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DOWNSTREAM MOVEMENT AND FOSTER DAM PASSAGE OF JUVENILE WINTER STEELHEAD IN THE SOUTH SANTIAM RIVER

Prepared for

U. S. ARMY CORPS OF ENGINEERS

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Summary

The goal of this project was to provide information on downstream dam passage timing and the size/age at passage for natural-origin juvenile winter steelhead (*Oncorhynchus mykiss*) at Foster Dam on the South Santiam River. This information will be used to help determine the best operational window for a new fish passage weir currently under construction by the US Army Corps of Engineers (USACE). The new weir is designed to improve passage conditions for juvenile steelhead and Chinook salmon (*O. tshawytscha*) and conserve life-history pathways of the species. We present data from our PIT-tagging efforts from 2014-2017 and subsequent detections of those tags.

Specific objectives of this project were to: 1) summarize the downstream movement patterns by age of wild juvenile steelhead entering Foster Reservoir; 2) determine the timing and age that juvenile steelhead pass Foster Dam, and 3) recommend the best operation window for the new weir to optimize passage utilization.

We monitored seasonal movement of juvenile steelhead into Foster Reservoir from 2011-2016 using a 1.5-m diameter rotary screw trap located upstream of Foster Reservoir near the town of Cascadia, Oregon. Juvenile steelhead ≥65 mm fork length (FL) were PIT-tagged at the screw trap and at various additional locations above Foster Dam from 2014-2017. We used boat electrofishing and Oneida Lake traps in Foster Reservoir to collect fish from February to June 2014-2017 and from October to November in 2014-2015. From July to October, we used a variety of techniques to collect and tag juveniles rearing throughout the South Santiam River and tributaries (Moose, Canyon and Soda Fork creeks) upstream of the reservoir. All tagged fish were measured and age was estimated based on length-frequency. Tagged fish detected at PIT antennas located in the weir at Foster Dam and at several locations downstream of the dam were used to calculate Foster dam passage timing and age at passage.

In the rotary screw trap upstream of Foster Reservoir, age-2 fish were only captured in the spring and were rare in some years (2011, 2012, and 2014). Age-1 fish were caught in both spring and fall and demonstrated highly variable peak timing in downstream movement among years. Fall peaks were observed in 2011 and 2014 and spring peaks observed in 2013, 2015, and 2016. The first age-0 juveniles began entering Foster Reservoir in late June each year, soon after emergence. This age-class continued to enter the reservoir throughout the rest of the year, and were generally the most abundant age class captured in the trap each year.

Overall, we tagged 5,778 juvenile steelhead upstream of Foster Dam from 2014-2017, comprised of 33% age-0, 50% age-1, 17% age-2, and <1% age-3 fish (age-1 fish were tagged in greater proportion to their abundance because they could be captured in all locations throughout the year and were >65 mm FL). Nearly all of the age-2 fish were captured and tagged in the reservoir or in the screw trap in the spring, and were rarely captured during the rest of the year.

Age-2 fish comprised the majority of fish passing the dam. Overall age structure of juveniles at dam passage was 0% age 0, 13% age 1, 84% age 2, and 2% age 3. Most tagged age-0 and age-1 fish reared for at least one additional year before migrating past the dam.

Passage at Foster Dam occurred primarily from March through June (>97%). Variability in spring (March-June) passage timing was evident among years, with a later migration in 2015 compared to other years. Within the spring, 30-68% of the fish passed prior to 15 May, 92-98% passed prior to 01 June, and 98-100% passed prior to 07 June during the three years of the study. We did not observe many tagged

fish passing the dam in the fall (<3%) although many age-0 and age-1 fish were present in the forebay in the fall. It remains unclear whether these fish overwinter in the reservoir or pass the dam through routes other than the weir.

We recommend that annual weir operations in the spring extend at least to 07 June to provide the safest passage route for juvenile steelhead. Even though our tag detection results showed <4% of the tagged fish passed the dam in the fall, this may be an underestimate of the passage occurring in the fall by younger juveniles. More work is needed to better understand age-0 distribution in the forebay and route selection at Foster Dam, given their abundance in the reservoir and potential survival disadvantage from a turbine passage route.

Introduction

Winter steelhead (*Oncorhynchus mykiss*) in the upper Willamette River basin were listed as threatened in 1999 under the Endangered Species Act (NMFS 1999). Four demographically-independent populations comprise the upper Willamette River distinct population segment (DPS): the Molalla, Calapooia, North Santiam, and South Santiam rivers. The South Santiam River population has been designated as a “core” population needed for species recovery and eventual delisting of the DPS (ODFW and NMFS 2011). Construction of Green Peter and Foster dams in 1968 blocked migration to historic spawning grounds and has been cited as a major cause of winter steelhead population decline in the South Santiam subbasin (NMFS 2008; ODFW and NMFS 2011).

Foster Dam is a 38.4-m high earthen dam on the South Santiam River used to regulate power-generating water releases from Green Peter Dam located on the Middle Santiam River (Figure 1). The dams were built for the main purpose of flood risk management with reservoir volumes lowered in the late fall to provide capacity for capturing flood events. Water levels in Foster Reservoir are regulated according to a rule curve whereby water levels are lowered in October to reach a pool elevation of 613 ft mean sea level (MSL) by mid-November and held at this level through January. Then, in February water levels are raised to reach a full pool elevation of 637 ft MSL by early May. Beginning in 1983, the spring fill schedule deviated slightly from the rule curve to accommodate the installation of a fish weir in one of the four spillways to improve juvenile steelhead passage (Figure 2). The weir was typically operated at a reservoir elevation of 615 ft MSL from mid-April to mid-May. Beginning in 2013, the weir has operated at 615 ft MSL from mid-March through mid-April before stoplogs are added to the spillway to operate the weir at 635 ft MSL through the summer.

Before dam construction, an estimated 2,600 adult winter steelhead migrated above the Foster Dam site with 700 spawning in the reaches now inundated by the Foster-Green Peter project (Buchanan et al. 1993). An estimated 63% of all winter steelhead spawning habitat in the South Santiam River was blocked by the dams (R2 Resources 2009). After dam construction, adult winter steelhead were trapped at a fish collection facility below Foster Dam and released into the Foster Reservoir forebay. Adults that originated above Green Peter Dam needed to migrate through Foster Reservoir to another adult collection facility below Green Peter Dam where they were transported above the dam. Adult returns to the Green Peter adult facility and smolt downstream passage through Green Peter Dam were too low to sustain the population and the program was discontinued in 1987 (Buchanan et al. 1993). Currently, the only winter steelhead production occurring above Foster Dam are from wild steelhead collected at Foster Dam and transported above the dam to spawn in the South Santiam River and its tributaries. From 2006-2016, the number of adults annually outplanted above the dam has ranged from 129-426 fish (Mapes and Sharpe 2017).

Downstream passage routes for juvenile steelhead through Foster Dam are via two turbine penstocks, four spillway gates, or when installed, the fish weir, positioned in the spillway adjacent to the turbine penstocks. Additional entrainment routes include the water supply intake for the adult fish ladder and the water supply intake for a hatchery located below the dam. Results of a radio-telemetry study of age-1 and age-2 juvenile hatchery steelhead showed that fish preferred to pass via the spillway and weir when the reservoir was at low pool elevations and through the weir during high pool elevations (Hughes et al. 2016). Fish passing over the weir can experience injury as they impact the spillway chute downstream of the weir, especially when at the reservoir is at high pool (Normandeau 2013; Duncan 2013). A new weir is currently being constructed with a design to improve downstream passage conditions. The new weir will be capable of operating with greater flexibility of operation at higher flows compared to the current weir and designed to provide better passage conditions at the spillway chute. Operation of the new weir is planned to start 01 October each year, after the reservoir is drawn down to 613 ft elevation, and will continue into the spring. Several scenarios are under consideration regarding the end date of weir operation in the spring, ranging from 15 May - 15 June. This report is intended to provide baseline information on the timing of wild juvenile steelhead passage to help inform future weir operations.

In this report, we summarize the downstream movement patterns by age of wild juvenile steelhead entering Foster Reservoir and dam passage timing. Downstream movement was based on information from juvenile *O. mykiss* captured in a screw trap located upstream of the reservoir from 2011-2016. Dam passage timing was assessed via detections of fish tagged with passive integrated transponder (PIT) tags. Recent development and installation of PIT tag antennas at and below Foster Dam allowed for the assessment of dam passage timing of tagged wild juvenile steelhead from 2015-2017. We were particularly focused on passage timing during the spring period (March-June) to help managers determine the best operational dates of the weir that would benefit juvenile steelhead.

