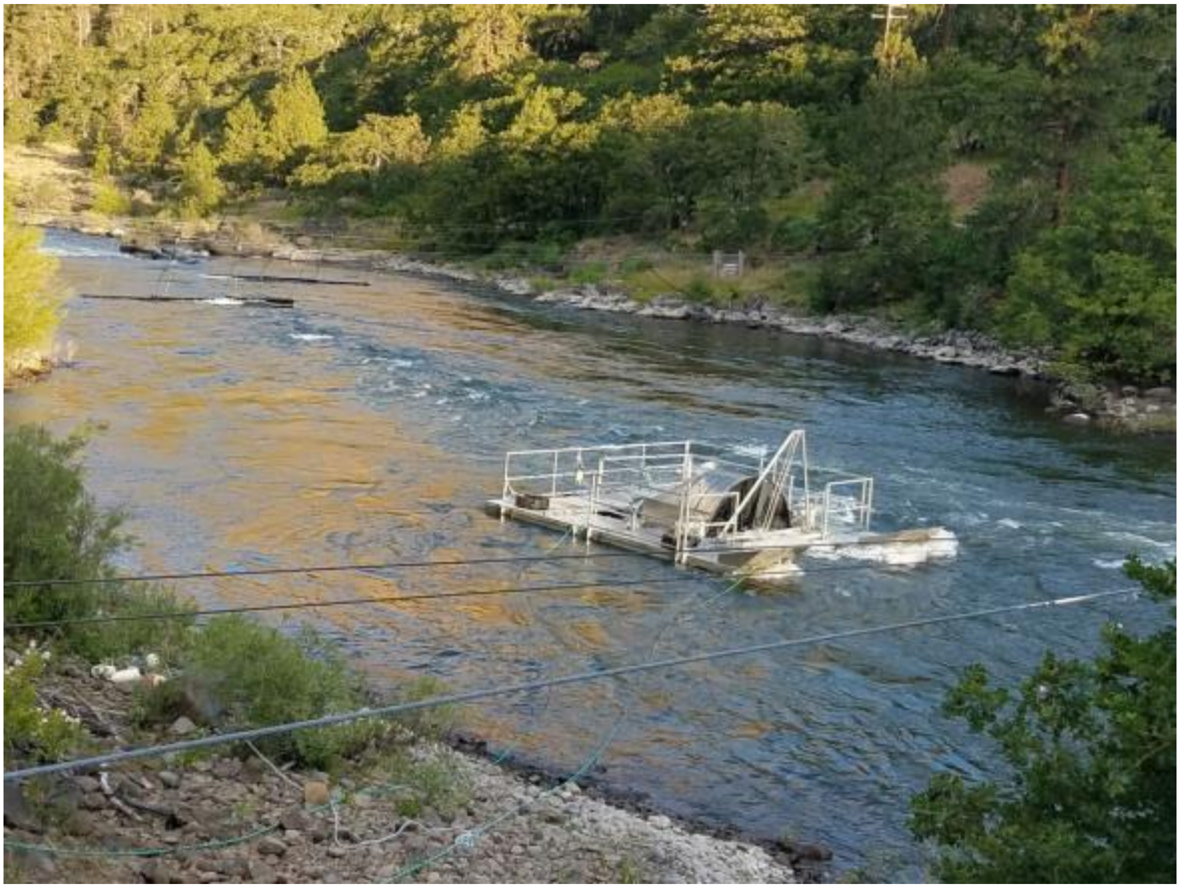
Monitoring of Juvenile Salmonids Emigrating from the Klickitat River Subbasin, Washington: Technical Report for Migration Years 2017-2019



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Cover: Photograph of rotary screw trap at river kilometer 4.5, Klickitat River, Washington. Photograph by Yakama Nation Fisheries, May 28, 2017

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List of Abbreviations and Acronyms

- BPA – Bonneville Power Administration
- CRE – Columbia River Estuary
- CRITFIC – Columbia River Intertribal Fish Commission
- DARR – Darroch Analysis with Rank Reductions
- DOP – Data over Power
- DPS – Distinct Population Segment
- ESA – Endangered Species Act
- ESU – Evolutionary Significant Unit
- HOR – Hatchery-origin
- KFO – Klickitat Field Office
- KRM&E – Klickitat Research, Monitoring, and Evaluation Project
- KRH – Klickitat River Hatchery
- LYLFAT – Lyle Falls Adult Fish Passage Facility
- MC – Master Controller
- MCR – Middle Columbia River
- MPG – Major Population Group
- NMFS – National Marine Fisheries Service
- NOR – Natural-origin
- PIT – Passive Integrated Transponder
- PTAGIS – PIT Tag Information System
- rkm – River kilometer
- SAR – Smolt to adult ratio
- SURPH – Survival Under Proportional Hazards
- USFWS – United States Fish and Wildlife Service
- VSP – Viable Salmonid Population
- WDFW – Washington Department of Fish and Wildlife

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Abstract

A rotary screw trap in the lower river was used to monitor out migrating juvenile salmonids from the Klickitat River, Washington. As part of an effort to provide more robust estimates of smolt abundance, a pilot study was initiated in 2017 after the rotary screw trap project underwent a revamping in personnel, protocol, and infrastructure following completion of the 2016 smolt migration year. Infrastructure upgrades included the installation of a new 2.4-meter rotary screw trap and cabling system, electronic trap winch, on-site laboratory, and floating Passive Integrated Transponder (PIT) tag interrogation array.

The rotary screw trap is located 4.5-kilometers upstream from the confluence with the Columbia River. The rotary screw trap was paired with a floating PIT tag interrogation array located approximately 100-meters downstream. The floating PIT tag interrogation array was used to temporally define the out-migration run window, collect seasonal and diel movement patterns, and collect mark-recapture information of PIT tagged fish. The rotary screw trap was operated intermittently late-May through early-October in 2017 and nearly continuously early-April through late-June in 2018 and 2019. The rotary screw trap was operated for 43, 78, and 67 days during 2017, 2018, and 2019, respectively.

The number of natural-origin (NOR) juvenile steelhead handled and enumerated in 2017 (n=233) was significantly less than 2018 (n=4,072) and 2019 (n=3,774). The mean fork length in millimeters (mm) and weight in grams (g) of NOR juvenile steelhead collected at the rotary screw trap was 171.9 mm (SE±1.38) and 51.7 g (SE±1.21) in 2017, 180.8 mm (SE±0.34) and 51.7 g (SE±1.21) in 2018, and 181.2 mm (SE±0.35) and 59.6 g (SE±0.35) in 2019.

To quantify rotary screw trap capture efficiency, a total of 26 (n=221 fish), 141 (n=3,186 fish), and 151 (n=3,384 fish) efficiency release trials with PIT tagged fish were conducted in 2017, 2018 and 2019, respectively. Trap efficiency could not be determined in 2017 because we were unable to recapture any efficiency released fish. A total of 158 fish were recaptured in 2018 and in 2019. Capture efficiency at the rotary screw trap for the trapping season was estimated at 5.0% in 2018 and 4.7% in 2019. Of the PIT tagged efficiency released fish detected at the trap, approximately 95% passed the floating PIT tag interrogation array within 4-days of being released 1.3-kilometers upstream of the rotary screw trap in 2018 and 2019. Unique PIT tag detections at the floating PIT tag interrogation array indicated that diel movement occurred

primarily at night with approximately 94% of NOR juvenile steelhead passing the interrogation array between sunset and sunrise in 2018 and 2019.

An abundance estimate for emigrating NOR juvenile steelhead could not be calculated in 2017 owing to the absence of recaptures during an abbreviated spring trapping season. We estimated 98,796 (95% CI = 78,927-118,663) and 95,167 (95% CI = 77,154-113,180) NOR juvenile steelhead emigrated from the Klickitat River subbasin in 2018 and 2019, respectively. NOR juvenile steelhead emigration peaked from late-April through early-May in 2018 and 2019. NOR juvenile steelhead survival from the Klickitat River to Bonneville Dam was approximately 56% in 2018 and 54% in 2019.

Introduction

The Columbia River was historically one of the most productive salmon fisheries in the world supporting an estimated 8 million – 16 million returning anadromous spawning fish each year (Chapman 1986). Natural-origin anadromous salmon populations are in decline throughout the Columbia River basin due to regional and global stressors such as habitat degradation, overfishing, interactions with hatchery-origin (HOR) fish, impediments to passage, predation, climate change, and adverse oceanic conditions (Wade et al. 2013; NOAA 2008;Bottom et al. 2005; McClure et al. 2003). Decades long declines in natural-origin spring Chinook and steelhead are also occurring in the Klickitat River subbasin. Although not listed under the Endangered Species Act (ESA), natural-origin spring Chinook salmon escapement to the Klickitat River has been tenuously low averaging ~300 fish since 1977 (Sharp et al 2018). The Middle Columbia River (MCR) steelhead/rainbow trout Distinct Population Segment (DPS) was listed as threatened on March 25, 1999 under the Endangered Species Act of 1973 after decades of low returns, poor abundance estimates, and declines in natural producing stocks (NOAA 2009). The National Marine Fisheries Service (NMFS) revised its species determinations to delineate anadromous steelhead only (excluding resident form) as distinct population segments on January 5, 2006.

Anadromous salmonid species present in the Klickitat River subbasin include spring and fall Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead (*O. mykiss*). These anadromous species are composed of six stocks: spring Chinook, early-run fall Chinook, late-run fall (upriver bright), coho, winter run steelhead, and summer run steelhead (Yakama Nation and WDFW 2004). Spring Chinook salmon and steelhead (winter and summer run) are native to the subbasin whereas fall Chinook and coho were introduced to the basin in the early 1950s by Washington Department of Fish and Wildlife (WDFW) (Yakama Nation and WDFW 2004). In addition, Pacific lamprey (*Entosphenus tridentatus*) was historically present and along with steelhead and spring Chinook provided important subsistence, cultural, and commercial fisheries to Native Americans.

The Klickitat River subbasin falls within the MCR Evolutionary Significant Unit (ESU) designation and the MCR steelhead DPS recovery domain. The geographic extent of the Middle Columbia River DPS is comprised of steelhead populations in Oregon and Washington tributaries from the White Salmon River to the west and Yakima River to the east. The Klickitat River subbasin steelhead population is part of the Eastern Cascades Major Population Group (MPG) within the Middle Columbia River DPS (Figure 1). The Klickitat River population is one of the five extant populations comprising the Eastern Cascades MPG (McClure et al. 2003). The Klickitat River subbasin is of particular interest for recovery and conservation efforts because it contains both winter and summer runs.

All anadromous salmonid stocks (with the exception of winter run steelhead and summer/early-fall Chinook) in the Klickitat River are supplemented through artificial production. The *U.S. v Oregon* Columbia River Fish Management Plan (1998) mandated the creation and persistence of a terminal fishery for Yakama Nation fishers to mitigate the decline of natural salmon runs due to hydroelectric dam operations on the Columbia River.

Hatchery production increased greatly in the Klickitat River subbasin since implementation of *U.S. v Oregon* in the late 1990s. Hatchery production of Chinook and coho is magnitudes greater than natural-origin Chinook and coho production in the Klickitat River subbasin. Approximately 4 million upriver bright fall Chinook are produced and released annually by the Klickitat River Hatchery (Glenwood, WA; Figure 2). Approximately 1 million coho are reared at the Klickitat River Hatchery (KRH) and released volitionally. An additional 2.5 million coho are produced at Washougal Hatchery and are released directly into the Klickitat River by WDFW at sites along the lower 24 river kilometers (rkm). The KRH produces approximate six hundred thousand spring Chinook smolts annually from natural brood stock collected at KRH and Lyle Falls Adult Fish Passage Facility (LYFAT). WDFW releases approximately ninety thousand Skamania stock steelhead smolts annually into the Klickitat River at rkm 17.

Large-scale hatchery releases and high flows continuously presented a challenge to rotary screw trap operations in the lower river since the late 1990s. A conservative approach to screw trap operations was implemented after numerous instances of trap damage and substantial fish mortality were sustained during high flows and large-scale hatchery releases. The timing of hatchery coho releases by WDFW (in late-March to early-April) and KRH (early-May) coincides with the emigrating window of NOR juvenile steelhead (early-March to early-July). Trapping operation protocol pre-2017 called for raising the trap cone during the run peak of large-scale coho hatchery releases. As a result, robust abundance estimates of NOR juvenile steelhead out-migration could not be generated due to wide temporal gaps in trap operations. Furthermore, the inability to operate the trap consistently through the peak of the NOR juvenile steelhead emigration period contributed to uncertainties in abundance, run-timing, age composition, survival, and smolt-adult-return (SAR).

The juvenile smolt monitoring study was restructured following completion of the 2016 rotary screw trap trapping season to address uncertainties in population-level performance metrics. A pilot project was initiated in 2017 following implementation of new personnel overseeing rotary screw trap operations and a revamping of infrastructure and protocol. Infrastructure upgrades included installation of a new 2.4-meter rotary screw trap and cabling system, on-shore electronic trap winch, on-site laboratory, floating PIT tag interrogation array, and electrical power. During the 2017 pilot study, emphasis was placed on refining the screw trap protocol and ensuring personnel became experienced with infrastructure upgrades prior to the 2018 trapping season. The floating PIT tag interrogation array was used to define the temporal (diel and seasonal) window that NOR juvenile steelhead emigrated from the Klickitat River subbasin.

The primary goal of the ESA Klickitat Steelhead Recovery Plan is for the Klickitat steelhead population to attain viable salmonid population (VSP) status to support recovery and de-listing of the Mid-Columbia steelhead DPS. VSP status is defined as an independent population with negligible risk of extinction over a 100-year time frame (McElhany et al. 2000). The ESA Klickitat Recovery Plan highlighted how additional information is needed to reduce population level uncertainties about natural-origin steelhead to meet recovery goals. Specifically, the plan calls for the need to quantify estimates of abundance and productivity of natural-origin spawners.

The rotary screw trap was operated early-April through late-June in 2018 and 2019 to generate robust estimates of natural spawner productivity called for by the ESA Klickitat Steelhead Recovery Plan. The main objective of the juvenile smolt monitoring study is to increase viability information and reduce uncertainties in population-level performance metrics of NOR juvenile steelhead emigrating from the Klickitat River subbasin. Specifically, information collected from the trap is being used to quantify abundance, run-timing, age composition, and survival (to Bonneville Dam) of emigrating NOR juvenile steelhead for each migration year. Additionally, information collected at the trap contributes to answering ongoing questions such as smolt-to-adult survival (SAR) to Bonneville dam, quantifying hatchery introgression, and quantifying genetic composition. The intent of data collected at the rotary screw trap is to contribute toward the growing body of MCR steelhead DPS information, reduce population-level uncertainties of Klickitat River steelhead, and help inform managers of the status of natural-origin Klickitat steelhead listed as threatened under the ESA.

Description of Study Area

The Klickitat River subbasin (HUC 17070106; WRIA 30) is located along the east slope of the Cascade Range in southwestern Washington. The subbasin encompasses an area of approximately 3,500 square kilometers that is equally divided between Klickitat and Yakima counties (Yakama Nation and WDFW 2004). The Cascade Mountain Range delineates the western border of the drainage. Mt. Adams, a 3,743 meter dormant volcano, dominates the western boundary and contributes extensive glacial run-off to the basin. The northern basalt plateaus located within the Yakama Nation Reservation form the eastern and northern boundaries. The Klickitat River drains into the Columbia River Gorge at the southern end of the subbasin near the town of Lyle, WA (Figure 2).

The Klickitat River is one of the longest free flowing rivers in the Pacific Northwest region. The Klickitat River originates in the Goat Rocks Wilderness (below Cispus Pass) at approximately 1,525 meter elevation and flows 153 rkm emptying into the Columbia River (rkm 290) at the town of Lyle, WA (23 meter elevation). The geology of the Klickitat River subbasin is dominated by a ~1,000 meter thick basalt plateau (Cline 1976). Deep and steep-walled basalt canyons carved by the Klickitat River and tributaries characterize the subbasin moving from the headwaters to the mouth. Channel gradients range from 8% or greater in the upper portions of the subbasin to less than 1% along the lower stretches of the mainstem. Tributaries are generally characterized by low gradient reaches on the Klickitat River valley floor to falls and high gradient reaches between the valley and plateau.

The Klickitat River subbasin is located in a transitional area between the east and west sides of the Cascades owing to its location in the Columbia River Gorge. Climate is characterized by the temperate influences of the moderate marine climatic zone and the arid influences of the interior continental climatic zone. Climatic gradients are observable across the subbasin moving from the temperate northwest to the arid southeast. Summers are generally hot and dry (averaging 13°C -21°C) and winters cold and wet (averaging -4°C -3°C). Precipitation increases across the subbasin from a low of 23 centimeters on the southeastern plateau to 356 centimeters on Mt. Adams. Mean monthly precipitation is highest in November and December and lowest in July and August with more than three-quarters of precipitation falling between November and May (YKFP and WDFW 2004). Snow is the dominant precipitation form in the upper 2/3 of the subbasin and higher elevations of the middle mainstem and Little Klickitat River from January-April. Mean annual discharge ranges from 9 $m^{-3} \cdot s^{-1}$ in the upper basin to 45 $m^{-3} \cdot s^{-1}$ in the lower basin (U.S. Geological Survey steam gage 1411300, Pitt, U.S. Geological Survey steam gage 1411300, near Castile, WA). Monthly mean discharge is highest in May ranging from 26 $m^{-3} \cdot s^{-1}$ in the upper basin to 70 $m^{-3} \cdot s^{-1}$ in the lower basin. Mean monthly discharge is lowest in September ranging from 3 $m^{-3} \cdot s^{-1}$ in the upper basin to 21 $m^{-3} \cdot s^{-1}$ in the lower basin.

Land ownership in the subbasin is divided among tribal, federal, state, county, and private entities. The Yakama Nation Reservation encompasses most of the northern half of the subbasin. Of the remaining land, nearly 90% is privately owned, approximately 10% state owned, and <1%

federally owned (U.S. Forest Service, U.S. Bureau of Land Management, and U.S. Fish and Wildlife Service).

