

# **Okanogan Basin Monitoring and Evaluation Program**

## **2021 Annual Progress Report**

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## **Abstract**

Within the Upper Columbia River Basin, the furthest upstream and northern-most extent of currently accessible anadromous salmonid habitat is found in the Okanogan River system. The Okanogan Basin Monitoring and Evaluation Program (OBMEP) conducted status and trend monitoring from 2004 through 2021 to evaluate viable salmonid population (VSP) criteria (abundance, productivity, spatial structure, and diversity) and identify limiting habitat factors in the Okanogan subbasin. Monitoring efforts primarily focused on summer steelhead *Oncorhynchus mykiss*, which are listed under the Endangered Species Act (ESA) as “threatened” as part of the Upper Columbia River Evolutionary Significant Unit (ESU). In 2021, it was estimated that 710 summer steelhead (573 hatchery origin and 137 natural-origin) spawned in the Okanogan subbasin. Over the past 17 years of monitoring (2005 through 2021), the average number of adult steelhead spawners in the Okanogan subbasin was 1,427 (geomean = 1,206). The total number of spawners to the subbasin reversed a generally declining trend that has persisted since 2010. The average number of natural-origin spawning steelhead was 278 (geomean = 241), the third lowest recorded since 2005. The two lowest years occurred in 2017 and 2018, with 115 and 120 natural-origin spawners, respectively. The number of natural-origin steelhead spawning in the Okanogan River subbasin has a fairly level trend and remains below the minimum abundance threshold for natural-origin spawners (500 in the US portion of the subbasin). Distribution of adult steelhead spawning within the subbasin has varied by survey reach, subwatershed, origin (natural or hatchery), and year, and was largely influenced by snowpack and spring discharge patterns.

An estimated  $15,349 \pm 2,226$  (95% CI) natural-origin juvenile steelhead outmigrated from creeks in the Washington State portion of the subbasin in 2021. The majority of the outmigrants were produced in Salmon Creek ( $10,580 \pm 1,249$ ) and Lower Omak Creek ( $2,421 \pm 502$ ). The total number of outmigrants in 2021 reversed a declining trend that began in 2018. Yearling Chinook *Oncorhynchus tshawytscha* (most likely Spring Chinook) were first observed in small numbers in Okanogan tributaries in 2016 and have increased up to an estimated  $2,352 \pm 361$  in 2019. After a decline to a population in 2020 ( $158 \pm 0$ ), numbers increased slightly in 2021 to  $693 \pm 254$  for the subbasin as a whole. From the fall of 2020 to the spring of 2021, an estimated  $89 \pm 36$  yearling Spring Chinook outmigrated from only Loup Loup and Salmon Creeks with 92 percent of those outmigrants attributed to Loup Loup Creek. This information will be critical to documenting the success of the experimental reintroduction of Spring Chinook in the Okanogan subbasin.

Habitat monitoring included collection of eight physical habitat metrics at eight annual and 47 rotating panel reaches. After testing and integrating a rapid assessment protocol in previous years, OBMEP continued full implementation of rapid assessment methods in 2021 designed to collect the most essential inputs for the Ecosystem Diagnosis and Treatment (EDT) model in all reaches. Data collection also included water quality (alkalinity), water temperature (22 locations), stream discharge (11 gaging stations), and benthic macroinvertebrates at reaches throughout the subbasin. In 2021, peak discharge in the mainstem Okanogan River was 12% less than the average peak flow. Many tributaries to the Okanogan River, including Omak, Salmon, and Loup Loup Creeks, experienced below average peak flows. 2021 was punctuated by extreme early-summer heat events in the Okanogan River subbasin that resulted in stream temperatures climbing near 30 degrees C in several tributaries. Weekly average

temperature observations in most subwatersheds reached the highest levels recorded. These occurrences correlate with a decline in overall abundance in juvenile salmonids in multiple subwatersheds, most notably Omak Creek below Mission Falls, where the instream abundance of *O. mykiss* dropped by 90% compared to the ten-year average. The EDT habitat status and trend analysis provided a detailed assessment of steelhead and Chinook habitat potential in the Okanogan subbasin and characterizes change in habitat conditions between 4-year monitoring cycles. The most recent 4-year EDT status and trend report was completed in 2018 and includes data collected through 2017. A model update incorporating the previous 4 years of data collection will occur in the second quarter of 2022. Status and trend results through 2017 suggest improving habitat capacity and abundance performance for both adults and juveniles. Between 2013 and 2017, modeled adult capacity increased 18% and adult abundance increased by 25%.

Monitoring staff continued to find creative solutions to obstacles, work safely throughout the year and successfully delivered on all contractual obligations and beyond. Data that the program collected were used for in-season decisions regarding harvest, hatchery management, and implementation of habitat restoration actions. The overall outcome of monitoring strategies is to guide natural resource managers' decisions to minimize threats to salmon and steelhead, choose restoration actions that will provide benefits to salmonid habitat, and evaluate progress toward measurable salmon and steelhead enhancement objectives across multiple jurisdictions. As monitoring efforts continue to progress, the Okanagan Basin Monitoring and Evaluation Program will continue to deliver practical status and trend monitoring data for use in more comprehensive broad-scale analyses.

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<sup>1</sup> Indigenous Peoples of the Okanagan are the exclusive owners of their cultural and intellectual properties and processes as reiterated through the United Nations Declaration on the Rights of Indigenous Peoples (2007).

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## **1.0 Introduction**

The Okanogan Basin Monitoring and Evaluation Program (OBMEP) conducted status and trend monitoring from 2004 through 2021 to collect and analyze fisheries data corresponding to adult and juvenile abundance and spatial and temporal distribution throughout the Okanogan<sup>2</sup> subbasin. These efforts specifically focused on Upper Columbia River summer steelhead *Oncorhynchus mykiss*, which are listed as “threatened” under the Endangered Species Act (NMFS 2009). Habitat capacity and productivity monitoring tasks included collecting physical habitat measurements, water quality, temperature, discharge, and benthic macroinvertebrate data. Over the long-term, status data can be used to examine trends, which may indicate if salmon and steelhead populations and respective habitats are improving or degrading. Due to the Washington-British Columbia international boundary intersecting the Okanogan subbasin, the Colville Confederated Tribes (CCT) and Okanagan Nation Alliance (ONA) began coordinating on this project in the Canadian portion of the subbasin in 2005. Continuing effort is put into maintaining consistent sampling programs on both sides of the border through frequent communications and cross-training initiatives to maintain consistency in methodologies.

### **Study Area**

Within the Upper Columbia River Basin, the furthest upstream and northern-most extent of currently accessible anadromous habitat is found in the Okanogan River. The Okanogan subbasin extends south from its headwaters in southern British Columbia (BC) through north central Washington State (WA), where it meets the confluence with the Columbia River (Figure 1). The total drainage area of the Okanogan subbasin is roughly 21,000 km<sup>2</sup>, more than twice the size of the Methow, Entiat, and Wenatchee subbasins combined (NPCC 2004, Morrison and Smith 2007); however, the total stream kilometers available to anadromous salmonids are limited due to natural falls and man-made barriers. The Okanogan subbasin is comprised of diverse habitat, from high mountain forests to semi-arid shrub-steppe lowlands. Often bordered by steep granite walls, water flows from north to south through a series of large lakes which give way to a low gradient mainstem river before entering the Columbia River near the town of Brewster, WA.

The subbasin supports a stable population of summer-fall Chinook Salmon *Oncorhynchus tshawytscha* in Washington, a greatly expanding number of Sockeye Salmon *Oncorhynchus nerka*, a threatened population of summer steelhead, an increasing number of Spring Chinook Salmon from an experimental reintroduction, occasional observations of Coho Salmon *Oncorhynchus kisutch* and rare transient use of Bull Trout *Salvelinus confluentus*. During the late summer months, water temperatures in the mainstem Okanogan River frequently exceed 24°C, representing a challenging environment for salmonids. A number of small tributaries to the Okanogan River can offer relatively cooler water and additional habitat for steelhead, but access is often limited by insufficient discharge, natural barriers and man-made impediments.

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<sup>2</sup> Spelled ‘Okanogan’ in the U.S. and ‘Okanagan’ in Canada; used interchangeably in this document.