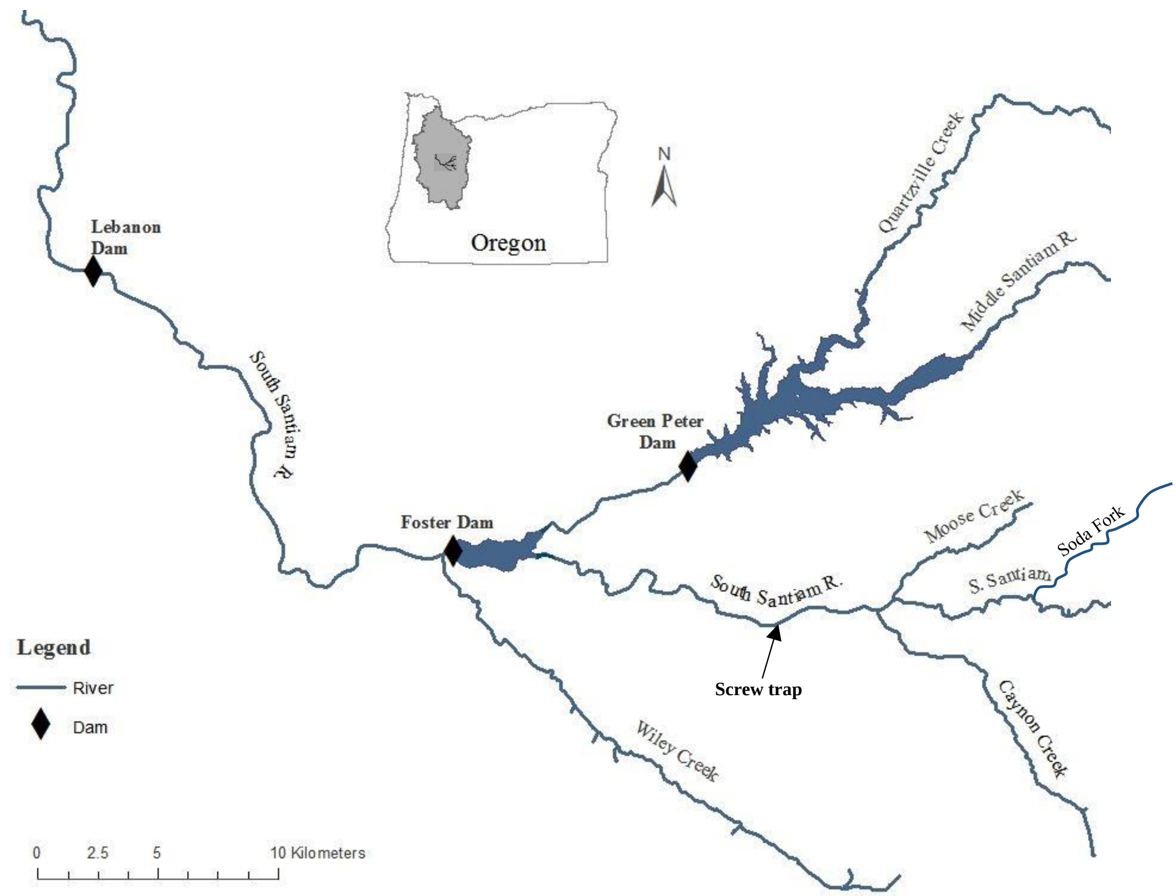

Figure 1. The Foster-Green Peter project and the South Santiam River.

Methods

Juvenile steelhead exist in sympatry with resident rainbow trout in the South Santiam River and cannot be distinguished from one another in the field. For this report, we presumed that all juveniles captured were the progeny of adult steelhead due to the large number of adult steelhead transported upstream of Foster Reservoir. Additionally, preliminary genetic pedigree analyses indicate that >85% of the juveniles sampled in 2013-2015 were progeny of outplanted adult steelhead (Chris Caudill, University of Idaho, *personal communication*).

Reservoir Entry Timing.- We monitored seasonal movement of juvenile steelhead into Foster Reservoir using a 1.5-m diameter rotary screw trap located upstream of the reservoir near the town of Cascadia, OR. Screw traps are designed to catch fish moving downstream. The trap was located on the mainstem South Santiam River approximately 10 km upstream from the head of Foster Reservoir. Details on the methods of trap operation and fish measurements can be found in Romer et al. (2016). We did not attempt to adjust catch numbers based on trap efficiency estimates since the number of fish recaptured for efficiency estimates were generally too low to provide accurate abundance estimates. For this report, we summarized steelhead captured by age each week for years 2011-2016. In addition, we summarized the proportion captured by age where data on complete cohorts was available (brood years 2011-2014).

PIT-tagging.- Juvenile steelhead were captured at various locations above Foster Dam from 2014-2017 with a variety of collection techniques. All juveniles ≥65 mm fork length (FL) that were not previously tagged were PIT-tagged following protocols of Prentice et al. (1990). In Foster Reservoir, we used boat electrofishing and Oneida Lake traps to collect fish from February to June each year and from October to November in 2014-2015. From July to October each year, we used several techniques to collect and tag juveniles rearing throughout the South Santiam River and tributaries (Moose, Canyon and Soda Fork creeks) upstream of the reservoir. A snorkel-seine technique was used in tributaries in all years and involved 1-2 snorkelers identifying the location of fish in a pool. A seine was set up downstream of the fish perpendicular to the stream flow and the snorkeler(s) herded fish into the seine. Hook and line sampling was also conducted to collect fish in the tributaries and mainstem South Santiam River in 2014-2015. In 2016, we used backpack electrofishing in tributaries and deployed small fish traps in tributaries and mainstem pools to collect juveniles. Additionally, we tagged any juvenile steelhead ≥65 mm FL caught in the rotary screw trap in the South Santiam River (Figure 1). PIT-tag files for each tagging date and location were uploaded to the PIT Tag Information System (PTAGIS) database maintained by the Pacific States Marine Fisheries Commission (PSMFC 1996).

All tagged fish were measured (fork length [FL], mm) and classified as age 0-3 based on length-frequency analysis (DeVries and Frie 1996). Because of the possibility of different growth rates for fish in different rearing location (e.g., reservoir vs tributary) we conducted separate length-frequency analyses for fish collected in the reservoir, screw trap, and each tributary (Appendix Figure A1). We used the American Fisheries Society aging convention where a fish was considered to have completed its current year of life on 01 January (DeVries and Frie 1996). We considered any fish >300 mm FL to be a resident trout; these were not aged.

Detection Sites.- Detection sites were located at the Foster Dam weir, Lebanon Dam, Willamette Falls, and the Columbia River estuary. In May 2014, USACE installed a PIT antenna array on the Foster Dam fish weir (Figure 2), allowing for the detection of PIT-tagged fish exiting the dam via the weir. In 2015, antenna arrays were installed on Lebanon Dam located 28 km downstream of Foster Dam (Figure 1). Antennas were first installed on the Lebanon Dam fish bypass pipe of the water diversion channel in April, the north and south fish ladders in May, and the spillway crest in October. In May 2016, multiple antennas were installed in the Foster adult fish ladder. Additional detection sites operating during the study period included the fish bypass at the Sullivan Dam powerhouse at Willamette Falls, located on the Willamette River 210 km downstream of Foster Dam, and a trawl detector deployed in the Columbia River estuary by NOAA personnel (Morris et al. 2017) approximately 341 km downstream of Foster Dam (Figure 3). We queried the PTAGIS database for tag detections to assess passage timing through the Foster Project.

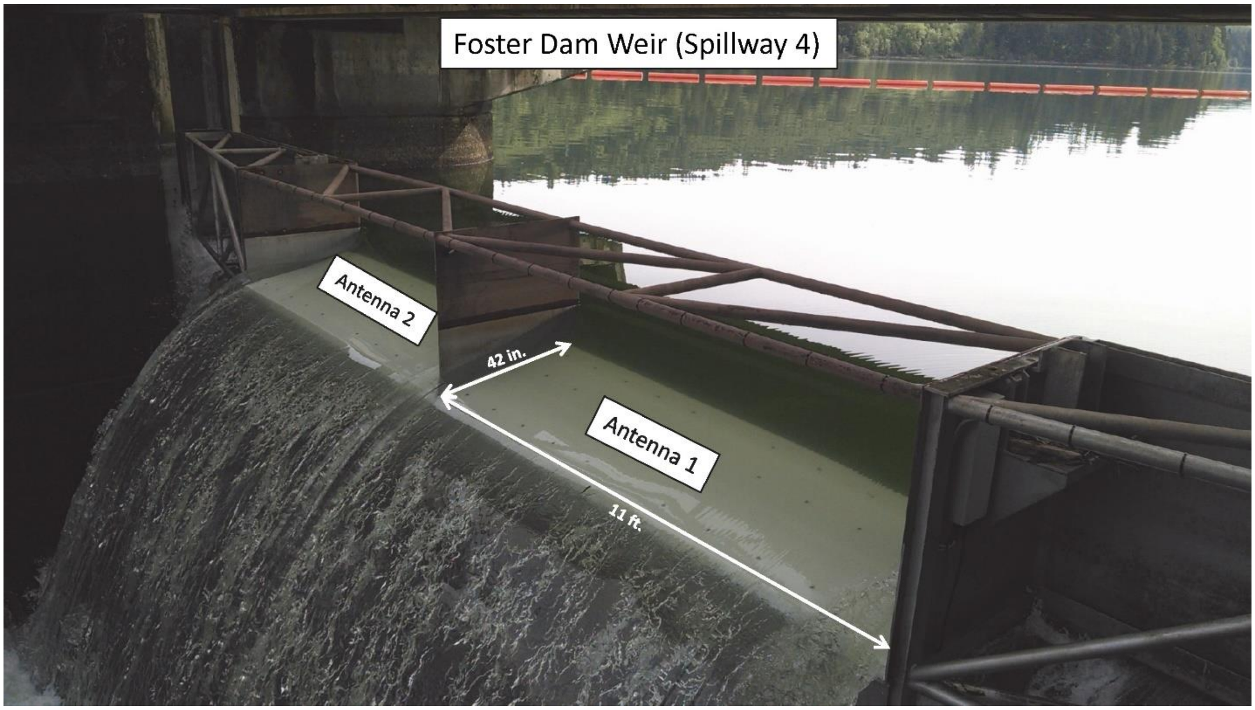

Figure 2. PIT antenna array installed on the Foster Dam fish weir. **The weir is installed in the fourth spillway of the dam closest to the turbine penstocks.**