There are a number of areas in the Klickitat River subbasin managed by federal and state agencies for recreational, scenic, cultural, and natural resources. The lower 17.5 river kilometers is designated as Wild and Scenic and is managed by the U.S. Forest Service as part of the Columbia River Gorge National Scenic Area. Washington State Parks (WSP) manages the popular Klickitat Trail. The trail, built along an old railroad, is a 50 kilometer recreational trail that starts at Lyle, WA and ends at Centerville, WA. The Klickitat Wildlife Area located in the upper one-third of the basin is owned and managed by WDFW. The wildlife area spans approximately 27,200 acres and is actively managed to restore and preserve fish and wildlife habitat. The United States Fish and Wildlife Service (USFWS) manages the Conboy Lake National Wildlife Refuge located at the southern end of Mt. Adams near Glenwood, WA. The 7,072 acre refuge is managed to preserve critical wetland habitat for fish, wildlife, and resident and migratory avian species. The diverse and rich array of plant species on the refuge provides important resources to Native Americans for cultural ceremonies.

The primary anadromous salmonid bearing tributaries are located in the lower 65 rkm of the mainstem Klickitat River. Major anadromous fish bearing tributaries to the Klickitat River include Snyder Creek (rkm 23), Swale Creek (rkm 28), Little Klickitat River (rkm 32), Dead Canyon Creek (rkm 50), Summit Creek (rkm 60), and White Creek (rkm 64; Figure 2). Waterfalls limit the distribution of anadromy in each of the major tributaries with the exception of White Creek. The extent of anadromy is limited to a low of 1.9 rkm in Outlet Creek to a high of 7 rkm in Dead Canyon Creek in streams that have complete barriers to anadromy. A waterfall located at rkm 10 on the Little Klickitat River presents a likely barrier to anadromous passage except under infrequent high discharge events. There are no natural barriers to anadromy in White Creek. Further studies are needed to assess the frequency and extent of anadromous use in Outlet Creek (limited to the lower 1.9 rkm by a natural barrier).

The presence of natural migration barriers located along the mainstem and tributaries likely limited historical anadromous production the Klickitat River subbasin (Figure 2). Major migration barriers that limit anadromous salmonid distribution in the Klickitat River include two waterfall complexes on the mainstem, a falls on the West Fork Klickitat, and a falls on the Little Klickitat River.

Lyle Falls at rkm 3.7 consists of a series of falls 1.2 to 3.7 meters high. The area provides an important subsistence, cultural, and commercial fishery to Yakama Nation tribal fishers. Historical passage data indicates that steelhead and spring Chinook were able to negotiate Lyle Falls but coho and fall Chinook could not (WSCC 2000). In 1952, WDFW constructed two passage fishways at the falls. A new adult passage facility and adult fish trap was completed in

2013 that is operated by the Yakama Nation. Currently, Lyle Falls is not a barrier to adult salmon and steelhead.

The distribution of anadromy in the Little Klickitat River is likely somewhat limited by a 5-meter falls located 10 rkm upstream from the Klickitat River confluence. The falls limits steelhead access to habitat areas in the upper drainage, with likely exceptions during high flow events, although frequency of steelhead passage is not well known. Steelhead redds were documented above the falls following extremely high flow events in 1996 and 1997, and after more moderate high flow events in 2007 anad 2012 (Zendt et al. 2013; Zendt and Babcock 2007).

A 6-meter falls restricts steelhead distribution to the lower 0.5 rkm of the West Fork Klickitat River. Although the falls likely hindered steelhead passage historically, the cold water habitat of the West Fork Klickitat River drainage is critical to the persistence of Bull Trout in the Klickitat River subbasin (Thiesfeld et al. 2011).

The Castile Falls complex, located on the mainstem at rkm 103, consists of a series of 11 falls with an elevation drop of 24 meters over approximately one kilometer. The falls were an historic impediment to upstream migration for the majority anadromous salmonids attempting to ascend the falls. In the early 1960s, Washington Department of Fisheries constructed fishways to provide access around the falls to provide anadromous access to approximately 53 rkm of spring Chinook habitat and 89 rkm of steelhead habitat. Limitations in design and infrequent maintenance contributed to failure of the fishway that inadvertently obstructed virtually all migration for over 40 years. Anadromous access to the upper Klickitat was enchanced in 2005 after completion of fishway improvements at the Castille Falls complex. A final facility upgrade funded through BPA Columbia Basin Fish Accords was completed in 2012 above the uppermost fishway tunnel, adding video enumeration and PIT tag detection.

Resident (or potamodromous) salmonids in the Klicktat River subbasin include Rainbow trout, Westlope cutthroat trout (*O. clarki lewisi*), Bull trout *(Salvelinus confluentus)*, and Brook trout (*S. fontinalis*). Natural-origin rainbow trout are distributed along the mainstem from the confluence with the Columbia to rkm 137 and most tributaries (Yakama Nation and WDFW 2004). The historic and current distribution of cutthroat is currently unknown. Cutthroat trout were observed in limited numbers in Summit Creek and McCreedy Creek watersheds during the 1980s and upper tributaries of the Little Klickitat River in the mid-1990s. Brook trout were introduced to the Klickitat River subbasin in the late-1970s and early-1980s by WDFW. The decline of cutthroat in the subbasin was likely attributable to interspecific competition with Brook trout. Bull trout are listed as threatened under ESA. Bull trout are found primarily in the West Fork Klickitat drainage but their entire distribution is currently unknown. The overlap in the distribution of Bull trout and Brook trout is of concern to fisheries managers due to the potential for hybridization and negative competitive interactions (Thiesfeld et al. 2001).

The four capital infrastructure facilities administered by the Yakama Nation include the Lyle Falls Fishway and Adult Trap (rkm 3.7), Klickitat Field Office (rkm 27), KRH (rkm 70), and the Castile Falls Fishway and Adult Enumeration Facility (rkm 103; Figure 2). The Lyle Falls Fishway and Adult Trap is used to facilitate anadromous adult fish passage around Lyle Falls, collect broodstock for local hatchery programs, and monitor anadromous adult escapement into the Klickitat River subbasin. The Klickitat Field Office (KFO) is the regional fishery office for the Yakima/Klickitat Fisheries Project in the Klickitat River subbasin and Southern Ceded Area. The KRH, funded under the Mitchell Act of 1938, artificially propagates coho and spring and fall Chinook salmon to mitigate loss of fish due to hydropower production and operation. The Castile Falls Fish Enumeration Facility was renovated in 2005 and 2012 to bring it into compliance with NOAA Fisheries' fish passage standards and facilitate and monitor anadromous fish passage to habitat in the upper subbasin.

The Klickitat Research, Monitoring, and Evaluation Project (KRM&E) project established and oversees multiple monitoring sites to assess juvenile emigration and adult escapement. Currently, KRM&E staff manages long-term remote PIT interrogation monitoring sites in White Creek, Summit Creek, Little Klickitat River, Swale Creek, Snyder Creek, and the lower mainstem (Figure 2). The floating PIT tag interrogation array was placed in the lower Klickitat River to pair with the rotary screw trap to help inform staff with trapping operations.

Study Methods

Rotary Screw Trap

Operations

The KRM&E Project operated a 2.4-meter rotary screw trap (E.G. Solutions Inc., Corvallis, Oregon) at rkm 4.5 on the Klickitat River (N 45.720489°, W 121.254385°; Figure 3). The trap was operated 24 hours a day and 7 days a week from early-April through late-June. Trapping operations were subject to temporal gaps due to large-scale hatchery releases, high debris loads, high discharge events and large wood, acting independently or in combination. The duration of the trapping season mirrored the spring emigration period of NOR juvenile steelhead.

The rotary screw trap was outfitted with two 6.7-meter long pontoons on each side of the cone. Manually operated winches (2W40-BM-S14, Thern Inc., Winona, MN) were mounted on each inner pontoon. The terminal end of each pontoon winch cable was attached to a steel carriage fixed to a channel spanning steel cable. The channel spanning cable is anchored to the bedrock substrate on the west bank and attached to an AC powered winch (3WG4-S19, Thern Inc., Winona, MN; (Appendix A) on the east bank. Located on each side of the live-box was a fish sorting station (Appendix B). Each sorting station was equipped with a workup table, cooler, and four tally counters for enumerating fish released from the trap. Each cooler had a battery operated aerator to maintain safe oxygen concentrations during fish processing.

Fish sampling occurred at an on-site workup laboratory equipped with AC power (Appendix C). The laboratory consists of a converted insulated Conex box approximately 6.1-meters in length and 2.4 meters in width. The lab provides a temperature controlled and secure environment to workup fish and store equipment.

Abiotic Variables

KlRM&E staff used hydrograph forecasts and real-time discharge levels to help inform and guide trapping operations (U.S. Geological Survey, streamgage 14113000). Large discharge events and/or increasing and sustained high flow posed potential risk to trap infrastructure and fish welfare in the live-box. The trap was checked and cleared of debris and fish at a minimum of once per day and more frequently when debris or fish densities posed a threat to fish welfare.

Wind was monitored to prevent excessive debris loading in the cone and live-box (Appendix D). A serious risk to fish welfare may occur with the amassing of fine debris in the live-box or cone during high wind events (Volkhardt) et al. 2007). In an effort to minimize injury and/or mortalities due to wind driven debris impacts, KRM&E staff monitored real-time wind conditions at a weather station located at Lyle, WA.

Spot measurements of water temperature (Celsius) were measured and recorded during each trap check via a thermometer in the trap live-box. Air temperature (Celsius) was measured and recorded during each trap check via an electronic weather station located in the laboratory. Additionally, thermographs deployed at the rotary screw trap site collect continuous water and air temperature (Hobo U22-001, Onset, Bourne, MA). Qualitative assessments of wind condition levels were recorded during each trap check and categorized as calm, light, or heavy. Live-box debris levels were categorized as low (<5 centimeters), medium (5-13 centimeters), or high (>13 centimeters). Water clarity was recorded during each trap check as <30, 30-91, or >91 centimeters. Percent cloud cover (0%, 20%, 40%, 60%, 80%, 100%) was visually assessed and recorded during each trap check as well as precipitation (none, light, moderate, heavy). The lateral trap location was tracked by recording the number of cable wraps present (from right to left) on the shore winch spool.

Hatchery Releases

Large-scale hatchery releases create a challenge for rotary screw trap operations in the Klickitat River. WDFW releases approximately 2.5 million coho smolts (from Washougal Hatchery) and 90,000 Skamania summer steelhead smolts (from Skamania Hatchery) directly into the Klickitat River during each trapping season. The Yakama Nation operated KRH volitionally releases 4 million fall Chinook, 1 million coho and 600,000 spring Chinook. Hatchery fish densities can significantly impact fish welfare in the live box and can be challenging for rotary screw trap staff. KRM&E staff worked proactively with WDFW and the KRH on release size and schedule.

Fish Collection and Sampling

Fish were netted from the live-box, placed in coolers, sorted by species, and either tallied or selected for mark/recapture studies. Tallied fish were released directly into the river from the trap. NOR juvenile steelhead and spring Chinook smolts (≥65 millimeter fork length) were selected for mark-recapture studies. Captured NOR juvenile steelhead and natural-origin spring Chinook were placed in 5-gallon buckets with aerated stream water. A maximum of 15 fish were held per bucket to avoid density dependent stressors on captured individuals. Buckets containing fish were held for no longer than 20-minutes on the trap to maintain physiologically safe water temperature and oxygen levels. Subsequently, bucket(s) filled with fish were transported back to shore for holding at a shoreline bucket corral (Appendix E). The bucket corral consisted of a rope spanning a length of five meters attached to a post (anchored by foundation blocks) at each end of the rope. Perforated 5-gallon buckets with lids were attached to the rope with clips on the bucket handle. Fish held in the trap buckets were transferred to the perforated buckets via a water-to-water transfer. Fish were held in ambient river conditions until they could be sampled. Fish from the bucket corral were transported to the on-site laboratory for sampling as needed. A maximum of two buckets or 20-30 fish were taken to the laboratory for sampling at a time.

Fish were anesthetized in a tricaine methanesulfonate (MS-222) ~ 69 mg/liter solution adhering to methods detailed in the PIT Tag Marking Procedures Manual (Columbia Basin Fish and Wildlife Authority 2014). Each individual was identified to species and categorized as either a parr or smolt. Fish were categorized as parr, if parr marks were present and scales slightly embedded. Individuals were categorized as a smolt if the parr marks were fading or not visible, had a chrome-like appearance, and had scales that easily shed ((PSMFSC 2001). All NOR juvenile steelhead and spring Chinook ≥65 millimeters were scanned for a PIT tag with a High Performance Reader (HPR) Plus PIT tag reader (Biomark Inc.,Boise,Idaho). Healthy NOR juvenile steelhead and spring Chinook ≥ 65 millimeters received a 12 mm 134.2 kHz full duplex PIT tag. PIT tagged and recaptured fish were weighed to the nearest one-tenth of a gram using an Ohaus digital scale (Scout Pro 600g, Parsippany, NJ). Fork length to the nearest millimeter was measured for newly PIT tagged and PIT recaptured fish. DNA was collected from each PIT tagged NOR juvenile steelhead and spring Chinook individual. The DNA sample consisted of a 2 x 2 millimeter piece of tissue collected from the upper caudal fin lobe. Each tissue sample was placed on to an assigned cell of a gridded Whatman sheet (Hagerman CRITFC Genetics Lab, Hagerman, ID). Scale samples were collected each day from the first 20 PIT tagged fish. Scales were also taken from each upriver recaptured NOR juvenile steelhead. Upriver recaptures consisted of fish PIT tagged in tributaries upstream of the rotary screw trap. Approximately 5-10 scales per fish were collected from an area above the lateral line and posterior to the dorsal fin and anterior to the anal fin (Love 2016). Upriver and efficiency release recaptured individuals were released approximately 100 meters below the trap to reduce the chance of a second recapture.

Efficiency Releases

Capture efficiency for the rotary screw trap was calculated from results of daily efficiency release trials. All PIT tagged fish were included in an efficiency release located at rkm 6. Injured individuals or fish tagged the day before the cone was pulled were excluded from efficiency releases. Prior to releasing each group of fish, staff inspected each bucket to ensure that all fish were alive. Mortalities were recorded, scanned for a PIT tag, and removed from the efficiency release groups. The release date and time of each efficiency release group was recorded in the database.

Access Database

All fish sampling data, abiotic trap check data, and efficiency release data was entered real-time into a Microsoft Access relational database housed on site in the Connex box and backed up at the Lyle Falls Fishway facility. The database was programmed to automatically populate the alpha numeric code of each scanned PIT tag. Each scanned PIT tag was assigned a unique identifying (ID) number by the database. Subsequently, all biological data (species, life stage, length, weight, DNA, and scale information) collected from an individual fish was associated with the assigned unique ID. All efficiency released fish were linked to a specific efficiency release trial by an efficiency release ID. The database facilitates real-time auto quality control checks, and data backup. Data was queried at the end of the season to create a tagging file that was uploaded to PIT Tag Information System (PTAGIS).

Floating PIT Tag Interrogation Array Operations

The Klickitat RM&E project has operated the floating PIT tag interrogation array since April 2017 (Figure 3). The array is located approximately 100 meters below the rotary screw trap at rkm 4.5. The floating PIT tag array is registered with PTAGIS under the acronym KLR. The array generally operates from early-March to late-December or until flows pose a threat to PIT tag array infrastructure. The floating PIT tag array was paired with the rotary screw trap to help inform staff with trapping operations. Juvenile and adult salmonid movement and run-timing information was used to assist staff on defining the start and end of each trapping season. KRM&E staff also used the floating PIT tag array to gather salmonid emigration information when the screw trap was not operating. Interrogation data collected at the floating PIT tag array is stored on the internal memory of the Master Controller (Biomark Inc., Boise,Idaho). Data is transferred from the MC to internal servers and subsequently uploaded to the PTAGIS database.

The floating PIT tag array is powered by four 12-volt Absorbent Glass Mat (AGM) deep cycle batteries (DC85-12, Full River Battery). Two separate 24-volt battery banks were created by connecting two 12-volt batteries in series and are charged by alternating current (AC) power. The floating PIT tag array consists of two arrays (upstream and downstream) comprised of three 3.05 meter antennas each. An IS1001 master controller (MC) controls six IS1001 readers at each antenna and is connected to the master controller via data over power (DOP) cable.

Juvenile Steelhead Population Performance Metrics

Abundance

NOR juvenile steelhead emigrant abundance was estimated using Darroch Analysis with Ranked Reductions software application script (DARR 2.9.1) in the open source statistical program R Studio (Bjorkstedt 2000; Bjorkstedt 2005; and Bjorkstedt 2010). DARR 2.9.1 applies algorithms to stratified mark-recapture data to pool strata with similar capture probabilities to generate a statistically acceptable abundance estimate using the 1961 Darroch stratified Petersen-Lincoln estimator. The DARR algorithm calculates an abundance estimate for each stratum by multiplying the total number of fish captured by the number of fish marked and dividing the product by the number of recaptures. Recaptured individuals are identifiable by the stratum they were marked and released and by the stratum they were recaptured. Strata were delineated by weekly intervals. The "one trap" and "no prior pooling of strata" options were selected for the analysis. Bjorkstedt 2005 describes a detailed statistical summary of the algorithm's application of Darroch's stratified Petersen-Lincoln estimator to mark-recapture data. Temporal gaps in trapping were filled by taking the mean of first time captured, marked, and recaptured individuals from the week preceding the start and the week following the end of each gap. The 95% confidence interval was calculated for each stratum by the method described in Volkhardt et al. 2007:

$$\hat{U} \pm 1.96\sqrt{V(\hat{U})}$$

where

$\hat{U}$ = Estimate of juvenile abundance
$V(\hat{U})$ = Variance associated with the abundance estimate

Run-Timing

Run-timing of emigrating NOR juvenile steelhead was quantified at multiple temporal and spatial scales by using capture data from the screw trap, detection data from the floating PIT tag array, and detections at Columbia River PIT tag interrogation sites. Rotary screw trap capture data was used to summarize daily emigration of NOR juvenile steelhead at the trap through each annual out-migration period. Interrogation data collected at the floating PIT tag array was used to identify diel movement patterns of PIT tagged NOR juvenile steelhead from the efficiency release location to the floating PIT tag array. The PTAGIS database was queried to estimate travel times of PIT tagged emigrating steelhead juveniles from the floating PIT tag array to Bonneville Dam and Bonneville Dam to the Columbia River Estuary (CRE).

