging goals are able to be met.
    b. We at Biomark feel comfortable tagging fish down to 60 mm with 12.5 mm tags when necessary but agree with the recommendations of tagging fish greater than 65 mm whenever possible.
2. Fish Handling. Moving/handling fish too soon after PIT tagging can increase the mortality and/or tag shedding rate.
    a. We recommend not moving fish for a minimum of two weeks post tagging.
3. Tag Collection. Collecting tags from mortalities and sheds is necessary to provide the best data. Keeping the mortality and shed tags separate is important for evaluating the quality of the tagging effort and helping insure the proper quality assurance.
    a. We also recommend that any tags collected after tagging and prior to release be kept in a container with the type of tag ("mortality" or "shed"), date collected and location (raceway or pond number).

ACKNOWLEDGEMENTS

We would like to acknowledge Dan Peck and his staff at the Willamette Hatchery as well as Greg Grenbemer and his staff at Marion Forks Hatchery for their assistance during tagging. It was a pleasure to work at both hatcheries.

REFERENCES

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, D. F. Brastow, and D.C. Cross. 1990. Equipment, methods, and an automated data-entry station for PIT tagging. American Fisheries Society Symposium 7:335-340.

FIGURES

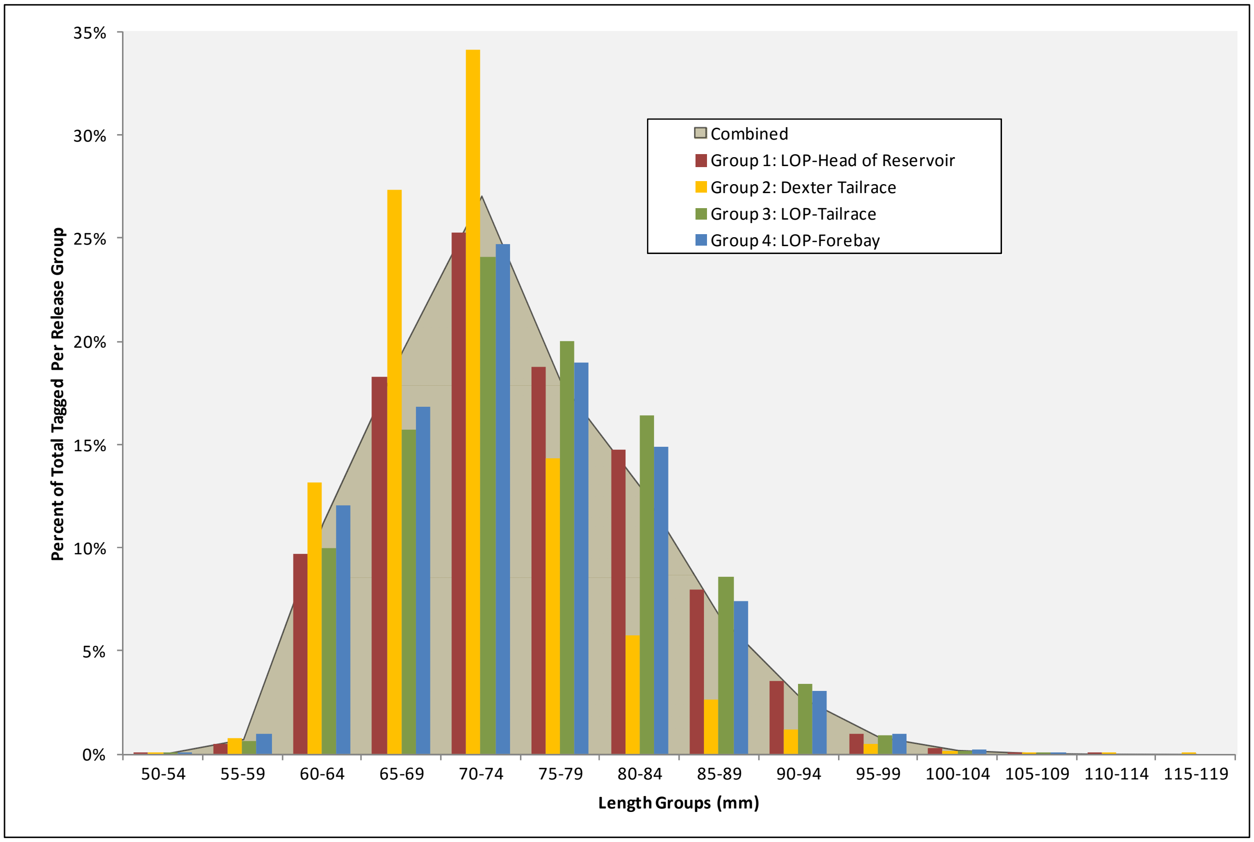

Figure 1. Length frequency of PIT-tagged juvenile subyearling Chinook salmon tagged for Task 1 at Willamette Hatchery, May 2014.