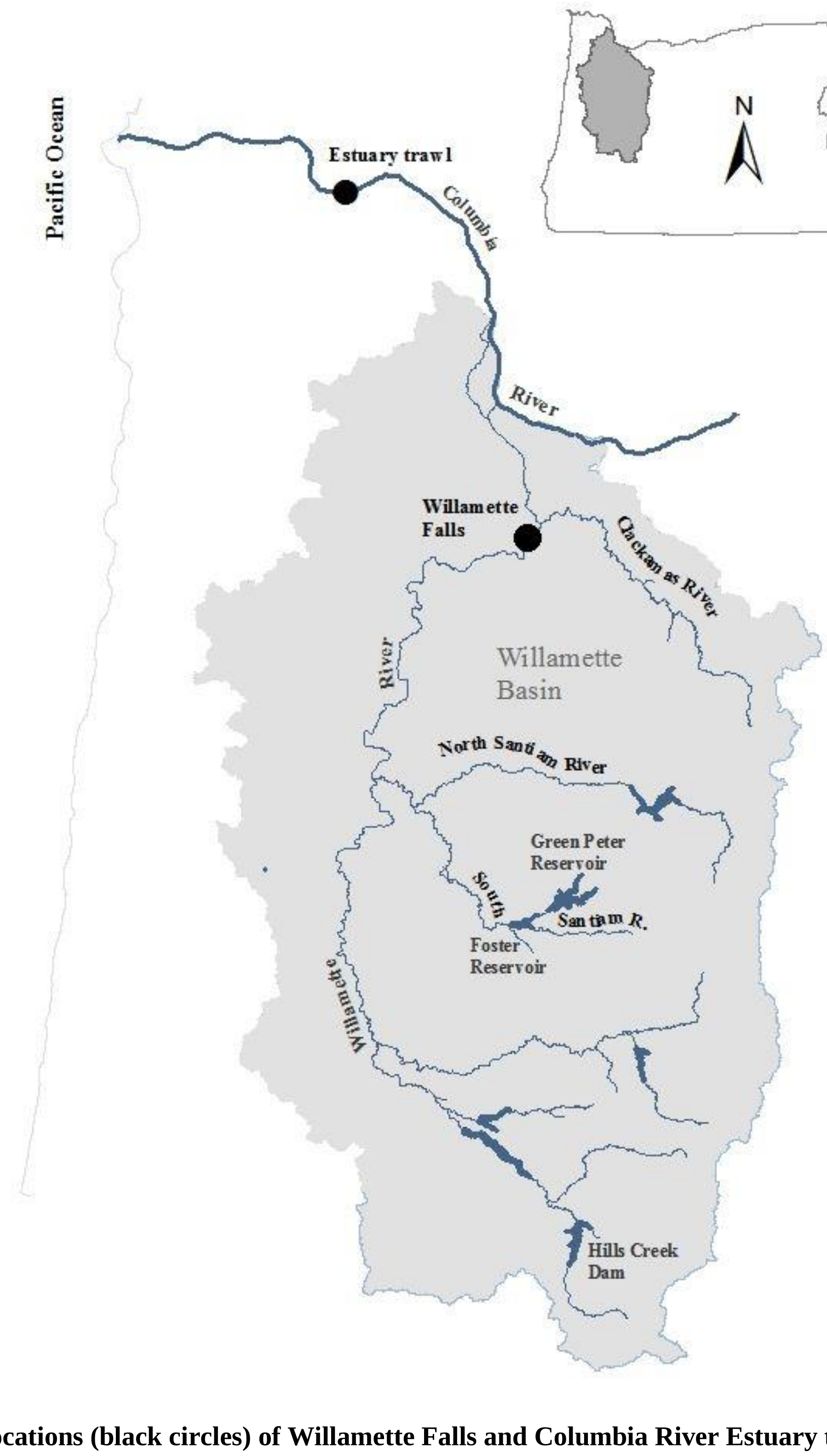

Figure 3. Locations (black circles) of Willamette Falls and Columbia River Estuary trawl PIT-tag detection sites.

Data Analysis.- Several potential biases regarding antenna operations were identified and accounted for prior to analyses. The late installation dates in 2015 of the antennas on the Lebanon Dam fish ladders and spillway could bias passage timing results, so we did not use detections from these arrays in 2015 for timing analyses. Similarly, we did not use detections at the Foster adult fish ladder in 2016. Additionally, we verified that each detection at the Foster weir antenna array occurred while the weir was open and omitted any detections that occurred while the weir was closed. The tainter gate behind the weir was closed occasionally during the study period which flooded the antenna area and detections during these occasions were from tagged fish milling in front of the closed gate.

Antennas recorded the date and time of each tag detection, allowing for the calculation of travel time between sites. For fish detected at both Foster Dam and a downstream site (Lebanon Dam, Willamette Falls, or the Columbia Estuary towed array), we calculated travel time between sites as the difference between detection times. The mean travel time to each downstream site was then used to back-calculate the estimated Foster Dam passage date for fish detected at just a downstream site. We were particularly focused on passage timing during the spring period. For the purposes of this report we defined spring as 1 March- 30 June. Passage dates were summarized by week each year. Age at dam passage was estimated based on initial age at tagging plus the time to the estimated dam passage date. We used all detection sites and years when evaluating travel time and age-structure of juveniles passing the dam.

Results

Reservoir Entry Timing.- Most juvenile steelhead in the South Santiam River moved into Foster Reservoir at age 0, age 1, or age 2 (Figure 4). Age-3 or older juvenile steelhead were rare, comprising <0.1% of the total screw trap catch during the study period (n=5).

Considerable interannual variability existed in the contribution of age groups to the annual catch. Age-2 juveniles were rare (<10 fish) in the catch in 2011, 2012, and 2014 (Figure 5). Age-2 fish were generally only present in the spring while age-1 fish were caught in both spring and fall. The first age-0 juveniles typically began entering the reservoir in late June, soon after emergence, continued to enter the reservoir through the rest of the year, and were generally the most abundant age class caught each year (Figure 4). However, age-1 and age-2 fish comprised the majority of the annual catch in 2015 (Figure 5). This appeared to be due to poor age-0 fish recruitment in 2015. The number of age-0 fish caught in 2015 (n=234) was lower compared to other years (range 319 - 1,247) which may reflect poor recruitment during the 2015 drought year or low stream flows that precluded downstream movement of age-0 fish during the summer months.

Regardless of interannual variability in the age proportions of total annual catch, age-0 steelhead consistently comprised the majority (56-88%) of fish caught from each cohort produced in brood years 2011-2014 (Table 1). Although we do not have complete 2015 brood year data, it appears age-0 will comprise the majority for this cohort as well since only 159 age-1 fish were caught in 2016.

Age-1 fish demonstrated seasonal variation in peak downstream movement among years. Fall peaks were observed in 2011 and 2014 and spring peaks observed in 2013, 2015, and 2016 (Figure 5). The reason for the variation in seasonal movement of age-1 fish is unclear. There were no discernable differences among years in river discharge at the trap site during peak catch periods (Appendix Figure A2-A4). We noted that the majority of age-0 (63%) and age-1 fish (74%) caught in 2014 occurred during a 5-d period in late October associated with the first freshet of the season (Appendix Figure A2).