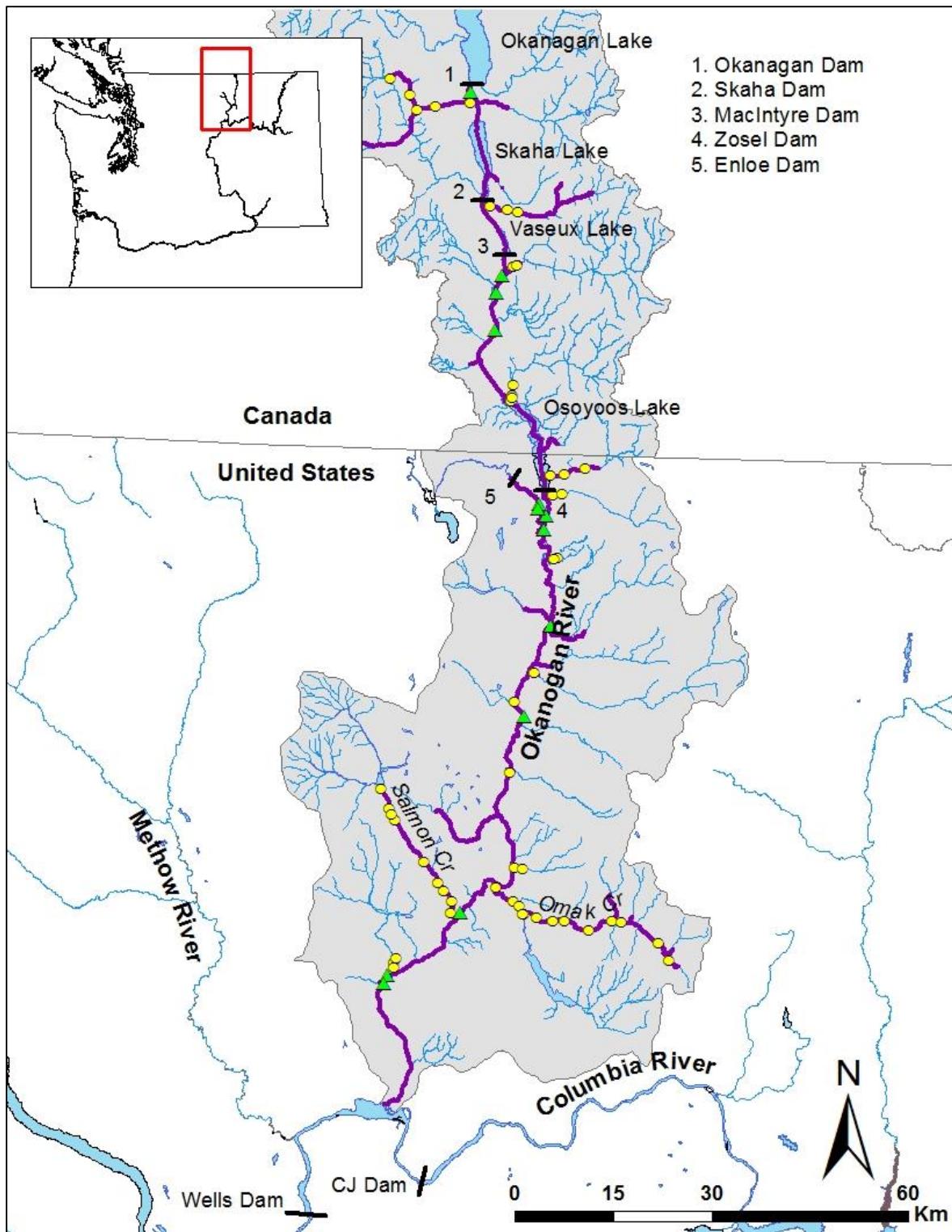


Figure 1. Study area, the Okanagan subbasin in north-central Washington State and southern British Columbia. Markers signify OBMEP monitoring sites: yellow markers represent electrofishing sites, green triangles represent mainstem snorkel sites, and stream segments highlighted in purple represent areas likely accessible to anadromous fish where habitat data collection occurs.

Within the Washington State portion of the Okanagan subbasin, the vast majority of land along the river is under private ownership, and landowner cooperation is required for fisheries research activities to occur. Economic activity in the subbasin is centered on fruit crops, ranching, agriculture, tourism, mining, and timber harvest. In this relatively arid environment, a complex system of fisheries and water management requires coordination between many local stakeholders, state (provincial) agencies, federal agencies, Tribes and First Nations, from both the United States and Canada.

In the Canadian portion of the Okanagan subbasin, man-made barriers are currently major constraints to salmonid migrations. Dams exist at all outlets of Canadian Okanagan lakes including, swiws (Osoyoos), akspaqmix (Vaseux), tucin (Skaha) and kłusxnitkʷ (Okanagan) Lakes. In 2009, the outlet dam at akspaqmix (Vaseux Lake), known as the McIntyre Dam, was refitted for fish passage. In 2014, the outlet dam at tucin (Skaha Lake) underwent improvements to further enhance fish passage. The upstream impediment for anadromous salmon species is currently the Okanagan Lake Dam, at the outlet of the kłusxnitkʷ (Okanagan Lake) in Penticton. In 2019, the ONA began manually operating the fish ladder at Okanagan Lake Dam. Anadromous salmonids have previously occupied the entire qawsitkʷ (Okanagan River) system (Ernst and Vedan 2000).

## Goals and Objectives

### Goal:

To monitor the status and trend of listed salmonids in the Okanagan Subbasin and salmonid habitat in the Okanagan/Methow Subbasins such that monitoring data and subsequent data products are meaningful, useful and timely for fishery managers and the general public.

### Objectives:

OBMEP conducted status and trend monitoring in the Okanagan River subbasin to evaluate the Upper Columbia River summer steelhead population in support of Bonneville Power Administration (BPA) Fish and Wildlife management sub-strategies<sup>[1]</sup> with the following objectives:

1. Assess the status and trend of Okanagan Subbasin natural and hatchery origin adult summer steelhead VSP criteria relative to NOAA recovery objectives (e.g. US spawning abundance of 500 natural-origin fish) annually through 2032 and beyond.
2. Assess the status and trend of natural-origin juvenile instream abundance and outmigration estimates of listed salmonids annually through 2032 and beyond.

This project also conducted status and trends monitoring to evaluate habitat in the Okanagan and Methow subbasin used by Endangered Species Act (ESA) Listed Upper Columbia River steelhead and summer/fall Chinook in support of BPA Fish and Wildlife sub-strategies<sup>[2]</sup> with the following objective:

3. Use modeled habitat outputs derived from annual empirical habitat observations to determine if there is a meaningful change over time in VSP criteria for focal species in the Okanagan (2025, 2035) and Methow (2030, 2040) subbasins.

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<sup>[1]</sup> Fish Population RM&E <https://www.cbfish.org/ProgramStrategy.mvc/Summary/1>

<sup>[2]</sup> Tributary Habitat RM&E <https://www.cbfish.org/ProgramStrategy.mvc/Summary/3>

More generally, OBMEP seeks to fulfill the following project management objectives annually:

4. OBMEP will collect accurate electronic field data, assimilate into a secure database, perform QA/QC and develop/provide reporting tools and public access.
5. Provide summarized information that is publically accessible and data to regional repositories within a year of data collection.
6. Actively participate in regional and local processes and coordinate with other agencies and programs.
7. Establish quantitative data where little existed and fill data gaps necessary to recovery of listed salmonid species as resources allow.

## 2.0 Methods

### 2.1 Fish Population Status and Trend Monitoring

#### Adult Steelhead Monitoring

OBMEP - Adult Abundance - Redd Surveys v1.0 (ID:192)

<https://www.monitoringresources.org/Document/Protocol/Details/192>

OBMEP - Adult Abundance - Adult Weir and Video Array (ID:6)

<https://www.monitoringresources.org/Document/Protocol/Details/6>

OBMEP – Adult Abundance – Analysis v1.0 (ID:2125)

<https://www.monitoringresources.org/Document/Protocol/Details/2125>

Upper Columbia River ESU Steelhead Stock Assessment (2010-034-00) v1.0 (ID:235)

<https://www.monitoringresources.org/Document/Protocol/Details/235>

A combination of methods have been utilized to derive annual spawner abundance estimates for steelhead in the subbasin: redd surveys, underwater video, Passive Integrated Transponder (PIT) tag interrogation sites and adult weir traps. Spawner abundance estimates were determined for each tributary and mainstem reach. The subbasin-wide estimate is the sum of those individual estimates. Enumeration of adult steelhead in the British Columbia portion of the subbasin has relied solely on expanded PIT tag detections. Specific calculations used to estimate annual steelhead spawning estimates from year-to-year are detailed in reports available at:

<https://www.okanoganmonitoring.org/Reports/ViewReportsForType/2>

#### Juvenile Salmonid Monitoring

OBMEP - Juvenile Abundance - Mark-Recapture (ID:194)

<https://www.monitoringresources.org/Document/Protocol/Details/194>

OBMEP - Juvenile Abundance - Snorkel surveys (ID:7)

<https://www.monitoringresources.org/Document/Protocol/Details/7>

Juvenile abundance monitoring in tributaries is accomplished through the implementation of an electrofishing mark-recapture study in the Washington State portion of the subbasin. To estimate outmigration, OBMEP operated a rotary screw trap from 2004 through 2011 on the mainstem Okanogan River; however, low capture efficiencies of naturally produced steelhead yielded highly variable and unreliable abundance estimates for that species. Challenges to derive meaningful outmigration

estimates required a shift in methodology. Starting in 2014, outmigration for natural-origin juvenile steelhead was calculated from PIT tags implanted during the mark-recapture study and subsequent detections within the subbasin and downriver the following spring. In 2021, electrofishing-based sampling was conducted in Loup Loup, Salmon, Omak, Wanacut, Tunk, Aeneas, Bonaparte, Tonasket, and Ninemile Creeks in the Washington portion of the subbasin. Additionally, Antoine Creek was comprehensively sampled for the first time in 2021. The remaining two creeks (Johnson and Wildhorse Spring Creeks) were not sampled due to lack of access, time, or available staff. Five subwatersheds were also sampled in the British Columbia side of the subbasin, including akskw̓əkʷant (Inkanieep), n̄faχʷlqaxʷiya (Vaseux), Shuttleworth, Shatford and akłxʷuminaʔ (Shingle) Creeks. Detailed methods for the juvenile mark-recapture/outmigration project are presented in Appendix B.