Survival

Survival rates and detection probability of PIT tagged emigrating steelhead were estimated from the rotary screw trap to Bonneville Dam. Tagging and interrogation data analysis files were generated in PTAGIS using the PitPro Interrogation Detail and PitPro Tagging standard report queries. Interrogation and tagging analysis files were subsequently imported into PitPro to generate a file output containing the detection history for each PIT tagged steelhead in each annual emigration period (Westhagen and Skalski 2009). Detection histories of juvenile steelhead PIT tagged at the rotary screw trap were analyzed in the Survival Under Proportional Hazards (SURPH) program which uses a Cormack-Jolly-Seber model to estimate survival rate and detection probability (Lady et al. 2001).

Study Results

Rotary Screw Trap

Operations

The rotary screw trap was operated intermittently from late-May to early-October for a total of 43 days in 2017 (Table 1). We could not quantify emigrant steelhead abundance, run timing, or survival estimates at the trap in 2017 because of the many missed sample days due to a late trap deployment, low catch numbers, and low recapture rates. The pilot study was used to refine rotary screw trap operating protocol and to delineate the end of the natural-origin steelhead emigration period.

The rotary screw trap was run more continuously in 2018 and 2019 (Table 1). The trap was operated from early-April to late-June in 2018 for a total of 78 days. The cone was raised for 4 days in April (Apr. 5 – Apr. 9) and 7 days in May (May 14 – May21) in 2018 due to large-scale coho hatchery releases by WDFW and the KRH. The trap was operated from early-April to mid-June for a total of 67 days in 2019. The cone was raised for 9 days at the start of the trapping season (April 5- April 14) due to high flows and debris and again Apr. 28 – May 1 to repair a broken support beam.

Abiotic Variables

Mean daily discharge ($m^{-3}•s^{-1}$) was substantially higher in 2017 than 2018 and 2019 (Figure 4). Mean daily discharge in 2017 peaked in March, prior to trap deployment, compared to February in 2018 and April in 2019. The peak discharge in 2017 was 2.5 and 1.7 times greater than 2018 and 2019, respectively. Mean discharge for the entire calendar year was 67.2 $m^{-3}•s^{-1}$ (SE±2.6) in 2017, 41.2 $m^{-3}•s^{-1}$ (SE±1.1) in 2018, and 35.3 $m^{-3}•s^{-1}$ (SE±1.1) in 2019. The mean daily discharge during the trapping season was 47.0 $m^{-3} \cdot s^{-1}$ (SE±3.73), 57.0 $m^{-3} \cdot s^{-1}$ (SE±1.88), and 67.6 $m^{-3} \cdot s^{-1}$ (SE±2.20) in 2017, 2018, and 2019, respectively (Table 1).

Mean daily water temperature generally exhibited a symmetrical bell shaped pattern each year with low temperatures occurring in February, increasing to a peak in late-July and early-August, followed by declining temperatures into the following February (Figure 5). Mean daily water temperature during each trapping season was characterized by cool temperatures that fell well within the thermal tolerance level of emigrating steelhead (Richter and Kolmes 2005). Mean daily water temperature during trapping operations was 13.1 °C (SE±0.20) in 2017, 11.2 °C (SE±0.20) in 2018, and 10.7 °C (SE±0.20) in 2019 (Table 1). Mean maximum daily water temperature during trapping operations ranged from a low of 15.5 °C in 2018 to a high of 16.0 °C in 2019. The higher mean daily water temperatures observed in 2017 was likely an artifact of the late start to the trapping season and extended operations during elevated water temperatures through summer into early-Fall.

Hatchery Releases

A total of approximately 8-million, 7-million, and 5.5 million HOR juvenile salmonids were released into the Klickitat River in 2017, 2018, and 2019, respectively (Table 2). HOR salmonid stocks released in the Klickitat River each year consisted of coho salmon, spring Chinook salmon, fall Chinook salmon, and summer steelhead. Fish reared at the KRH were volitionally released spring Chinook, fall Chinook, and coho. Volitional releases from the KRH occurred early-March to early-April for spring Chinook, mid-April to mid-May for coho, and late-June to mid-July for fall Chinook. WDFW released coho from Washougal Hatchery and summer steelhead from Skamania Hatchery directly into the river from transport trucks. Direct releases by WDFW occurred in late-April to early-May for summer steelhead and late-March for coho. All four HOR salmonid stocks were released in the river during the 2017 trapping season (n=8 million). Rotary screw trap operations in 2018 and 2019 were impacted by releases of HOR coho salmon, summer steelhead, and spring Chinook. Trapping operations ended prior to the release of HOR Fall Chinook in 2018 and 2019 (Table 2). Spring Chinook and summer steelhead were the only HOR stocks marked with PIT tags. PIT tags were injected into 3.9%, 3.3%, and 2.9% of the spring Chinook smolts released from the KRH in 2017, 2018, and 2019, respectively. A greater percentage of the HOR steelhead were PIT tagged compared to HOR spring Chinook. Approximately 11% of Skamania Hatchery steelhead smolts released in the Klickitat River were PIT tagged in 2017, 2018, and 2019 (Table 2; Appendix F).

Fish Collection and Sampling

A total of 147,285 individual fish comprising 13 species and seven families (Salmonidae, Petromyzontidae, Catostomidae, Cyprinidae, Cottiidae, Centrarchidae, and Ictaluridae) were captured at the trap during the 2017-2019 trapping seasons (Tables 3 and 4). HOR salmonids dominated the catch comprising 88.9% of the fish collected during the 2017-2019 trapping seasons. Natural-origin salmonids and lamprey comprised 7.4% and 3.7% of the remaining catch, respectively. Blue gill (*Lepomis macrochirus*), bullhead catfrish (*Ameiurus melas*), and pumpkinseed (*Lepomis gibbosus*), consisting of 10 individuals, were the only invasive species collected over the three trapping seasons (Table 4). Approximately 3.5 and 1.6 times more fish were captured in 2019 than 2017 and 2018, respectively. The observed 30,000 fish difference between 2018 and 2019 was the result of approximately 35,000 more HOR coho salmon smolts captured in 2019 because the trap was operated continuously through the KRH coho release.

A total of 7,316 NOR juvenile steelhead were captured at the trap during the 2017-2019 trapping seasons (Table 5). The total number of captured NOR juvenile steelhead was 231 in 2017, 3,610 in 2018, and 3,475 in 2019. The number of NOR juvenile steelhead PIT tagged was 221, 3,186, and 3,384 for 2017, 2018, and 2019, respectively. Genetic tissue samples were collected from 221 fish in 2017, 3,202 in 2018, and 3,393 in 2019. Scales samples were collected from 690 fish in 2018 and 923 fish in 2019. The mean fork length in millimeters (mm) and weight in grams (g) of NOR juvenile steelhead collected at the trap was 171.9 mm (SE±1.38) and 51.7 g (SE±1.21) in 2017, 180.8 mm (SE±0.34) and 51.7 g (SE±1.21) in 2018, and 181.2 mm (SE±0.35) and 59.6 g (SE±0.35) in 2019 (Table 6). NOR juvenile steelhead measuring 151-200 millimeter (mm) fork length (FL) accounted for 83%, 81.7% and 82.3% of the total first time captures in 2017, 2018 and 2019, respectively. NOR juvenile steelhead >200 mm FL comprised 8.3%, 14.1%, and 13.9% of the run in 2017, 2018 and 2019. Fish ≤ 150 mm FL accounted for only 8.7% of the fish collected in 2017, 4.1% in 2018, and 3.7% in 2019. Capture efficiency could not be determined in 2017 but was 5% 2018 and 4.7% in 2019.

A total of 701 NOR juvenile Chinook were captured at the trap during the 2017-2019 trapping seasons (Table 6). The 591 NOR juvenile Chinook captured in 2017 was substantially greater than the 84 fish in 2018 and 26 fish in 2019. All 591 NOR Chinook collected in 2017 were captured within a 10-day span (June 13-June 23) whereas only 33 of 86 and 21 of 26 fish were captured in June during 2018 and 2019, respectively. June mean daily discharge in 2017 was 2-fold higher than 2018 and 2019. The higher June discharge was the only observable difference and may partially explain the higher number of NOR Chinook collected in 2017. Of the captured NOR juvenile Chinook collected, ~21%, ~40%, ~85% of the fish were injected with PIT tags in 2017, 2018, and 2019, respectively. Genetic samples were collected from 89 fish in 2017, 33 fish in 2018, and 22 fish in 2019. The mean fork length (millimeters) and weight (grams) of natural origin Chinook collected at the trap was 71.1 mm (SE±0.39) in 2017, 95.2 mm (SE±1.74) and 9.8 g (SE±0.55) in 2018, and 92.5 mm (SE±3.82) and 10.3 g (SE±1.39) in 2019 (Table 6).

Lamprey *spp*. were captured in each of the years spanning 2017 to 2019 (Table 4). Ammocoete was the primary life-stage collected during each trapping season comprising 98.5% in 2017, 99.5% in 2018, and 98.2% of the lamprey collection. The number of macropthalmia captured in trap was 27 in 2017, 34 in 2018, and 6 in 2019 (Table 4). A nominal number of macropthalmia genetic tissue samples were collected in 2017 and 2018 (Table 6).

Efficiency Releases

We conducted a total of 318 efficiency release trials involving 6,571 PIT tagged NOR juvenile steelhead over 185 aggregated days (2017-2019) to determine capture efficiency at the rotary screw trap (Table 5). Substantially fewer efficiency release trials were conducted in 2017 compared to 2018 and 2019 due to the abbreviated trapping effort during the steelhead emigration period. Trap efficiency could not be determined in 2017 because we were unable to recapture any efficiency released fish. A total of 141 and 151 release trials were conducted in 2018 and 2019, respectively. The capture efficiency release trials included 3,186 PIT tag marked fish in 2018 and 3,384 in 2019 resulting in 158 efficiency recaptured fish for each year. Capture efficiency at the trap was estimated to be 5.0% in 2018 and 4.7% in 2019 (Table 5).

Floating PIT Tag Interrogation Array Operations

The floating PIT tag interrogation array was operational from late-April to late-November for 215 days in 2017, early-March to mid-December for 279 days in 2018, and late-March to mid-December for 273 days in 2019 (Table 7). A total of 436 of 6,791 NOR juvenile steelhead PIT tagged at the trap were detected by the PIT tag interrogation array during the 2017-2019 emigration seasons (Figure 7). The percent of PIT tagged NOR juvenile steelhead detected at the array ranged from a low of 5.2% in 2019 to a high of 9.5% in 2017. NOR juvenile steelhead detection probability at the floating array was higher than capture probability at the rotary screw trap each year (Tables 5 and 7; Appendix F). The largest observed difference between detection probability and capture probability was in 2017. Detection probability was slightly higher than capture probability in 2018 and 2.5% greater in 2019.

We observed an additional 27, 40, and 43 unique detections at the floating PIT tag array from fish tagged in upstream tributaries in 2017, 2018, and 2019, respectively (Table 8; Appendix G). April through June marked the dominant out-migration months for upriver tributary steelhead smolts in 2017, 2018, and 2019. The months of April-June accounted for 70% (in 2017), 98% (in 2018), and 93% (in 2019) of the total unique detections from fish tagged in tributary streams upstream of the rotary screw trap (Appendix H). The last detection occurred in November, September, and October in 2017, 2018, and 2019, respectively. Although there appears to be a small emigrating pulse of NOR juvenile steelhead in the fall, the bulk of the fish emigrate from the Klickitat River by the end of spring (Table 8).

Juvenile Steelhead Population Performance Metrics

Abundance

The estimated abundance of NOR juvenile steelhead emigrating from the Klickitat River subbasin was similar between out-migration years 2018 and 2019 (Table 9). The number of NOR juvenile steelhead out-migrating from the Klickitat River subbasin was estimated at 98,796 (95%

CI = 78,927-118,663) and 95,167 (95% CI = 77,154-113,180) in 2018 and 2019, respectively (Table 9). The peak in emigration abundance shifted from late-April to late-April/early-May in 2018 and 2019, respectively. In 2018, the 05/20 – 05/26 weekly strata had the highest number of emigrants passing the rotary screw trap at 19,592 (95% CI = 6,159-33,025) compared to the 04/28-05/04 weekly strata estimate of 22,902 (95% CI = 12,170-33,635) in 2019.

Run-Timing

Emigrating NOR juvenile steelhead arrived at the trap April 9 – June 23 in 2018 and April 2 – June 16 in 2019 (Table 10). The median arrival date was May 5 in 2018 and May 9 in 2019. Ninety percent of the out-migrating NOR juvenile steelhead arrived at the trap by the end of May in both 2018 and 2019.

NOR juvenile steelhead exhibited a bi-modal movement pattern during the 2018 trapping season. In 2018, NOR juvenile steelhead collected at the trap increased from early–April to an initial peak in late-April, declined through the first week of May, increased to a prominent peak in the second week of May, and gradually declined through the third week of June (Figure 7). A tri-modal movement pattern was observed in 2019. NOR juvenile steelhead collected at the rotary screw trap in 2019 displayed a similar pattern to 2018 but differed in the formation of a tertiary peak observed in the third week of May (Figure 7). In both years, fish began arriving at the trap near the peak of the hydrograph and continued emigrating through the receding limb (Appendix I).

NOR juvenile steelhead collected at the rotary screw trap, PIT tagged, released upstream for efficiency trials, and detected at the floating PIT tag array exhibited similar diel movement patterns during the 2018 to 2019 trapping seasons. In both years, the vast majority of unique fish detections occurred after sunset and before sunrise (dark) (Figures 8 and 9). Of the unique fish detections at the floating PIT tag array, 93.7% and 93.8% of the detections occurred during the period after sunset and before sunrise in 2018 and 2019, respectively. More specifically, the majority of detections occurred shortly after sunset to midnight. In 2018, 66.4% of the unique detections occurred between sunset and midnight as opposed to 27.3% from midnight to sunrise (Figure 8). A similar diel movement pattern was observed in 2019 where 63.6% of the unique detections occurred between sunset and midnight compared to 30.1% midnight to sunrise (Figure 9). The mean length (181.4 mm FL; SE=1.8 mm) of fish detected at dark was substantially larger than fish (168.1 mm FL; SE=6.7 mm) detected during daylight hours in 2018. NOR juvenile steelhead detected at dark (179.9 mm FL; SE=1.5 mm) were slightly larger than fish detected during daylight (175.2 mm FL; SE=4.4 mm) in 2019.

NOR juvenile steelhead collected and PIT tagged at the rotary screw trap were detected at the floating PIT tag array April 11 –August 29 and April 14-July 4 in 2018 and 2019, respectively (Table 10). The median detection date for PIT tagged and released for capture efficiency trials was May 7 in 2018 and May 13 in 2019. The minimum and maximum travel time from the release location (rkm 6) to the floating PIT tag array (rkm 4.5) was <1 hour and 139 days in 2018 and <1 hour and 45 days in 2019 (Table 11). The median travel time from the release location to the floating PIT tag array was approximately 12-hours for both the 2018 and 2019 emigration periods. Of the fish detected at the floating PIT tag array, ninety-five percent passed the floating array within 4 days of release in 2018 and 2019 (Figures 10 and 11).

PIT tagged NOR juvenile steelhead were detected at Bonneville Dam April 12 –July 1 and April 16-June 17 in 2018 and 2019, respectively (Table 10). The median detection date was May 7 in 2018 and May 13 in 2019. The minimum and maximum travel time from the release location to Bonneville Dam was 1-day and 25 days in 2018 and 1-day and 26 days in 2019 (Table 11). The median travel time from the release location (rkm 6) to Bonneville Dam was 2 days in both the 2018 and 2019 emigration periods. Ninety percent of the fish were detected at Bonneville Dam within 5 days of being released at rkm 6 in both the 2018 and 2019 emigration periods (Figures 10 and 11). Fish emigrating from the Klickitat River appeared to time entry into the Columbia River at the peak of the hydrograph (Appendix J).

NOR juvenile steelhead emigrating from the Klickitat River were detected at the Columbia River Estuary (CRE) April 30 –July 14 and April 19-June 4 in 2018 and 2019, respectively (Table 10). The median detection date was May 9 in 2018 and May 16 in 2019. The minimum and maximum travel time from the release location (at rkm 6) to the CRE was 2 days and 22 days in 2018 and 2 days and 14 days in 2019 (Table 11). The median travel time was 4 days in both the 2018 and 2019 emigration periods. Ninety percent of the fish arrived at the CRE in 7 and 8 days of release (from rkm 6) during the 2018 and 2019 emigration periods, respectively.

Survival

Survival of NOR juvenile steelhead from the Klickitat River screw trap site to Bonneville Dam was low but consistent between 2018 and 2019 emigration years. NOR juvenile steelhead emigrant survival to Bonneville Dam was estimated at 56.2% (CI=26.7-85.6%) and 53.9% (CI=32.9-75.0%) in 2018 and 2019, respectively (Table 12). HOR steelhead smolt survival to Bonneville Dam was 17.8% greater than NOR juvenile steelhead in 2018 and 11% higher in 2019. HOR spring Chinook survival was significantly higher than NOR juvenile steelhead in 2018 but similar in 2019. We estimated that 55,513 (CI=39,119-71,907) and 52,133 (CI=41,517-62,149) NOR juvenile steelhead from the Klickitat River survived to Bonneville Dam in 2018 and 2019, respectively (Table 12).

Discussion

A pilot study was initiated in 2017 after the rotary screw trap project underwent a revamping in personnel, protocol, and infrastructure following completion of the 2016 smolt out-migration year. The objective of the 2017 pilot study was to refine and validate operation and sampling protocol, temporally define the trapping season, and to demonstrate the feasibility of continuous trapping efforts through the duration of a trapping season. The newly implemented protocol met or exceeded target goals in several ways. First, we captured more NOR juvenile steelhead in an abbreviated spring trapping season than the entirety of many previous seasons. Second, capture rates of emigrating NOR juvenile steelhead in 2017 were significantly higher than most previous trapping seasons even though water discharge in May and June 2017 (91.2 $m^{-3} \cdot s^{-1}$) was well above the 90-year mean for the same period (62.2 $m^{-3} \cdot s^{-1}$; USGS stream gage 141113000, Klickitat River near Pitt, WA). Third, the rotary screw trap was operated intermittently into early-fall 2017 to quantify emigration through the latter tail of the out-migration period to determine the duration of trapping for subsequent seasons. A small pulse of NOR juvenile steelhead (n=59) were captured by the trap in late-summer/early-fall. Also, there were no natural-origin Chinook smolts collected in the trap after June 23. The small number of additional NOR juvenile steelhead and lack of natural-origin Chinook smolts collected after June did not justify the continuous operation of the rotary screw trap through early-fall for subsequent seasons. This decision was affirmed in several ways. First, approximately 98% and 93% of the unique detections at the floating PIT tag interrogation array of NOR juvenile steelhead tagged in upstream tributaries occurred by June in 2018 and 2019, respectively. Second, the number of NOR juvenile steelhead captured in September 2017 accounted for only ~1.5% of the total NOR juvenile steelhead trap catch in 2018 and 2019. Third, we collected over 19,000 HOR Chinook smolt between late-June through early-October but did not collect a single natural-origin Chinook smolt over the same period. Based on results from 2017, a late-March/early-April through June trapping season was defined for subsequent seasons.