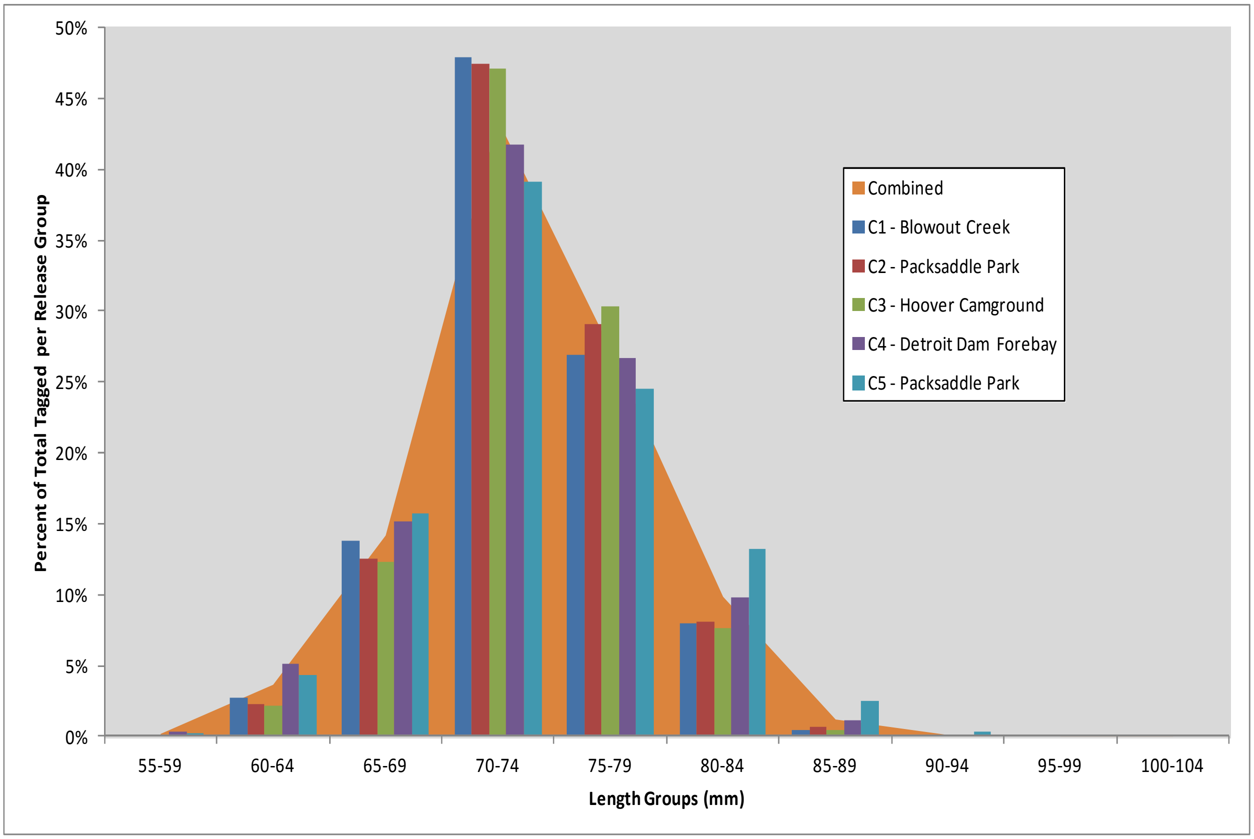

Figure 2. Length frequency of PIT-tagged juvenile Chinook salmon tagged for Task 2 at Marion Forks Hatchery, June 2014.