Snorkel surveys have been conducted in both Washington State and British Columbia from 2004 through 2021. In this document, snorkel survey metrics have been presented as density of juvenile *O. mykiss*/area, which were derived by dividing the observed number of fish by the wetted surface area of the survey site. Wetted surface area was calculated by measuring 22 evenly spaced wetted width measurements during habitat surveys and multiplying the average width by the total survey reach length.

## 2.2 Habitat Status and Trend Monitoring

Okanogan Basin Monitoring and Evaluation Program- Habitat Status and Trend (ID: 3366)

<https://www.monitoringresources.org/Document/Protocol/Details/3366>

Method: Ecosystem Diagnosis and Treatment (EDT) v1.0

<https://www.monitoringresources.org/Document/Method/Details/3973>

The data collection protocols and a habitat modeling methodology are implemented by OBMEP on a four-year data collection and analysis cycle. The supporting protocols and methods are detailed in the web links listed above. The OBMEP Habitat Status and Trend protocol is applied to a total of 194 reaches (127 in US, 67 in Canada) in the Okanogan subbasin over the data collection cycle with 55 reaches (8 annual panel and 47 rotating panel) visited per year.

The OBMEP/EDT integration method transforms the extensive and complex body of habitat monitoring data collected by OBMEP into information that is easier for use in decision making and communication with stakeholders and the public (CCT 2015). The EDT integrates quantitative and qualitative OBMEP habitat data with empirical observations of the relationship between habitat and fish species abundance. This product provides characterization of status and trends, in the ability of the habitat to support a species of interest over time (CCT 2015). This relationship is arranged hierarchically. Higher level indicators (survival factors) of habitat performance are the product of one or more environmental attributes, which are in turn the product of empirically-derived transformations of habitat data. Detailed methods describing this hierarchy and the translation of habitat data into EDT environmental attributes are found in Lestelle (2005). Further methods describing linkages between environmental attributes, survival factors, status and trend model spatial structure and data sources are provided in CCT 2013 and 2015.

## 3.0 Results

### 3.1 Fish Population Status and Trend Monitoring

#### Adult Steelhead Monitoring

Since 2005, OBMEP has monitored the status and trends of summer steelhead spawning abundance and distribution within the Okanogan subbasin through a combination of redd surveys, underwater video counts, and PIT tag expansion estimates. In 2021, it was estimated that 710 summer steelhead (573 hatchery-origin and 137 natural-origin) spawned in the Okanogan subbasin (Table 1). The total number of spawners to the subbasin reversed a generally declining trend that has persisted since 2010. When specifically looking at natural-origin spawners, 2021 was the third lowest return on the period of record. The two lowest years occurred in 2017 and 2018, with 115 and 120 natural-origin spawners, respectively. Over the past 17 years of monitoring, the average number of adult steelhead spawners in the Okanogan subbasin was 1,427 (geomean = 1,206). The average number of natural-origin spawning steelhead was 278 (geomean = 241). The abundance trend of natural-origin steelhead spawning in the Okanogan River subbasin is generally level since data collection began in 2005; unfortunately beginning in 2017 return numbers declined below the 12-year geomean and the minimum abundance threshold for ESA-recovery for natural-origin spawners in the Washington State portion of the subbasin (500) was not reached (Figure 2). Steelhead returns in 2021 continued a similar low abundance trend seen in the past three years.

Table 1. Estimated summer steelhead spawner abundance in the Okanogan subbasin, 2005–2021.

Year	Total	Hatchery Steelhead	Natural-Origin Steelhead	Natural-Origin 12-yr geomean
2005	1,226	1,080	146	
2006	899	702	197	
2007	1,268	1,116	152	
2008	1,386	1,161	225	
2009	2,133	1,921	212	
2010	3,496	2,768	728	
2011	1,674	1,341	333	
2012	2,802	2,475	327	
2013	1,937	1,687	250	
2014	1,356	838	518	
2015	1,461	1,009	452	
2016	1,566	1,175	391	292
2017	1,044	929	115	286
2018	453	333	120	274
2019	473	306	167	277
2020	374	114	260	280
2021	710	573	137	271
Average	1,427	1,149	278	278

The abundance of hatchery steelhead has been variable, ranging from a low of 114 in 2020 up to 2,768 recorded in 2010. The proportion of hatchery origin spawners (pHOS) from 2005 through 2013 averaged 0.85, but decreased to 0.68 for 2014 through 2021. The 17-year (2005–2021) average pHOS was higher for the mainstem Okanogan River (0.89) compared with tributaries (0.72).

In the Washington State portion of the subbasin, distribution of adult steelhead spawning varied by survey reach, subwatershed, natal origin (natural or hatchery), and year. Summer steelhead spawning has been documented throughout the mainstem Okanogan River, although due to a relatively low gradient, spawning is narrowly focused to distinct areas that contained suitable water velocities and spawning substrate e.g. the reach below Zosel Dam near the town of Oroville, WA (see Table A-3, Appendix A). On average, Omak (64) and Salmon (36) Creeks host the most natural-origin spawners followed by Bonaparte Creek (28) (Table A-3). The proportion of steelhead spawning in many of the tributaries to the Okanogan River appeared to be regulated in part by stream discharge, which in turn was influenced by winter snowpack, spring precipitation in small creeks, runoff timing, and surface water diversions.

Detailed spawning distribution data in the British Columbia portion of the subbasin is limited. Determining total abundance of spawners remains difficult, but improved with the installation of a PIT tag antenna array (OKC) above sw̓iws (Osoyoos Lake) and representative marking of returning adults at Priest Rapids Dam (BPA Project # 2010-034-00). A relatively small proportion of the total adult steelhead pass into British Columbia, averaging 3.3% for the past nine years (2013–2021); however, average pHOS was much lower in British Columbia (0.35) than Washington State (0.76) during that timeframe.

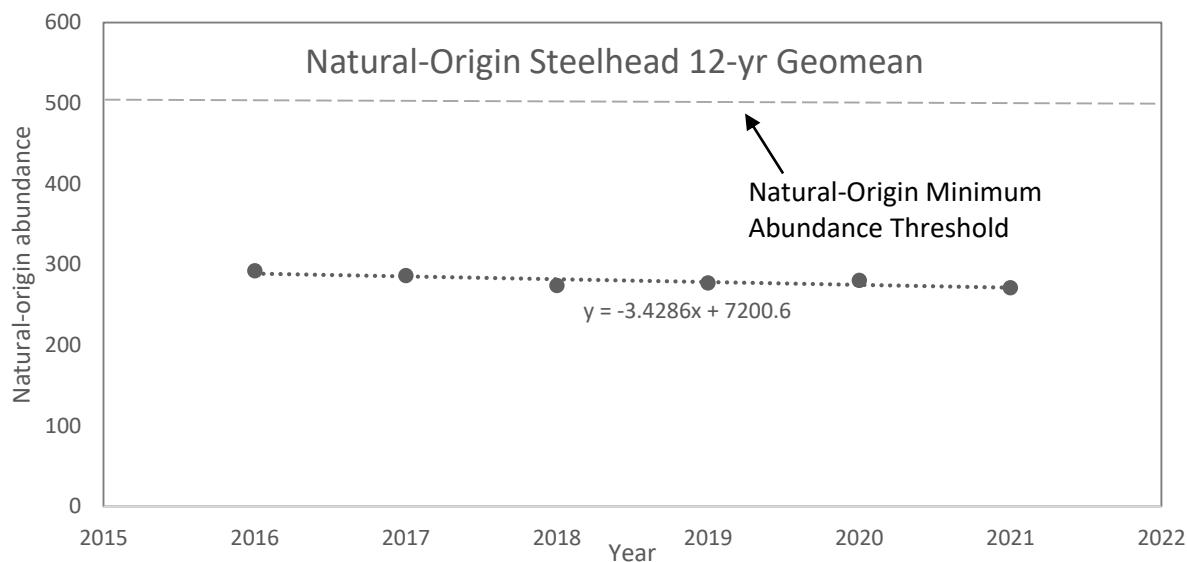


Figure 2. Twelve-year geomean for natural-origin summer steelhead spawners in the Okanogan River subbasin showing the trend (dotted line) and the ESA-recovery objective for the natural-origin minimum abundance thresholds (dashed line).