Large-scale HOR salmonid releases present an ongoing challenge to rotary screw trap operations in the Klickitat River subbasin. Direct and volitional hatchery releases consisting of coho salmon, spring Chinook salmon, and summer steelhead occurred late-March through mid-May in both 2018 and 2019 resulting in large numbers of HOR fish collected in the trap through the majority of the trapping season. The mean daily number of HOR salmonid smolts collected in the trap each was 482 $fish \bullet day^{-1}$ in 2018 and 1,107 $fish \bullet day^{-1}$ in 2019. In comparison, the mean daily number of NOR juvenile steelhead collected in the trap was 46 $fish \bullet day^{-1}$ in 2018 and 52 $fish \bullet day^{-1}$ in 2019. Daily catch of HOR salmonid smolts outnumbered NOR juvenile steelhead by ratios of 10:1 and 21:1 in 2018 and 2019, respectively. As a result, significant effort was required to collect and process emigrating NOR juvenile steelhead.

Considering hatchery releases coincided with the peak of the NOR juvenile steelhead out-migration, an attempt was made to operate the rotary screw trap continuously to minimize loss of emigration data during the out-migration period. Ultimately, it was deemed imperative to run the trap continuously to generate robust population-level metric estimates (abundance, survival, run timing, genetic composition, and age structure composition) for ESA listed MCR steelhead. A major concern of operating the trap through hatchery releases was holding high densities of fish in the live box. Elevated stress levels, disease transmission, and deleterious inter-and-intra species behavioral interaction were a few of the concerns with holding NOR juvenile steelhead under high fish density conditions in the live box (Music et al. 2010; Congleton et. al 2000; Wedemeyer 1976). The substantially larger body-size of NOR juvenile steelhead likely mitigated against aggressive behavior from smaller HOR coho and spring Chinook in the live-box (Congleton et. al 2000; Kelsey 1997). However, potential levels of stress and disease transmission are unknown. Furthermore, environmental impacts such as debris loading (resulting from wind driven events and elevated flows) and high turbidity events posed additional risk of mortality to fish held in the live box (Appendix D). Crews monitored the trap diligently for fish densities, debris accumulation, and water quality to minimize fish injuries and mortalities in the live box.

The unique challenges associated with operating the Klickitat River rotary screw trap are underscored when compared to HOR salmonid releases in other tributary river subbasins with screw trap operations in the Columbia River Gorge area. The Klickitat River screw was operated in 2018 and 2019 through releases numbering approximately 4.1 million hatchery-reared salmonids each year. The KRH released 2.7 million fall Chinook in 2018 and 1.5 million in 2019 after trapping operations were completed. In comparison, the Carson National Fish Hatchery released 1.2 million spring Chinook in the Wind River in 2018 and 2019. Releases of HOR salmonids in the Hood River numbered ~300 thousand in 2018 and ~250 thousand in 2019. There is no HOR salmonid supplementation in the White Salmon River. A multi-agency agreement to allow natural-origin salmonid recolonization was implemented after Condit Dam was removed in 2012.

The mainstem floating PIT tag array was used to quantify diel movement patterns of NOR juvenile steelhead captured and PIT tagged at the rotary screw trap. Diel movement patterns quantified at the floating PIT tag array were used to inform release strategy for capture efficiency trials. A common practice is to release fish for efficiency trials at night because studies have documented that downstream migration of natural-origin salmonids predominantly occurs during darkness (Roper and Scarnecchia 1996), capture efficiency in rotary screw traps is higher when releases occur after sunset (Tattam et al. 2013), and predation is lower at dark (Roper and Scarnecchia 1996). Tattam et. al 2013 found that capture efficiency was significantly higher for downstream migrating NOR juvenile steelhead released at twilight compared to fish released at daylight and fish released in daylight were often detected by a PIT tag interrogation antenna during daylight in the South Fork John Day River. We released all fish used in capture efficiency trials during daylight. Unlike downstream migrants released during daylight in the South Fork John Day River, approximately 94% of the PIT tagged fish we released during the day were detected at the floating PIT tag array between sunset and sunrise. Our results suggest that our capture efficiency estimates were unlikely affected by daytime releases because fish appeared to maintain a holding pattern until sunset before actively moving downstream.

The floating PIT tag array was paired with the rotary screw trap to monitor salmonid smolt out-migration timing before, during, and after rotary screw trap operations each trapping season. In general, out-migration timing results from the rotary screw trap and mainstem floating PIT tag array were in accordance. However, detection efficiency at the floating PIT tag array for NOR juvenile steelhead was higher than capture efficiency at the trap in 2017, 2018, and 2019. The floating PIT tag array was also used to monitor NOR juvenile steelhead emigration for 1.5 months in 2017, 6 months in 2018, and 6 months in 2019 after removal of the rotary screw trap from the river. There were minimal detections of fish tagged in upstream tributaries after June in 2018 and 2019. Minimal detections at the floating PIT tag array after June indicated that the bulk of NOR juvenile steelhead emigrated from the Klickitat River by late-spring/early-summer.

The timing of captures at the rotary screw trap and detections at the floating PIT tag array were characteristic of a skewed right distribution. The bulk of NOR juvenile steelhead captured at the trap occurred over a short period of time between late-March to late-June in 2018 and 2019. The initial captures of out-migrating NOR juvenile steelhead occurred in March, increased steadily to a peak in late-April/mid-May, and gradually decreased through mid-June in 2018 and 2019. NOR juvenile steelhead tagged in upriver tributaries and subsequently detected at floating PIT tag array peaked in April in 2018 and May in 2019 with the bulk of unique detections occurring by the end of June in both years (Appendix H). A small number of detections occurred in late-summer/early-fall but accounted for only 2.5% and 7% of the unique detections in 2018 and 2019, respectively.

The hydrology in a number of key anadromous producing tributaries may partially explain why most NOR juvenile steelhead emigrated during a condensed spring window. The majority of observed steelhead production occurs in 11 tributaries located in the lower 65 rkm. Only 3 of the 11 anadromous salmonid producing tributaries in the lower 65 rkm maintain perennial surface flow connectivity to the mainstem. Surface flow typically becomes disconnected along the alluvial fan at the terminus of each stream from late-May/mid-June to December/January. NOR juvenile steelhead appear to synchronize out-migration to spring flows in rearing streams to ensure access to the mainstem (Appendix I). Another reason for accessing the mainstem before tributary surface flows become disconnected is to time entry into the Columbia River during peak discharge to reduce travel time through the Bonneville pool (Appendix J). The small pulse of fish observed emigrating in early-fall were likely rearing in the mainstem for some period after leaving tributary rearing streams. Unlike the bi-modal (spring and fall) NOR juvenile steelhead out-migration observed in other tributary subbasins throughout the Columbia River basin (Poole et al. 2019; Simpson et al. 2019; Grote and Desgroseillier 2016), our results indicate that the bulk of NOR juvenile steelhead emigrate from the Klickitat River in a condensed spring window.

Natural-origin steelhead production is high in the Klickitat River subbasin. The Klickitat River produced an estimated 98,796 (95% CI = 78,927-118,663) and 95,167 (95% CI = 77,154-113,180) emigrants in 2018 and 2019, respectively. In 2018, steelhead emigrant production in the Klickitat River was 17-fold greater than the White Salmon, 6-fold greater than the Hood River, and 3-fold greater than the Wind River (Buehrens and Cochran 2019; Ian Jezoreck, personal communication, July 7, 2020; Simpson 2018). Although production of NOR juvenile steelhead from each tributary basin is important to the persistence of natural-origin steelhead populations at-large, the high steelhead production value of the Klickitat River subbasin places it as a key Cascade Eastern Slope Tributary MPG subpopulation and critical to recovery and delisting of MCR steelhead DPS.

The Klickitat River subbasin contains a number of geo-physical characteristics that likely present conditions favorable to high NOR juvenile steelhead production. First, the Klickitat River is one of the longest free-flowing rivers in the Pacific Northwest containing more than 137 rkm of mainstem free of barriers to anadromy. This high level of connectivity provides steelhead access to spawning and rearing habitat in twenty-six tributaries and along 137 rkm of the mainstem. High spatial connectivity along most of its longitudinal length is critical to steelhead production and persistence. High spatial connectivity promotes genetic diversity through multi-directional gene flow among tributary and mainstem subpopulations. High spatial connectivity increases diversity, expression, and exchange of life history types critical for persistence in an uncertain and dynamic environment. High spatial connectivity increases the ability for steelhead to access different habitats for trophic, reproductive, rearing, and refuge requirements (Northcote 1997). Second, Lyle Falls (located at river rkm 3.7) is a barrier to the movement and colonization of predacious fish (such as the northern pikeminnow and small mouth bass) from Bonneville pool. The near absence of non-salmonid fish predators undoubtedly improves survival of rearing steelhead in the Klickitat River subbasin.

Although production was high for NOR juvenile steelhead in 2018 and 2019, survival to Bonneville Dam was low. We estimated NOR juvenile steelhead survival from the screw trap to Bonneville Dam to be approximately 56.2% in 2018 and 53.9% in 2019. Survival to Bonneville Dam was lower for NOR juvenile steelhead than in-basin HOR salmonids smolts in 2018 and 2019. Survival of HOR spring Chinook smolts was 81% in 2018 and 53% in 2019. HOR steelhead smolt survival was estimated at 74% in 2018 and 64% in 2019. The substantially larger body size of HOR steelhead smolts may partially explain their higher survival rate to Bonneville Dam each year. Survival held constant for NOR juvenile steelhead in 2018 and 2019 whereas survival for HOR spring Chinook and steelhead was more variable. Survival of NOR juvenile steelhead emigrating from the Klickitat River was also significantly lower than fish emigrating from the Hood River in 2018 (73%) and 2019 (80%; Simpson 2019; Simpson 2018).

Observed differences in survival between Hood River and Klickitat River may partially be explained by differences in habitat characteristics at the respective confluences with the Columbia River. Although a shallow delta (sand spit) is present at both confluences with the Columbia River, water velocities in Hood River are minimally influenced by Bonneville Pool and likely have minimal effect on smolt travel time through the section affected by the impounded Columbia River. Conversely, the Klickitat River is heavily influenced by the impounded Columbia River. Water velocity in the lower 1.5-kilometer section is dramatically reduced due to backwater effects of the impounded Columbia River. The backwater conditions result in significantly slower water velocities than the unaffected upstream river. Backwater conditions likely increase smolt travel time and consequently likely increase vulnerability to piscivorous predators and fish (Rieman et al. 1991).

The additional 19-kilometers of travel through Bonneville Pool by NOR juvenile steelhead emigrating from the Klickitat River compared to the Hood River may also partially explain the lower observed survival rates. The low survival of emigrating Klickitat River NOR juvenile steelhead through the Bonneville pool is concerning considering nearly half of the emigrants do not survive beyond Bonneville Dam.

High mortality through the Bonneville pool is likely due to predation by piscivorous fish and avian species. Predaceous fish are ubiquitous throughout the Bonneville pool. Fish predators with the most measurable impacts on out-migrating smolts include northern pikeminnow, smallmouth bass, channel catfish, and walleye (Ward et a. 1995; Viggs et al. 1991; Tinus and Beamesderfer and Ward 1994; Rieman et al. 1991). Studies have shown that predation rates on out-migrating smolts by northern pikeminnow in the Columbia River are highest from the John Day pool to immediately below Bonneville Dam (Ward et al. 1995; Viggs et al. 1991). Channel catfish consume thousands of juvenile salmonids during each out-migration year which can comprise 50-100% of their diet (Viggs et al. 1991). Walleye, which are well established throughout the Columbia River, are estimated to consume 250,000 to 2,000,000 out-migrating salmonids annually in the Columbia River (Tinus and Beamesderfer 1994; Rieman et al. 1991). Smallmouth bass have become so prolific in some areas of the Columbia River system they have displaced the native pikeminnow. Smallmouth bass become piscivorous by two years of age whereas higher predation rates in pikeminnow are associated with larger and more mature individuals. Consequently, the consumption of salmonids by smallmouth bass is highest for the smaller size classes (Fitts and Pearsons 2006). Cumulatively, predation by nonindigenous fish on out-migrating salmonid smolts is considered to be as impactful to productivity as declines attributed to habitat loss and degradation (Beechie et al. 1994) and the Columbia River hydro-system (Sanderson et al. 2009).

Avian predation accounts for significant mortality of juvenile steelhead during the out-migration to the ocean. In general, the highest avian predation rates for out-migrating salmonid smolts are observed for steelhead (Evans et al. 2012; Antolos et al. 2005; Collis et al. 2001). Studies have shown juvenile steelhead to be more susceptible to avian predation than salmon due to their larger body size, surface orientation, and tendency to migrate close to the surface (Beeman and Maule 2006; Ryan et al. 2003; Collis et al. 2001). Payton et al. 2019 estimated that between nine bird colonies avian predators consumed 31% of juvenile steelhead from Lower Granite Dam to the ocean during the 2014 out-migration. Although juvenile steelhead survival was high between John Day Dam and Bonneville Dam (92%) in 2014, aggregate avian predation accounted for 96% of the observed juvenile steelhead mortality. Considering the compounding impact that fish and avian predators have on juvenile steelhead survival, more information is needed to quantify the extent of predation on juvenile steelhead emigrating from the Klickitat River.

Quantifying SAR rates, age composition for brood year reconstruction, genetic stock identification, and sibship analysis are additional monitoring and evaluation activities currently being addressed for emigrating NOR juvenile steelhead. We hope these data in addition to the data presented in this report will enhance understanding of VSP parameters needed to evaluate the status of ESA listed Middle Columbia steelhead.

- **SAR rates.** NOR juvenile steelhead PIT tagged at the rotary screw trap and subsequently detected at Bonneville Dam as adults will be used to estimate SAR rates to Bonneville Dam.
- **Age composition.** Scales collected from NOR juvenile steelhead at the rotary screw trap are being used to age fish, assign brood year to smolts and returning adults, and reconstruct brood cohort survival and escapement.
- **Genetic analysis.** Genetic Stock Identification (GSI) and sibship analysis are currently underway for tissue samples collected in 2018 and 2019. GSI will be used to quantify the level stock mixing and introgression in natural-origin steelhead. Sibship analysis will be used to link tissue samples collected at the rotary screw trap to upstream anadromous bearing tributaries to estimate relative contribution of each tributary subpopulation to annual out-migration abundance estimates.

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References Cited

Antolos, M., Roby, D.D., Lyons, D.E., Collis, K., Evans, A.F., Hawbecker, M., and Ryan, B.A. 2005. Caspian Tern Predation on Juvenile Salmonids in the Mid-Columbia River. Transactions of the American Fisheries Society 134.2 (2005): 466-80.

Beeman, J. W., and Maule, A.G. 2006. Migration depths of juvenile Chinook salmon and steelhead relative to total dissolved gas supersaturation in a Columbia River reservoir. Transactions of the American Fisheries Society 135:584–594.

Beamesderfer, R.C. and Ward, D.L. 1994. Review of the Status, Biology, and Alter- natives for Management of Smallmouth Bass in John Day Reservoir. Clackamas (OR): Oregon Department of Fish and Wildlife Fish Division. Informational Reports 94-4.

Beechie, T., Beamer, E., and Wasserman, L. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. North American Journal of Fisheries Management 14:797-811.

Buehrens, T.W. and Cochran, P.C. 2019. Abundance and Productivity of Wind River Steelhead and Preliminary Assessment of their Response to Hemlock Dam Removal, 2019. Annual Report to BPA on project no. 1998-019-00 covering work completed from 1/1/2018-12/31/2018. Washington Department of Fish and Wildlife, Vancouver, WA.

Bjorkstedt, E. 2000. DARR (Darroch analysis with rank reduction): A method for analysis of stratified mark-recapture data from small populations with application to estimating abundance of smolts from outmigrant trap data. NOAA-NMFS Southwest Fisheries Science Center. Administrative Report SC-00-02. 28 pp. http://santacruz.nmfs.noaa.gov/files/pubs/00116.pdf

Bjorkstedt, E. 2005. DARR 2.0: Updated software for estimating abundance from stratified mark-recapture data. NOAA-TM-NMFS-SWFSC 68. 21pp. http://santacruz.nmfs.noaa.gov/files/pubs/00439.pdf

Bjorkstedt, E. 2010. DARR 2.02: DARR for R. http://swfsc.noaa.gov/textblock.aspx?Division=FED&id=3346

Bottom, D.L., Simenstad, C.A., Burke, J., Baptista, A.M., Jay, D.A., Jones, K.K., Casillas, E. and Schiewe, M.H. 2005. Salmon at river's end: the role of the estuary in the decline and recovery of Columbia River salmon. U.S. Dept. Commerce, NOAA Tech. Memo. NMFS-NWFSC-68, 246 p.

Chapman, D. W. 1986. Salmon and steelhead abundance in the Columbia River in the nineteenth century. Transactions of the American Fisheries Society 115:662-670.

Cline, D. R. 1976. Reconnaissance of the Water Resources of the Upper Klickitat River Basin, Yakima Indian Reservation, Washington: U.S. Geological Survey Open-File Report 75-518. 54 pp.

Columbia Basin Fish and Wildlife Authority. 2014. PIT Tag Marking Procedures Manual. PIT Tag Steering Committee, Portland, Oregon (see Supplemental Material, Reference S3, http://www.ptagis.org/docs/default-source/ptagis-program-documents/2014-mark-procedures-manual.pdf?sfvrsn=2 (September 2014).

