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Open-File Report 2022–1117

U.S. Department of the Interior
U.S. Geological Survey

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^2/s)
	Mass	
milligram (mg)	0.00003527	ounce, avoirdupois (oz)
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F = (1.8 × °C) + 32.

Datum

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Altitude, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Abbreviations

CI	confidence interval
CRITFC	Columbia River Intertribal Fish Commission
DPS	Distinct Population Segment
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
FL	fork length
FPC	Fish Passage Center
GSI	Genetic Stock Identification
JMX	Juvenile Migrant Exchange
kHz	kilohertz
LCFRB	Lower Columbia Fish Recovery Board
LCR	Lower Columbia River
LWD	large woody debris
MCR	Middle Columbia River
MS-222	tricaine methanesulfonate
NMFS	National Marine Fisheries Service
NPCC	Northwest Power and Conservation Council
PIT	passive integrated transponder
PTAGIS	PIT Tag Information System
rkm	river kilometer
SAR	smolt-to-adult return
SE	standard error
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VSP	viable salmonid population
WDFW	Washington Department of Fish and Wildlife
WSTWG	White Salmon Technical Work Group
YN	Yakama Nation

Juvenile Salmonid Monitoring to Assess Natural Recolonization Following Removal of Condit Dam on the White Salmon River, Washington, 2016–21

By Ian G. Jezorek and Jill M. Hardiman

Abstract

Condit Dam was removed from river kilometer (rkm) 5.3 of the White Salmon River, Washington, in 2011 and 2012 after blocking upstream passage of anadromous fish for nearly 100 years. The dam removal opened habitat upstream and improved habitat downstream with addition of cobble and gravel to a reach depauperate of spawning and rearing habitat. We assessed juvenile anadromous salmonid abundance and distribution in the subbasin from 2016 through 2021 to evaluate the efficacy of natural recolonization. We sampled for outmigrant smolts and other life-history stages at a rotary screw trap at rkm 2.3 and for juvenile abundance at sites in Buck and Rattlesnake Creeks, two primary tributaries upstream from the former dam location.

We estimated smolt abundance of steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) at the screw-trap site during most years of the study. High flow and missed trapping days in 2017 precluded estimates, and the trap was not fished during 2020 because of the onset of the COVID-19 pandemic. Steelhead smolt-abundance estimates ranged from 3,581 to 5,851 fish; coho salmon smolt-abundance estimates ranged from 1,093 to 1,773 fish, although in 2021, only 2 coho salmon smolt were captured and no estimate was made.

Other species and life stages also were captured in the screw trap. Steelhead and coho salmon fry and parr, and Chinook salmon (*O. tshawytscha*) fry were captured, indicating the presence and likely use of improved habitat downstream from the former dam site by multiple life stages and spawning success upstream from the screw-trap site. Chinook salmon fry were captured, indicating spawning success upstream from the screw-trap site. Fry numbers varied greatly by day and year. Yearly variation in Chinook and coho salmon fry numbers may have been influenced by high flows following spawning causing redd scour and egg-to-fry mortality. Three bull trout (*Salvelinus confluentus*) were caught in the screw trap, one in June 2018, one in June 2019, and one in June 2021. All three bull trout showed smolt characteristics and were tagged with passive integrated transponders (PITs). The bull trout captured in June 2018 was detected at Bonneville Dam Corner Collector several days later, indicating likely anadromy. We also captured lamprey in the screw trap: 44 during 2018, 31 during 2019, and 11 during 2021; we believe most were adult brook lamprey (*Lampetra richardsoni*), although some could have been Pacific lamprey (*Entosphenus tridentatus*) macropthalmia.

We confirmed the presence of juvenile steelhead (through smolt origin data) and coho salmon in Mill, Buck, and Rattlesnake Creeks, which are all upstream from the former site of Condit Dam. Juvenile salmonid abundance sampling at a site in Buck Creek during 2016–20 indicated the presence of juvenile coho salmon in all years except 2020. Total salmonid abundance (steelhead and coho salmon combined) at the Buck Creek site each year exceeded abundance in sampling prior to dam removal in 2009 and 2010. Juvenile salmonid abundance sampling in Rattlesnake Creek during 2016–20 indicated the presence of juvenile coho salmon in 2017, 2018, and 2019. Total juvenile salmonid abundance at the Rattlesnake Creek site was highly variable, sometimes exceeding and sometimes less than abundance prior to dam removal during 2001–05. During the period covered by this report, adult salmonid returns to the Columbia River were decreasing, largely because of marine survival. The extent to which this basin-wide decrease affected adult returns and juvenile populations in the White Salmon River subbasin is not known.

Despite a period of poor marine survival, PIT-tagged smolt and juvenile steelhead and coho salmon from the screw trap and tributaries returned to Bonneville Dam. Smolt-to-adult return rates from the screw trap to Bonneville Dam were similar to those in other nearby rivers during this period. However, data are still incomplete for some years and sample sizes were low. Future tagging and monitoring would be beneficial to track this valuable metric.

Genetic samples from steelhead smolt and parr collected at the screw trap and some main-stem electrofishing during 2016 were analyzed for Genetic Stock Identification (GSI) by CRITFC. Preliminary data showed that White Salmon River fish were the most common at about 42 percent, with 19 percent typing to Hood River, Oregon stock, and about 26 percent typing to Skamania stock, a common hatchery stock in the area. Winter and summer runs were represented in the samples.

Juvenile salmonid sampling in the White Salmon River, Washington, following removal of Condit Dam, demonstrated that anadromous salmonids are using newly opened habitat upstream from the former dam site and improved lower river habitat. Steelhead and coho salmon smolts are being produced upstream from the former dam site, and some have returned to Bonneville Dam as adults. Chinook salmon spawning upstream from our smolt trap site are producing fry. These results are encouraging for success of the strictly natural recolonization strategy. However, declines in anadromous runs to the larger Columbia River Basin also likely have affected the White Salmon runs and our data may not reflect full capacity of the White Salmon River subbasin juvenile production. Continued abundance, distribution, and GSI monitoring will help to track the evolution of anadromous fish in the White Salmon River under a natural recolonization strategy.

Introduction

Condit Dam, on Washington's White Salmon River, blocked upstream fish passage for nearly 100 years. The dam, at river kilometer (rkm) 5.3 (fig. 1), was breached in 2011 and completely removed by September 14, 2012. Ten years after the removal, the river continues to recover, with riparian revegetation and channel evolution in the former reservoir reach, and a large volume of sediment and gravel redistributing from the former dam site to the Columbia River confluence. Gravel bars and shoreline from the reservoir reach to the Columbia River change with each high-water event (Wilcox and others, 2014; Hatten and others, 2016). The White Salmon River historically supported steelhead (*Oncorhynchus mykiss*), spring and fall Chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), and chum salmon (*O. keta*; Cowan, 1999; National Marine Fisheries Service [NMFS], 2013a, 2013b). The river provided local Native Americans with valuable fishing areas (NMFS, 2013b).

The White Salmon River watershed is in the Lower Columbia River (LCR) Evolutionary Significant Unit (ESU) salmon recovery domain and the Middle Columbia River (MCR) Distinct Population Segment (DPS) steelhead recovery domain (NMFS, 2009, 2013b). Removal of Condit Dam opened passage for anadromous salmonids, including LCR Chinook salmon (fall and spring runs), LCR coho salmon and MCR steelhead, which are all listed as threatened under the Endangered Species Act (ESA; NMFS, 2009, 2013a, 2013b). White Salmon River fall and spring Chinook salmon are contributing populations in the Gorge Strata of the LCR ESU, and White Salmon River coho salmon are part of the primary population of the upper part of the Gorge Strata (Lower Columbia Fish Recovery Board [LCFRB], 2010a). However, the ESA Recovery Plan for the White Salmon River Watershed (NMFS, 2013b) suggests that White Salmon River coho salmon may be functionally extinct and spring chinook salmon likely extirpated. White Salmon River steelhead are part of the East Cascades Major Population Group of the MCR steelhead DPS and may include one of the most inland runs of winter steelhead (NMFS, 2013b). In this report, we refer to *O. mykiss* caught in the main-stem screw trap as steelhead because they were actively migrating, but because we did not know migratory status of *O. mykiss* caught in electrofishing surveys, we simply refer to them as *O. mykiss* or steelhead/rainbow trout. The MCR Steelhead ESA Recovery Plan (NMFS, 2009) considered White Salmon River steelhead "functionally extirpated." However, based on migratory life-histories identified by pre-dam removal studies, the plan recognized that potential for anadromy remained from the *O. mykiss* isolated upstream from Condit Dam.

Tagging of *O. mykiss* with radio and passive integrated transponder (PIT) tags upstream from Condit Dam prior to removal revealed migratory life-histories and smoltification. Tagged *O. mykiss* from Rattlesnake Creek, the White Salmon River, and Northwestern Lake (the impoundment behind Condit Dam) indicated fluvial and adfluvial life histories (Allen and others, 2006a). During pre-dam removal studies, one *O. mykiss* PIT-tagged in Buck Creek was detected at Bonneville Dam juvenile passage, one *O. mykiss* PIT-tagged in Rattlesnake Creek was detected at Bonneville Dam in an adult ladder, and a PIT tag from an additional fish from Rattlesnake Creek was detected on East Sand Island in the Columbia Estuary (*O. mykiss* PIT tagged—700 in Buck Creek during 2009 and 2010; 3,946 in Rattlesnake Creek during 2001–05). These data suggested that *O. mykiss* from the White Salmon River watershed still expressed an anadromous life history and could act as a native source for recolonization.

The removal of Condit Dam reopened main-stem and tributary habitat for anadromous fish. Condit Dam blocked 27 kilometers (km) of potential coho salmon habitat, 15 km of potential spring Chinook salmon habitat, 7 km of potential fall chinook salmon habitat, and 50 km of potential steelhead habitat (Northwest Power and Conservation Council [NPCC], 2004; NMFS, 2013a, 2013b). Habitat downstream from the Condit Dam site has improved for salmonid spawning and rearing as gravel and cobbles have distributed throughout (Hardiman and Allen, 2015; Hatten and others, 2016). The newly accessible and improved areas of the White Salmon River comprise a significant habitat gain in the Gorge Strata of the LCR ESU and the East Cascades Major Population Group of the MCR DPS.

Numerous Federal and State plans call for monitoring of listed stocks in ESUs and their subunits to gage viable salmonid population (VSP) status and trends (McElhany and others, 2000; NMFS, 2009, 2013a, 2013b; LCFRB, 2010a, 2010b). These data include direct measures or indices of abundance, population growth rate, population spatial structure, and diversity. Managers need VSP data to inform population status and trends of ESA listed stocks.