## **Juvenile Salmonid Monitoring**

### *Instream Abundance (Electrofishing)*

In June 2021, weekly average temperature observations in most subwatersheds reached the highest levels recorded. These occurrences correlate with a decline in overall abundance in juvenile salmonids in multiple subwatersheds, most notably Omak Creek below Mission Falls, where the instream abundance of *O. mykiss* dropped by 90% compared to the ten-year average. Other stream sections that appeared to be most affected by high water temperatures also included Upper Omak, Wanacut and Tunk Creeks. Interestingly, a second subset of subwatersheds continued an increasing 5-year trend in the abundance of *O. mykiss*, which included Loup Loup, Salmon and Ninemile Creeks (Refer to appendix B, Figures B-15 and B-16).

Four streams in the British Columbia portion of the subbasin akskw̓əkʷant (Inkaneep), akłxʷuminaʔ (Shingle), Shatford and Shuttleworth Creeks were sampled in 2016 through 2021 using this method. In addition, n̄fačʷlqaxʷiya (Vaseux Creek) was sampled from 2018 on. Subwatershed abundance metrics and trend information are presented in Table 2 for young-of-year and Table 3 for age-1+ *O. mykiss*. Further detail can be found in Appendix B for each tributary sampled.

Additional details concerning fish abundance by specific reach, length frequency data, and growth rates by tributary, etc. can also be found in Appendix B or by contacting OBMEP staff directly.

### *Outmigration*

Based on remote PIT tagging, an estimated total of  $15,349 \pm 2,226$  (95% CI) juvenile steelhead outmigrated from defined sample areas. The total number of outmigrants in 2021 reversed a declining trend that began in 2018 (Table 4). Salmon Creek's estimated production of  $10,580 \pm 1,249$  continues to be the leading contributor to the outmigrant population from the Okanogan subbasin, accounting for 69% of the estimated production of all sampled tributaries from Fall 2020 through Spring 2021. Production from outside the sampling area, including the mainstem Okanogan River, Similkameen River (below Enloe Dam), or British Columbia was not factored into those estimates; therefore, the sum is not a subbasin-wide population estimate. Preliminary data based on PIT tag detections suggest that juvenile *O. mykiss* utilize the mainstem Okanogan River seasonally in the fall, winter, and spring. Additional details are presented in Appendix B.

Table 2. Instream population estimates of young-of-year natural-origin *O. mykiss* ( $\pm 95\% \text{CI}$ ) in tributaries to the Okanogan River in Washington State and British Columbia. Only five most recent years shown, refer to Appendix B for complete dataset.

Tributary	2017	2018	2019	2020	2021
Salmon Cr	$27,717 \pm 3,065$	$32,646 \pm 3,982$	$36,667 \pm 3,378$	$51,691 \pm 6,346$	$60,414 \pm 4,707$
Lower Omak Cr	$4,064 \pm 1,755$	$9,360 \pm 2,147$	$19,717 \pm 1,797$	$10,818 \pm 1,555$	$921 \pm 396$
Upper Omak Cr	$10,510 \pm 4,311$	$30,212 \pm 6,583$	$17,905 \pm 2,018$	$23,226 \pm 5,658$	$5,539 \pm 1,811$
Lower Loup Loup Cr	$728 \pm 181$	$2,014 \pm 405$	$4,979 \pm 335$	$4,839 \pm 397$	$6,435 \pm 495$
Upper Loup Loup Cr	Not sampled	Not sampled	Not sampled	Not sampled	$3,484 \pm 1,168$
Ninemile Cr	$5,304 \pm 1,763$	$3,992 \pm 500$	$11,244 \pm 1,150$	$5,261 \pm 1,081$	$17,109 \pm 2,403$
Bonaparte Cr	$208 \pm 125$	$662 \pm 108$	$3,057 \pm 1,538$	$670 \pm 124$	$3,185 \pm 463$
Tonasket Cr	$5,684 \pm 497$	$1,862 \pm 391$	$2,496 \pm 321$	$3,567 \pm 465$	$1,817 \pm 250$
Tunk Cr	$212 \pm 131$	$1,267 \pm 167$	$3,067 \pm 229$	$2,692 \pm 217$	$6 \pm 0$
Aeneas Cr	$697 \pm 102$	$728 \pm 415$	$111 \pm 18$	$406 \pm 92$	$488 \pm 82$
Wanacut Cr	$3,407 \pm 793$	$2,300 \pm 344$	$1,644 \pm 351$	$1,896 \pm 230$	$0 \pm 0$
Johnson Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Lower Antoine Cr	Not sampled	Not sampled	Not sampled	Not sampled	$493 \pm 69$
Upper Antoine Cr	Not sampled	Not sampled	Not sampled	Not sampled	$16,152 \pm 6,115$
Wildhorse Sp Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Inkaneeep Cr	$2,327 \pm 1,480$	$30,936 \pm 6,139$	$19,856 \pm 2,720$	$14,450 \pm 2,810$	NA
Vaseux Cr	Not sampled	$3,543 \pm 1,351$	$8,630 \pm 4,274$	$16,998 \pm 6,514$	$10,312 \pm 3,291$
Shuttleworth Cr	$16,078 \pm 7,211$	$18,239 \pm 3,703$	$17,459 \pm 1,786$	$19,286 \pm 2,247$	$8,796 \pm 8,895$
Lower Shingle Cr	$7,112 \pm 4,639$	$2,399 \pm 1,286$	$846 \pm 655$	$686 \pm 108$	$1,783 \pm 1,629$
Upper Shingle Cr	$6,593 \pm 1,703$	$8,086 \pm 2,748$	$33,297 \pm 10,368$	$11,560 \pm 1,745$	NA
Shatford Cr	$104,611 \pm 30,251$	$14,419 \pm 3,427$	$53,899 \pm 11,865$	$33,625 \pm 5,206$	$21,953 \pm 5,490$

Table 3. Instream population estimates of age-1+ natural-origin *O. mykiss* ( $\pm 95\% \text{CI}$ ) in tributaries to the Okanogan River in Washington State and British Columbia. Only five most recent years shown, refer to Appendix B for complete dataset.

Tributary	2017	2018	2019	2020	2021
Salmon Cr	$38,556 \pm 2,136$	$28,203 \pm 2,058$	$27,284 \pm 1,603$	$31,715 \pm 1,979$	$32,827 \pm 1,938$
Lower Omak Cr	$7,264 \pm 812$	$3,101 \pm 1,335$	$4,163 \pm 325$	$5,284 \pm 641$	$224 \pm 50$
Upper Omak Cr	$16,820 \pm 1,642$	$13,330 \pm 1,839$	$11,300 \pm 917$	$17,040 \pm 2,217$	$7,675 \pm 1,236$
Lower Loup Loup Cr	$2,722 \pm 295$	$1,214 \pm 185$	$556 \pm 86$	$1,681 \pm 86$	$1,223 \pm 55$
Upper Loup Loup Cr	Not sampled	Not sampled	Not sampled	Not sampled	$8,229 \pm 705$
Ninemile Cr	$6,971 \pm 673$	$3,519 \pm 361$	$4,524 \pm 367$	$2,847 \pm 153$	$1,814 \pm 201$
Bonaparte Cr	$437 \pm 104$	$348 \pm 36$	$423 \pm 60$	$1,279 \pm 87$	$538 \pm 115$
Tonasket Cr	$1,423 \pm 71$	$3,652 \pm 338$	$340 \pm 43$	$596 \pm 62$	$144 \pm 0$
Tunk Cr	$138 \pm 19$	$109 \pm 23$	$80 \pm 15$	$318 \pm 45$	$61 \pm 24$
Aeneas Cr	$112 \pm 23$	$105 \pm 11$	$36 \pm 5$	$24 \pm 0$	$13 \pm 0$
Wanacut Cr	$2,113 \pm 177$	$1,762 \pm 62$	$1,151 \pm 61$	$609 \pm 46$	$659 \pm 32$
Johnson Cr	Not sampled				
Lower Antoine Cr	Not sampled	Not sampled	Not sampled	Not sampled	$298 \pm 123$
Upper Antoine Cr	Not sampled	Not sampled	Not sampled	Not sampled	$12,930 \pm 1,281$
Wildhorse Sp Cr	Not sampled				
Inkaneeep Cr	$4,556 \pm 2,368$	$149 \pm 56$	$4,351 \pm 452$	$3,333 \pm 311$	$1,211 \pm 319$
Vaseux Cr	Not sampled	$3,588 \pm 1,405$	$3,424 \pm 978$	$6,374 \pm 2,693$	$3,110 \pm 1,120$
Shuttleworth Cr	$2,658 \pm 798$	$3,696 \pm 776$	$10,830 \pm 981$	$4,906 \pm 828$	$1,261 \pm 404$
Lower Shingle Cr	$13,515 \pm 6,622$	$8,136 \pm 1,125$	$6,284 \pm 3,277$	$5,679 \pm 715$	$2,189 \pm 813$
Upper Shingle Cr	$2,286 \pm 366$	$5,071 \pm 498$	$7,169 \pm 1,517$	$5,930 \pm 528$	$1,391 \pm 787$
Shatford Cr	$9,465 \pm 3,863$	$4,182 \pm 664$	$3,718 \pm 839$	$8,460 \pm 916$	$3,770 \pm 3,583$

Table 4. Juvenile steelhead outmigration estimates (95%CI) by year from subwatersheds within the Okanogan subbasin.