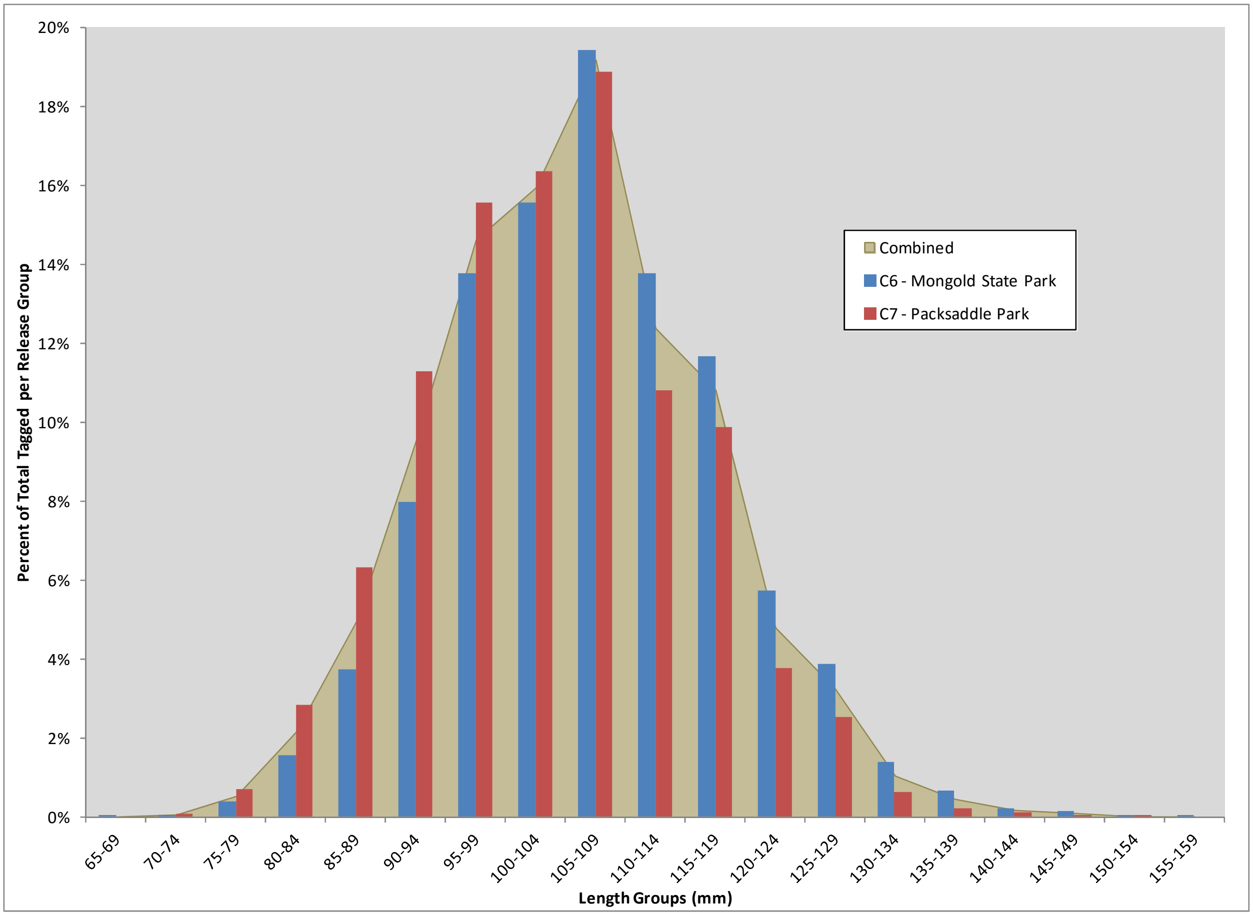

Figure 3. Length frequency of PIT-tagged juvenile winter steelhead tagged for Task 2 at Marion Forks Hatchery, June 2014.

TABLES

Table 1. Summary of juvenile subyearling spring Chinook salmon handled and PIT-tagged for Task 1 at Willamette Hatchery, May 2014.

Tag Site	Release Site / River Km	Release Group	RCY/ Trough	# Tagged (A)	Mortality/Shed Tags (Combined) (B)	%	Tagged Fish Available for Release (A-B)	Short (C)	Injured/ Diseased (D)	Total Fish Handled (A+C+D)
Willamette Hatchery	Head of Lookout Point Reservoir / 163.301.050	1	14A & 14B	35,001	2,231	6.37%	32,770	7,399	71	42,471
	Dexter Dam Tailrace / 163.301.027	2	13B & 13C	34,997	1,472	4.21%	33,525	2,562	123	37,682
	Lookout Point Reservoir - Tailrace / 163.301.031	3	12B & 12C	34,988	1,032	2.95%	33,956	4,414	100	39,502
	Lookout Point Reservoir - Forebay / 163.301.032	4	11B & 11C	34,993	447	1.28%	34,546	5,284	150	40,427
Total for Willamette Hatchery				**139,979**	**5,182**		**134,797**	**19,659**	**444**	**160,082**

Table 2. Length Summary for juvenile subyearling spring Chinook salmon PIT-tagged for Task 1 at Willamette Hatchery, May 2014.