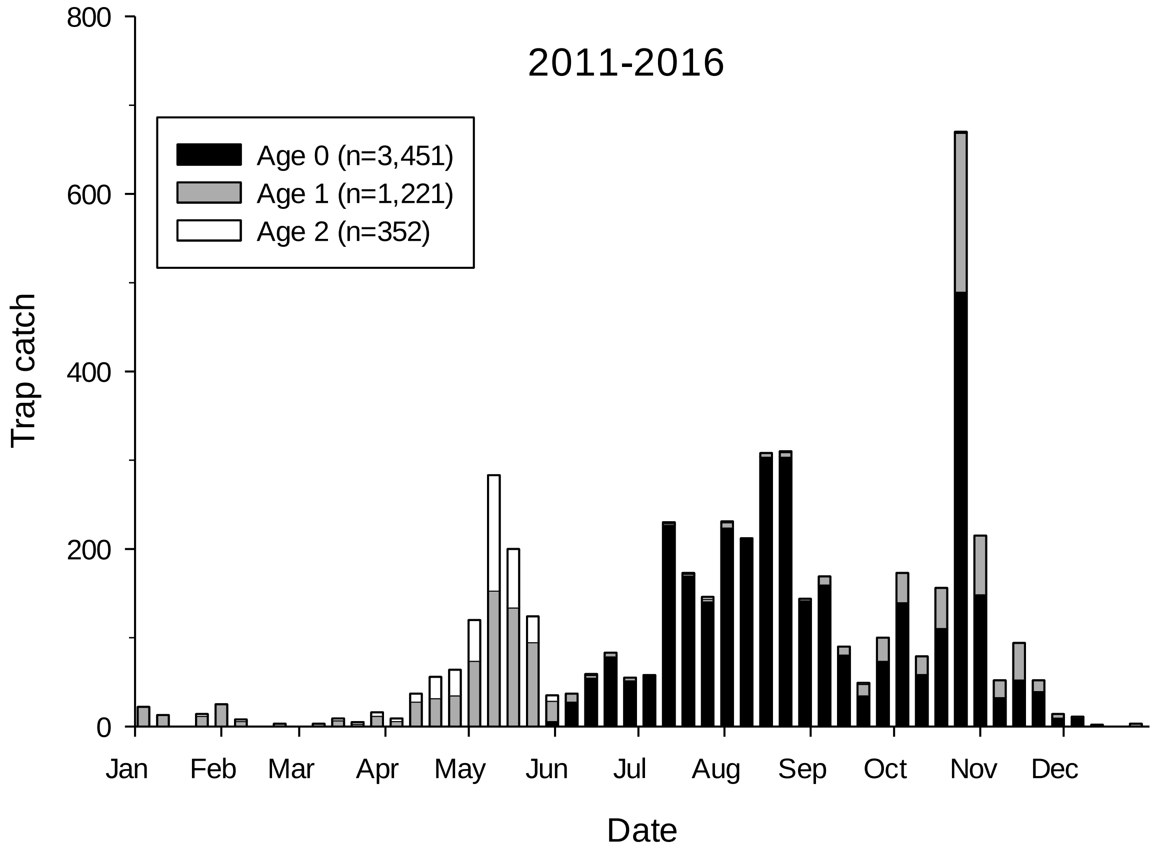

Figure 4. Weekly catch of juvenile steelhead by age group in the rotary screw trap above Foster Reservoir from 2011 to 2016 (combined). Catch was not adjusted for capture efficiency differences among age groups.

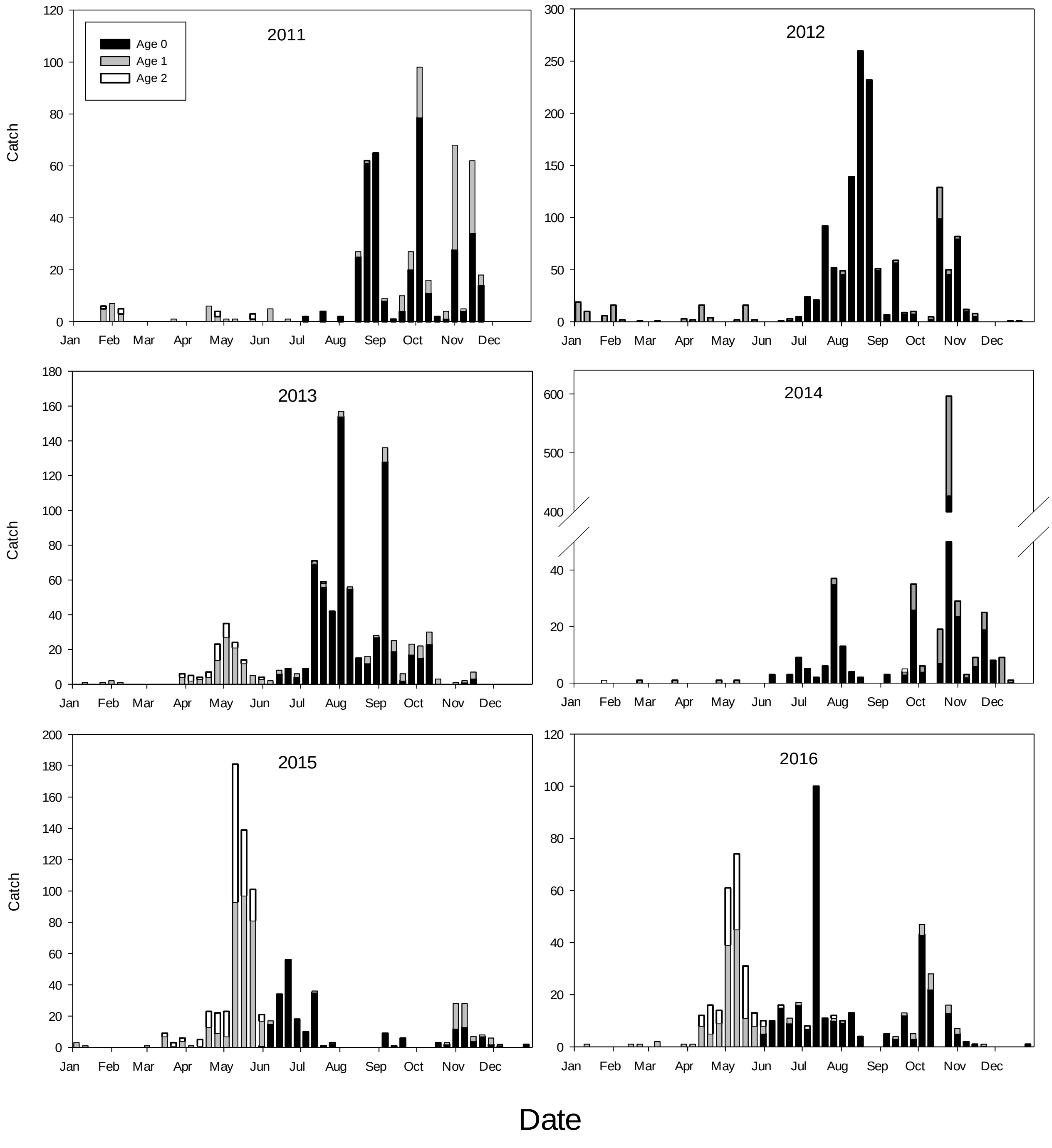

Figure 5. Number of juvenile steelhead captured in the South Santiam rotary screw trap upstream of Foster Reservoir, summarized by week, 2011-2016. Note differences in the y-axis scales.

Table 1. Number of juvenile steelhead captured in the rotary screw trap above Foster Reservoir by age for each cohort from brood years (BY) 2011-2014. Capture numbers do not include recaptures.

	BY11		BY12		BY13		BY14	
Age	n	%	n	%	n	%	n	%
0	364	66	1,247	88	666	61	621	56
1	154	28	165	12	214	20	379	34
2	34	6	3	0.2	204	19	102	9

PIT-tagging.- We tagged 5,778 juvenile steelhead upstream of Foster Dam from 2014-2017, comprised of 33% age-0, 50% age-1, 17% age-2, and <1% age-3 fish (Table 2). Most age-2 fish were tagged in the reservoir or in the screw trap on the mainstem South Santiam River and fish tagged in the tributaries were mainly age-0 and age-1 (Table 2). Age-1 fish were tagged in greater proportion to their abundance in the basin because they could be captured in all locations (i.e., reservoir, screw trap, and tributaries) throughout the year and were >65 mm FL. Age-0 fish were more abundant in tributaries but were generally not large enough to tag until late summer. We also slightly skewed our capture and tagging efforts in late summer towards age-1 fish with the assumption that they would have a greater probability of detection given they would have less total exposure to natural mortality before outmigration compared to age-0 fish. The size of tagged fish is presented in Appendix Table A1.

Foster Dam Passage Timing.- A total of 306 tagged fish were detected on antennas at the detection sites during the study period. Of the 142 detections on the Foster weir antenna, 38 were during periods when the weir was closed to passage and therefore were excluded from analyses. Many of the 38 detections occurred during brief periods of weir closure during the spring and fall (Appendix Table A2). Two of the 38 fish were later detected at downstream sites and travel time to those detections sites were used to estimate Foster Dam passage timing. After excluding fish detected when the weir was closed, there were a total of 104 unique detections of fish passing the weir. An additional three fish were detected moving downstream through the Foster Dam adult ladder. Most detections at downstream sites occurred at Lebanon Dam (n=99) followed by the Sullivan powerhouse at Willamette Falls (n=59) and the Columbia River estuary trawl (n=5). Mean travel times to downstream detection sites from Foster Dam were used to back-calculate passage timing at Foster Dam.