Collis, K., Roby, D.D, Craig, D.P., Ryan, B.A., Ledgerwood, R.D. 2001.Colonial waterbird predation on juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary: vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society 130:385–396.

Congleton, J.L, Lavoie,W.L., Schreck,C.B., and Davis, L.E. 2000. Stress Indices in Migrating Juvenile Chinook Salmon and Steelhead of Wild and Hatchery Origin before and after Barge Transportation. Transactions of the American Fisheries Society 129.4 (2000): 989-1004.

Evans, A.F., Hostetter, N.J., Roby, D.D., Collis, K., Lyons, D.E., Sandford, B.P., Ledgerwood, R.D., and Sebring. S. 2012. System wide Evaluation of Avian Predation on Juvenile Salmonids from the Columbia River Based on Recoveries of Passive Integrated Transponder Tags. Transactions of the American Fisheries Society 141.4 (2012): 975-89.

Fritts, A.L. and Pearsons, T.N. 2006.Effects of predation by nonnative smallmouth bass on native salmonid prey: The role of predator and prey size. Transactions of the American Fisheries Society 135:853-860

Grote, J. D. and Desgroseillier, T. J. 2016. Juvenile Salmonid out-migration monitoring on the Entiat River, 2015. U.S. Fish and Wildlife Service, Leavenworth, Washington.

Jezorek, I.G. (2020, July 7). Interviewed by N. Romero. Juvenile salmonid monitoring following removal of Condit Dam in the White Salmon River watershed, Washington. U.S. Geological Survey. Cook, WA.

Johnson, D.H, Shrier, B.M., O'Neal, J.S., Knutzen, J.A., Augerot, X., O'Neal, T.A. and Pearsons, T.N. 2007. The Salmonid Field Protocol Handbok. Techniques for Assessing

Status and Trends in Salmon and Trout Populations. American Fisheries Society. Betheseda, Maryland.

Kelsey, D.A. 1997. Effects of steelhead trout (*Oncorhynchus mykiss*) on Chinook salmon (*O. tshawytscha*) behavior and physiology. Master's thesis. Oregon State University, Corvalllis, Oregon.

Lady, J., P. Westhagen and Skalski, J. 2001. SURPH, Survival under Proportional Hazards. Available. Prepared for the Bonneville Power Administration. Project No. 1989-107-00, Contract Number DE-B179-90BP02341. Portland, Oregon. http://www.cbr.washington.edu/analysis/apps/surph/

Love, D. C. 2016. Manual for aging steelhead trout scales based on scale sampling from Sitkoh Creek, Big Ratz Creek, and other Southeast Alaska streams, 2003-2011. Alaska Department of Fish and Game, Special Publication No. 16-13, Anchorage.

McClure, M.M., Holmes, E.E., Sanderson, B.L., and Jordan, C.E. 2003. A Large-scale, Multispecies status assessment: Anadromous Salmonids in the Columbia River Basin. Ecological Applications 13.4 (2003): 964-89.

McElhany, P., Ruckelshaus, M.H., Ford, M.J., Wainwright, T.C., and Bjorkstedt, E.P. 2000. Viable salmonid populations and the recovery of evolutionary significant units. U.S. Dept. of Commerce, NOAA Tech Memo., NMFS-NWFSC-42, 156p.

Music, P. A., Hawkes, J.P., and Cooperman, M.S. 2010. Magnitude and causes of smolt mortality in rotary screw traps: An Atlantic salmon case study. North American Journal of Fisheries Management 30:713–722.

NOAA-Fisheries. 2008. Supplemental Comprehensive Analsis of the Federal Columbia River Power System and Mainstem Effects of the Upper Snake and other Tributary Actions. National Marine Fisheries Service, Northwest Region. Portland, OR. See: https://archive.fisheries.noaa.gov/wcr/publications/hydropower/fcrps/final-sca.pdf

NOAA-Fisheries. 2009. Recovery Plan for the Klickitat River Population of the Middle Columbia River Steelhead Distinct Population Segment. Appendix B in Middle Columbia River Steelhead Distinct Population Segment ESA Recovery Plan. National Marine Fisheries Service, Northwest Region. Portland, OR. See: http://www.westcoast.fisheries.noaa.gov/publications/recovery_planning/salmon_steelhead/domains/interior_columbia/middle_columbia/mid-c-klickitat.pdf

Northcote, T. G. 1997a. Potamodromy in Salmonidae: living and moving in the fast lane. North American Journal of Fisheries Management 17:1029-1045

Payton, Q., Hostetter, N.J., and Evans, A.F. 2019. Jointly estimating survival and mortality: Integrating recapture and recovery data from complex multiple predator systems. Environmental and Ecological Statistics 26:107-125.

Plante, N., L.-P. Rivest, and G. Tremblay (1998). Stratified capture-recapture estimation of the size of a closed population. *Biometrics 54*, 47–60.

Poole J.R., E. Felts, M. Dobos, B. Barnett, M. Davison, M. Dobos, C.J. Roth. B.A. Knoth, E.J. Stark. 2019. Idaho anadromous emigrant monitoring. 2018 annual report. Idaho Department of Fish and Game Report 19-11, Boise.

Pacific States Marine Fisheries Commission (PSMFSC). 2001. Smolt Monitoring Program. Guide to fish handling, identification, and condition. Portland, OR.

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

Rieman B.E., Beamesderfer R.C., Vigg, S., and Poe, T.P. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120: 448–458.

Roper, B., and D. L. Scarnecchia. 1996. A comparison of trap efficiencies for wild and hatchery age-0 Chinook Salmon. North American Journal of Fisheries Management 16:214–217.

Ryan, B. A., Smith,S.G., Butzerin, J.M., and Ferguson, J.W. 2003. Relative vulnerability to avian predation of juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary, 1998–2000. Transactions of the American Fisheries Society 132:275–288.

Sanderson, B.L., K.A. Barnas, and A.M. Wargo Rub. 2009. Nonindigenous species of the Pacific Northwest: An overlooked risk to endangered salmon? BioScience 59(3):245-256.

Sharp, W., Zendt, J., Bosch, W., Rau, J., and Frederiksen, C. 2018. Klickitat River Spring Chinook Master Plan. Yakima/Klickitat Fisheries Project 1988-115-35. Toppenish, Washington.

Simpson, P.S., R.E. Reagan and H.A. Griffin 2018. Hood River Production Program Monitoring and Evaluation Annual Progress Report For Calendar Year 2018. Oregon Department of Fish and Wildlife (Project Number 1988-053-04) to Bonneville Power Administration, Portland, Oregon. . https://www.cbfish.org/PiscesPublication.mvc

Simpson, P.S., R.E. Reagan and H.A. Griffin 2019. Hood River Production Program Monitoring and Evaluation Annual Progress Report For Calendar Year 2019. Oregon Department of Fish and Wildlife (Project Number 1988-053-04) to Bonneville Power Administration, Portland, Oregon. . https://www.cbfish.org/PiscesPublication.mvc

Tattam, Ian A. , James R. Ruzycki , Peter B. Bayley , Hiram W. Li & Guillermo R. Giannico (2013): The Influence of Release Strategy and Migration History on Capture Rate of Oncorhynchus mykiss in a Rotary Screw Trap, North American Journal of Fisheries Management, 33:2, 237-244

Thiesfeld, S.L., R. McPeak, B. McNamara, and I. Honanie. 2001. Fiscal Year 2001 Annual Report. Bull Trout Population Assessment in the White Salmon and Klickitat rivers, Columbia River Gorge, Washington. Prepared by WDFW and YN under BPA Contract #00004474-00001 for Bonneville Power Administration. Portland, Oregon.

Tinus, E.S. and Beamesderfer, R.C. 1994. An Update on the Distribution, Fisheries, and Biology of Walleye in the Lower Columbia River. Portland (OR): Oregon Department of Fish and Wildlife. Information Report 94-3.

Vigg S, Poe TP, Prendergast LA, Hansel HC. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in the John Day Reser- voir, Columbia River. Transactions of the American Fisheries Society 120: 421–438.

Volkhardt, G.C., Johnson, S.L., Miller, B.A., Nickelson, T.E., and Seiler, D.E. 2007, Rotary screw traps and inclined plane screen traps, in Johnson, D.H., Shrier, B.M., O'Neal, J.S., Knutzen, J.A., Augerot, X. O'Neal, T.A., and Pearsons, T.N., eds., Salmonid field protocols handbook: Techniques for assessing status and trends in salmon and trout populations: American Fisheries Society, p. 235–266.

Wade,A. A., T. J. Beechie, E. Fleishman, N. J. Mantua, H. Wu, J.S. Kimball, D.M. Stoms, and J.A. Stanford. 2013. Steelhead Vulnerability to Climate Change in the Pacific Northwest. Journal of Applied Ecology 50.5 (2013): 1093-104. (ask Kory to locate)

Ward, D.L., J.H, Petersen, and J.L. Loch. 1995. Index of predation on juvenile salmonids by Northern Squafish in the Lower and Middle Columbia River and in the Lower Snake River. Transactions of the American Fisheries Society 124.3 (1995): 321-34.

Wedemeyer, Gary A. 1976. Physiological Response of Juvenile Coho Salmon (*Oncorhynchus Kisutch*) and Rainbow Trout (*Salmo Gairdneri*) to Handling and Crowding Stress in Intensive Fish Culture. Journal of the Fisheries Board of Canada 33.12 (1976): 2699-702.

Westhagen, P, and J R Skalski. 2009. Program PitPro 4.0. Columbia Basin Research, University of Washington, Seattle.

Yakama Nation, Klickitat County, and Washington Department of Fish and Wildlife. 2004. Klickitat Subbasin Plan. Prepared for the Northwest Power and Conservation Council. Portland, OR.

Zendt, J., and Babcock, M. 2007. Klickitat Subbasin Monitoring and Evaluation - Yakima/Klickitat Fisheries Project, 5/1/2006 – 4/30/2007 Report to Bonneville Power Administration, Portland, OR. https://www.cbfish.org/Document.mvc/Viewer/P104163

Zendt, J., N. Romero, S. Keep, and M. Babcock. 2013. Klickitat Subbasin Monitoring and Evaluation - Yakima/Klickitat Fisheries Project, 5/1/2010 - 12/31/2012 Report to Bonneville Power Administration, Portland, OR. https://www.cbfish.org/Document.mvc/Viewer/P132813

Figures

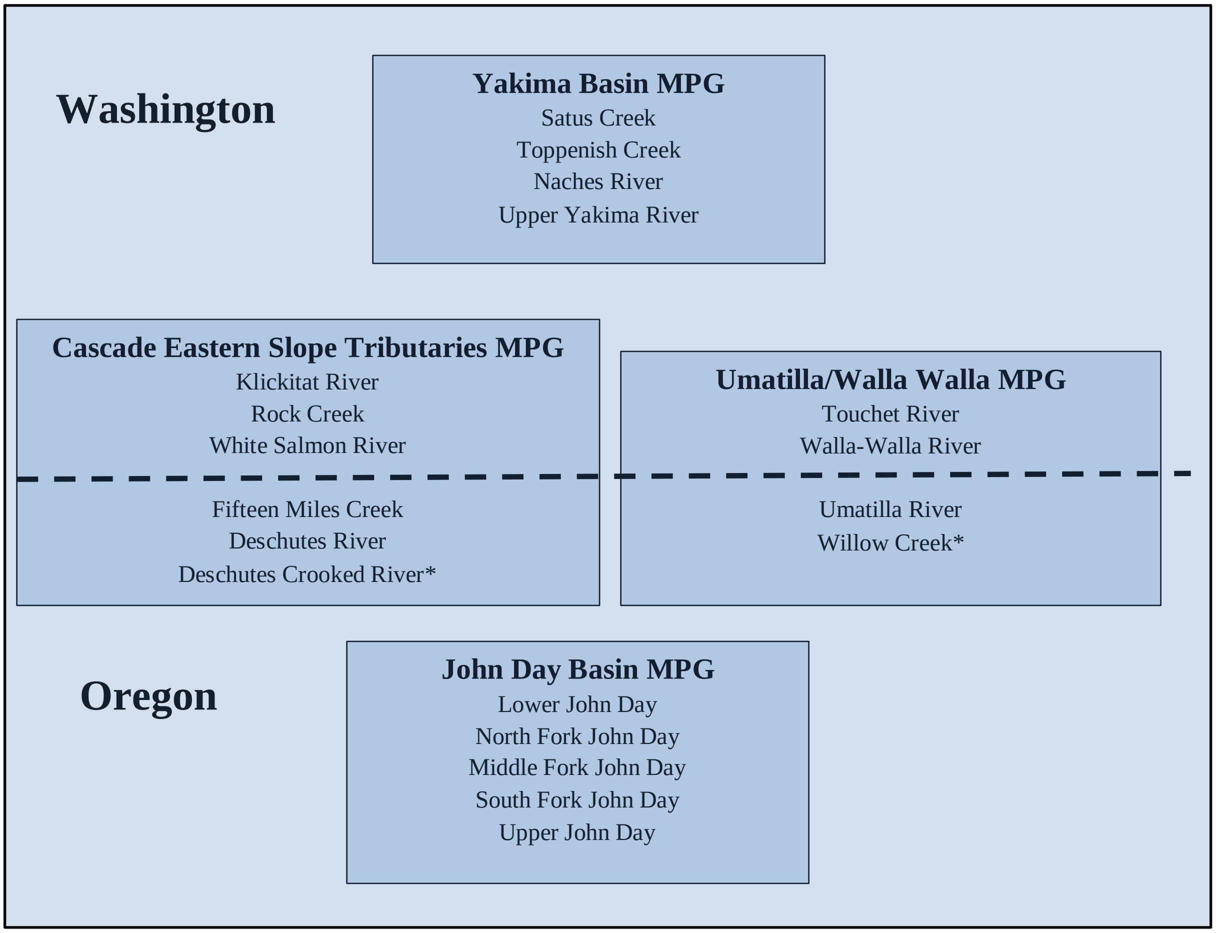

Figure 1. Four major population groups and associated independent populations in the Middle Columbia Steelhead Distinct Population Segment (DPS) in Washington and Oregon (NOAA 2009). Asterisk (*) denotes extinct independent populations.

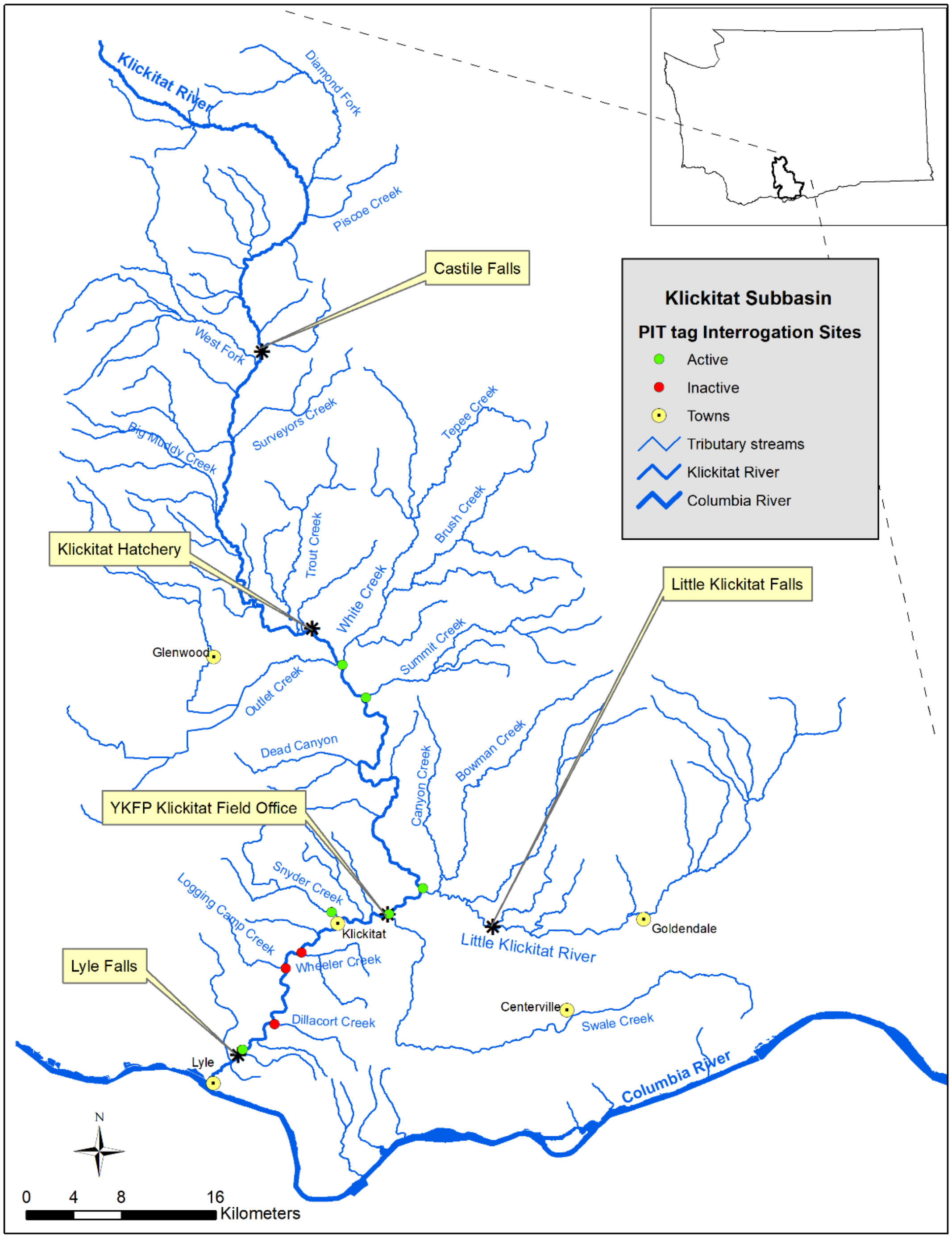

Figure 2. Map of the Klickitat River subbasin showing the location of Yakama Nation Fisheries infrastructure (Lyle Falls Adult Fish Passage Facility, rotary screw trap, Klickitat Field Office, Klickitat River Hatchery, and Castile Falls Fishway and Adult Enumeration Facility) and remote PIT tag interrogation sites in the Klickitat River subbasin, Washington.