Tributary	2014	2015	2016	2017	2018	2019	2020	2021
Salmon Cr	9,077 ± 1,130	7,918 ± 1,159	8,831 ± 1,902	20,730 ± 6,700	9,593 ± 3,781	6,578 ± 990	5,357 ± 1,003	10,580 ± 1,249
Lower Omak Cr	3,063 ± 415	3,156 ± 466	1,688 ± 272	4,590 ± 1,359	4,934 ± 1,392	1,376 ± 638	1,251 ± 298	2,421 ± 502
Upper Omak Cr				20,954 ± 18,841	2,235 ± 1,669	236 ± 208	455 ± 243	NA
Loup Loup Cr		1,193 ± 255	600 ± 112	1,984 ± 433	980 ± 432	501 ± 125	323 ± 84	946 ± 125
Ninemile Cr		0	655 ± 250	836 ± 387	1,918 ± 444	2,382 ± 3,771	511 ± 215	942 ± 235
Bonaparte Cr	201 ± 71	112 ± 0	195 ± 62	767 ± 151	211 ± 103	174 ± 65	224 ± 78	671 ± 132
Tonasket Cr		24 ± 0	2 ± 2	30 ± 26	441 ± 129	1,178 ± 296	159 ± 64	343 ± 98
Tunk Cr		131 ± 119	NA	NA	0	NA	49 ± 23	264 ± 52
Aeneas Cr		198 ± 103	32 ± 32	54 ± 16	78 ± 24	80 ± 18	18 ± 11	14 ± 9
Wanacut Cr		0	0	0	1,610 ± 843	818 ± 231	270 ± 103	110 ± 59
Sum <sup>1</sup>	12,341 ± 1,616	12,732 ± 2,102	11,348 ± 2,382	49,109 ± 27,526	20,082 ± 8,373	10,941 ± 2,234	8,106 ± 1,907	15,349 ± 2,226

NA = could not calculate outmigration estimate due to an insufficient number of PIT tag detections.

<sup>1</sup>Does not include outmigration estimates from Ninemile Creek due to a largely adfluvial life history type associated with Osoyoos Lake.

## Snorkel Surveys

Results from snorkel surveys suggest that during the summer base-flow periods, considerably higher densities of juvenile *O. mykiss* are found in tributaries, as compared to the mainstem Okanogan River. These findings have remained constant throughout all years of data collection. Although observed densities of fish do vary by sample site and between subwatersheds, an example data set from Loup Loup Creek and the mainstem Okanogan River are presented in Figures 3 and 4. Juvenile abundance estimates in the mainstem Okanogan River remained near or at zero for nearly all mainstem survey sites. Density of salmonids at survey sites in the British Columbia mainstem Okanogan River also remained low when compared to tributaries, averaging 3 fish/ha in two channelized sections. However, densities of fish were noticeably higher in the ‘natural section’, averaging 29 fish/ha across survey years. Detailed results showing general trends in observed abundance from annual monitoring sites are presented in Appendix C.

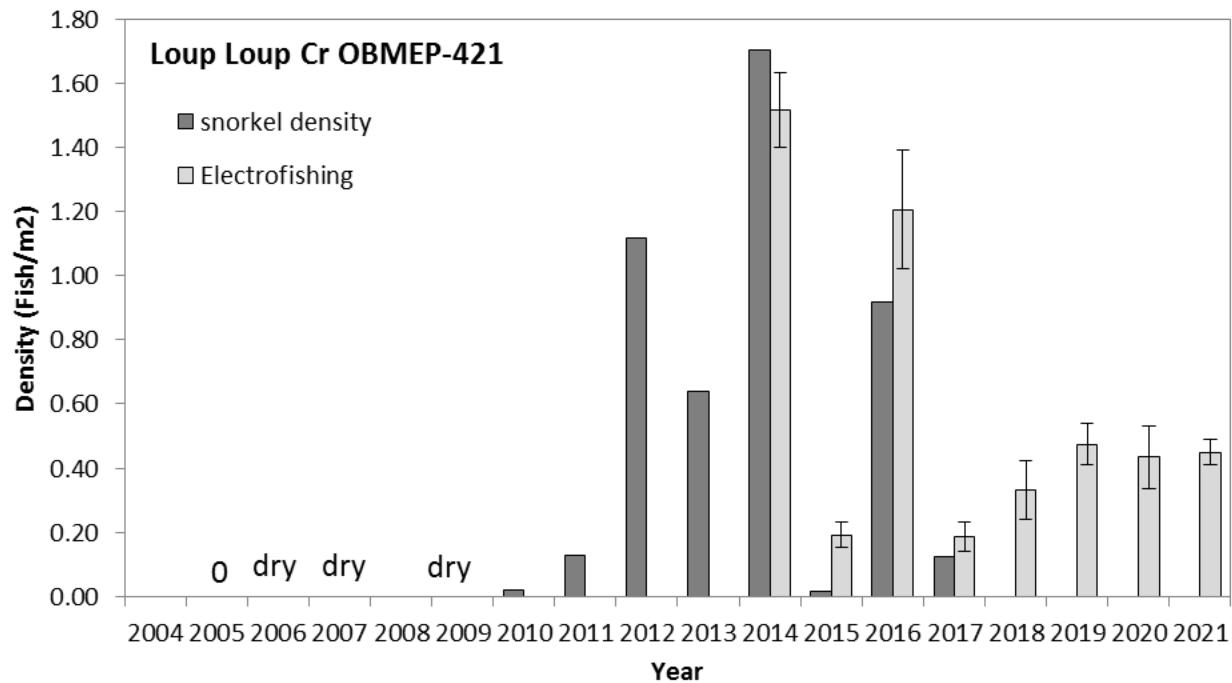


Figure 3. Observed densities of juvenile (< 300mm) *O. mykiss* in Loup Loup Creek.

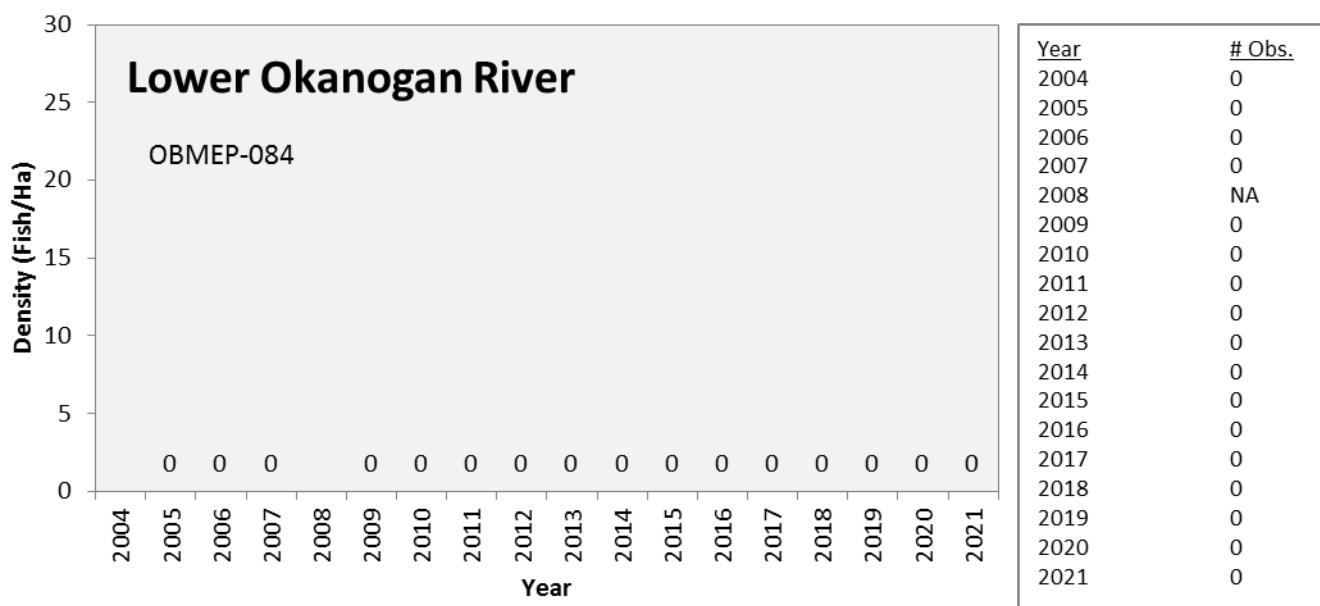


Figure 4. Observed densities of juvenile (< 300mm) *O. mykiss* in the Okanogan River, upstream of the confluence with Salmon Creek.

### **3.2 Habitat Status and Trend Monitoring**

The Okanogan subbasin habitat status and trends analyses are presented in one online reporting tool, with user-selectable options to view summer steelhead or summer/fall Chinook results. The most recent status and trends reports, updated in 2020, and containing data collected through 2017 can be accessed at the web link below.