There were a total of 46 fish detected at both Foster Dam and a downstream site that were used to calculate travel times (Table 3). The mean travel time from Foster Dam to Lebanon was 2.5 d with 92% of fish traveling this distance in <3 d (Table 3). The mean time for fish to travel the 210 km to Willamette Falls was less than a week (5.9 d). Travel time from Foster Dam to the Columbia River estuary trawl averaged 10.2 d based on only four fish detected at both sites. Although the sample size was small, the travel time estimate appears accurate considering that the mean travel time from Willamette Falls to the estuary calculated for five fish detected at both downstream sites was 3.4 d. Adding this to the travel time estimate from Foster Dam to the Willamette Falls (5.9 d) results in a travel time from Foster Dam to the estuary of 9.3 d, less than a day difference than the estimate based on four fish. Overall, based on the relatively short duration and small variances in travel times to downstream sites from Foster Dam, the use of downstream detections to estimate Foster Dam passage timing appears valid.

Age-2 fish comprised the majority of fish passing Foster Dam. The overall age structure was 0% age-0, 13% age-1, 84% age-2, and 2% age-3 fish (Figure 7). Despite tagging 1,892 age-0 fish, none were detected passing the dam at age 0 (there were seven detections of age-0 fish at the Foster weir antenna, all during periods when the weir was closed to passage in the fall). All tagged age-0 and most age-1 fish reared for at least one additional year before migrating past the dam (Table 4).

Passage at Foster Dam occurred primarily in the spring with few tagged fish passing in the fall (Figure 6). In 2015, 98% of the 123 fish detected passed Foster Dam in the spring. A total of 108 fish were detected passing the dam in 2016, with 95% occurring in the spring. A total of 38 fish were detected in 2017, but the study ended on 30 June 2017 so we were unable to calculate the annual proportion that passed during the spring.

Variability in spring passage timing was evident among years, with a later migration in 2015 compared to other years (Table 5). The median date for fish passing the dam in spring 2015 was 21 May with only 30% passing by 15 May (Table 5). Spring passage timing in 2017 was over two weeks earlier than 2015 with a median migration date of 27 April and 68% of passage prior to 15 May (Table 5). During the spring, 92-98% of fish passed prior to 01 June among years (Table 5). Keeping the weir open for about one week beyond 01 June to accommodate late migrating fish could help improve passage for the 2-8% of the migrant population that pass after this date. Of the 25 fish detected passing Foster Dam in June, 80% occurred within the first week of June. In other words, 98-100% of all juvenile steelhead that passed Foster Dam in the spring period did so by 07 June (Table 5). The latest date a fish was detected passing the dam was 20 June (2015). No fish were detected at any site from July-September.

Table 2. Tagging location, estimated age, and number of juvenile steelhead PIT tagged upstream of Foster Dam in the upper South Santiam basin, 2014-2017. Three age-3 steelhead captured upstream of the dam and suspected resident trout >300 mm FL were excluded. Fish captured and tagged in the mainstem South Santiam and tributaries above the screw trap site were not necessarily active migrants.

Tagging location	Age-0	Age-1	Age-2	Total
		2014		
Foster Reservoir	88	333	76	497
Screw trap	333	201	3	537
Mainstem South Santiam	0	27	53	81
Canyon Creek	50	46	5	101
Moose Creek	263	155	7	425
		2015		
Foster Reservoir	29	243	73	345
Screw trap	52	373	195	620
Mainstem South Santiam	0	3	3	6
Canyon Creek	226	141	21	388
Moose Creek	1	77	2	80
		2016		
Foster Reservoir	0	177	128	305
Screw trap	106	165	97	368
Mainstem South Santiam	0	5	2	7
Canyon Creek	416	352	17	785
Moose Creek	265	323	9	598
Soda Fork	63	114	9	186
		2017		
Foster Reservoir	0	138	265	403
Screw trap	0	36	10	46
Total	**1,892**	**2,909**	**977**	**5,778**

Table 3. Travel times of PIT-tagged juvenile steelhead from Foster Dam to downstream detection sites.

				Travel time (d)			
Detection site	n	Distance from Foster Dam (km)	Rate (km/d)	Mean	Min	Max	SE
Lebanon Dam	25	28	11.2	2.5	0.7	13.1	0.53
Sullivan Plant	17	210	35.6	5.9	3.9	9.0	0.29
Columbia Estuary Trawl	4	341	33.4	10.2	4.7	17.3	2.62

Table 4. The proportion of juvenile steelhead passing Foster Dam by age, in relation to age when PIT-tagged. Numbers in parentheses are the total number of unique detections indicating dam passage.

	Age at detection			
Age at tagging (n)	0	1	2	3
0 (17)	0.00	0.59	0.41	0.00
1 (118)	--	0.26	0.72	0.02
2 (164)	--	--	0.98	0.02

Table 5. March-June passage timing of juvenile steelhead at Foster Dam, 2015-2017.

Year	Number of detections	Median passage date	Passage date range	% passed prior to 15 May	% passed prior to 01 June	% passed prior to 07 June
2015[a]	87	21 May	21 March – 20 June	30	94	99
2016	104	10 May	15 March – 15 June	66	98	98
2017	37	27 April	12 March – 05 June	68	92	100

[a] Lebanon fish ladder and spillway detections not included in 2015.

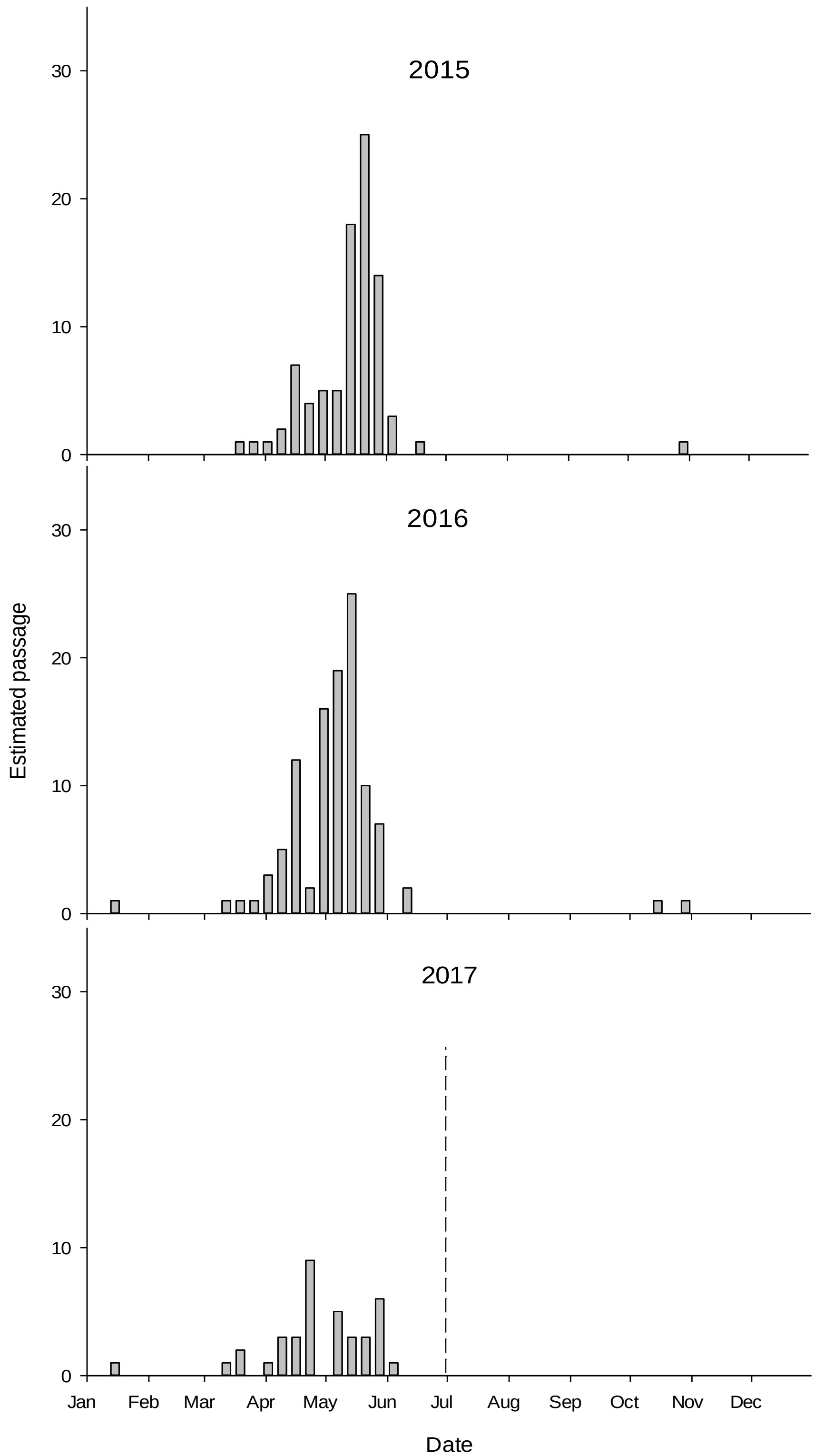

Figure 6. The weekly number of tagged juvenile steelhead passing Foster Dam, 2015-2017. The 2015 graph does not include detections at Lebanon Dam fish ladders or spillway. The dashed vertical line indicates the end of the study period.