Prior to removal of Condit Dam, the White Salmon Technical Work Group (WSTWG) formed to develop a fish-recolonization strategy. The group included representatives of U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (USFWS), U.S. Forest Service, Yakama Nation (YN), Washington Department of Fish and Wildlife (WDFW), NMFS, and PacifiCorp. The WSTWG recommended natural recolonization for each species with 5 years of post-dam removal monitoring (NMFS, 2013b). Following the initial recolonization period, monitoring data would be examined and decisions about recolonization success, management, and supplementation options would be reconsidered for individual species as needed (Allen and others, 2016). The WSTWG's recommendations were accepted by NMFS and incorporated in the ESA Recovery Plan for the White Salmon River Watershed (NMFS, 2013b). However, available funding for monitoring has been minimal.

The ESA Recovery Plan for the White Salmon River Watershed (NMFS, 2013b) set abundance goals for fall Chinook salmon, spring Chinook salmon, coho salmon, chum salmon, and steelhead, and recommends efforts to "monitor current population status and habitat conditions" (NMFS, 2013b, page 8-8). Key questions were as follows: (1) what is the source and abundance of colonizing salmon and steelhead, (2) what is the productivity of those fish, (3) what are limiting factors by life stage, and (4) are those fish producing viable offspring to support population persistence? The recommended monitoring includes population monitoring in the White Salmon River and major anadromous tributaries, PIT-tagging of juvenile salmonids each year to track movement and growth rates, and genetic analysis of smolts and adult salmonids. Population viability criteria include juvenile outmigrant productivity and trends, population diversity, and spatial structure. Data outlined in the ESA Recovery Plan for the White Salmon River Watershed can inform managers about specifics to White Salmon River and Gorge strata populations and contribute to the growing body of dam-removal science.

Dam removals have increased nationwide (O'Connor and others, 2015; Bellmore and others, 2017), and their removal and fish reintroduction involves uncertainty and management concerns regarding physical and biological consequences (Anderson and others, 2014; Tullos and others, 2016). Many dam removals are not scientifically monitored for biological effects or are monitored for a short duration (O'Connor and others, 2015; Brewitt, 2016; Bellmore and others, 2017), and few have biological data before and after removal (Bellmore and others, 2017). More and longer-duration dam removal response studies are required to develop predictive models to inform managers and the public about effects of dam removal (Gregory and others, 2002; Hart and others, 2002; Pess, 2009; Anderson and others 2014; Brewitt, 2016).

The removal of Condit Dam provides an opportunity to evaluate the efficacy of dam removal and natural recolonization as a restoration strategy and to contribute to the science of dam removals. Condit Dam is a relatively unique case to date (December 2022) because it was a high dam (38 meters [m]), and a large amount of sediment was released (1.8 million cubic meters [m^3]; Wilcox and others, 2014; O'Connor and others, 2015), and, to date (2022) there have been no hatchery releases or supplementation. Additionally, data on fish in the White Salmon River watershed pre-dam removal is available.

Several pre-dam removal studies were done in the White Salmon River upstream and downstream from Condit Dam. In Buck and Rattlesnake Creeks, USGS assessed abundance of *O. mykiss* and collected extensive habitat data (Rattlesnake Creek studies from 2001 to 2005, Allen and others, 2003a, 2003b, 2006a, 2006b; Buck Creek studies 2009 and 2010, Allen and others, 2012). To determine species composition and relative abundance downstream from Condit Dam, USGS and USFWS used a rotary screw trap to assess juvenile fish from 2006 through 2009 (Allen and Connolly, 2011). Chinook salmon genetic samples from naturally produced fry captured in the screw trap were analyzed by USFWS to determine relatedness to nearby hatchery tule and upriver bright fall Chinook salmon populations that stray and spawn in the lower White Salmon River (Smith and Engle, 2011). These projects resulted in the finding that, although the non-native Upriver Bright Fall Chinook salmon spawned in greater numbers (based on data from WDFW spawning surveys), native Tule Fall Chinook salmon outmigrants were more common. These existing pre-dam removal data offer a baseline for understanding changes in fish distribution, abundance, and genetics.

In 2008, biologists from USFWS captured adult fall Chinook salmon in the lower White Salmon River and released some upstream from Condit Dam to assess capture methods and potential spawning success (Engle and Skalicky, 2009). This evaluation provided guidance for an effort to transport Chinook salmon prior to the breaching of the dam because during that fall, the release of sediment and debris likely would destroy any redds downstream from the dam. The test effort was successful in capture, transport, and survival to spawning of the adult Chinook salmon.

Limited monitoring on the White Salmon River had been done since the removal of Condit Dam, but the members of the WSTWG continued to coordinate (Allen and others, 2016) despite minimal funding. Chinook salmon spawning surveys were done by USFWS in 2012 and have been continued since by WDFW, following VSP guidelines (McElhany and others, 2000; Crawford and Rumsey, 2011) to estimate adult abundance and distribution and to investigate adult origin through tag recovery and genetic sampling (Allen and others, 2016; Elise Olk, WDFW, written commun., 2019). Chinook salmon spawning surveys have identified that fall and spring Chinook have spawned in the White Salmon River upstream from the former dam site (Elise Olk, WDFW, written commun., 2019), although spawning success in those locations was unknown. Steelhead spawning surveys in tributaries were done by YN from 2012 through 2020 (Allen and others, 2016; Joe Zendt, YN Fisheries, written commun., 2016), when a volunteer effort coordinated by WDFW began, which for the first time in White Salmon River, included coho salmon spawning surveys.

Steelhead and coho salmon spawning survey limitations and difficulties (prolonged spawning period, high flows, turbidity, iteroparity) are exacerbated by the confined and high-gradient character of the main-stem White Salmon River. Steelhead spawning surveys in tributaries are providing spatial distribution data and an index of abundance, but not a subbasin adult population estimate. Additionally, it was unknown if steelhead and coho spawning in tributaries were producing viable anadromous offspring. Because of the challenges of surveying adult steelhead and coho salmon, a monitoring approach that includes smolt and juvenile abundance and life-history data was needed. The LCFRB's Research Monitoring and Evaluation Program for Lower Columbia Salmon and Steelhead (LCFRB, 2010a, page 26) states, "Juvenile surveys are particularly useful for population status assessments where spawner surveys are difficult," and that "juvenile census sampling can provide extensive information on abundance and productivity." A combination of adult and juvenile monitoring will provide the most robust information to assess the efficacy of natural recolonization and to inform management actions in the White Salmon River watershed.

During 2016, USGS began monitoring of juvenile salmonids in the White Salmon River post-dam removal and this report conveys findings from 2016 to 2021. The goals of our work were to assess (1) smolt production from anadromous spawning upstream from rkm 2.3; (2) juvenile salmonid distribution throughout the watershed; and (3) juvenile salmonid abundance in select reaches of Rattlesnake and Buck Creeks, two primary tributaries of the White Salmon River. We assessed smolt production with a rotary screw trap at rkm 2.3, which is a new location for a rotary screw trap in the White Salmon River (the site used from 2006 through 2009 at rkm 1.5 is no longer viable because of sediment deposition, a very dynamic channel, and lack of access). We assessed juvenile salmonid distribution and abundance by backpack electrofishing. Because we used PIT tags for mark-recapture estimates, future recaptures or detections of these fish will contribute to knowledge of life-history diversity of naturally produced salmonids in the White Salmon River. These data are (1) helpful in evaluating (a) the efficacy of dam removal as a restoration and recovery strategy, and (b) the efficacy of a natural recolonization strategy for anadromous salmonids; and (2) in informing managers of the status of salmonid stocks listed as threatened under the Endangered Species Act.

Description of Study Site

The White Salmon River watershed encompasses about 1,000 square kilometers (km^2) of Klickitat, Yakima, and Skamania Counties in south-central Washington (Haring, 2003). The White Salmon River is a tributary of the Columbia River at rkm 270 (fig. 1). The topography of the surrounding area is varied, including mountains, deeply incised canyons, rolling hills, and low-gradient valley floors (NPCC, 2004; NMFS, 2013b). The White Salmon River is in the transitional ecotone between the more moderate coastal maritime climate zone and the more continental inland climate zone. The climate is temperate, and about 80 percent of the annual precipitation falls between October and March. Precipitation in the winter is primarily rain in the lower watershed, and rain or snow in the higher altitudes, and ranges from 100 centimeters in the east to 240 centimeters in the north and west (NPCC, 2004).

Water quantity and quality in the White Salmon River are favorable for salmonids (Haring, 2003; NPCC, 2004; Allen and Connolly, 2005). Mean daily main-stem discharge varies from about 19 cubic meters per second (m^3/s) during fall to about 44 m^3/s in spring (USGS streamgage 14123500 [White Salmon River Near Underwood, WA]; Haring, 2003). Water temperatures in the main stem remain cold throughout the year, with maximum and minimum temperatures and dissolved oxygen concentrations favorable for salmonids. Discharge is maintained by cold springs and seeps fed by high-altitude snowmelt (Haring, 2003; NPCC, 2004; Allen and Connolly, 2005). Much of the main-stem White Salmon River is in a narrow, naturally incised bedrock and boulder canyon (NPCC, 2004; Plummer and Zuckerman, 2012).

The main-stem White Salmon River has many waterfalls. The largest is Big Brother Falls (about 7.3 m high) at rkm 26, which is likely the upstream extent of anadromous distribution. BZ Falls (about 4.5 m high) is at rkm 20 and is likely a barrier to salmon, although steelhead can most likely ascend it (Reiser and others, 2006). Husum Falls (about 3 m high) is at rkm 12.2, and is a barrier to some salmon, although Spring Chinook salmon and their redds have been found upstream from it (Allen and others, 2016; Jeremy Wilson, WDFW, written commun., 2016).

The characteristics of the lower 8.0 km of the main-stem White Salmon River have rapidly changed since the breaching of Condit Dam at rkm 5.3. An estimated 1.8 million m^3 of reservoir sediments were impounded (Wilcox and others, 2014) behind Condit Dam. The dam was breached with an explosive blast that opened a 3.6 × 5.5-m hole at the base, rapidly emptying the reservoir (Wilcox and others, 2014). This exposed the old river channel in the reservoir reach and the outflow of silt, sand, and gravel filled pools throughout the lower river created gravel bars and sediment deposits at the confluence with the Columbia River. This influx of sediment to the lower river has increased salmonid spawning habitat (Hardiman and Allen, 2015; Hatten and others, 2016) and improved rearing habitat. Natural watershed processes delivering large woody debris (LWD), cobbles, and gravel to the lower reaches have been restored (Wilcox and others, 2014; Hardiman and Allen, 2015; Allen and others, 2016; Hatten and others, 2016).