<https://ecosystems.azurewebsites.net/hstr-okanogan/>

Results are presented in a series of hierarchically arranged web-based report cards scaling down from the population level (Okanogan subbasin), to the diagnostic unit level (6th order subwatershed Hydrologic Unit Code or HUC) and finally to the geomorphic reach level. A summary and index of this report hierarchy is available at the link listed above. The trends in habitat condition in the 2017 habitat status and trend scenarios are the result of both changes in habitat condition and improvements in the quality and quantity of empirical information supporting status and trends modeling. The 2020 version of the report cards reflects updates to the Template habitat scenario as well as the addition of an Implementation Tab and increased attribute reporting resolution.

#### **Summer Steelhead Population (US)**

The trend shown in the population report card for Okanogan (U.S.) steelhead suggests an increasing habitat performance capacity and abundance for both adults and juveniles. Between 2009 and 2013, modeled adult habitat capacity showed a 10% increase and adult abundance increased by 26%. Between 2013 and 2017, modeled adult habitat capacity showed a 18% increase and adult abundance increased by 25%, indicating that current habitat conditions have the capacity to support a viable population of summer steelhead (>500) in the U.S. portion of the Okanogan. Improvements in the quality and quantity of habitat data changed between model runs in addition to the correction of several key obstructions throughout the model scenarios.

Salmon Creek remained the highest priority for protection because it had the highest potential for reductions in population abundance if habitat conditions were to degrade. Priority habitats in Salmon Creek also showed some of the largest potential gains for increased population abundance if restored, ranking fifth of all assessment units in the US Okanogan. Steelhead habitat potential in Salmon Creek showed a positive trend in all parameters from 2009 to 2017. Model results highlighted that Johnson Creek has potential for increasing population productivity with restoration. However, no habitat improvement projects were conducted before the end of the data collection cycle in Johnson Creek that fed the 2017 model run so most of the trends were negative or neutral.

#### **Summer/fall Chinook Population (US)**

The population report card for Okanogan (U.S.) summer/fall Chinook shows positive trends in habitat capacity and abundance between 2009 and 2017, with capacity increasing by 58% during this period. Juvenile habitat capacity increased substantially during this period to 125% of template, while modeled juvenile abundance increased 78%. Habitat productivity is similar between the 2009, 2013 and 2017 scenarios, but the proportion of self-sustaining trajectories drops from 35% to 13% during this period, indicating that the 2017 scenario was supported by a narrower range of life histories.

Most Okanogan River reaches show potential for increasing population productivity with restoration actions. Diagnostic unit and reach specific habitat performance can be found in the summer/fall Chinook status and trend report link above.

### **Comparison of Summer Steelhead model abundance and outmigrant monitoring**

OBMEP/EDT integration abundance estimates from the 2014–2017 modeling cycle were relatively consistent with 2014–2017 mark-recapture outmigrant estimates from tributary diagnostic units (Table 5). Model performance undervalued estimated smolt production by a significant margin in Lower Omak Creek, which is attributable to a considerable increase in water temperature during the model run years.

Table 5. OBMEP/EDT integration juvenile outmigration abundance estimates from the 2014–2017 modeling cycle and estimated juvenile steelhead outmigration by subwatershed and outmigration year.

Tributary	2014–2017 Model Abundance	Actual Estimated Outmigration 2014–2017 Median <sup>1</sup>
Salmon Cr	7,495	8,954
Lower Omak Cr	682	3,110
Loup Loup Cr	640	1,193
Ninemile Cr	1,321	655
Bonaparte Cr	85	198
Tonasket Cr	0	24
Tunk Cr	0	131
Aeneas Cr	0	54
Wanacut Cr	40	0
Sum	10,263	14,319

<sup>1</sup>Values taken from data presented in Table 4

### *Additional Habitat Monitoring Results*

#### **Water Temperature**

Maximum weekly maximum temperature (MWMT) and maximum weekly average temperature (MWAT) values were calculated for all streams in Washington and British Columbia that had complete data sets for the months of June, July, August, and September. Median MWAT values for the current dataset (2005–2021) were above 23°C for the mainstem Okanogan in Washington State and British Columbia; median MWAT values for most tributaries were between 18 and 23°C (Figure 5). Based on long-term monitoring data and known limitations of cold-water salmonid species (reviews by Currie et al. 1998 and Beitingen et al. 2000), high water temperature represents a limiting factor for rearing summer steelhead parr in the Okanogan River. Overall, temperature observations in 2021 were above ‘normal’ (within the 13 year Q2–Q3 range) (Figure 5). Detailed results, including differences in amplitude in daily water temperature measurements and effects of water temperature during incubation and rearing are further discussed in Appendix D.

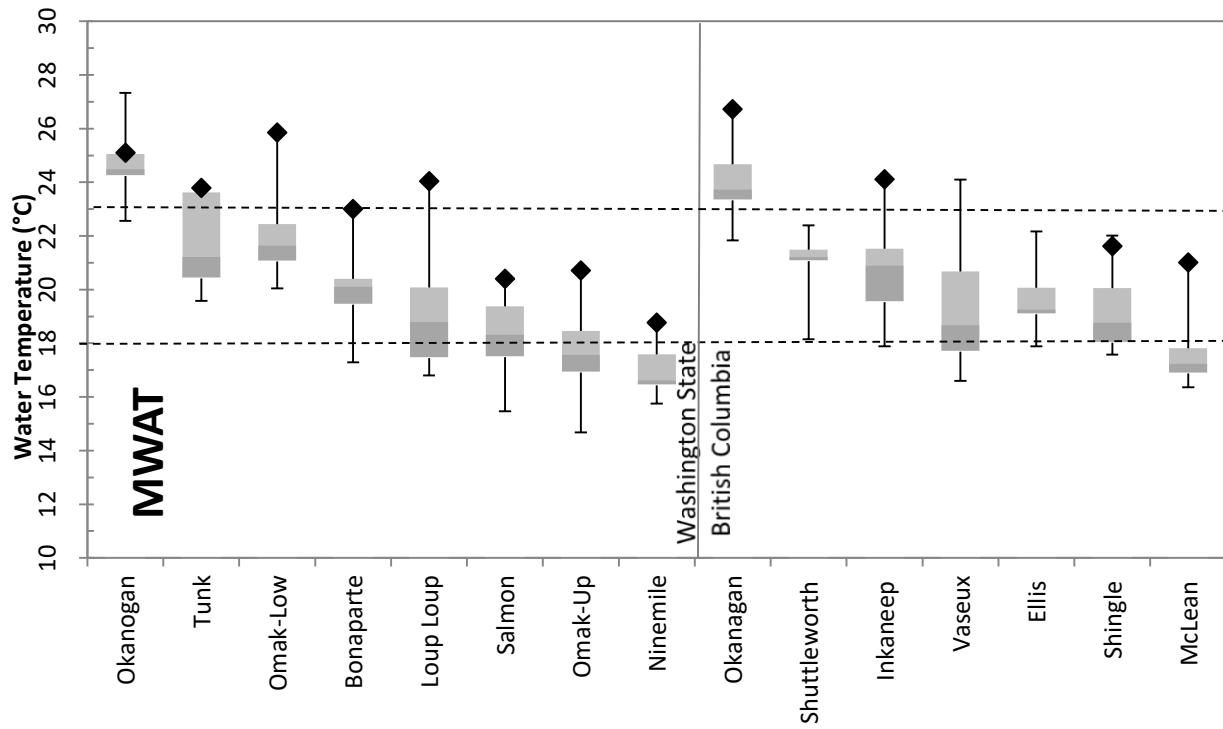
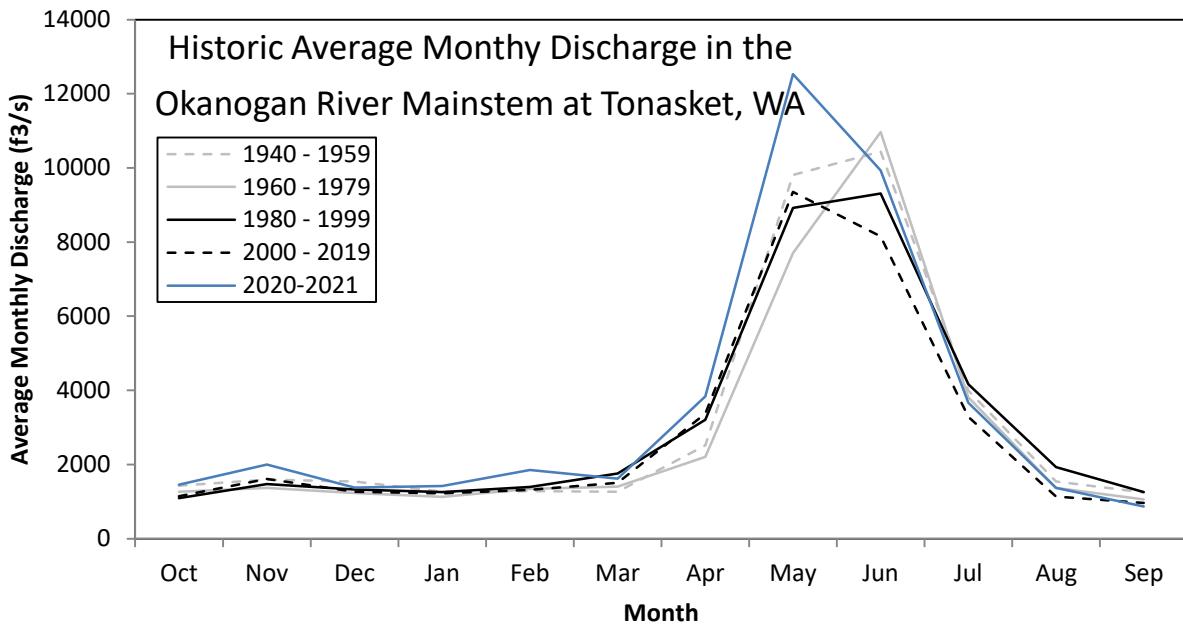