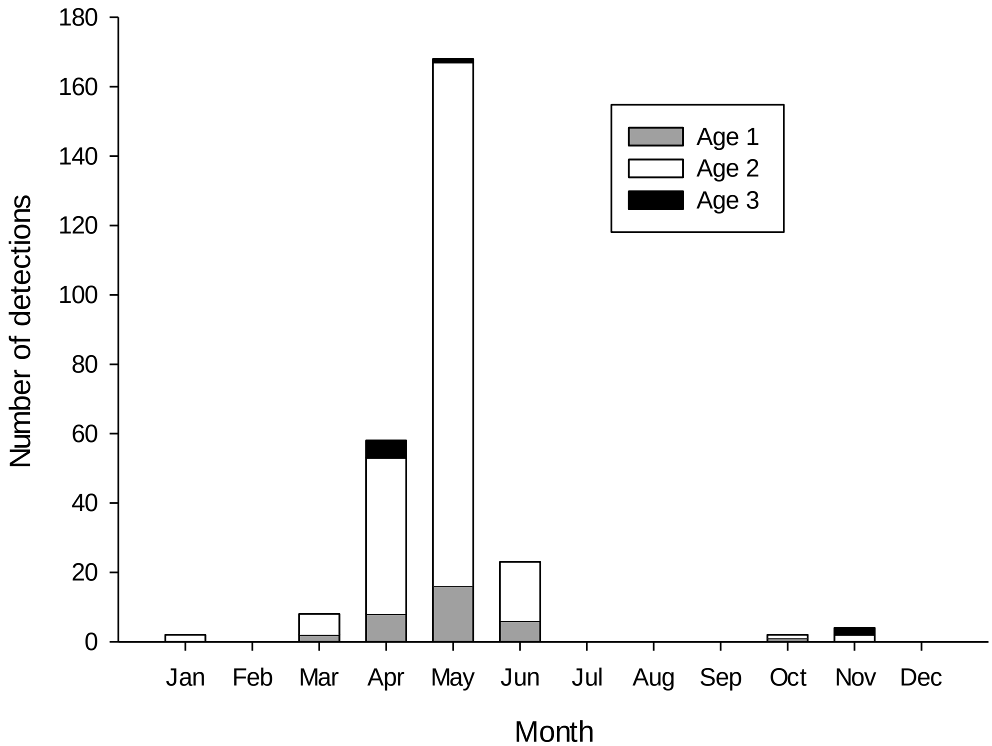

Figure 7. Monthly detections by age of juvenile steelhead passing Foster Dam, 2014-2017. Detections include all antennas and years and does not necessarily reflect passage timing since some antennas were installed in the middle of the migration season in some years.

Discussion

Given that our results showed that most juvenile steelhead entered Foster Reservoir at age-0 and most juveniles passed the dam at age-2, it appears that one of the more prevalent juvenile steelhead life-history pathways is for fish to rear in the reservoir for approximately two years before exiting as smolts. There is apparently considerable plasticity in this strategy, as demonstrated by the range of ages and times that fish entered and exited the reservoir. Bjornn et al. (1971) reported a similar age range of steelhead juveniles moving out of Idaho streams, with age-0 fish comprising a large part of the downstream movement. Although age-0 fish in the fall comprised the majority of fish in our rotary screw trap, we did not attempt to adjust catch numbers with trap efficiency estimates by season or age group. It is possible that older age fish were able to avoid the rotary screw trap upstream of the reservoir, and were underrepresented in our trap catch.

The vast majority (95-98%) of tagged fish passed Foster Dam in the spring (March-June) with the remainder passing during the fall and winter. Within the spring, 30-68% of the fish passed prior to 15

May, 92-98% passed prior to 01 June, and 98-100% passed prior to 07 June during the three years of the study. The end date that the new weir will operate in the spring is still to be determined and will likely involve a tradeoff between maximizing fish passage survival and fulfilling other functions of the project. We recommend keeping the weir open until at least 07 June. Given that spill generally occurs infrequently in June, turbine passage, with its higher mortality (Normandeau 2013), would likely be the only route available if the weir was not operating.

We estimated <3% of the tagged fish passed the dam in the fall, which was consistent with radio-telemetry results from Hughes et al. (2016), but may underestimate the amount of passage occurring in the fall by younger-aged juveniles. Over half (56%) of the 39 fish we detected at the Foster weir when it was closed to passage were age-0 and age-1 fish in the fall (October-December), suggesting these age groups were present in the forebay and available for passage (Appendix Table A2). No age-0 fish were detected passing the Foster weir antenna; however, Romer et al. (2012, 2013, 2014, and 2015) consistently observed the greatest annual juvenile steelhead catch in the fall from a rotary screw trap located in the turbine tailrace below the dam, with most of the fall migrants comprised of age-0 fish. There are two possible explanations for the discrepancies in results between the screw trap study and the tagging studies: there are inherent biases in each study type, and age-0 fish are more likely to be entrained by the turbine penstocks than older juveniles. Hughes et al. (2016) used age-1 and age-2 fish for their telemetry study because age-0 fish were too small to burden with a radio-tag, so the passage route preferences of age-0 fish is currently unknown. In our study, most tagged age-0 fish were caught in the upper tributaries in the summer. If only a small proportion survived to the fall or moved downstream as subyearlings, this could explain the low detection numbers. In addition, higher discharge levels in the fall may have resulted in more passage route opportunities (i.e., spill) and decreased detection efficiencies at downstream antennas. Lastly, the low catch of older juveniles in the screw trap below the dam may simply reflect their preference for spill and weir passage routes (the location of the screw trap in the turbine tailrace prevented accurate assessment of fish that passed via the spillways). However, the high proportional catch of age-0 fish in the screw trap in the fall does suggest this age group may use the turbine penstock route to a greater extent than older juveniles. A hydroacoustic evaluation of juvenile-sized fish passing Foster Dam indicated that both the weir and spill had the lowest passage effectiveness in the fall and winter (Hughes et al. 2014), suggesting a greater proportion of juvenile steelhead use the turbine route in these seasons. Little is known about dam passage behavior of age-0 steelhead and a better understanding of their distribution in the forebay and route selection at Foster Dam are needed given their abundance in the reservoir and potential survival disadvantage from a turbine passage route.