Lengths (mm)							
Release Group	Length Count	Average	Median	Mode	Max	Min	% Lengths Recorded
1	34,901	74.7	74	72	113	54	99.7%
2	34,860	71.3	71	70	115	54	99.6%
3	34,907	75.1	74	74	109	54	99.8%
4	34,886	74.3	74	74	108	51	99.7%
Combined	139,554	73.9	73	72	115	51	99.7%

Table 3. Summary of juvenile subyearling spring Chinook salmon and winter steelhead handled and tagged for Task 2 at Marion Forks Hatchery, June 2014.

					Mortality and Shed Tags							
					During Tagging							
Tag Site	Release Site / River Km	Species	RCY/ Trough	# Tagged (A)	Collected (B)	# Reused (C)	After Tagging (D)	Total Mort/ Shed Tags (E = (B+D))	Tagged Fish Available for Release (A-E)	Short (F)	Injured/ Diseased (G)	Total Fish Handled (A+F+G)
Marion Forks Hatchery	Blowout Creek/ 163.174.019.093	Chinook	C1	10,058	0	0	29	29	10,029	145	12	10,215
	Packsaddle Park / 163.174.019.066	Chinook	C2	10,053	3	3	37	40	10,013	153	20	10,226
	Hoover Campground/ 163.174.019.091	Chinook	C3	33,520	11	9	40	51	33,469	362	78	33,960
	Detroit Dam Forebay / 163.174.019.078	Chinook	C4	33,535	25	25	50	75	33,460	451	90	34,076
	Packsaddle Park / 163.174.019.066	Chinook	C5	33,533	42	37	65	107	33,426	430	94	34,057
		Chinook Total		***120,699***	***81***	***74***	***221***	***302***	***120,397***	***1,541***	***294***	***122,534***
	Mongold State Park/ 163.174.019.085	Steelhead	C6	6,997	1	0	39	40	6,957	18	11	7,026
	Packsaddle Park / 163.174.019.066	Steelhead	C7	6,213	6	0	60	66	6,147	8	12	6,233
		Steelhead Total		***13,210***	***7***	***0***	***99***	***106***	***13,104***	***26***	***23***	***13,259***
Total for Marion Forks Hatchery				**133,909**	**88**	**74**	**320**	**408**	**133,501**	**1,567**	**317**	**135,793**

Table 4. Length Summary for juvenile subyearling spring Chinook salmon PIT-tagged for Task 2 at Marion Forks Hatchery, June 2014.

Lengths (mm)							
Pond	Length Count	Average	Median	Mode	Max	Min	% Lengths Recorded
C1	10,033	73.3	73	74	89	56	99.8%
C2	10,019	73.6	74	74	103	58	99.7%
C3	33,397	73.6	74	74	91	56	99.6%
C4	33,396	73.3	74	74	95	56	99.6%
C5	33,402	73.8	74	74	103	56	99.6%
Combined	120,247	73.5	74	74	103	56	99.6%

Table 5. Length Summary for juvenile winter steelhead PIT-tagged for Task 3 at Marion Forks Hatchery, June 2014.

Lengths (mm)							
Pond	Length Count	Average	Median	Mode	Max	Min	% Lengths Recorded
C6	6,979	106.5	106	105	155	69	99.7%
C7	6,178	103.6	104	106	151	73	99.4%
Combined	13,157	105.1	105	106	155	69	99.6%

APPENDIX A

Table A.1. List of tagging files submitted to PTAGIS for Task 1.

File Name
CSM14128.A08
CSM14128.B08
CSM14129.A02
CSM14129.B02
CSM14130.A01
CSM14130.B01
CSM14131.A03
CSM14131.B03
CSM14132.A04
CSM14132.B04
CSM14133.A05
CSM14133.B05
CSM14134.A06
CSM14134.B06
CSM14135.A09
CSM14135.B09

Table A.2. List of tagging files submitted to PTAGIS for Task 2.

File Name
CSM14175.M5A
CSM14175.M5B
CSM14175.M5C
CSM14175.M5D
CSM14176.M4A
CSM14176.M4B
CSM14176.M4C
CSM14176.M4D
CSM14178.M3A
CSM14178.M3B
CSM14178.M3C
CSM14178.M3D
CSM14179.M2A
CSM14179.M2B
CSM14180.M1A
CSM14180.M1B

Table A.3. List of tagging files submitted to PTAGIS for Task 3.

File Name
CSM14174.M6A
CSM14174.M7A