Figure 5. Maximum weekly average water temperatures (MWAT) in the Okanogan subbasin from 2005–2021. Black diamonds are 2021 MWAT values. Boxes represent 50–75<sup>th</sup> (Q3, light grey) and 25–50<sup>th</sup> (Q2, dark grey) quartiles of the MWAT distribution during 2005–2021 while whiskers display the maximum and minimum range of values. Dashed lines delineate 18°C (preferred rearing) and 23°C (lethal) thresholds (EPA 2003).

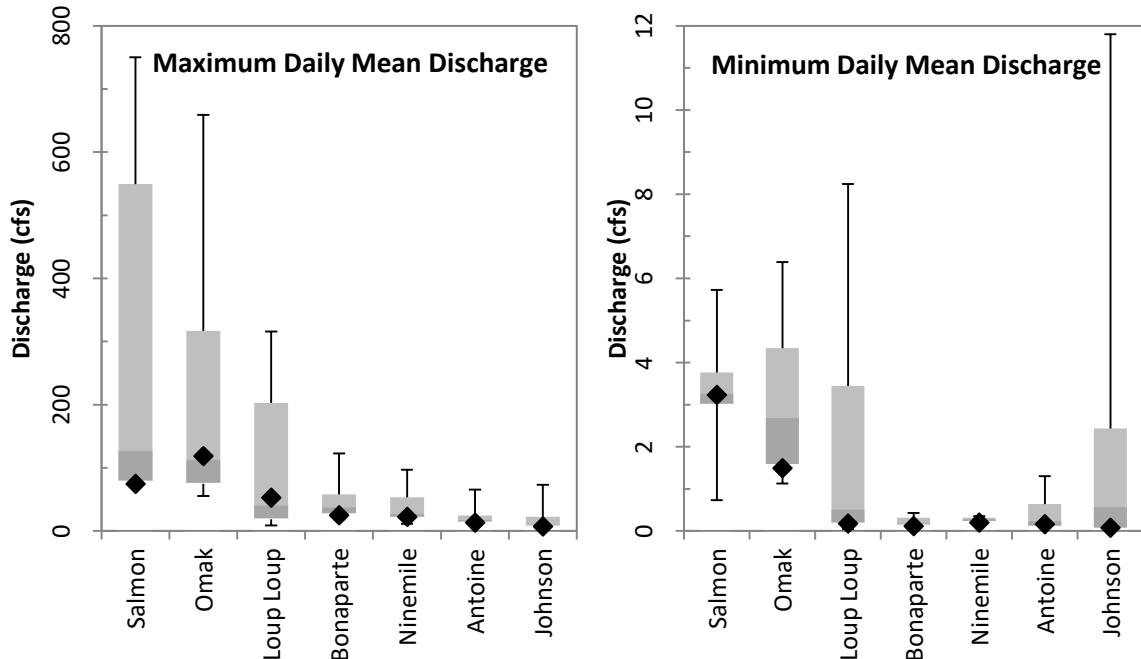
## Water Quantity

The USGS has continuously operated the Okanogan mainstem stream gage at Tonasket for the last 92 years. Historic average monthly discharge at this location is displayed by averaging two decades per hydrograph (Figure 6). In 2021, a low snowpack in both the Canadian and US portions of the Okanogan Subbasin resulted in a 2021 peak flow that was only 85% of the average peak flow for the 92 year period of record.

Below-normal precipitation and snowpack in the United States portion of the Okanogan River subbasin resulted in a reduced runoff period for small streams as observed at seven cooperatively operated USGS stream gages in tributaries to the Okanogan River which have been operated from 2014-2021. Peak flows for these tributaries were all below the ‘normal’ (8 years of data) range, as shown in Figure 7. Base flows were also below the ‘normal’ range (Figure 7). Additional trends in water quantity are presented in Appendix E.



**Figure 6.** Average monthly discharge of the Okanogan River at Tonasket, WA (USGS Station 12445000, Okanogan River near Tonasket, WA).



**Figure 7.** Maximum and Minimum Daily Mean Discharge of seven tributaries to the Okanogan River, or the mean discharge for the highest peak and lowest flow day of the year. Black diamonds are 2021 MDMD values. Boxes represent 50–75<sup>th</sup> (Q3, light grey) and 25–50<sup>th</sup> (Q2, dark grey) quartiles of the MDMD distribution during 2014–2021 while whiskers display the maximum and minimum range of flow values.

## **4.0 Discussion/Conclusion**

With the listing of several salmonid species within the Columbia River Basin as threatened or endangered under the Endangered Species Act, federal, state, tribal, and other entities have made considerable investments in salmon and steelhead population monitoring and habitat restoration. Tracking status of salmon and steelhead populations as they relate to habitat capacity and limiting factors remains an important part of determining if conditions are improving or degrading. Over the long-term, status data are used to examine trends, which may indicate if salmon and steelhead populations and their respective habitats are improving or degrading. In the absence of OBMEP monitoring efforts, very little empirical information would exist on the Okanogan subbasin. Data collected through this program has helped to address Reasonable and Prudent Alternative (RPA) 50.6 fish population status monitoring, RPA 56.3 habitat status and trend monitoring, RPA 71.4 data management, and RPA 72.1 coordination forums. Future monitoring will continue to support validation of trends, while some modifications of protocols may be needed to evaluate identifiable uncertainties.

### **Adult Steelhead Monitoring**

Monitoring has benefitted steelhead populations in the Okanogan subbasin by informing specific restoration actions and prioritizing restoration and enhancement efforts. Steelhead spawning surveys have provided a means to document spawning distribution, timing, and an estimate of escapement in years when spring runoff occurs post-spawning. Defining the physical location of redds has helped to inform managers about the location of habitats being used for spawning and allow for tracking of spatial status and trends through time. Spatial distribution of redds has also been important when considering locations for restoring and/or protecting habitat. Detailed percent natural-origin information has been provided and every attempt has been made to ensure that these estimates are accurate. Values presented in this document represent a best estimate from available information, but the variability surrounding some point estimates are currently undefined. Given the expanse of potential habitat for anadromous fish in the British Columbia portion of the Okanagan subbasin, continuing to expand the number of PIT tag interrogation sites in British Columbia will help increase knowledge concerning trends in abundance and spatial distribution of summer steelhead throughout the subbasin.

Since OBMEP began collecting steelhead spawning data in 2005, the importance of not relying solely on redd surveys for determination of spawning estimates has become evident. Implementation of an Upper Columbia Basin-wide PIT tag interrogation system, coupled with the representative marking of returning adults at Priest Rapids Dam (Project # 2010-034-00) has allowed managers an additional means to estimate abundance on years with poor water visibility, to validate redd survey efficiency, and describe spatial distribution and upstream extent of spawning, where previously unknown or walking access was limited. Continuation of these efforts will allow managers to describe the spatial extent of spawning in tributaries, monitor effectiveness of migration barrier removal, and better define escapement estimates with confidence intervals.

### **Juvenile Abundance and Outmigration Monitoring**

The electrofishing-based juvenile abundance study implemented by OBMEP demonstrated that it was possible to determine an instream population estimate of juvenile salmonids in small creeks with a defined measure of precision. Over the past several years, it has been possible to detect change in

status and trends in sub-populations of juvenile steelhead in relatively small, spatially distinct watersheds. Expanding these methods to the remaining subwatersheds within the Okanogan subbasin will allow for further examination of juvenile steelhead production and increase the number of PIT tagged fish available for interrogation to estimate outmigration for the subbasin as a whole. Detailed results from juvenile monitoring can be used to prioritize restoration or protective measures for habitat practitioners pertaining to priority stream reaches. Although the methods used in this study might not be applicable for larger systems (refer to Appendix B), the representative fish sampling approach was shown to provide an estimate of juvenile steelhead in small watersheds, including outmigration estimates, with a high degree of precision.