Four tributaries to the White Salmon River in our study area were accessible to anadromous fish. Mill, Buck, Spring, and Rattlesnake Creeks all enter the White Salmon River between the former dam site and Husum Falls. We sampled fish in Mill, Buck, and Rattlesnake Creeks, but did not have permission to access Spring Creek.

Mill Creek flows to the White Salmon River from the west at rkm 6.4 (fig. 1). The drainage basin is 11 km^2, with a mix of private- and Washington State-owned lands. Altitude ranges from 90 m at the confluence with the White Salmon River to about 800 m in the headwaters. The basin is steep and heavily forested. Plummer and Zuckerman (2012) reported many springs contributing flow to Mill Creek, which presumably maintain low water temperatures and a stream bed with many areas of gravel and cobble suitable for spawning. Length estimates of potential habitat for anadromous fish in Mill Creek range from 3.2 to 7 km (NPCC, 2004; Plummer and Zuckerman, 2012).

Buck Creek flows into the White Salmon River from the northwest at rkm 7.5 (fig. 1). The watershed is 36 km^2, about 90 percent of which has been managed by Washington Department of Natural Resources since 1921. Altitude in the drainage basin ranges from 92 m at its mouth to 1,219 m at its headwaters. The drainage basin is characterized by primarily forested (second growth and early successional mixed conifer and deciduous), steep canyons with an incised basalt bedrock channel. Since 1923, the City of White Salmon has been diverting water for its municipal supply from Buck Creek, with a 10-year hiatus during 2000–10 owing to surface water contamination. Buck Creek was brought back online as the consumptive supply source on July 23, 2010, after completion of construction of the Buck Creek sand filtration plant at an altitude of 327 m downstream from the city's concrete headworks dam.

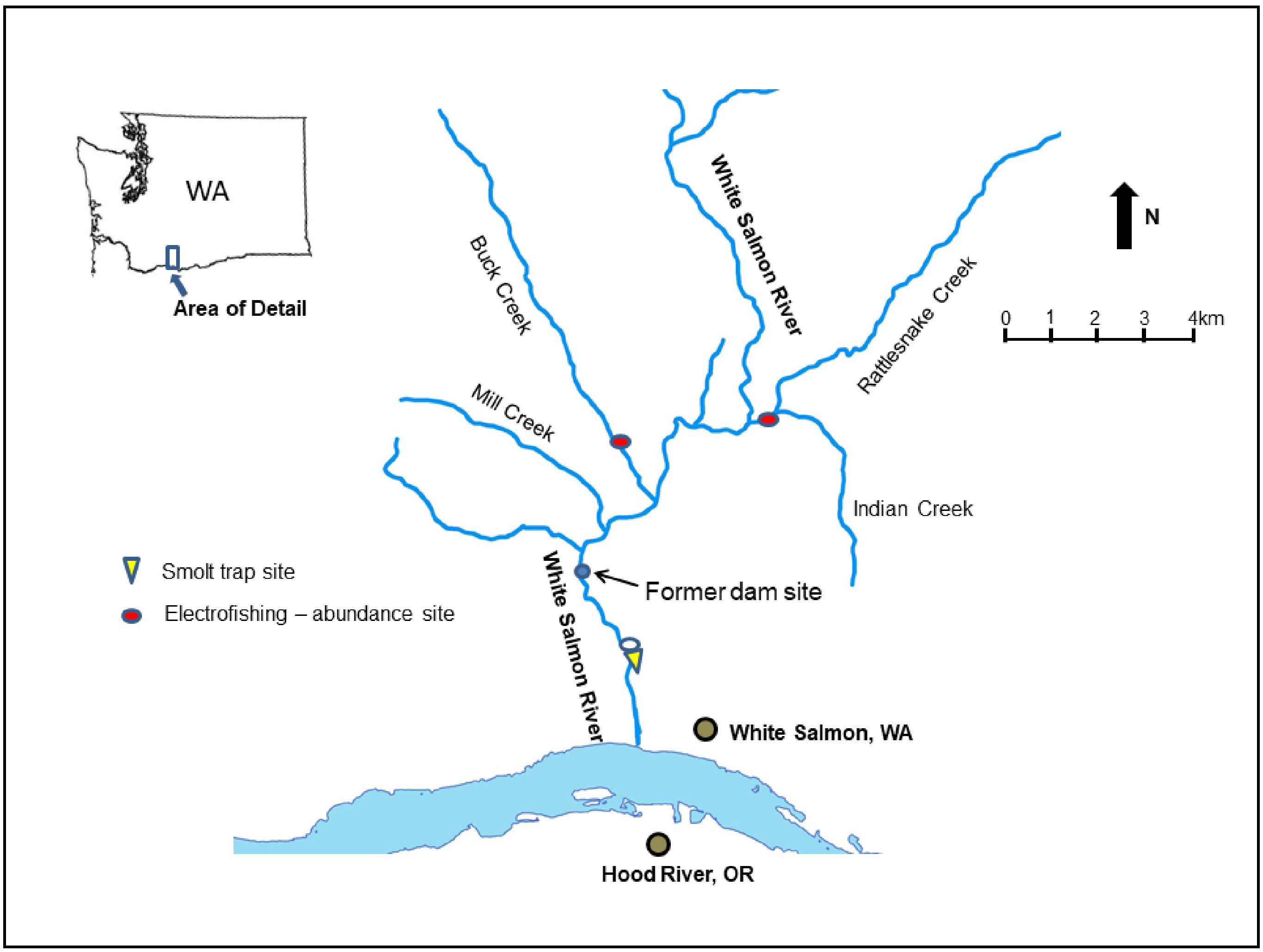

Figure 1. White Salmon River watershed accessible to anadromous salmonids and the locations of rotary screw trapping and electrofishing surveys, Washington, 2018–21. The former location of Condit Dam, which was breached in 2011, also is shown. OR, Oregon; WA, Washington.

Allen and others (2012) defined four reaches in the part of Buck Creek accessible to anadromous fish. Reach 1 began at the confluence with the White Salmon River and extended upstream 2.0 km to a narrowing of valley confinement. Reach 2 was confined by valley walls and extended from rkm 2.0 to 3.1, where there was a 1.1-m-high irrigation diversion dam (0.76 m concrete dam with 0.35-m-high seasonal, wooden flash boards), which has a water right for 0.004 m^3/s (Aspect Consulting, 2011). The diversion dam was thought to be a partial barrier to upstream fish movement and was removed in 2019 and replaced by a roughened channel that is passable to fish. Reach 3 extended from rkm 3.1 to 5.0, where there is a 4.3-m waterfall. Reach 4 extended from rkm 5.0 to 6.4, where there is a 6-m waterfall (the likely end of anadromy and immediately downstream from the City of White Salmon municipal water facility). A habitat survey by Allen and others (2012) noted that most habitat in Buck Creek was large cobble riffles. Boulders and cobbles were the dominant substrate with little spawning gravel. They reported instream LWD to be less frequent and smaller than in unmanaged basins of similar size and character. Minimum discharge in Buck Creek was reported by Allen and others (2012) as 0.02 m^3/s at the mouth, and 0.009 m^3/s downstream from the water diversion at rkm 3.1. Water temperatures in Buck Creek were favorable to salmonids. Temperatures at the lower end of Buck Creek only occasionally exceeded 16 degrees Celsius (°C) and never exceeded 18 °C during 2009 and 2010 (Allen and others, 2012). Our Buck Creek fish sampling site for the work presented in this report was near the upper end of reach 2 about 500 m downstream from the diversion dam. This site is within the same section of reach 2 sampled by Allen and others (2012).

Rattlesnake Creek flows to the White Salmon River from the east at rkm 13.8 (fig. 1). The Rattlesnake Creek watershed covers 143 km^2, nearly all privately owned forest and agricultural land. The altitude is 114 m at the mouth and 927 m at headwater ridge tops. Two notable sets of waterfalls are present in Rattlesnake Creek. The lower set of falls, at rkm 2.4, has three individual drops, with the middle one being the largest (about 3.6-m total height, but with a step and 1.5-m-deep pocket at 2.1 m). The lower falls are likely a barrier to resident fish and salmon but are passable to steelhead. Adult steelhead and redds have been confirmed upstream from these falls (Joe Zendt, Yakama Nation Fisheries, written commun., 2021). The upper falls, at rkm 17, has two separate drops of about 22–25 m each and is a fish barrier.

Allen and others (2006a) defined four reaches in Rattlesnake Creek based on geomorphology and potential fish barriers. The lowermost reach was from the confluence with the White Salmon River to the lower set of waterfalls at about rkm 2.4. The next reach was a canyon section that extended from the lower falls for about 3.1 km to a lessening of valley confinement. The next upstream reach was a less-constrained alluvial reach extending 5.3 km to the beginning of another canyon section. The uppermost reach extended about 6.6 km to the base of the upper falls. Allen and others (2006a) reported that habitat conditions in all reaches of Rattlesnake Creek were poor. Pool frequency and quality were low. Counts of LWD were low, and in many areas the riparian condition was degraded (Allen and others, 2006a; Plummer and Zuckerman, 2012). Our Rattlesnake Creek fish sampling site for the work presented in this report was in the lower end of reach 1 about 200 m upstream from the confluence with the White Salmon River. This site is within the same section of reach 1 sampled by Allen and others (2006a, 2006b).

Discharge in Rattlesnake Creek is extremely low during summer (NPCC, 2004; Allen and Connolly, 2005; Allen and others, 2006a, 2006b; Plummer and Zuckerman, 2012). Discharge near the mouth of Rattlesnake Creek can be less than 0.0018 m^3/s, and surface flow in riffles is barely discernible in some reaches. Water temperature in Rattlesnake Creek is high and can approach lethal limits for salmonids, frequently exceeding 20 °C, with a maximum temperature of 23.6 °C at rkm 0.9 (Allen and others, 2006b).

Methods

Smolt Trapping

We operated a 1.5-m-diameter rotary screw trap (E.G. Solutions, Corvallis, Oregon) at rkm 2.3 of the White Salmon River (fig. 1) during spring of 2018, 2019, and 2021 to estimate salmonid steelhead and coho salmon smolt abundance, species compositions, and life-stage diversity. Screw trapping was not done during 2020 because of the outbreak of the COVID-19 pandemic and subsequent “stay-at-home” orders from the Washington Governor’s Office and lack of USGS protocols in place for working safely. The trap also was operated at this location during 2016 and 2017 (Jezorek and Hardiman, 2017, 2018).