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Appendix

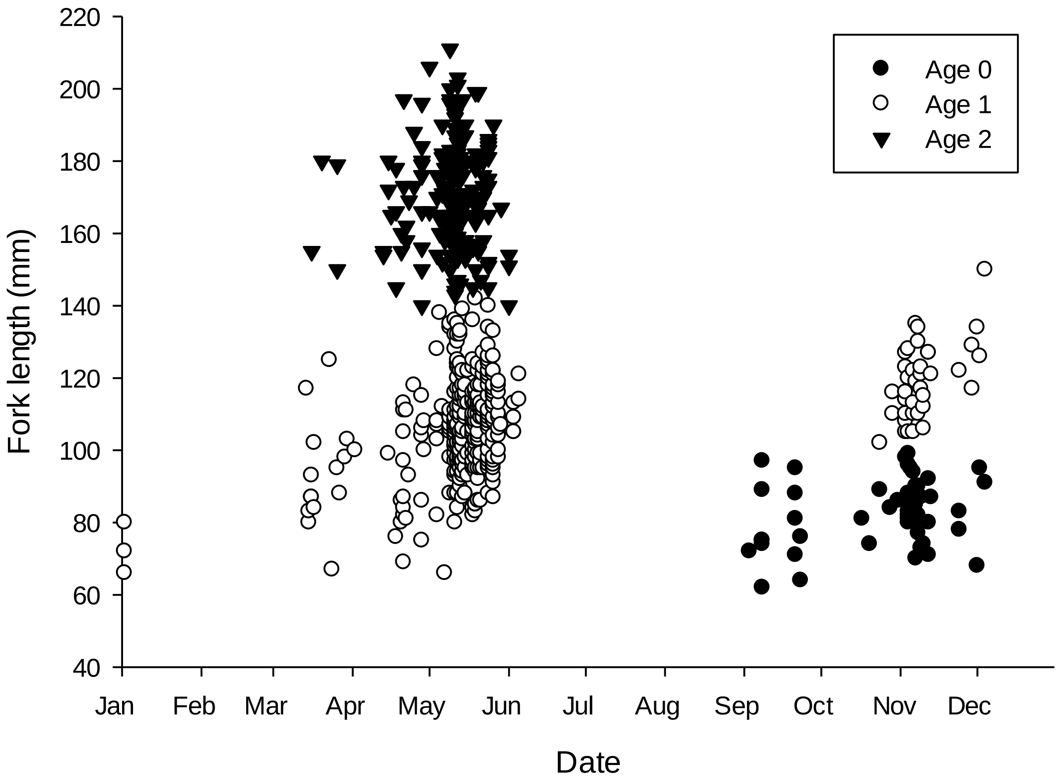
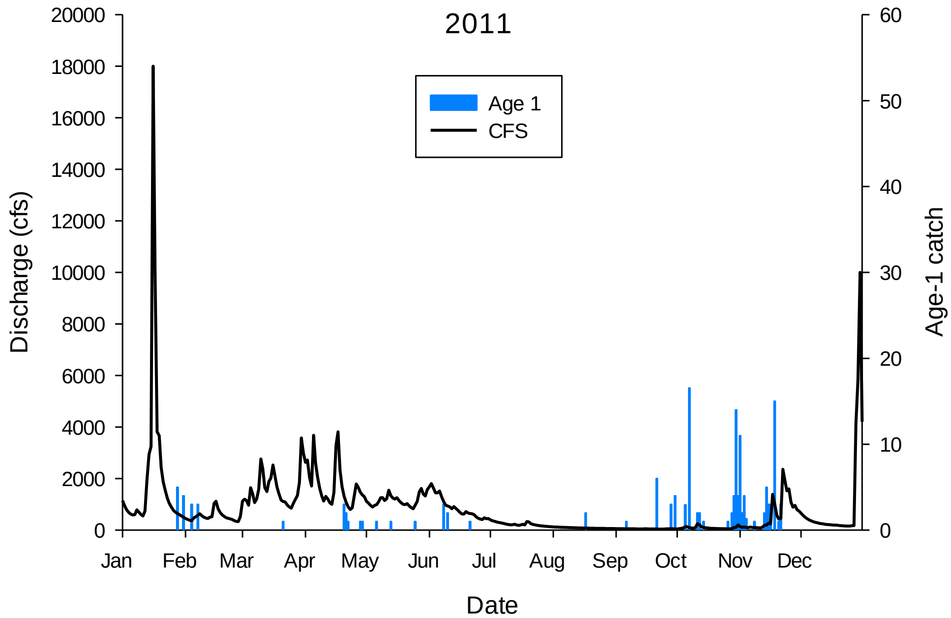


Figure A1. Example of fish age designations based on length-frequency analysis of juvenile steelhead caught and tagged in the rotary screw trap above Foster Reservoir in 2015.



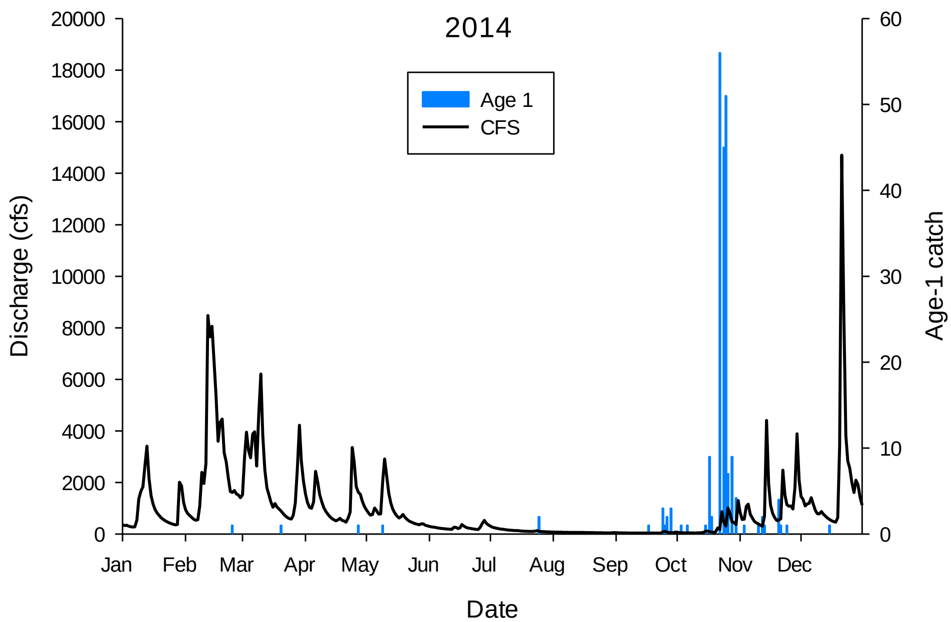


Figure A2. Daily river discharge and catch of age-1 juvenile steelhead at the screw trap located on the South Santiam River, 2011 and 2014. Fall peaks in age-1 catch were observed in each of these years.

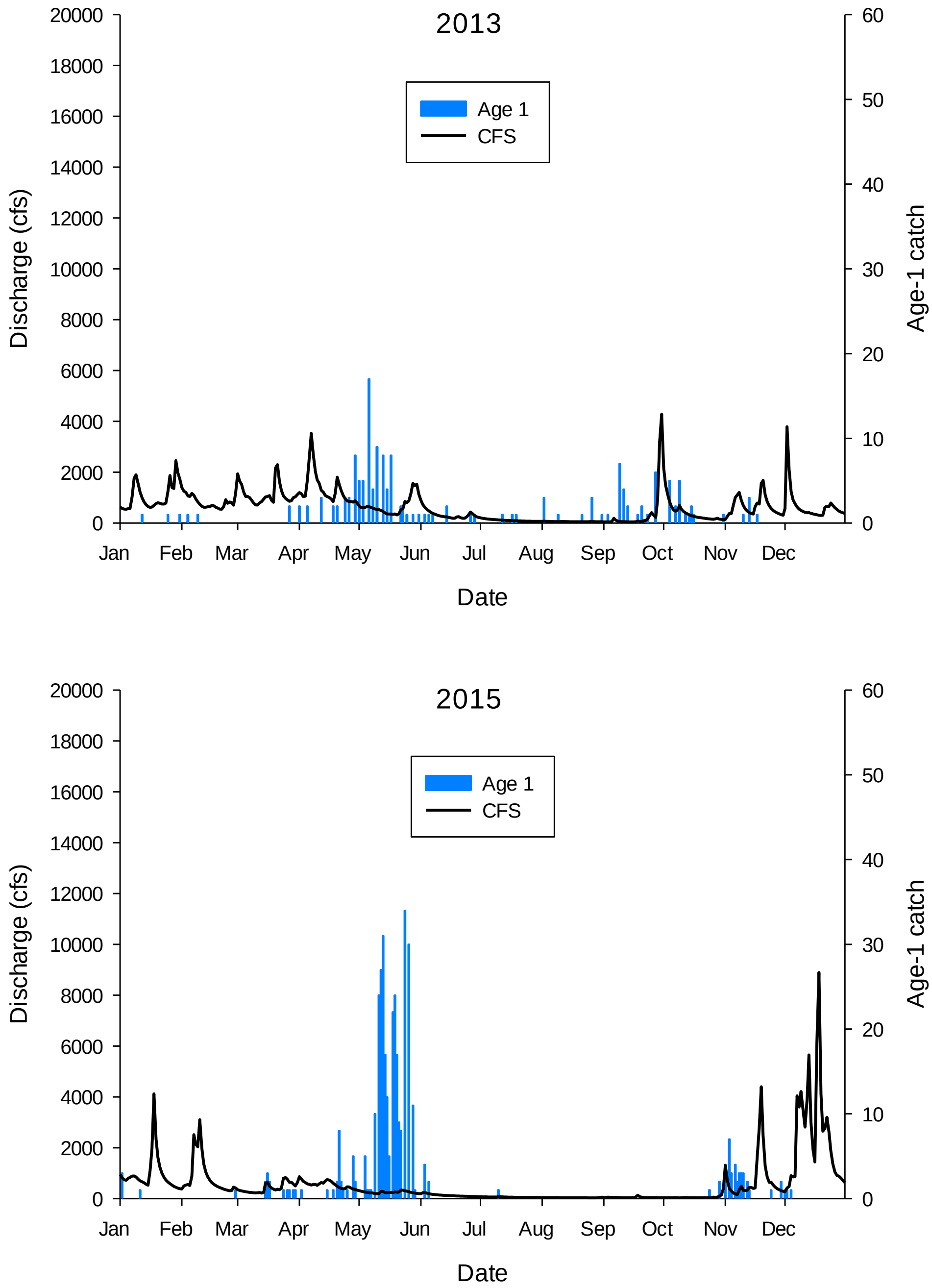


Figure A3. Daily river discharge and catch of age-1 juvenile steelhead at the screw trap located on the South Santiam River, 2013 and 2015. Spring peaks in age-1 catch were observed in each of these years.