Figure 3. Photos of the rotary screw trap and floating PIT tag interrogation array at river kilometer 4.5. Photo descriptions starting at top left and proceeding clockwise: aerial view looking north to south, aerial view south to north, and downstream to upstream view at the channel level (aerial photos by David Lindley).

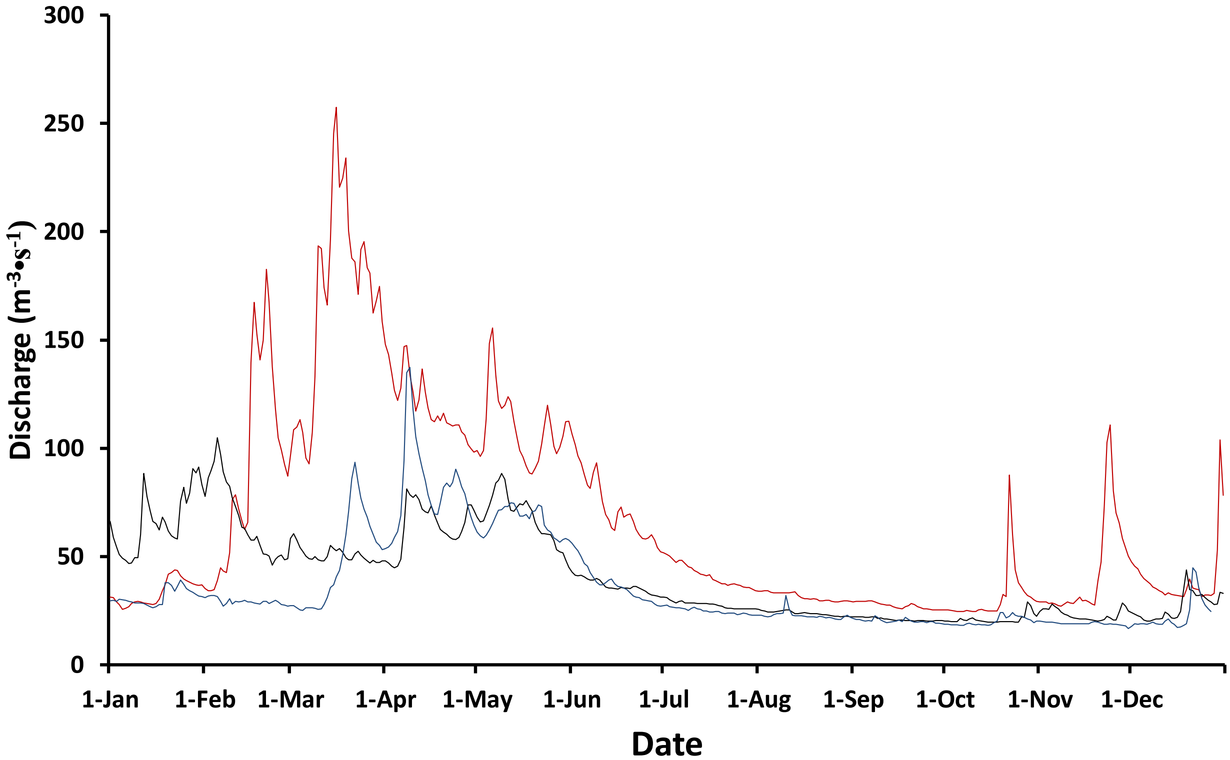

Figure 4. Graph displaying mean daily water discharge (m^{-3}•s^{-1}) in the lower Klickitat River for calendar years 2017 (maroon line), 2018 (black line), and 2019 (blue line).

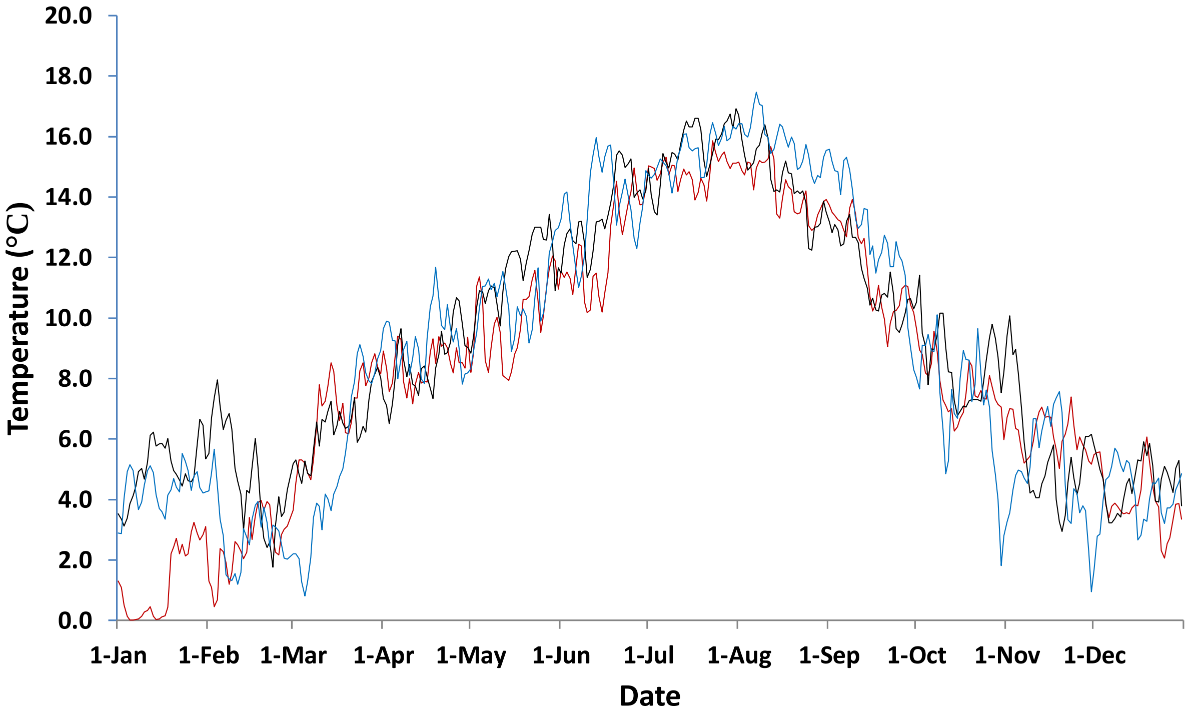

Figure 5. Graph showing mean daily water temperature (°C) in the lower Klickitat River for calendar years 2017 (maroon line), 2018 (black line), and 2019 (blue line).

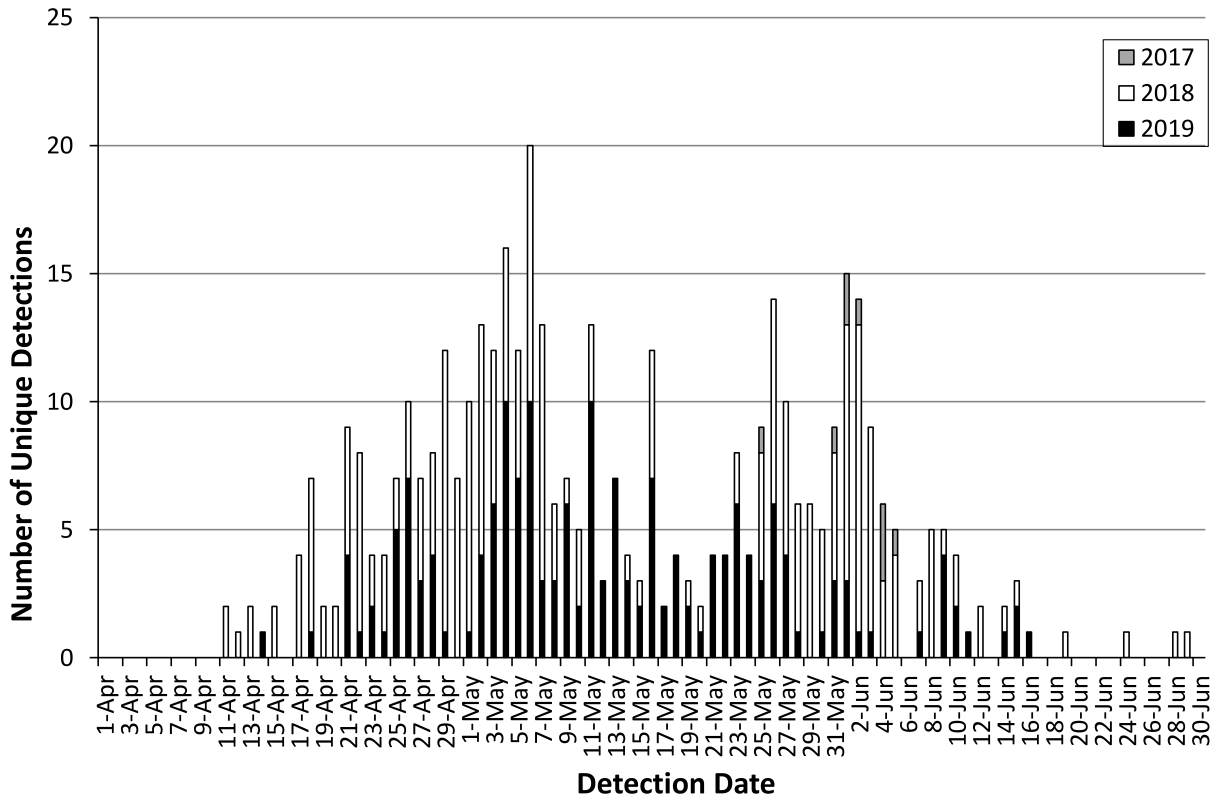

Figure 6. Graph showing the number of unique daily PIT tag detections of emigrating natural-origin juvenile steelhead (*O. mykiss*) PIT tagged at the rotary screw trap and detected at the floating PIT tag interrogation array during calendar years 2017 (n=9; grey bar), 2018 (n=239; white bar), and 2019 (n=176; black bar) at river kilometer 4.5, Klickitat River, Washington.

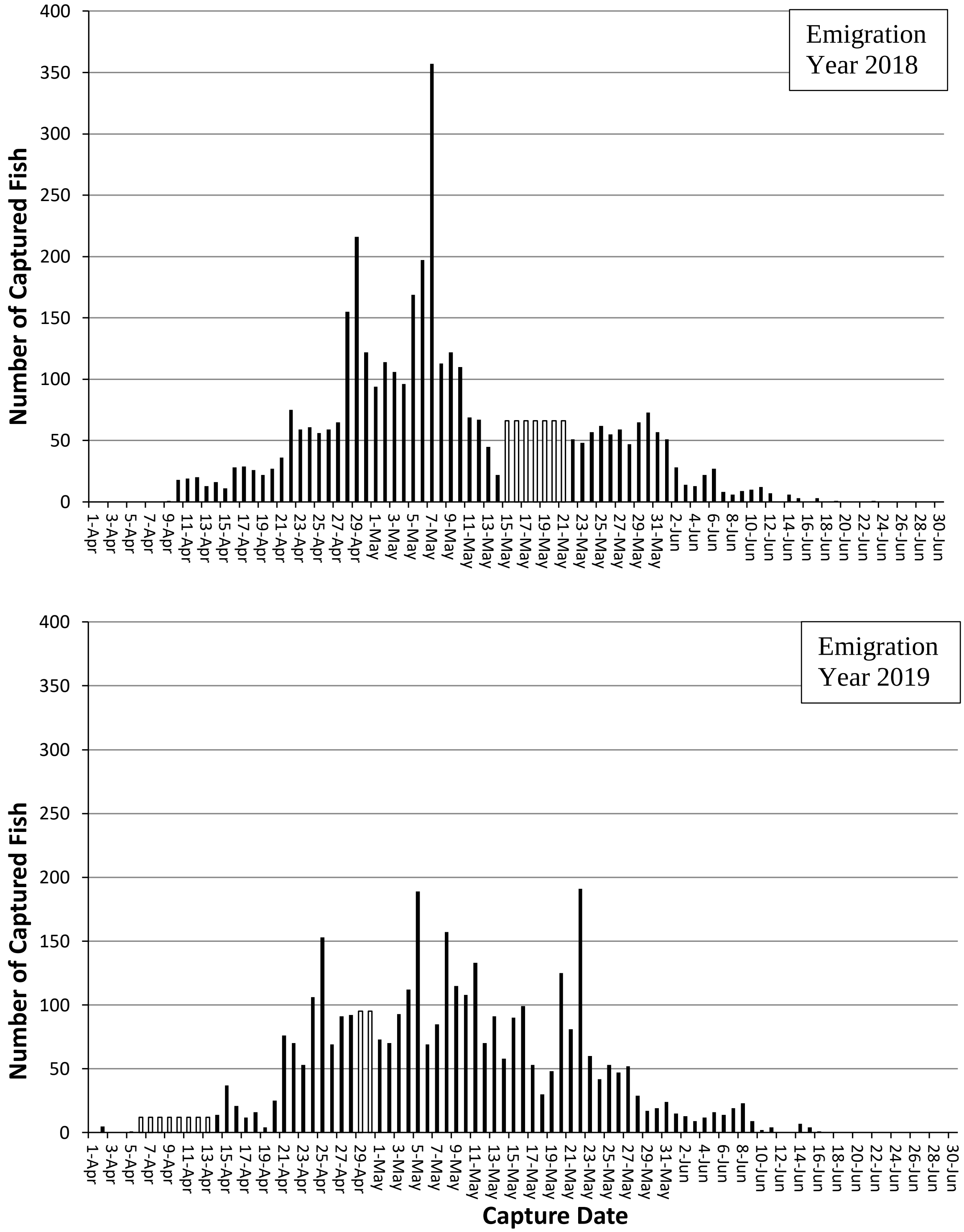

Figure 7. Graph showing the number of first time daily captures of emigrating natural-origin juvenile steelhead (*O. mykiss*) collected at the rotary screw trap during calendar years 2018 (n=4,072) and 2019 (n=3,774) at river kilometer 4.5, Klickitat River, Washington. White bars denote the estimated number of daily first time captures had the screw trap been fishing during non-operational periods (n=462 for 05/15-05/21/18; n=96 for 04/06-04/19/19; n=190 for 04/29-04/30/19).

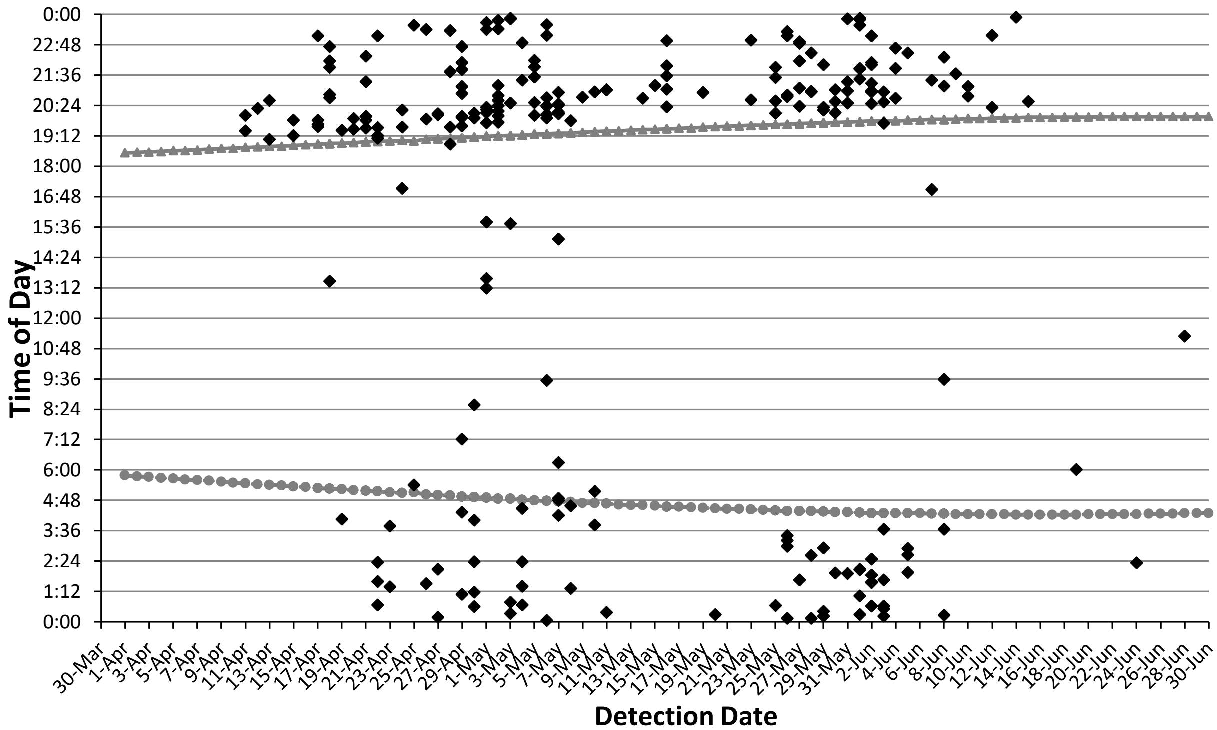

Figure 8. Graph showing diel movement patterns of emigrating natural-origin juvenile steelhead (*O. mykiss*) captured and PIT tagged at the rotary screw trap and detected at the floating PIT tag interrogation array (n=238) during the 2018 screw trapping season at river kilometer 4.5, Klickitat River, Washington. Unique fish detection (⧫); sunrise (-●-); sunset (-▲-).