The screw trap was operated continuously during trapping periods each year; occasional outages occurred because of high water or debris. Each day, debris was removed from the live box, and captured fish were netted into buckets and transported to shore. Captured fish were held in buckets or coolers with ambient aerated stream water. Fish were anesthetized with 50 milligrams per liter of tricaine methanesulfonate (MS-222), identified to species, measured for fork length (FL) to the nearest millimeter (mm), and weighed to the nearest 0.1 gram (g). All salmonids captured were classified to life stage as fry (< 46 mm FL), parr, transitional, or smolt. Salmonids were checked for marks to determine if they were recaptures. Fish 70 mm or greater FL were scanned for PIT tags and PIT-tagged (12-mm, 134.2-kilohertz [kHz] tags; Biomark, Boise, Idaho) if not previously tagged. Tags were injected into the peritoneal cavity following methods outlined by Columbia Basin Fish and Wildlife Authority (2014). Tissue samples were collected from samples of all species found (first 10 fish found per day).

Scale samples were taken from most steelhead smolts during 2021 for aging by WDFW personnel. Five to eight scales were removed from the lateral line below and just posterior to the dorsal fin.

Capture efficiency, defined as the percentage of fish passing the trap that are captured (Thedinga and others, 1994), is a valuable variable to measure to estimate the total number of migrating fish. We calculated capture efficiency and migrant estimates following standard methods outlined in Volkhardt and others (2007). Each day, newly marked fish (PIT-tagged or fin clipped) were transported by vehicle to an access point at the PacifiCorp Powerhouse at rkm 3.0 where they were released. Recaptured fish and fry were released each day downstream from the trap. We estimated the number of smolt migrants and associated variance as:

$$\hat{U} = \frac{u(M+1)}{(m+1)} \quad (1)$$

$$V(\hat{U}) = \frac{(M+1)(u+m+1)(M-m)u}{(m+1)^2(m+2)} \quad (2)$$

where

- $\hat{U}$ is the estimate of unmarked fish migrating during sample period,
- u is the number of unmarked fish captured during sample period,
- M is the number of fish marked and released during sample period,
- m is the number of marked fish captured during sample period, and
- V is the variance.

All screw-trap data were electronically entered on a field computer provided by WDFW and configured to accept data into their Juvenile Migrant Exchange (JMX) database. All screw-trap data were entered into the JMX database. All mark and recapture data from PIT-tagged fish were provided to the PIT Tag Information System (PTAGIS) database administered by the Pacific States Marine Fisheries Commission. Estimates of smolt migrants will be provided to the Coordinated Assessments Database.

Electrofishing

We used backpack electrofishing to assess juvenile salmonid abundance at a site in the most downstream reach of Rattlesnake Creek (starting at rkm 0.2; site length, 245 m) and a site in reach 2 of Buck Creek (starting at rkm 2.0; site length, 222 m) during summer 2018, 2019, and 2020 (fig. 1). Funding was not available for electrofishing sampling in 2021. Both reaches were sampled in 2016 and 2017, as well as for multiple years prior to Condit Dam removal (Rattlesnake Creek 2001–05, Allen and others, 2006a, 2006b; Buck Creek 2009 and 2010, Allen and others, 2012). Other reaches of Rattlesnake and Buck Creeks were sampled prior to dam removal, but we lacked funding to sample all of them following dam removal. The two sites selected had the most consistent sampling record prior to dam removal, allowing the best pre-and post-removal comparison.

We estimated abundance of fish using the mark-recapture methods outlined in Temple and Pearsons (2007). Each stream section was about 220 m long, and we block-netted the stream at the upstream and downstream ends. The net lead lines were secured to the streambed with boulders and large cobble and the upper net line was tied off so that it was at least 0.5 m above the water surface.

Once the nets were secured to prevent immigration or emigration, we electrofished the section in an upstream pass to collect and mark fish. Two or three crew members dip-netted fish, which were immediately placed in buckets or coolers with ambient, aerated stream water. Captured fish were anesthetized with the lightest possible dose of MS-222, measured for FL to the nearest mm, weighed to the nearest 0.1 g, and marked. Salmonids with a 70-mm or greater FL were PIT-tagged with a 12-mm tag, and salmonids with a 60–69-mm FL were PIT-tagged with a 9-mm tag (both tags were 134.2 kHz). Salmonids less than 60 mm in size were given a caudal fin clip. Fish were released as close as possible to their point of capture. Block nets were left overnight, and the following day we repeated the electrofishing effort as a recapture pass. During fish workup for the recapture pass, all fish were checked for a PIT tag or fin clip mark. Fin clips from fish too small to tag were archived for potential genetic analysis, and genetic clips were taken from at least 20 larger fish as well.

Mark-recapture estimates followed methods outlined in Temple and Pearsons (2007). We used length-frequency histograms to assign ages to age-0 and age-1 or older fish. We estimated the abundance of fish and associated variance, by species and age class (age-0, and age-1 and older) in study reaches using Chapman's modification of the Peterson estimate (Chapman, 1951), as follows:

$$\hat{N} = \left[\frac{(M+1)(C+1)}{(R+1)}\right] - 1, \text{ and} \quad (3)$$

$$V(\hat{N}) = \frac{(\hat{N}^2)(C-R)}{(C+1)(R+2)} \quad (4)$$

where

- $\hat{N}$ is the population estimate,
- M is the number of fish marked during the mark sample effort,
- C is the total number of fish captured in the recapture sample effort,
- R is the number of marked fish captured in the recapture sample effort, and
- V is the variance.

To quantify habitat area, we measured width and depth at 10 or more transects, equally spaced through the mark-recapture section. With these data, we calculated the study section length and area to estimate fish-per-meter and fish-per-square meter.

Results

Smolt-Trapping Results

During all sample years (2016–19 and 2021), we captured steelhead, coho salmon, and Chinook salmon in the screw trap (table 1). Multiple life stages were observed for each species. We estimated steelhead smolt abundance during 2016, 2018, 2019, and 2021 (range = 3,581–5,851; table 2). We estimated coho salmon smolt abundance during 2016, 2018, and 2019 (range = 1,093–1,773; table 2). During 2017, extreme high flow and missed sampling days owing to debris and high water precluded making viable estimates. During 2021, we did not capture enough coho salmon smolts (n = 2) to generate an estimate. Age-0 Chinook salmon were batch-marked with Bismark Brown dye on numerous occasions but were not recaptured enough to generate a fry migrant estimate. Capture of age-0 Chinook salmon varied greatly by year (table 1) and by day. We took genetic samples from fish of each species and of multiple life stages during all sample years (table 1). Detailed results of 2016 and 2017 screw trapping are available in Jezorek and Hardiman (2017, 2018).

During 2018, the screw trap was fished continuously from March 27 to June 15, except for 4 days because of high water or thunderstorms (sample days = 76). Flow was generally moderate. Recapture rates during 2018 were 6.9 percent for steelhead smolts and 10.4 percent for coho salmon smolts. Steelhead and coho salmon smolt estimates were 5,841 and 1,163, respectively (table 2; fig. 2).

During 2019, the screw trap was fished continuously from March 25 to June 12, except for 4 days because of high water or thunderstorms (sample days = 75). Flow was moderate to low. Recapture rates during 2019 were 8.1 percent for steelhead smolts and 10.7 percent for coho salmon smolts. Steelhead and coho salmon smolt estimates were 4,031 and 1,773, respectively (table 2; fig 2).

During 2021, the screw trap was fished continuously from March 29 to June 8, with moderate to low flow. We captured steelhead fry, parr, and smolt (table 1). The recapture rate for steelhead smolts was 7.6 percent. The steelhead smolt estimate was 3,876 (95-percent confidence interval [CI], 2,362–5,389), which was similar to estimates in both 2016 and 2019 (table 2; fig 2), but less than the estimate of 5,851 in 2018. Few coho salmon were captured in 2021 (table 1; fry, n = 1; smolt, n = 2), and it was not possible to generate a smolt estimate. Few Chinook salmon were caught in 2021 (table 1; fry, n = 14; parr, n = 1). Scale samples were taken from steelhead smolts during 2021 for ageing and were processed by WDFW personnel. One hundred and fifty-four steelhead smolts were aged, 16 (10.4 percent) were age-1, 128 (83.1 percent) were age-2, and 10 (6.5 percent) were age-3.

Screw trapping provided timing data of fish movement in the lower river. Age-0 coho and Chinook salmon typically were present throughout the sampling period. Age-0 steelhead were present through the sampling period in 2018 and 2019; during 2016, first capture was on May 7, and during 2017, first capture was on May 17. We were not able to determine any peak of age-0 abundance owing to the capture of age-0 fish being highly dependent upon debris load and operation of the cleaning drum (age-0 fish easily get rotated out). Each year, steelhead parr were present throughout the season. The date for 50-percent capture of steelhead parr varied from April 25 to May 18; however, parr capture rate was relatively steady throughout the sample periods without a pronounced peak. The extent of parr movement past our spring monitoring period is unknown. First capture of steelhead smolts occurred during the last week of March (except in 2017, when sampling started later because of high water) and last capture generally occurred around the second week of June (except in 2016, when sampling ended early because of damage to the trap). The date range of 50-percent capture of steelhead smolts was from May 1 to 10. First capture of coho salmon smolts ranged from March 25 to April 20 and last capture occurred during the first or second week of June (except in 2016). The date range of 50-percent capture of coho salmon smolts was from May 7 to May 11.

During our screw-trap sampling efforts, we periodically captured steelhead smolts previously tagged in the Hood River, Oregon as parr or smolts. Two steelhead smolts captured in the screw trap in 2018 were PIT-tagged as parr in the Hood River during 2017, one as a 104-mm parr at the main-stem screw trap on May 25, 2017, and the other as a 139-mm parr in the East Fork Hood River screw trap on September 27, 2017. Neither of these fish were detected at the PIT-tag interrogation site at the mouth of the Hood River, so we do not know when they migrated from the Hood River to the White Salmon. During 2019, two steelhead smolts captured at the White Salmon screw trap were originally PIT-tagged in the Hood River during 2018, one at the East Fork Hood River screw trap on May 23, 2018 (FL = 153 mm), and the other at the main-stem screw trap on September 14, 2018 (FL = 170 mm). The fish from the East Fork Hood River trap was detected at the mouth of the Hood River PIT-tag detection system on November 5, 2018.

Other fish of interest captured during screw-trap sample efforts include lamprey and bull trout. We captured 44 lamprey in the screw trap during 2018, 31 lamprey during 2019, and 11 lamprey during 2021. Genetic samples were collected from lamprey for years 2016–21. We captured three bull trout in the screw trap, one on June 5, 2018 (FL = 193), one on June 10, 2019 (FL = 153 mm) and one on June 4, 2021 (FL = 177 mm). All three showed smolt characteristics, had genetic samples taken, and were PIT-tagged. The bull trout captured on June 5, 2018 was detected at Bonneville Dam Corner Collector on June 7, 2018, indicating likely anadromy.