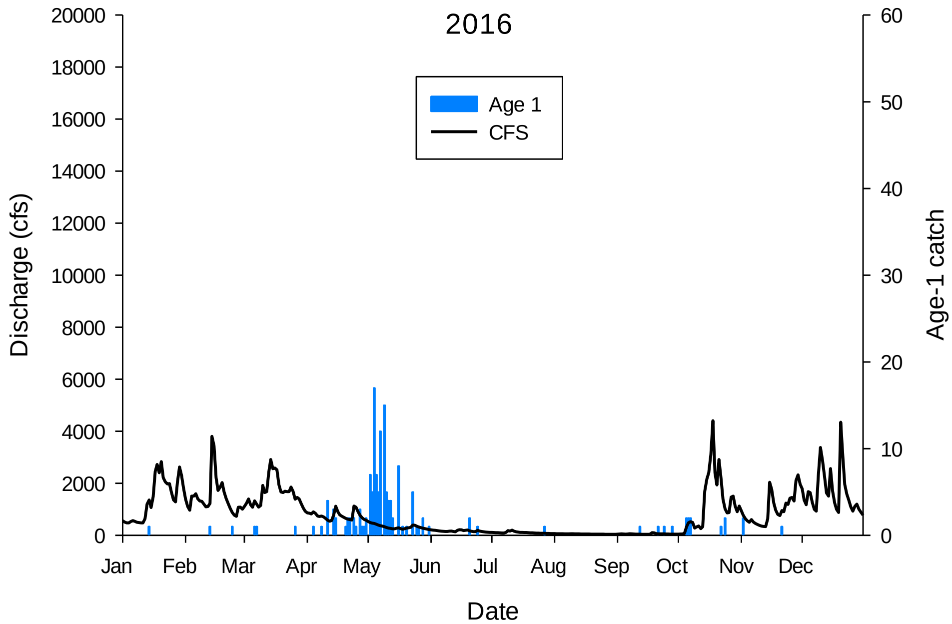


Figure A4. Daily river discharge and catch of age-1 juvenile steelhead at the screw trap located on the South Santiam River, 2016. Spring peaks in age-1 catch were observed in this year in addition to 2013 and 2015 (Figure A3).

Appendix Table A1. Mean fork length (mm) and range of PIT-tagged juvenile steelhead by year, tagging location, and age.

Tagging location[a]	Age 0	Age 1	Age 2
		2014	
Foster Reservoir	86 (65-113)	109 (67-185)	171 (118-283)
Screw trap	80 (60-104)	131 (76-162)	191 (180-200)
Canyon Creek	74 (65-98)	135 (106-165)	182 (164-210)
Moose Creek	70 (63-92)	118 (88-170)	181 (164-205)
Mainstem South Santiam		134 (116-151)	186 (155-285)
		2015	
Foster Reservoir	89 (70-103)	105 (71-164)	168 (127-241)
Screw trap	83 (62-99)	108 (66-150)	171 (140-211)
Canyon Creek	77 (64-102)	139 (108-181)	204 (182-263)
Moose Creek	68 (68-68)	137 (97-185)	203 (201-204)
Mainstem South Santiam		135 (130-146)	219 (193-248)
		2016	
Foster Reservoir		115 (75-152)	180 (134-251)
Screw trap	79 (65-105)	112 (69-170)	166 (135-218)
Canyon Creek	73 (42-95)	134 (98-173)	192 (177-230)
Moose Creek	79 (64-101)	140 (105-186)	218 (190-274)
Soda Fork	70 (64-90)	124 (95-173)	192 (175-210)
Mainstem South Santiam		144 (121-161)	196 (176-215)
		2017	
Foster Reservoir		104 (73-159)	162 (112-247)
Screw trap		97 (69-129)	161 (135-179)

[a] See Table 2 for sample sizes

Appendix Table A2. Detections of tagged fish at the Foster weir when the weir was closed to passage, 2015-2017.

Tag Code	Detection Date/time	Forebay elevation	Spill	Fish Age	Weir operation comment
3DD.007739D644	3/18/15 16:32[a]	616.4	N	Age-1	Weir not open until 20 March
3DD.0077531066	3/19/15 2:09	615.5	N	Age-1	Weir not open until 20 March
384.3B239EB3E4	3/19/15 3:07	615.5	N	Age-2	Weir not open until 20 March
3DD.0077537F1B	3/19/15 17:59	615.5	Y	Age-1	Weir not open until 20 March
3DD.0077536781	3/19/15 18:15	615.5	Y	Age-1	Weir not open until 20 March
3DD.0077792AD2	11/3/15 0:48	615.7	Y	Age-0	Weir closed for 8 d starting on 30 October
3DD.003BD29C1A	11/4/15 2:35	615.2	Y	Age-1	Weir closed for 8 d starting on 30 October
3DD.00777494D9	11/5/15 7:00	614.3	Y	Age-1	Weir closed for 8 d starting on 30 October
3DD.003BD29D1B	11/5/15 7:05	614.3	Y	Age-1	Weir closed for 8 d starting on 30 October
3DD.003BD29CF6	11/5/15 7:24	614.3	Y	Age-0	Weir closed for 8 d starting on 30 October
3DD.003BD29D14	11/5/15 7:24	614.3	Y	Age-0	Weir closed for 8 d starting on 30 October
3DD.0077526E37	11/6/15 2:37	613.3	Y	Age-1	Weir closed for 8 d starting on 30 October
3DD.0077539390	11/6/15 11:17	613.3	Y	Age-1	Weir closed for 8 d starting on 30 October
3DD.003BD29D22	11/6/15 21:04	613.3	Y	Age-1	Weir closed for 8 d starting on 30 October
3DD.003BD29D2C	11/6/15 23:53	613.3	Y	Age-0	Weir closed for 8 d starting on 30 October
3DD.003BD29C04	11/7/15 3:34	612.5	Y	Age-1	Weir closed for 8 d starting on 30 October
3DD.003BD29D37	11/7/15 4:05	612.5	Y	Age-1	Weir closed for 8 d starting on 30 October
3DD.003BD29D1A	11/7/15 5:09	612.5	Y	Age-1	Weir closed for 8 d starting on 30 October
3DD.003BD29D2D	11/7/15 5:15	612.5	Y	Age-1	Weir closed for 8 d starting on 30 October
3DD.00773FE739	11/30/15 7:14	615.0	N	Age-0	Weir closed for 15 d starting 17 November
3DD.007753227B	12/1/15 17:19	614.0	N	Age-0	Weir closed for 15 d starting 17 November
3DD.00777829B2	12/7/15 17:44	613.0	Y	Age-1	Weir ended weir operation on 7 December, 2015
3DD.007741B640	1/7/16 1:57	615.3	Y	Age-2	Weir ended weir operation on 7 December, 2015
3DD.003BDAA0F4	2/26/16 20:35	615.9	N	Age-2	Weir not open until 21 March
3DD.003BDAA117	2/28/16 7:44	617.1	N	Age-2	Weir not open until 21 March
3DD.003BD29D1E	3/19/16 18:10[b]	616.1	Y	Age-2	Weir not open until 21 March
3DD.003BD29DF4	4/22/16 14:16	#N/A	N	Age-1	Closed to raise elevation for summer operations
3DD.003BD2A328	4/22/16 15:00	#N/A	N	Age-1	Closed to raise elevation for summer operations
3DD.003BD29EE3	4/28/16 19:03	#N/A	N	Age-1	Closed to raise elevation for summer operations
3DD.00777A4FD5	4/29/16 2:31	#N/A	N	Age-2	Closed to raise elevation for summer operations
3DD.003BD2A6B3	5/20/16 11:41	635.1	N	Age-1	Closed weir for 6 h for PNNL crew
3DD.003BD59287	10/18/16 8:56	619.0	N*	Age-0	*Spill of 500cfs began within minutes of detection
3DD.003BD5940E	11/4/16 6:38	619.0	N	Age-1	Closed for 3 d on 03 Nov due to res elevations
3DD.003BDAA95B	11/4/16 6:38	619.0	N	Age-1	Closed for 3 d on 03 Nov due to res elevations
3DD.003BDAA8DC	11/4/16 14:55	619.0	N	Age-1	Closed for 3 d on 03 Nov due to res elevations
3DD.003BD5926A	11/4/16 22:38	619.0	N	Age-1	Closed for 3 d on 03 Nov due to res elevations
3DD.003BD593EB	2/18/17 18:29	617.5	Y	Age-2	Spring weir ops not started until 01 March
3DD.003BD59408	2/25/17 5:48	617.0	Y	Age-2	Spring weir ops not started until 01 March
3DD.003BDAA280	2/25/17 18:47	617.0	Y	Age-2	Spring weir ops not started until 01 March

[a] later detected at Lebanon Dam on 3/17/2016. [b] later detected at Willamette Falls on 4/17/2016