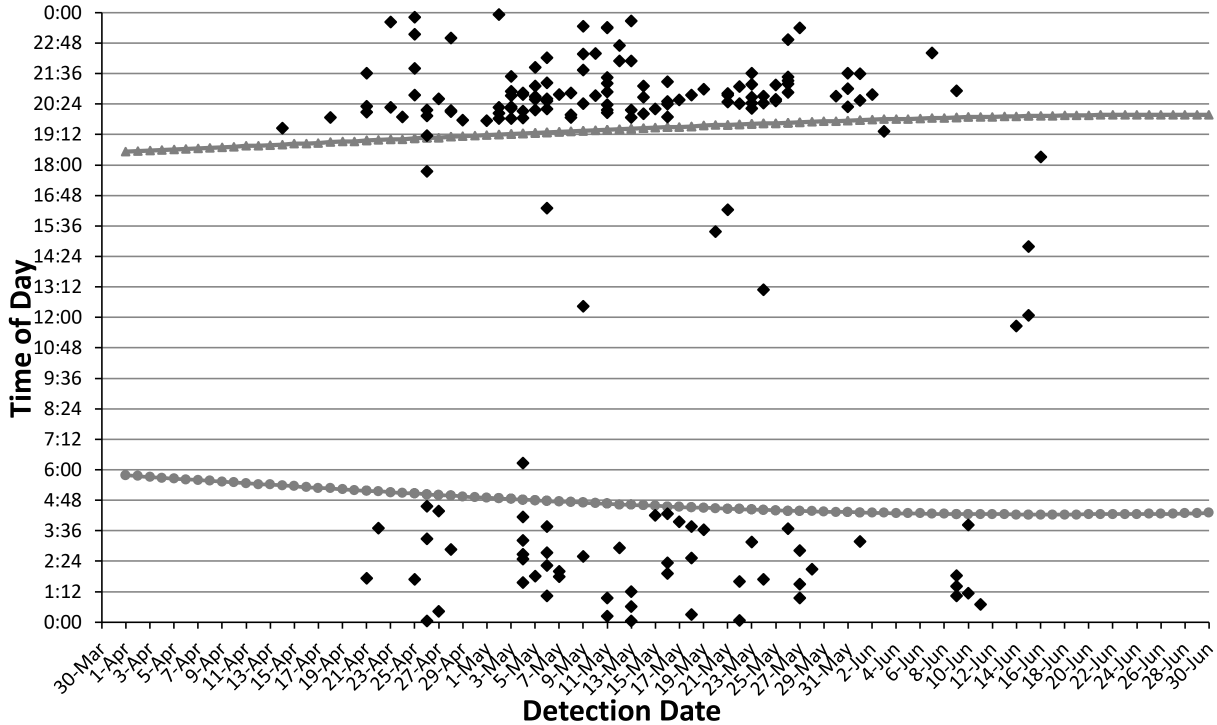

Figure 9. Graph showing diel movement patterns of emigrating natural-origin juvenile steelhead (*O. mykiss*) captured and PIT tagged at the rotary screw trap and detected at the floating PIT tag interrogation array (n=176) during the 2019 screw trapping season at river kilometer 4.5, Klickitat River, Washington. Unique fish detection (⧫); sunrise (-●-); sunset (-▲-).

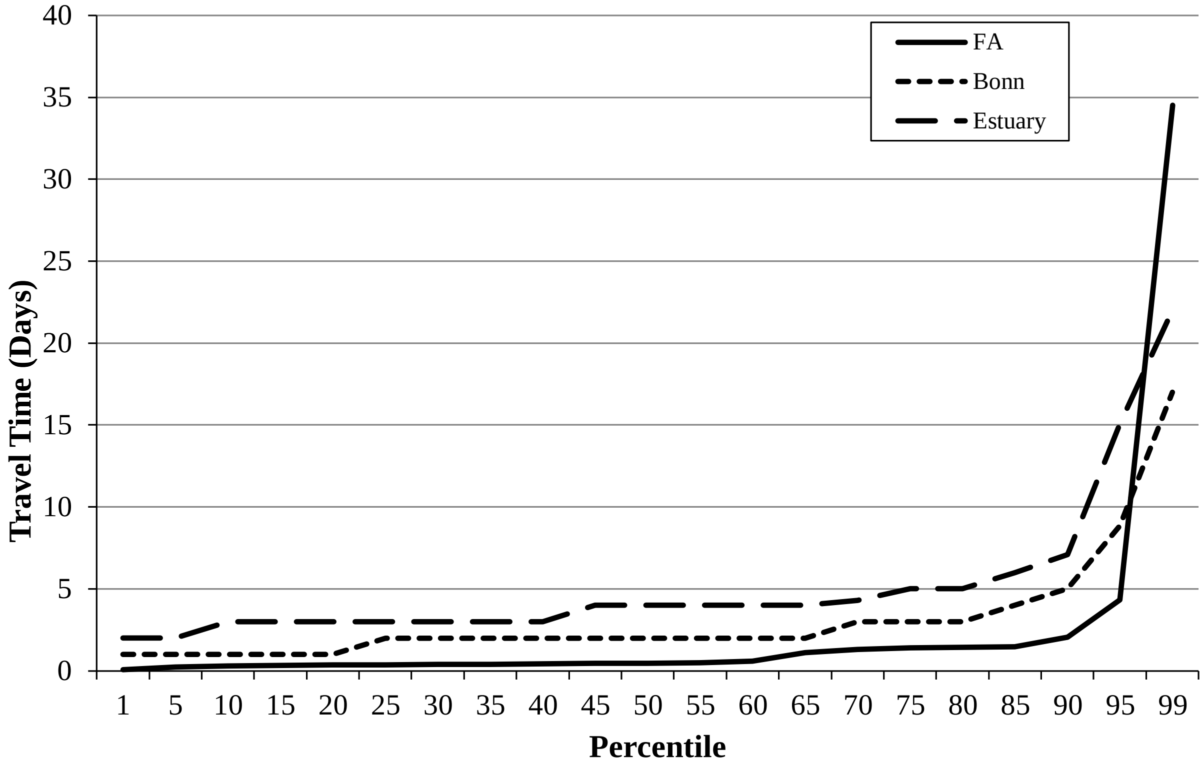

Figure 10. Cumulative travel time (days) to the Klickitat River floating PIT tag interrogation array (FA; n=239), Bonneville Dam (Bonn; n=342), and the Columbia River Estuary (CRE; n=58) for natural-origin juvenile steelhead captured at the rotary screw trap, PIT tagged, and released at river kilometer 6.0 (Klickitat River, Washington) during the 2018 trapping period.

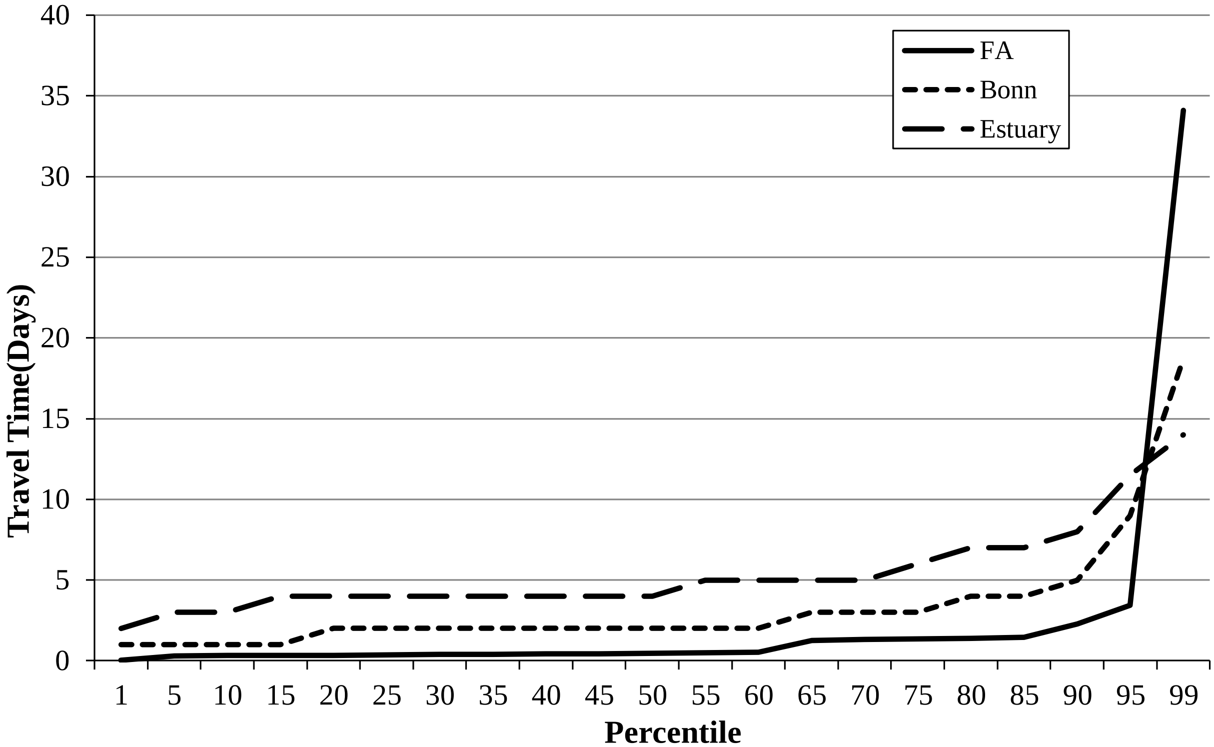

Figure 11. Cumulative travel time (days) to the floating PIT tag interrogation array (FA; n=173), Bonneville Dam (Bonn; n=422), and the Columbia River Estuary (CRE; n=69) for natural-origin juvenile steelhead captured at the rotary screw trap, PIT tagged, and released at river kilometer 6.0 (Klickitat River, Washington) during the 2019 trapping period.

Tables

Table 1. Summary of screw trap operations and physical characteristics collected at the rotary screw trap located at river kilometer 4.5, Klickitat River, Washington, 2017-2019. Parentheses indicate ± one standard error of the mean.

Variables	**2017**	**2018**	**2019**
Trapping Dates	24 May-01 Oct.	3 Apr.-28 June	2 Apr.-16 June
Total Operational Days	43	78	67
Mean Cone Rotation Per Minute	8.7 (0.14)	10.1 (0.18)	9.4 (0.11)
Min Cone Rotation Per Minute	6.7	7	8
Max Cone Rotation Per Minute	10.5	13	12
Mean Discharge (m^{-3}•s^{-1})	54.4 (5.01)	56.2 (1.90)	63.8 (1.77)
Minimum Discharge (m^{-3}•s^{-1})	24.7	32.1	36.2
Maximum Discharge (m^{-3}•s^{-1})	116.4	88.8	98.0
Mean Daily Water (°C)	13.1 (0.20)	11.2 (0.20)	10.7 (0.20)
Mean Daily Min Water (°C)	9.0	6.5	7.8
Mean Daily Max Water (°C)	15.9	15.5	16.0

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Table 2. Number of hatchery-origin summer steelhead (*O. mykiss*), spring and fall Chinook salmon *O. tshawytscha*), and coho salmon (*O. kisutch)* released and tagged in the Klickitat River, Washington, 2017-2019.

Release Year	Stock	Agency[1]	Hatchery	Release Type[2]	Release Dates	Total Released	Total PIT Tagged[3]
2017	Sp. Chinook	YN	Klickitat	V	03/01 - 03/02	248,380	9,591
	Coho	YN	Klickitat	V	04/10 – 04/12	1,090,000	-
	Fall Chinook	YN	Klickitat	V	07/05 – 07/07	4,101,750	-
	Coho	WDFW	Washougal	D	03/28-03/31	2,474,694	-
	Su. Steelhead	WDFW	Washougal	D	05/01-05/03	87,502	9,566
	Total					**8,002,326**	**19,157**
2018	Sp. Chinook	YN	Klickitat	V	03/26 – 03/29	618,650	20,011
	Coho	YN	Klickitat	V	05/14 – 05/17	1,158,880	-
	Fall Chinook	YN	Klickitat	V	07/09 – 07/12	2,752,596	-
	Coho	WDFW	Washougal	D	03/28-03/31	2,229,074	-
	Su. Steelhead	WDFW	Washougal	D	04/23-04/25	91,786	9,994
	Total					**6,850,986**	**30,005**
2019	Sp. Chinook	YN	Klickitat	V	04/09 – 04/11	634,090	18,631
	Coho	YN	Klickitat	V	05/07 – 05/10	900,825	-
	Fall Chinook	YN	Klickitat	V	06/24 – 06/28	1,467,250	-
	Coho	WDFW	Washougal	D	3/30-04/02	2,460,342	-
	Su. Steelhead	WDFW	Washougal	D	04/22-04/24	90,036	9,968
	Total					**5,552,543**	**28,599**

[1]YN = Yakama Nation; WDFW = Washington Department of Fish and Wildlife
[2]V = Volitional Release; D = Direct Release
[3]PIT tagging completed by Yakama Nation fisheries personnel

Table 3. Number of salmonids by rear type and life stage collected at the rotary screw trap located at river kilometer 4.0, Klickitat River, Washington, 2017- 2019.

			Number of fish		
Species	**Rear Type[1]**	**Life Stage**	**2017**	**2018**	**2019**
Steelhead	N	Fry	2	0	0
	N	Pre-smolt	0	0	22
	N	Smolt	231	3,610	3,453
	H	Smolt	125	5,944	5,743
Chinook	N	Fry	19	0	1
	N	Pre-smolt	2	14	12
	N	Smolt	591	87	26
	H	Smolt	19,309	55	1,432
Coho	N	Fry	42	17	16
	N	Pre-smolt	52	438	53
	N	Smolt	18	678	494
	H	Smolt	1,138	31,587	66,970
Unknown Salmonid	N	Fry	465	533	95
	N	Pre-smolt	0	0	11
	N	Smolt	0	0	31
Mountain Whitefish	N		0	0	2
		Total	**21,983**	**42,949**	**76,915**

[1]N = Natural-origin; H = Hatchery-origin

Table 4. Number of native non-salmonid and invasive fish species by rear type and life stage collected at the rotary screw trap located at river kilometer 4.5, Klickitat River, Washington, 2017- 2019.

			Number of fish		
Species	**Life Stage**	**Origin**	**2017**	**2018**	**2019**
Pacific Lamprey	Adult	Native	7	14	11
Lamprey spp.	Ammocoete	Native	457	4,067	613
Lamprey spp.	Macropthalmia	Native	27	34	6
Bridgelip Sucker	Juvenile	Native	24	59	53
Bridgelip Sucker	Adult	Native	1	0	0
Chiselmouth	Unknown	Native	0	1	0
Dace spp.	Unknown	Native	23	29	9
Sculpin spp.	Unknown	Native	12	53	13
Redside Shiner	Unknown	Native	3	2	0
Blugill	Unknown	Invasive	0	1	0
Bullhead Catfish	Unknown	Invasive	0	1	2
Pumpkinseed	Unknown	Invasive	0	2	4
		Total	**554**	**4,263**	**711**

Table 5. Number of natural-origin juvenile steelhead (*O. mykiss*) captured, tagged with passive integrated transponder (PIT) tags, and recaptured at the rotary screw trap located at river kilometer 4.5, Klickitat River, Washington in 2017, 2018, and 2019.

Year	Number of efficiency release days	Number of efficiency release groups	Total fish captured	Number of marked fish released	Number of fish recaptured	% of tags recaptured
2017	26	26	231	221	0	0.0
2018	62	141	3,610	3,186	158	5.0
2019	54	151	3,475	3,384	158	4.7

Table 6. Number of emigrating natural-origin juvenile steelhead, spring Chinook (*O. tshawytscha*) smolts, and macropthalmia lamprey (*Lampetra sp.*) captured, tagged with passive integrated transponder (PIT) tags, scale and genetic tissue samples, and biometric data collected at the rotary screw trap located at river kilometer 4.5, Klickitat River, Washington in 2017, 2018, and 2019. Parentheses indicate ± one standard error of the mean.

	Steelhead			Chinook			Macrothalmia Lamprey		
Variable	2017	2018	2019	2017	2018	2019	2017	2018	2019
Total Captured	231	3,610	3,475	591	84	26	27	34	6
Total Tagged	221	3,187	3,384	122	34	22	0	0	0
Scale Samples	0	690	923	0	0	3	0	0	0
Genetic Samples	221	3202	3393	89	33	22	18	1	0
Mean Length	171.9 (1.38)	180.8 (0.34)	181.2 (0.35)	71.1 (0.39)	95.2 (1.74)	92.5 (3.82)	115.5 (1.65)	-	-
Median Length	169	180	180	71	97	85	116	-	-
Min Length	78	74	78	54	70	70	70	-	-
Max Length	242	280	296	111	113	130	131	-	-
Mean Weight	51.7 (1.21)	59.1 (0.34)	59.6 (0.37)	-	9.8 (0.55)	10.3 (1.39)	2.6 (0.11)	-	-
Median Weight	48.5	56.5	55.9	-	10.3	7.3	2.5	-	-
Min Weight	4.5	3.8	5.2	-	3.3	3.6	1.6	-	-
Max Weight	123	210.9	266	-	17.7	27.1	3.5	-	-

Note: Lengths collected in millimeters and weights in grams; Fork length collected for salmonids and total length for lamprey

Table 7. Natural-origin juvenile steelhead collected at the rotary screw trap, PIT tagged, and detected at the floating PIT tag interrogation array located at river kilometer 4.5, Klickitat River, Washington in 2017, 2018, and 2019.

Variable	2017	2018	2019
Operational Dates	21 Apr-21 Nov	03 Mar-10 Dec	22 Mar-19 Dec
Total Operational Days	215	279	273
Number of fish PIT tagged	221	3,186	3,384
Number of unique PIT tag detections	21	239	176
% of PIT tags detected	9.5	7.5	5.2

Table 8. Temporal summary of unique detections of emigrating natural-origin juvenile steelhead (*O. mykiss*) at the floating PIT tag interrogation array for fish collected and tagged at the rotary screw trap (ST) and upstream tributaries (UT) in the Klickitat River, Washington during the 2018 and 2019 out-migration periods.

Year	Source	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Total
2017	RST	0	0	2	8	0	0	11	0	0	21
	UT	0	6	8	5	0	0	4	3	1	27
2018	RST	0	69	115	54	0	1	0	0	0	239
	UT	1	18	16	4	0	0	0	1	0	40
2019	RST	0	30	129	17	1	0	0	0	0	176
	UT	2	7	26	5	0	0	1	2	0	43
	Total	**3**	**130**	**295**	**93**	**1**	**1**	**16**	**4**	**1**	**547**

Table 9. Total trap catch, tagged efficiency release numbers, efficiency release recaptures, capture efficiency (CE), and emigrant abundance estimates (AE) with standard error (SE), 95% confidence intervals (CI), and coefficient of variation for emigrating juvenile natural-origin juvenile steelhead (*O. mykiss*) by stratum and emigration year from the rotary screw trap located at river kilometer 4.5, Klickitat River, Washington during calendar years 2018 and 2019.