Table 1. Number of steelhead (*Oncorhynchus mykiss*), Chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*), by life stage, captured, tagged with passive integrated transponder (PIT) tags, and sampled for genetic material at the screw trap at river kilometer 2.3, White Salmon River, Washington, **Sampling dates:** March 24–May 28, 2016; April 11–June 12, 2017; March 27–June 15, 2018; March 25–June 12, 2019; and March 29–June 8, 2021.

[Fry were 45 millimeters in fork length or less. **2016–21 Year:** The trap was fished for 62 days in 2016, 45 days in 2017, 76 days in 2018, 75 days in 2019, and 73 days in 2021. **Abbreviations:** N, number of fish captured; PIT-tagged, passive integrated transponder-tagged; Gen**.,** fin tissue sample taken for genetic analysis; NA, not applicable—fry were not PIT-tagged. --, no data]

Life stage	Steelhead			Chinook salmon			Coho salmon		
	N	PIT-tagged	Gen.	N	PIT-tagged	Gen.	N	PIT-tagged	Gen.
2016									
Fry	9	NA	0	4	NA	2	19	NA	17
Parr	23	20	21	0	0	0	2	0	2
Smolt	153	150	149	0	0	0	82	79	79
Total	**185**	**170**	**170**	**4**	**0**	**2**	**103**	**79**	**98**
2017									
Fry	14	NA	1	203	0	124	55	NA	0
Parr	61	57	59	19	3	16	25	12	0
Smolt	40	39	40	1	1	1	13	11	2
Total	**115**	**96**	**100**	**223**	**4**	**141**	**93**	**23**	**2**
2018									
Fry	23	NA	0	239	NA	132	58	NA	19
Parr	54	46	37	3	0	3	4	0	4
Smolt	404	403	278	2	2	3	122	117	109
Total	**481**	**447**	**315**	**244**	**2**	**138**	**184**	**117**	**132**
2019									
Fry	12	NA	2	147	NA	101	80	NA	12
Parr	66	52	46	11	0	11	8	4	8
Smolt	328	321	267	1	0	1	196	191	151
Total	**396**	**373**	**315**	**159**	**0**	**113**	**284**	**195**	**171**
[1]2020									
Not fished	--	--	--	--	--	--	--	--	--
2021									
Fry	2	NA	1	14	NA	13	1	NA	1
Parr	40	36	39	1	1	1	0	--	--
Smolt	308	301	280	0	0	0	2	2	2
Total	**350**	**337**	**319**	**15**	**1**	**14**	**3**	**2**	**3**

[1]The trap was not fished in 2020 because of the COVID-19 pandemic.

Table 2. Number of steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) smolt, and age-0 Chinook salmon (*O. tshawytscha*) captured, marked, and recaptured at the smolt trap at river kilometer 2.3, White Salmon River, Washington, 2016–21.

[Because of prolonged high water and missed trapping days during 2017, we could not generate estimates. We did not fish the trap during 2020 because of the onset of the COVID-19 pandemic. **Sampling dates:** March 24–May 28, 2016; April 11–June 12, 2017; March 27–June 15, 2018; March 25–June 12, 2019; and March 29–June 8, 2021. **Year and species:** The trap was fished for 62 days in 2016, 45 days in 2017, 76 days in 2018, 75 days in 2019, and 73 days in 2021. **Abbreviations:** SE, standard error; 95-percent CI, 95-percent confidence interval; NA, not applicable]

Species	Number captured	Number marked	Number recaptured	Estimate	SE	95-percent CI
			2016			
Steelhead	153	150	5	3,851	1,454	1,001–6,700
Coho	82	79	5	1,093	412	286–1,900
Age-0 Chinook	4	0	NA	NA	NA	NA
			2017			
Steelhead	40	39	1	NA	NA	NA
Coho	13	12	0	NA	NA	NA
Age-0 Chinook	222	192	4	NA	NA	NA
			2018			
Steelhead	420	403	28	5,851	1,064	3,765–7,937
Coho	127	118	12	1,163	307	559–1,766
Age-0 Chinook	242	168	1	NA	NA	NA
			2019			
Steelhead	[1]338	321	26	4,031	758	2,546–5,516
Coho	[1]198	187	20	1,773	375	1,038–2,507
Age-0 Chinook	159	79	0	NA	NA	NA
			2020			
Not fished	--	--	--	--	--	--
			2021			
Steelhead	308	301	23	3,876	772	2,362–5,389
Coho	2	2	0	NA	NA	NA
Age-0 Chinook	14	0	NA	NA	NA	NA

[1]Includes estimated catch for missed sample days.

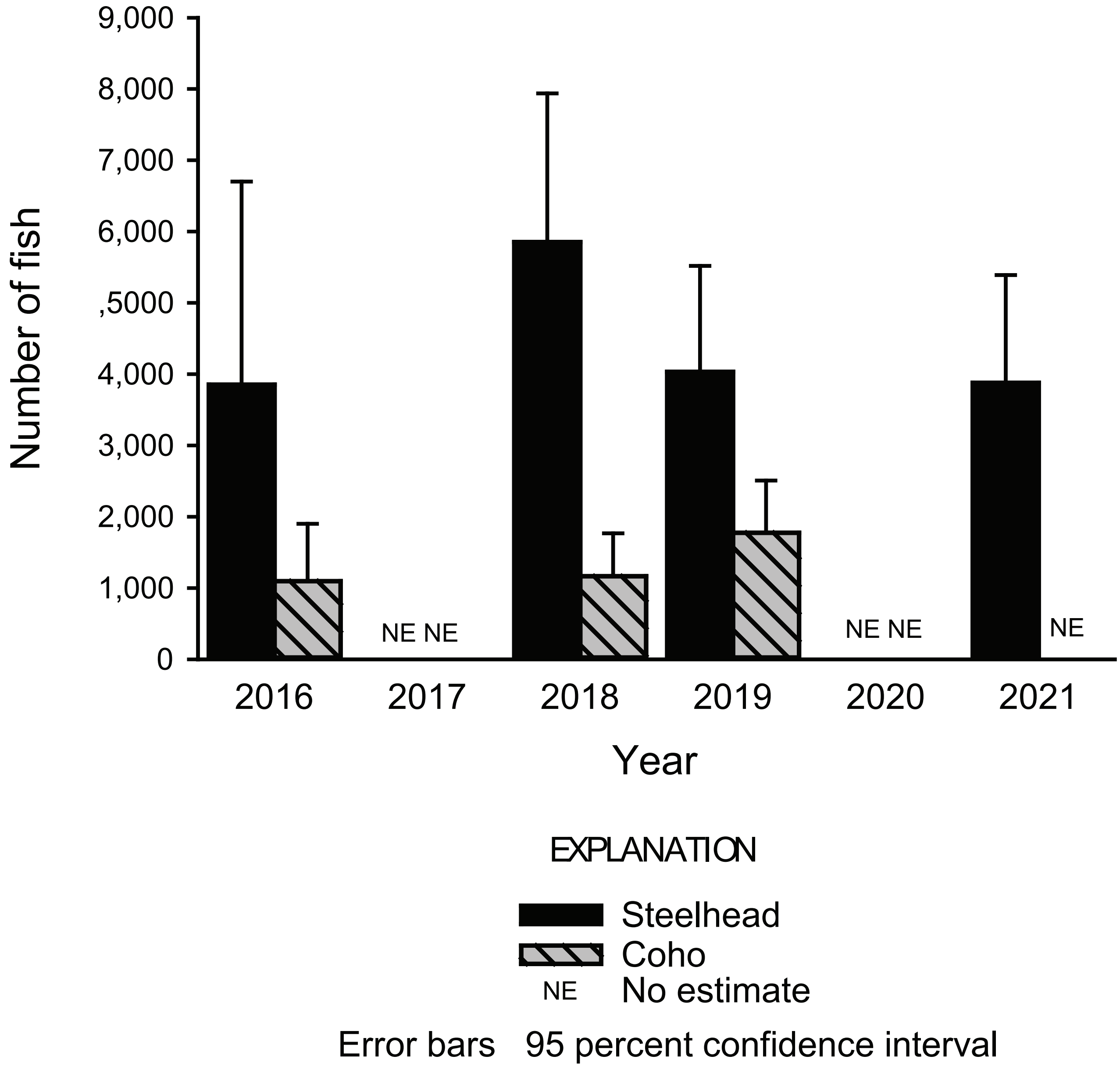

Figure 2. Steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) smolt estimates at a screw trap operated at river kilometer 2.3 of the White Salmon River, Washington, 2016–21. Estimates could not be generated during 2017 because of prolonged high water and trap outage days, the trap was not fished during 2020 because of the COVID-19 pandemic, and only two coho salmon smolts were captured in 2021. * indicates that two coho salmon were captured in 2019, but we could not generate an abundance estimate. Error bars indicate upper half of 95-percent confidence intervals.

Electrofishing Results

During 2016–20, we estimated abundance of age-0 and age-1 or older *O. mykiss* and age-0 coho salmon in sections of Rattlesnake (table 3; fig 3) and Buck Creeks (table 4; fig. 4). We determined that *O. mykiss* from multiple cohorts were present in both creeks each year. In Rattlesnake Creek, age-0 *O. mykiss* abundance ranged from 0.7 to 3.6 fish per meter (fish/m; mean = 1.8), and age-1 or older *O. mykiss* abundance ranged from 0.1 to 0.3 fish/m (mean = 0.2). In Buck Creek, age-0 *O. mykiss* abundance ranged from 1.2 to 3.0 fish/m (mean = 2.4), and age-1 or older *O. mykiss* abundance ranged from 0.5 to 1.1 fish/m (mean = 0.8). Age-0 coho salmon were found in the Rattlesnake Creek sample site in 2017, 2018, and 2019; the abundance range when present was 0.1 to 0.9 fish/m. Age-0 coho salmon were found in the Buck Creek sample site in all years except 2020 (and only 2 individuals were found in 2019); the abundance range during 2016–18 was 0.5–0.7 fish/m. Detailed results of 2016 and 2017 sampling in Rattlesnake and Buck Creeks are available in Jezorek and Hardiman (2017 and 2018).

During 2018, we estimated abundance of age-0 and age-1 and older salmonids in sections of Rattlesnake and Buck Creeks (tables 3–4). Abundance of age-0 *O. mykiss* during 2018 was 1.2 fish/m (standard error [SE] = 0.11) at the Rattlesnake Creek site and 2.9 fish/m (SE = 0.27) at the Buck Creek site. Abundance of age-1 and older *O. mykiss* was 0.2 fish/m (SE = 0.03) at the Rattlesnake Creek site and was 0.5 fish/m (SE = 0.04) at the Buck Creek site. Abundance of age-0 coho salmon during 2018 was 0.9 fish/m (SE = 0.08) at the Rattlesnake Creek site and 0.6 fish/m (SE = 0.07) at the Buck Creek site.

During 2019, we estimated abundance of age-0 and age-1 and older salmonids in sections of Rattlesnake and Buck Creeks (tables 3–4; figs. 3–4). During 2019, abundance of age-0 *O. mykiss* in the Rattlesnake Creek section was 0.7 fish/m (SE = 0.06) and in the Buck Creek section was 2.0 fish/m (SE = 0.13). Abundance of age-1 and older *O. mykiss* was 0.3 fish/m (SE = 0.02) at the Rattlesnake Creek site and was 0.8 fish/m (SE = 0.05) at the Buck Creek site. Abundance of age-0 coho salmon during 2019 was 0.1 fish/m (SE = 0.01) at the Rattlesnake Creek site. We only captured two age-0 coho salmon in Buck Creek during 2019 and thus could not generate an abundance estimate (one of the two fish was recaptured during the recapture day).

Table 3. Abundance estimates and standard error, fish per meter, and fish per meter squared of steelhead/rainbow trout (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) at an abundance electrofishing site in Rattlesnake Creek, Washington, in fall 2016, 2017, 2018, 2019, and 2020.

[No coho salmon were captured during 2016 or 2020. **Age:** ≥, greater than or equal to. **Site and species:** Sth/Rbt, *O. mykiss* (steelhead or rainbow trout). **SE:** Standard error for abundance estimate column to left]

Species	Age (year)	Number of fish marked	Number of fish captured	Number of fish recaptured	Abundance estimate	SE	Fish per meter	Fish per meter squared
				2016				
Sth/Rbt	0	125	149	25	727	113.3	3.6	0.46
Sth/Rbt	≥1	7	3	1	16	5.7	0.1	0.01
				2017				
Sth/Rbt	0	165	157	49	525	50.8	2.4	0.35
Sth/Rbt	≥1	41	34	20	70	6.7	0.3	0.05
Coho	0	45	39	15	115	17.4	0.5	0.08
				2018				
Sth/Rbt	0	118	111	44	296	26.6	1.2	0.18
Sth/Rbt	≥1	32	22	12	58	8.0	0.2	0.04
Coho	0	84	102	39	219	19.5	0.9	0.13
				2019				
Sth/Rbt	0	85	70	36	165	14.0	0.7	0.11
Sth/Rbt	≥1	41	40	23	72	6.0	0.3	0.05
Coho	0	25	12	9	34	3.8	0.1	0.02
				2020				
Sth/Rbt	0	129	138	55	323	24.9	1.3	0.20
Sth/Rbt	≥1	15	19	9	32	4.2	0.1	0.02

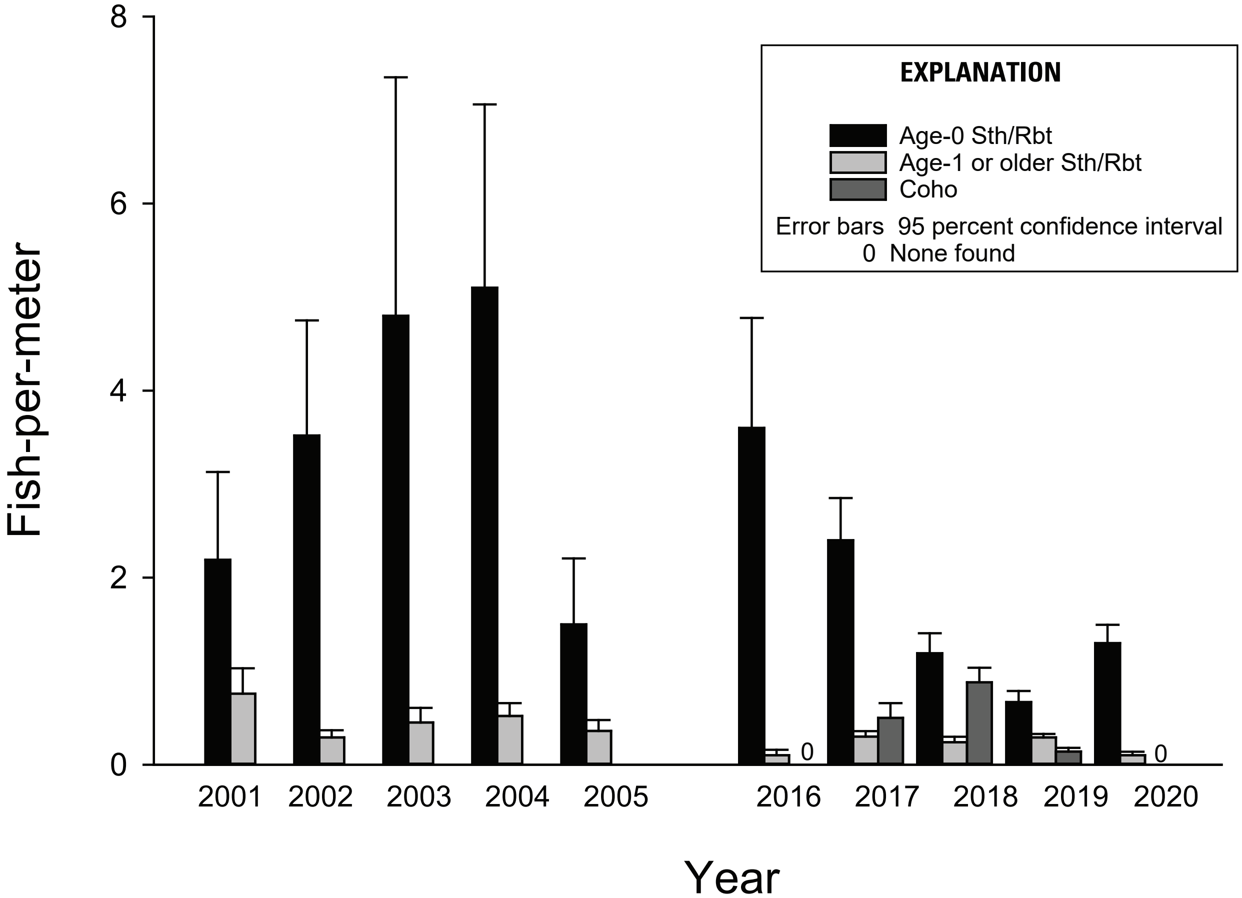

Figure 3. Abundance estimates of steelhead/rainbow trout (*Oncorhynchus mykiss*; Sth/Rbt) and coho salmon (*O. kisutch*) in a sample section in the lower kilometer of Rattlesnake Creek, Washington. Estimates are shown for 5 years (2001–05) prior to the removal of Condit Dam and for 5 years (2016–20) after the removal of Condit Dam. Error bars indicate upper half of 95-percent confidence intervals.

Table 4. Abundance estimates and standard error, fish per meter, and fish per meter squared of steelhead/rainbow trout (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) at an abundance electrofishing site in Buck Creek, Washington, in fall 2016, 2017, 2018, 2019, and 2020.

[No coho salmon were captured in 2020. **Age:** ≥, greater than or equal to. **Site and species:** Sth/Rbt, *O. mykiss* (steelhead or rainbow trout). **SE:** Standard error for abundance estimate column to left]

Species	Age (year)	Number of fish marked	Number of fish captured	Number of fish recaptured	Abundance estimate	SE	Fish per meter	Fish per meter squared
2016								
Sth/Rbt	0	113	128	25	566	85.5	3.0	0.37
Sth/Rbt	≥1	33	31	9	109	22.9	0.6	0.07
Coho	0	35	29	10	98	18.8	0.5	0.06
2017								
Sth/Rbt	0	61	54	11	284	62.6	1.2	0.20
Sth/Rbt	≥1	92	106	37	262	25.9	1.1	0.18
Coho	0	75	62	27	171	18.8	0.7	0.12
2018								
Sth/Rbt	0	183	193	55	637	59.4	2.9	0.45
Sth/Rbt	≥1	67	61	35	117	8.6	0.5	0.08
Coho	0	52	56	23	126	14.2	0.6	0.09
2019								
Sth/Rbt	0	185	178	74	444	30.0	2.0	0.34
Sth/Rbt	≥1	103	89	49	187	12.6	0.8	0.14
Coho	0	2	1	1	--	--	--	--
2020								
Sth/Rbt	0	244	224	89	612	39.6	2.7	0.42
Sth/Rbt	≥1	69	60	23	178	22.5	0.8	0.12