Date Strata	Number Caught[1]	Number Tagged[2]	Number Recaps[3]	% CE	AE	SE	95% CI	% CV
04/09 - 04/21/18	266	262	8	3.1	8,712	3,031	2,770-14,653	34.8
04/22 - 04/28/18	530	512	14	2.7	19,383	5,107	9,373-29,393	26.3
04/29 - 05/05/18	917	892	67	7.5	12,208	1,430	9,405-15,012	11.7
05/06 - 05/12/18	1,035	747	41	5.5	18,857	2,860	13,252-24,463	15.2
05/13 - 05/19/18	397	380	17	4.5	8,874	2,101	4,756-12,992	23.7
05/20 - 05/26/18	405	387	8	2.1	19,592	6,853	6,159-33,025	35.0
05/27 - 06/02/18	380	312	14	4.5	8,469	2,210	4,137-12,800	26.1
06/03 - 06/09/18	98	95	5	5.3	1,862	809	276-3,488	43.5
06/10 - 06/28/18	43	39	2	5.1	839	577	0-1,970	68.8
Total	**4071**	**3626**	**176**	**4.9**	**98,796**	**10,137**	**78,927-118,663**	**10.3**
03/31 - 04/27/19	849	828	26	3.1	27,460	5,340	16,993-37,927	19.4
04/28 - 05/04/19	630	618	17	2.8	22,902	5,476	12,170-33,635	23.9
05/05 - 05/11/19	856	852	51	6.0	14,300	1,938	10,502-18,099	13.6
05/12 - 05/18/19	491	481	24	5.0	9,840	1,956	6,008-13,673	19.9
05/19 - 05/25/19	600	565	38	6.7	8,921	1,395	6,187-11,655	15.6
05/26 - 06/08/19	309	301	8	2.7	11,626	4,054	3,680-19,572	34.9
06/09 - 06/16/19	27	13	3	23.1	117	58	2-232	50.0
Total	**3762**	**3658**	**167**	**4.6**	**95,167**	**9,190**	**77,154-113,180**	**9.7**

[1]Estitimated number of fish caught had the screw trap been fishing during non-operational periods (n=462 for 05/15-05/21/18; n=96 for 04/06-04/13/19; n=190 for 04/29-04/30/19).

[2]Estimated number of tagged fish had the screw trap been fishing during non-operational periods (n=441 for 05/15-05/21/18; n=88 for 04/06-04/13/19; n=186 for 04/29-04/30/19).

[3]Estitimated number of fish recaptures had the screw trap been fishing during non-operational periods (n=18 for 05/15-05/21/18; n=2 for 04/06-04/13/19; n=7 for 04/29-04/30/19).

Table 10. First arrival, 10th percentile, 25th percentile, median, 75th percentile, 90th percentile, and last arrival dates to the rotary screw trap (ST), floating PIT tag interrogation array (FA), Bonneville Dam (BD), and Columbia River Estuary (CRE) for emigrating natural-origin juvenile steelhead (*O. mykiss*) from the Klickitat River, Washington during the 2018 and 2019 out-migration periods.

Year	Site	n	First	10th	25th	Median	75th	90th	Last
2018	ST	3,610	04/09	04/22	04/29	05/05	05/13	05/30	06/23
	FA	239	04/11	04/21	04/29	05/07	05/31	06/04	08/29
	BD	342	04/12	04/26	05/01	05/07	05/24	06/03	07/01
	CRE	58	04/30	05/01	05/03	05/09	05/31	06/06	06/14
2019	ST	3,186	04/02	04/24	05/01	05/09	05/19	05/25	06/16
	FA	173	04/14	04/26	05/04	05/11	05/23	06/01	07/04
	BD	422	04/16	04/30	05/08	05/13	05/23	05/27	06/17
	CRE	69	04/19	04/29	05/06	05/16	05/20	05/27	06/04

Table 11. Travel time to the Klickitat River floating PIT tag interrogation array (FA; n), Bonneville Dam (BD), and Columbia River Estuary (CRE) for PIT tagged emigrating natural-origin juvenile steelhead (*O. mykiss*) captured at the Klickitat River rotary screw trap and released at river kilometer 6.0 (Klickitat River, Washington) during the 2018 and 2019 emigration periods.

Year	Site	n	Min	10th Percentile	25th Percentile	Median	75th Percentile	90th Percentile	Max
2018	FA	239	0.03	0.29	0.37	0.47	1.39	2.05	139
	BD	342	1	1	2	2	3	5	25
	CRE	58	2	3	3	4	5	7.1	22
2019	FA	173	0.05	0.31	0.36	0.46	1.35	2.27	44.7
	BD	422	1	1	2	2	3	5	26
	CRE	69	2	3	4	4	6	8	14

Table 12. Estimated survival for natural-origin juvenile steelhead (*O. mykiss*), hatchery-origin steelhead, and hatchery-origin spring Chinook (*O. tshawytscha*) emigrants to Bonneville Dam for migration years 2018 and 2019 from the Klickitat River, Washington. Parentheses indicate ± one standard error of the mean.

Year	Stock	Emigrant Abundance	Number PIT Tagged	Survival Rate to Bonneville	Detection Probability at Bonneville	Abundance Estimate to Bonneville	95% CI Bonneville Abundance
2018	NOR Steelhead	98,796	3,627	0.5619 (0.1503)	0.1897 (0.0515)	55,513	39,119-71,907
	HOR Steelhead	91,786	9,994	0.7397 (0.1333)	0.1718 (0.0313)	67,894	50,121-85,667
	HOR spring Chinook	618,650	20,011	0.8236 (0.3205)	0.0813 (0.0317)	509,520	189,491-509,520
2019	NOR Steelhead	95,167	3,670	0.5394 (0.1075)	0.2576 (0.0523)	51,333	40,517-62,149
	HOR Steelhead	90,036	9,968	0.6493 (0.0682)	0.3213 (0.0342)	58,460	50,650-66,270
	HOR spring Chinook	634,090	18,631	0.5370 (0.1788)	0.1051 (0.0351)	340,506	221,193-459,819

Appendix

Appendix A. Photo of electronically powered winch used to laterally move the rotary screw trap across the river channel. The winch is located on the east bank at river kilometer 4.5, Klickitat River, WA.

Appendix B. Photo of fish sampling stations located port and starboard of live-box at the stern of the rotary crew trap.

Appendix C. Photos of rotary screw trap sampling laboratory located at river kilometer 4.5. Starting with top left photo and proceeding clockwise: entrance of sampling laboratory, sampling station inside the laboratory, and real-time Microsoft Access data entry form.

Appendix D. Photo documenting debris accumulation in live-box after a high debris loading event during elevated spring flows at the rotary screw trap in the Klickitat River, WA.

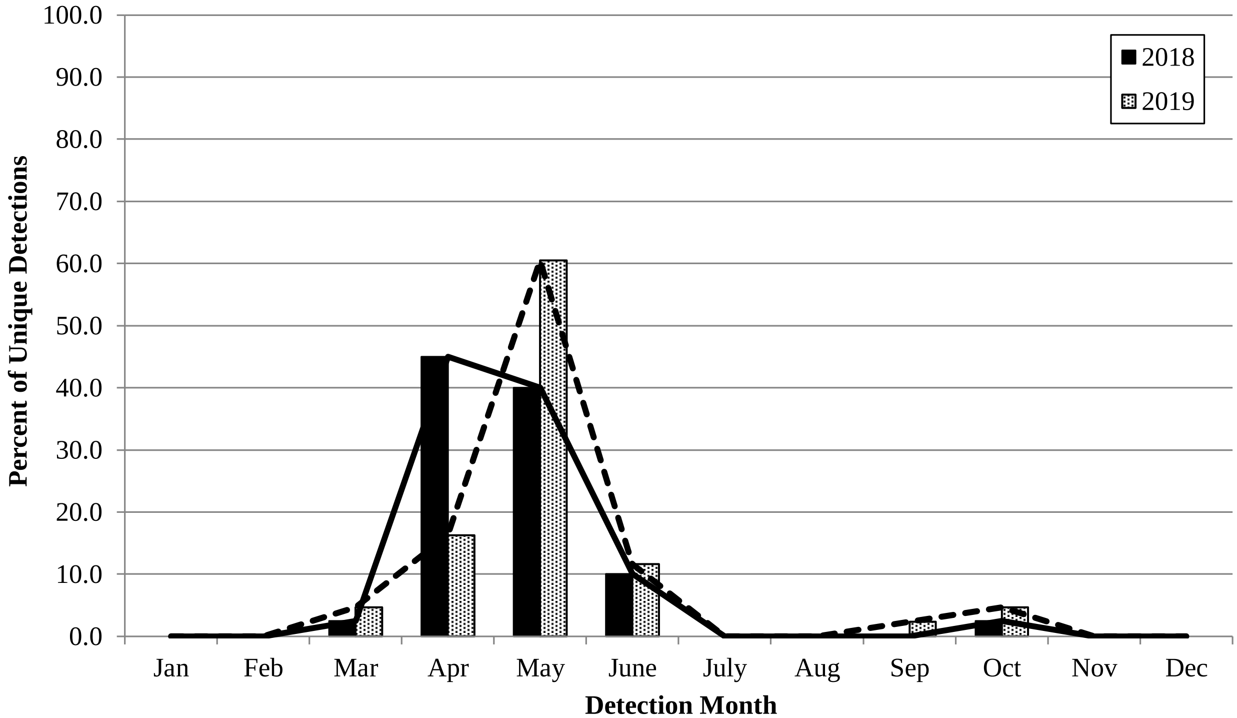
Appendix E. Photo of bucket corral located along the east bank at river kilometer 4.5, Klickitat River, WA. The bucket corral is used to hold fish collected from the rotary screw trap in ambient river conditions until removed for sampling.

Appendix F. Unique detections of PIT tagged natural-origin juvenile steelhead (*O. mykiss*) (PIT tagged at the rotary screw trap), hatchery-origin juvenile steelhead, and hatchery-origin spring Chinook (*O. tshawytscha*) at the floating PIT tag interrogation array located at river kilometer 4.5, Klickitat River, Washington in 2017, 2018, and 2019.

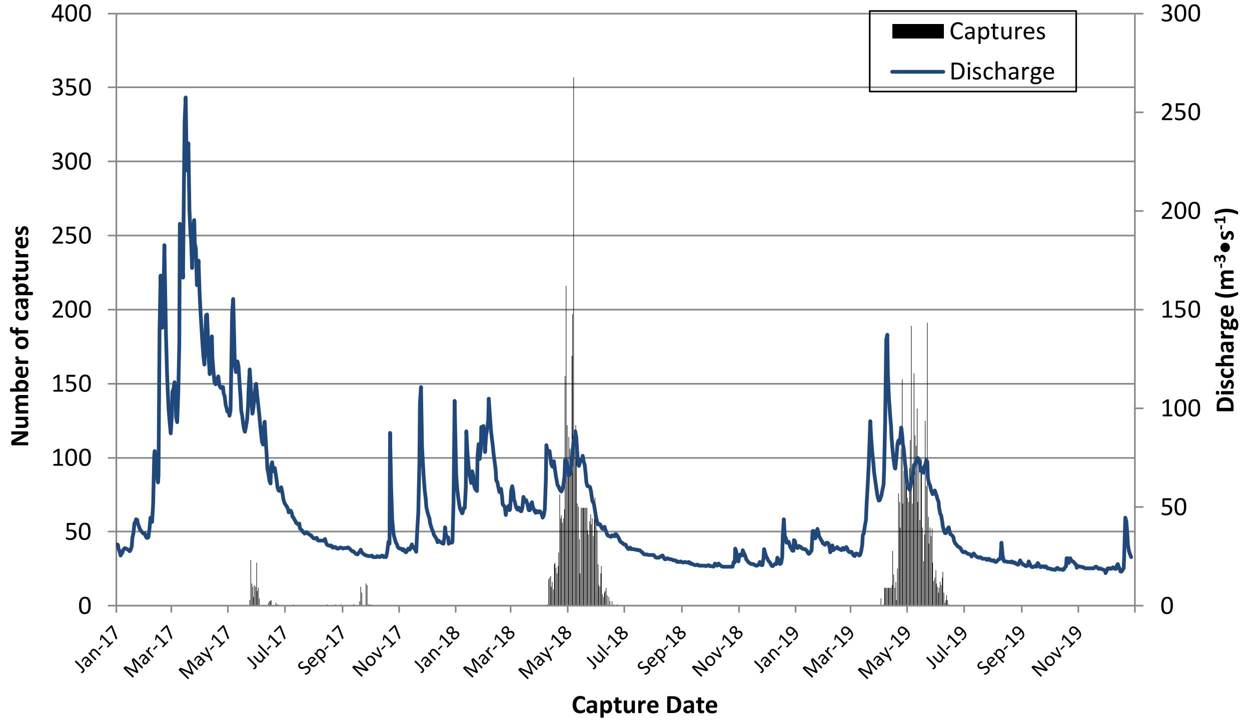
	Natural-origin steelhead			Hatchery-origin steelhead			Hatchery-origin spring Chinook		
Variables	2017	2018	2019	2017	2018	2019	2017	2018	2019
Number of fish PIT tagged	221	3,186	3,384	9,566	9,994	9,968	9,591	20,011	18,631
Number of unique PIT tag detections	21	239	176	386	808	1,104	0	6,019	221
% of PIT tags detected	9.5	7.5	5.2	4.0	8.1	11.1	0	30.0	1.2

Appendix G. Number of natural-origin juvenile steelhead (*O. mykiss*) tagged with passive integrated transponder (PIT) tags in tributaries upstream of the rotary screw trap 2009-2019 and detected by the mainstem floating PIT tag interrogation array, Klickitat River, Washington. Asterisks denote years that were not sampled.

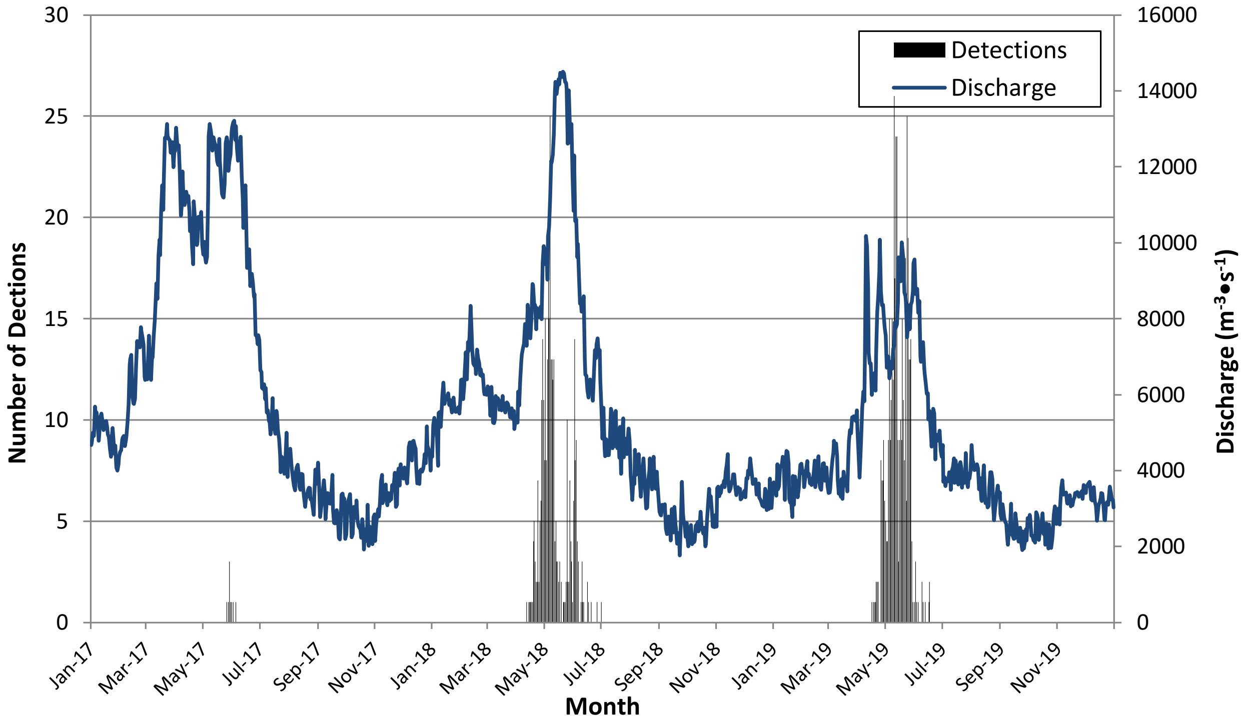
	Number of PIT Tags											Unique Detections			
Stream	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2017	2018	2019	2020
Dillacort	*	*	*	*	*	94	74	83	75	*	*	5	1	0	0
Logging Camp	*	*	*	364		55	416	81	*	*	*	0	2	0	0
Wheeler	*	*	*	167	138	245	178	109	141	*	*	4	0	0	0
Snyder	*	*	*	*	*	654	736	480	613	1,408	*	7	12	17	0
Swale	*	*	*	*	*	218	206	163	302	*	*	1	5	0	0
Bowman	*	*	*	*	*	*	*	*	*	*	523	0	0	0	0
Summit	*	*	*	*	*	*	349	343	298	482	318	1	5	11	0
White	1,723	1,172	2,306	1,763	2,621	1,563	1,120	925	1,526	2,171	811	9	15	15	0
Total	**1,723**	**1,172**	**2,306**	**2,294**	**2,759**	**2,829**	**3,079**	**2,184**	**2,955**	**4,061**	**1,652**	**27**	**40**	**43**	**0**



Appendix H. Percent of unique daily detections of emigrating natural-origin juvenile steelhead (*O. mykiss*) PIT tagged in upstream tributaries and detected at the floating PIT tag interrogation array during calendar years 2018 (n=40; solid bar and line) and 2019 (n=43; dashed bar and line) at river kilometer 4.5, Klickitat River, Washington.



Appendix I. Graph showing the relationship between Klickitat River discharge and number of first time daily captures of emigrating natural-origin juvenile steelhead (*O. mykiss*) collected at the screw trap during calendar years 2017 (n=231), 2018 (n=4,072), and 2019 (n=3,774) at river kilometer 4.5, Klickitat River, Washington.



Appendix J. Graph showing the relationship between Columbia River discharge and number of PIT tagged emigrating natural-origin juvenile steelhead (*O. mykiss*) detected at Bonneville Dam during calendar years 2017 (n=9), 2018 (n=342) and 2019 (n=422), Bonneville Dam, Washington.