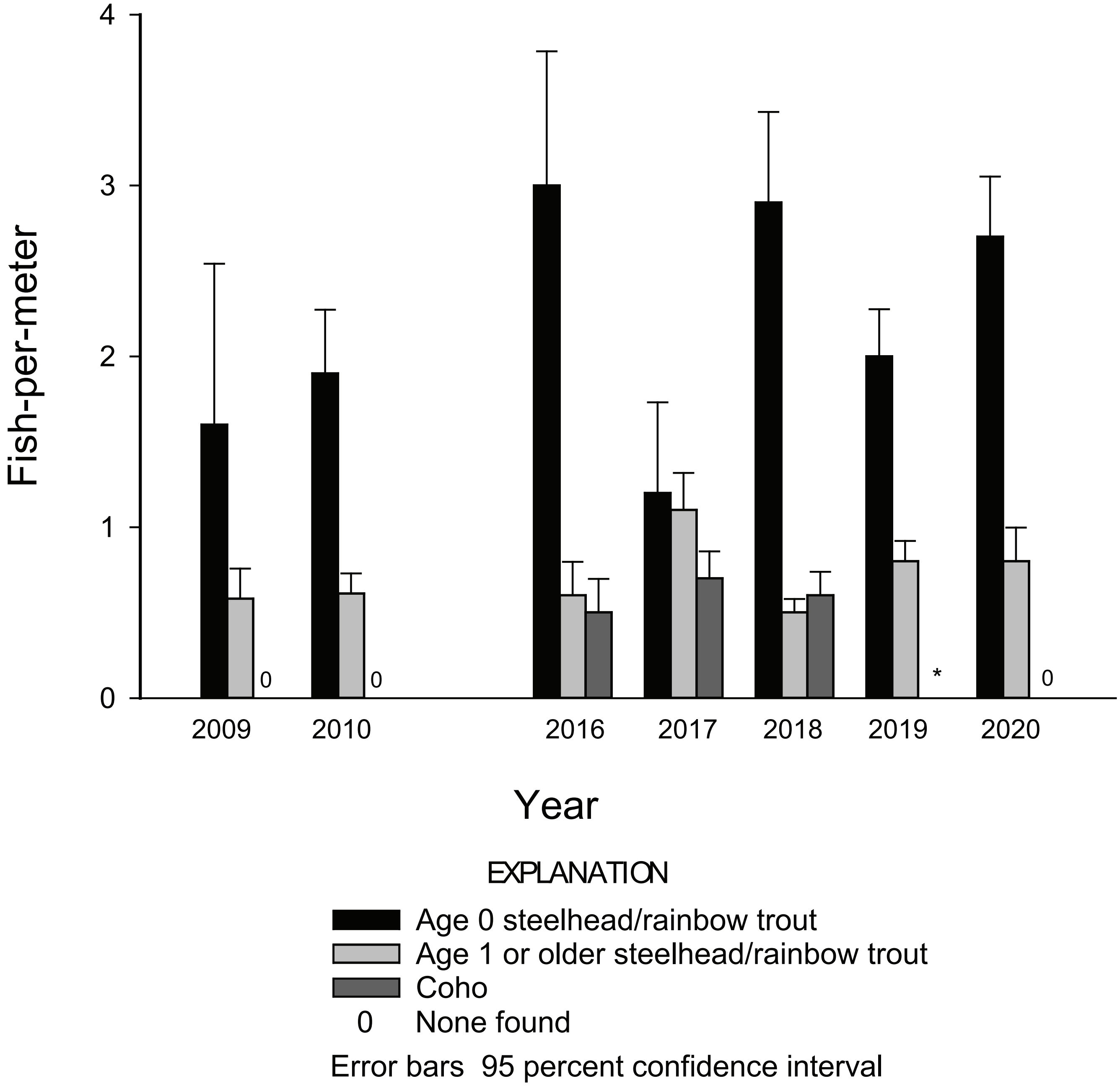

Figure 4. Abundance estimates of steelhead/rainbow trout (*Oncorhynchus mykiss*; Sth/Rbt) and coho salmon (*O. kisutch*) in a sample section at river kilometer 2 of Buck Creek, Washington. Estimates are shown for 2 years (2009–10) prior to the removal of Condit Dam and for 5 years (2016–20) after the removal of Condit Dam. * indicates that two coho salmon were captured in 2019, but we could not generate an abundance estimate. Error bars indicate upper half of 95-percent confidence intervals.

During 2020, we estimated abundance of age-0 and age-1 and older salmonids in sections of Rattlesnake and Buck Creeks (tables 3–4; figs. 1–4). During 2020, abundance of age-0 *O. mykiss* in the Rattlesnake Creek section was 1.3 fish/m (SE = 0.10) and in the Buck Creek section was 2.7 fish/m (SE = 0.17). Abundance of age-1 and older *O. mykiss* was 0.1 fish/m (SE = 0.01) at the Rattlesnake Creek site and was 0.8 fish/m (SE = 0.10) at the Buck Creek site. No juvenile coho salmon were captured at either site in 2020.

Salmonid abundance sampling done in Rattlesnake and Buck Creeks prior to dam removal provides a comparison with abundance found in our post-dam removal sampling. Juvenile salmonid abundance in our Rattlesnake Creek sample site during 2016–18 (range = 2.3–3.7 fish/m) was within the range measured in pre-dam removal surveys during 2001–05 (fig. 3; pre-removal range = 1.9–5.6 fish/m), but during 2019 and 2020 (1.1 and 1.4 fish/m, respectively), abundance was lower than that measured during pre-dam removal sampling. Juvenile salmonid abundance in our Buck Creek sample site during 2016–20 exceeded abundance measured during the pre-dam removal study in 2009 and 2010 (fig. 4; pre-removal range = 2.2–2.5 fish/m; post-removal range = 2.8–4.1 fish/m).

Columbia River and Other Detections

Steelhead and coho salmon PIT-tagged as smolts and parr at the screw trap have been detected as juveniles at Bonneville Dam and other downstream detection sites. Median travel times to Bonneville Dam for coho salmon smolts PIT-tagged at the screw trap were 2 days in 2016 (n = 16; range 1–34), 2.5 days in 2018 (n = 14; range = 1–49), and 4.5 days in 2019 (n = 36; range = 1–36). Median travel times to Bonneville Dam for steelhead smolts PIT-tagged at the screw trap were 3 days in 2016 (n = 26; range = 1–49), 2 days in 2018 (n = 56; range = 1–27), 3 days in 2019 (n = 54; range = 1–42), and 2 days in 2021 (n = 62; range = 1–34). Steelhead and coho salmon PIT-tagged as parr in tributaries have subsequently also been detected at Bonneville Dam or other downstream detection sites, confirming anadromous life histories originating from the tributaries.

Additional detections of PIT-tagged juvenile steelhead have occurred aside from the expected smolt detections at Bonneville Dam and the estuary trawl. Three steelhead that were PIT tagged as age-0 (FLs = 62, 67, 71 mm) fish in Rattlesnake Creek during summer 2017 were detected at the PIT-tag interrogation system at the mouth of the Hood River (PTAGIS site code = HRM) during February 2018. Several juvenile steelhead PIT-tagged in 2019 in the White Salmon subbasin also were detected at HRM. One steelhead PIT-tagged as a parr (FL = 118 mm) at the White Salmon screw trap on May 5, 2019 was detected at HRM on May 31, 2019; another steelhead PIT-tagged in Rattlesnake Creek as an age-0 (FL = 61 mm) on September 4, 2019, was detected at HRM on September 13, 2020; and a third steelhead PIT-tagged in Buck Creek on August 27, 2019 as an age-0 (FL = 60 mm) was detected at HRM on January 15, 2021. An age-0 steelhead PIT-tagged in Rattlesnake Creek (FL = 67 mm) on September 3, 2020 was detected at HRM on September 1, 2021. A steelhead parr PIT-tagged at the White Salmon River screw trap in 2018 (FL = 104 mm) was detected in the fish ladder at Spring Creek National Fish Hatchery on September 22, 2018. A steelhead smolt PIT-tagged at the White Salmon River screw trap in 2018 (FL = 159 mm) was detected moving upstream through the Washington shore ladder at Bonneville Dam on August 29, 2018, possibly an early maturing adult.

Adult Returns

Steelhead and coho salmon PIT-tagged at the White Salmon River screw trap have returned as adults to Bonneville Dam on the Columbia River (rkm 233). Four steelhead and two coho salmon smolts PIT-tagged in 2016 at the screw trap (150 steelhead and 79 coho salmon smolts tagged at the screw trap) have returned as adults to Bonneville Dam (tables 5–6), and one of the steelhead was subsequently detected in the Hood River. To date (December 2022), no adults have returned from smolts tagged at the screw trap during 2017; however, few smolts were captured and tagged that year (39 steelhead and 11 coho salmon smolts) because of high water and missed sampling periods. Five steelhead and three coho salmon PIT-tagged as smolts in 2018 at the screw trap (403 steelhead and 117 coho salmon smolts tagged) have returned as adults to Bonneville Dam, and one of the steelhead was subsequently detected in the Hood River. Five coho salmon PIT-tagged and released as smolts in 2019 at the screw trap (321 steelhead and 191 coho salmon smolts tagged) have returned as adults to Bonneville Dam. As of this writing (December 2022), one steelhead PIT-tagged at the screw trap in 2019 has returned to Bonneville Dam, and it was subsequently detected in the Hood River.

Smolt-to-adult return (SAR) rate estimates, for steelhead and coho salmon, from the screw trap to Bonneville Dam, ranged from 1.2 to 2.7 percent for the years in which we can estimate them (tables 5–6). However, sample sizes were small, with coefficients of variation greater than 44 percent, resulting in broad confidence intervals. Adult return data for tagging years 2019 and 2021 are incomplete as of this writing (December 2022).

To date (November 27, 2022), two coho salmon PIT-tagged as juveniles in tributaries have returned to Bonneville Dam as adults. One was tagged in Rattlesnake Creek in 2017 and returned to Bonneville Dam on October 29, 2019, and the other was tagged in Buck Creek in 2018 and returned to Bonneville Dam on September 16, 2020.

Because the White Salmon River does not currently have any PIT-tag detection infrastructure or adult capture facilities, we do not know how many of the adults detected at Bonneville Dam returned to the White Salmon River to spawn. Instream PIT-tag detection systems in Buck and Rattlesnake Creeks would provide valuable data.

Table 5. Smolt-to-adult return rate and ocean age of steelhead (*Oncorhynchus mykiss*) passive integrated transponder-tagged as smolts at the White Salmon River screw trap that returned as adults to Bonneville Dam, Washington, from time of tagging through November 27, 2022.

[**SAR:** Smolt-to-adult return rate; NE, no estimate. **CV:** Coefficient of variation (Standard error ÷ SAR estimate × 100). No estimate. **95% CI:** 95-percent confidence interval. **Symbol:** --, no value calculated]

Year	Smolts tagged	Ocean age			Total adults	SAR	CV	95% CI
		1 Ocean	2 Ocean	3 Ocean				
2016	150	1	3	0	4	2.7	49.3	0.1–5.2
[1]2017	39	0	0	0	0	NE	--	--
2018	403	1	4	0	5	1.2	44.4	0.1–2.3
2019	321	0	1	0	1	0.3	99.9	0–0.9
[2]2020	0	--	--	--	--	--	--	--
2021	301	0	--	--	--	--	--	--

[1]High water and missed trap periods resulted in few fish tagged at the screw trap in 2017.

[2]Trap not fished in 2020 because of the COVID-19 pandemic.

Table 6. Smolt-to-adult return rate and ocean age of coho salmon (*Oncorhynchus kisutch*) passive integrated transponder-tagged as smolts at the White Salmon River screw trap that returned as adults to Bonneville Dam, Washington, from time of tagging through November 27, 2022.

[**SAR:** Smolt-to-adult return rate; NE, no estimate **CV:** Coefficient of variation (Standard error ÷ SAR estimate × 100). **95% CI:** 95-percent confidence interval. --, no value calculated]

Year	Smolts tagged	Adults returned	SAR	CV	95% CI
2016	79	2	2.5	69.8	0–6.0
[1]2017	11	0	NE	--	--
2018	117	3	2.6	57.0	0–5.4
2019	191	5	2.6	44.1	0.3–4.9
[2]2020	0	--	NE	--	--
2021	2	--	--	--	--

[1]High water and missed trap periods resulted in few fish tagged at the screw trap in 2017.

[2]Trap not fished in 2020 because of the COVID-19 pandemic.

Genetic Samples Provided for Analysis

Genetic samples were taken from fish during both the screw trapping and electrofishing efforts. Genetic samples taken from *O. mykiss* during 2017–19 at the screw trap (n = 740) and from tributary electrofishing (n = 299) were submitted to Columbia River Intertribal Fish Commission (CRITFC) for analysis. Genetic Stock Identification (GSI) of *O. mykiss* samples from the screw trap and from some electrofishing in the main-stem White Salmon River from 2016 (Steven Micheletti, Columbia River Intertribal Fish Commission, written commun., 2018) suggested the most common reporting group (42 percent) was for White Salmon River fish followed by Skamania stock (26.6 percent) and Lower Columbia stock (19.3 percent). More than 90 percent of the Lower Columbia stock fish were assigned to the East Fork Hood River. Both winter and summer run steelhead were present. All genetic samples taken from Chinook salmon at the screw trap during 2016–19 (n = 393) were submitted to the USFWS. A report published in 2021 noted that the yearly percentage of tule (native) and upriver bright Chinook salmon hybrids in fry sampled at the screw trap ranged from 17 to 32 percent (Smith and others, 2021). This percentage was greater than that of the samples taken during 2006–08 (Smith and Engle, 2011), although that sampling occurred lower in the river. Some spring Chinook salmon were identified in the samples as well.

Discussion

The breaching and removal of Condit Dam on the White Salmon River, Washington, in 2011 and 2012, successfully provided anadromous salmonids access to historical habitats. Anadromous salmonids began using newly accessible habitats quickly following the dam removal. Upon implementation of our study in 2016, we observed production of juvenile steelhead, coho salmon, and Chinook salmon upstream from our screw-trap site and production of juvenile steelhead and coho salmon in three main tributaries upstream from the former Condit Dam site. Steelhead and coho salmon from the White Salmon River subbasin have returned as adults to Bonneville Dam. These results are encouraging considering that our study period corresponded to poor marine survival of Columbia River anadromous stocks and sharp declines in adult returns to the Columbia River Basin (Fish Passage Center [FPC], 2021; Welch and others, 2020). Despite this recent basin-wide decline, and relatively low tag numbers, anadromous juveniles that reared in the White Salmon subbasin were detected as returning adults at Bonneville Dam on the Columbia River.

The screw-trapping site at river kilometer 2.3 proved to be an effective location for generating estimates of steelhead and coho salmon smolts produced upstream from the site. Maximum smolt estimates for steelhead and coho salmon were 5,851 fish (standard error [SE] = 1,064; year = 2018) and 1,773 fish (SE = 375; year = 2019), respectively. These estimates likely do not reflect the full smolt-production potential of the White Salmon subbasin because they occurred during a period of declining returns of Columbia River stocks (FPC, 2021; Welch and others, 2020). Future smolt-trapping estimates would benefit from additional marked fish to reduce uncertainty. Additional trapping and tagging locations could provide added marked fish with which to estimate smolt migration. Additional years of monitoring are required to begin to understand full production capacity of the White Salmon River subbasin.

The estimates of steelhead and coho salmon smolts during 2016 may be low because of a shorter duration of sampling (2016 = 62 days, 2018 = 76 days, 2019 = 75 days, 2021 = 73 days), owing to trap damage, which ended sampling on May 28. The missed days occurred late in the season when daily counts generally tapered off. The percentages of steelhead smolts captured after May 28 during 2018, 2019, and 2021 were 6.7, 4.0, and 3.9 respectively; the percentages of coho smolts captured after May 28 during 2018 and 2019 were 32.0 and 9.2, respectively. However, additional years of smolt monitoring would provide data to help us better understand the timing of the run and confidently estimate the percentage of the smolt run potentially missed during 2016.

Data from PIT-tagged fish showed that some steelhead and coho salmon smolts captured at the screw trap originated in tributaries upstream from the Condit Dam site. We were not able to evaluate the proportion of steelhead and coho salmon smolt production from tributaries and main-stem rearing areas. Further monitoring and outmigrant traps or PIT-tag infrastructure would serve to address questions of smolt origin and identify production areas or areas worthy of protection or restoration.

Although the primary goal of the screw trap was to estimate steelhead and coho salmon smolts, we also collected data on other species and life stages. Fry and parr steelhead, coho salmon, and Chinook salmon were captured, suggesting that there are multiple life stages and life histories likely using the improved habitat downstream from the former dam site. Chinook and Coho salmon spawn there, and although steelhead spawning distribution is unknown, downstream moving parr likely rear for at least some time in the main-stem habitat. Downstream movements of steelhead parr have been noted in other Columbia River tributaries (Zendt and others, 2016; Buehrens and Cochran, 2019; Crawford 2019; Simpson, 2020); however, as with the White Salmon River, this life history, factors influencing it (for example, available habitat, thermal stress), and contribution to adult recruitment are not well understood. The full extent of parr downstream movement also is unknown. Differing steelhead parr rearing strategies also have been identified in rivers outside the Columbia River Basin (Hayes and others, 2008; Sogard and others, 2009). Important questions are raised regarding whether steelhead parr move into larger rivers including the Columbia River, and if so, what habitats they are seeking or using.

Capture of fry was highly variable by day and year (particularly with Chinook salmon). We suspect that variable daily capture of fry was influenced by the operation of the live-box cleaning drum. When there was little debris in the trap and the cleaning drum was working, the fry were rotated out of the live box on the drum (this effect likely also applies to steelhead and coho salmon fry). We periodically disabled the cleaning drum to capture Chinook fry for genetic sample collection.

Yearly variability in Chinook and coho salmon fry was potentially influenced by high flow events that occurred after spawning (Chinook spawning, September–November; coho salmon spawning, October–January) and may have caused redd scour and egg-to-fry mortality. The river upstream from the screw-trap site is confined and subject to much bedload movement in the event of high flow. We captured few fry during 2016 and 2021; both brood years had high flow events that occurred after much of the spawning period (December 8, 2015, discharge > 113 cubic meters per second [m^3/s], estimated 25-year event; January 13, 2021, discharge = 133 m^3/s). No coho salmon were found at our sample sites in Rattlesnake and Buck Creeks during summer 2020, indicating a lack of spawning or poor spawning success in brood year 2020, the fish from which year would have smolted in 2021.

Steelhead and coho salmon have used Mill, Buck, and Rattlesnake Creeks following removal of Condit Dam. Juvenile salmonid abundance estimates at the Buck Creek site following Condit Dam removal were greater in all years than in the 2 years sampled prior to Condit Dam removal, suggesting that Buck Creek may have been below carrying capacity prior to removal. Variability of juvenile salmonid abundance was pronounced in Rattlesnake Creek prior to and following Condit Dam removal. Juvenile coho salmon were not found in all years at our abundance sampling sites in Buck (none found in 2020) and Rattlesnake Creeks (none found in 2016 and 2020). Additional sampling in Buck Creek is warranted to determine potential coho salmon use upstream from the modified water diversion and in Buck and Rattlesnake Creeks to determine consistency of use and upstream extent.

Numerous factors could have influenced variation in abundance of juvenile *O. mykiss* and coho salmon in Rattlesnake and Buck Creeks. Spawner abundance certainly influences juvenile abundance, and the decline in adult returns to the Columbia Basin during our study may have been reflected in the White Salmon River subbasin. Environmental conditions also could have influenced spawning success or caused juveniles to emigrate prior to our sampling period each year. Flow and temperature conditions in Rattlesnake Creek are tenuous for salmonids (Allen and others, 2006a), and salmonid fry and parr may emigrate in search of better conditions. The high variation in juvenile *O. mykiss* abundance in Rattlesnake Creek also could result from expression of a diversity of life histories such as migrant parr or fry that were less represented prior to dam removal and the addition of definitive anadromous parents.

Interesting questions were raised regarding movement of juvenile steelhead between the White Salmon and Hood Rivers. Movements that we have documented include (1) the capture of steelhead smolts in the screw trap, which originally were tagged with passive integrated transponder (PIT) tags in the Hood River the prior year; and (2) detections at the PIT-tag detection system at the mouth of the Hood River (PTAGIS site code = HRM) of steelhead tagged in the White Salmon River subbasin. These data show that some fish are leaving the Hood and White Salmon Rivers as parr. This movement may be density-dependent movement or a life-history expression independent of abundance. Preliminary genetic analysis of screw-trap and main-stem electrofishing showed that there is a component of steelhead in the White Salmon with close relation to the Hood River, suggesting a possible metapopulation (Anderson and others, 2014), or that the Hood River is a source of some recolonizing fish. Continued PIT-tagging and monitoring of tagged fish and collection of genetic samples for GSI would help to understand the relation between White Salmon River and Hood River steelhead and possible changes as the population in the White Salmon River evolves following the dam removal.

The return of natural-origin adults from steelhead and coho salmon PIT-tagged at the smolt trap and in tributaries of the White Salmon River is encouraging. Although our sample sizes were small, smolt-to-adult returns to date (November 27, 2022) from the smolt trap to Bonneville Dam were similar to recent estimates from wild steelhead in the Hood River, Oregon (Simpson, 2020; range = 1.0–2.5 percent during 2011–16) and in the Wind River, Washington, (Buehrens and Cochran 2019; range = 1.0–4.0 percent during 2011–15). These data suggest that natural-origin fish from the White Salmon River are performing at a level similar to other wild stocks in the area, a critical metric for natural recolonization.

Data from our study suggest that natural recolonization of anadromous salmonids is occurring in the White Salmon River subbasin. Ten years following removal of Condit Dam, viable steelhead and coho salmon smolts are being produced upstream from the former dam site. Steelhead and coho salmon are using tributaries for spawning and rearing. Spring and fall run Chinook salmon have access to and have used new spawning areas downstream and upstream from the former dam site, and natural-origin steelhead, coho salmon, and Chinook salmon adults are returning.

Although results and research to date (December 2022) are encouraging, much remains to be learned. Long-term monitoring and research would help to assess the pace of recolonization and basin capacity, particularly because this study period had some of the lowest Columbia River Basin adult salmon returns ever. Additionally, the full extent of dam removal effects and recolonization may take decades to be realized (Pess, 2009; Anderson and others, 2014). Further studies of the genetics of recolonizing fish, particularly steelhead, would provide valuable data regarding natural recolonization through relic populations. Questions such as the full extent of species distribution, life-history strategies to emerge, and use of tributary and main-stem habitats remain and could be examined with additional research and would provide much information toward recolonization and dam-removal science.

Data Availability

All data from the White Salmon screw trapping are in Washington Department of Fish and Wildlife's Juvenile Migrant Exchange Database. All PIT-tag data from screw trapping and electrofishing were submitted to the PTAGIS database (Coordinator ID = IGJ; Site Codes = WHITSR, BUCK3C, RATTLC). Electrofishing data are currently owned and archived by Yakama Nation Fisheries, Yakama Klickitat Fisheries Project. Genetics data for year 2016 *O. mykiss* samples are archived by CRITFC (contact Jon Hess, hessj@critfc.org).

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For information about the research in this report, contact
Director, Western Fisheries Research Center
U.S. Geological Survey
6505 NE 65th Street
Seattle, Washington 98115-5016
https://www.usgs.gov/centers/western-fisheries-research-center

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