Snorkel surveys of juvenile salmonids can show changes in relative abundance over time (Schill and Griffith 1984, Thurow 1994). Annual variation in observed abundance is calculable from the current long-term snorkel dataset for the Okanogan subbasin, but it was not known how these values related to total abundance until the recent implementation of electrofishing sampling at all tributary sample sites. Snorkel surveys conducted over the past 11 years showed trends in observed fish abundance, but results varied by site, even among subwatersheds. One of the difficulties in snorkel data collection is that the observation rate can vary, particularly in smaller tributaries with very shallow water depths. This effect can be further confounded on low water years, such as was experienced in 2015. While OBMEP strived to maintain consistency in observer bias by using consistent snorkeler(s) to collect tributary snorkel survey data for 9 years (2009–2017) and documenting variable observation rates annually by site, without a statistical evaluation it is not possible to definitively state the accuracy of observed trends. While snorkel survey methods have value and are relatively inexpensive, some level of caution should be used when interpreting these data, as many geomorphic and biological factors can affect results.

### **Habitat Status and Trend Monitoring**

The quantity of water in streams in the semi-arid Okanogan River system plays a fundamental role in regulating abundance and distribution of salmonid species, particularly in small tributaries. Effects of extremely low discharge rates are compounded by warm water temperatures during the summer base flow period, which contribute to increased competition for food resources and rearing space. Results of stream flow and other habitat influences are illustrated in the habitat status and trend report, where specific limiting factors are clearly defined by life stage. Results are provided at population, diagnostic unit and reach levels using habitat survival factors that can be “directly linked to existing management platforms like the Columbia Basin Expert Panel process and NMFS ecological concerns used to track regional trends in habitat condition and restoration actions” (CCT 2015). Habitat status and trend results also include an assessment of the “reliability of results based on the strength of the underlying data and information used to generate survival factor results”. Collectively, this information can be used to report on habitat status and trends, identify habitat protection and restoration priorities, and evaluate the success or failure of habitat restoration actions by inference (CCT 2015). Based on findings from the most recent EDT analysis, a list of recommendations has been developed for prioritization of habitat protection and restoration and is embedded in the online report card set.

The comparison of integration results and mark-recapture based juvenile outmigrant estimates at the diagnostic unit scale serves as an enlightening cross validation exercise. Currently, the most appropriate

comparison is made between theoretical abundance estimates from the 2014–2017 modeling cycle and 2014-2017 out-migrant estimates. It is notable that respective estimates from tributary habitats agree on an order-of-magnitude basis. In tributaries with relatively few observed outmigrants (< 200, Bonaparte, Tunk, Aeneas Creek) integrated abundance is estimated at either zero or fewer than 100 smolts in the 2014–2017 modeling cycle. In tributaries with a consistently greater demonstrated capacity (Loup Loup, Ninemile, Omak Creek) the empirical and modeled estimates of smolt abundance are generally between 500-1500 and in the consistently most important Okanogan tributary (Salmon Creek) estimates are both between 7500-8500 smolts. Though model abundance is not intended to be 1:1 estimate of smolt abundance, these results suggest that the EDT model is characterizing trends in habitat appropriately.

The overall outcome of monitoring in the Okanogan subbasin is to guide natural resource managers' decisions to minimize threats to salmon and steelhead, choose restoration actions that will have the most positive impact, and set measurable salmon and steelhead enhancement objectives to coincide with fiscal investments over multiple jurisdictions. Salmonid population monitoring also includes collecting applicable data that can be used in real-time decisions about harvest, hatchery management, and habitat project implementation. Information related to status and trends for salmon and steelhead within the Okanogan requires a long-term vision and commitment to provide answers about population-level actions and trends in habitat quantity and quality. As monitoring efforts proceed the Okanogan Basin Monitoring and Evaluation Program expects to continually deliver practical status and trend monitoring data and to make those data readily available for use in more comprehensive, broad-scale analyses.

## **5.0 Adaptive Management & Lessons Learned**

*Explain how your results could be used by managers to inform program strategies; including habitat restoration, predation, or hatchery and hydrosystem operations.*

Status and trend data collected through OBMEP under the Fish Population and Tributary Habitat Research Monitoring and Evaluation (RM&E) program strategies have been used by a variety of managers. Long-term monitoring data collected and analyzed have been particularly useful for habitat practitioners (e.g., Colville Tribes Habitat Program, Trout Unlimited, Cascade Columbia Regional Fisheries Enhancement Group) performing restoration work within the Okanogan subbasin. Although data and analysis derived from OBMEP can be used to address effectiveness of habitat or hatchery projects, identifying causal mechanisms was not the intent of original program research questions.

Some of the most requested monitoring data from managers have been fish abundance estimates for both adults and juveniles. Adult abundance metrics have been used by habitat practitioners to evaluate success of tributary instream flow projects, irrigation management, potential water purchases, habitat protection measures, passage success before and after impediment removal/redesign, and hatchery stocking, among others. Percent of adults spawning in individual subwatersheds have been analyzed by origin (hatchery and natural) to examine current status and success of habitat projects and to modify hatchery broodstock collection goals. Juvenile abundance data have been used to prioritize reach-based

habitat plans, manage flow patterns, examine survival by life stage, and in the future may be used to estimate survival or growth. Detailed results from juvenile monitoring can be used to prioritize restoration or protective measures for habitat practitioners pertaining to priority stream reaches. Collection of detailed fish abundance data will also be used to validate or adjust EDT model parameters.

Metrics derived from long-term habitat monitoring in the Okanogan subbasin are also valuable for habitat practitioners. The OBMEP habitat status and trend approach has allowed the program to use a complex set of broad-ranging habitat data types to be integrated into a single model and output at multiple spatial scales. Data collected over the past 10 years have resulted in determination of limiting factors for salmonids and a list of recommendations for prioritization of habitat protection or potential restoration. The habitat status and trend analysis provided a detailed assessment of steelhead habitat potential in the Okanogan subbasin and characterized change in habitat conditions between 4-year monitoring cycles. The revision of subbasin plans, recovery plans, and/or strategies will rely heavily on these documents.

*Describe how your results could be applied at the watershed, subbasin, and Columbia Basin scale.*

Fisheries monitoring programs within the Columbia Basin are designed to detect changes in fish populations or habitat, identify potential sources of change, and/or measure success of management activities. Monitoring generally requires collecting and analyzing fine scale data and in turn, those data are rolled up to larger spatial analyses. At the Columbia Basin or Upper Columbia River scale, high level information, such as trends in spawner abundance or yearly outmigration estimates, are frequently used for ESU population-level tracking purposes. Temperature data collected at many sites throughout the subbasin over the past 10 years can be incorporated in to larger spatial analyses. Regional climate studies have utilized data collected through OBMEP. The USGS low snowpack river flow study in 2015 measured flow and temperature of hundreds of streams and rivers, including many of the stream flow stations in the Okanogan River subbasin. Habitat status and trend information can be directly linked to existing management platforms, such as the Northwest Power and Conservation Council (NPCC) subbasin plan, Upper Columbia Salmon Recovery plan, Columbia Basin Expert Panel process and NMFS Columbia River Biological Opinion (BiOp) among others. Collectively, this information can be used to report on habitat status and trends, identify habitat protection and restoration priorities, and evaluate information needs and data gaps to guide future monitoring activities.

While high level, subbasin-wide indicators are some of the most commonly used information utilized in large-scale Columbia Basin-wide analyses, there is also substantial value in smaller, more site-specific datasets. Watershed, subwatershed, or reach-scale data are arguably more valuable for actively managing fish, hatcheries, and habitat restoration/protective actions, which lead to informed on-the-ground decisions that directly affect recovery of listed species. Adult abundance metrics and habitat status and trend information have been used by habitat practitioners to evaluate success of instream flow projects in specific subwatersheds. This information has been used for the management of irrigation systems, the evaluation of passage impediments, and the identification of measures to protect habitat. Juvenile abundance and small-scale habitat data have been used to prioritize reach-based habitat plans, manage flow patterns, and examine survival by life stage. Numeric escapement goals have

been set based upon habitat capacity estimates and hatchery stocking of juvenile salmonids adjusted by specific subwatershed based on the adult returns and the proportion of natural-origin spawners. In season fish passage and temperature data have been used to inform international harvest goals. Information collected may also help to inform or update recovery goals, providing objective data about adult returns and juvenile habitat capacity based on actual data rather than subjective or professional opinion.

*Discuss how your results will be shared with other resource managers.*

According to the Framework for the Fish and Wildlife Program Data Management (BPA 2013) and the Guidance for Monitoring Recovery of Pacific Northwest Salmon & Steelhead listed under the Federal Endangered Species Act (Crawford and Rumsey 2011), there is a need for readily available data to support fisheries management processes and entities such as the Fish and Wildlife Program, the Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp), and NOAA's 5-year review of ESA-listed species to determine their listing status. BPA's strategy for achieving this goal is to develop compatible networks of data management systems that have standardized documentation and data exchange formats. OBMEP has made significant gains in coordinating, standardizing, and disseminating data which support the RM&E program. As a BPA-funded project, the program has been keeping pace with these goals by utilizing tools such as Monitoring Resources.org to document and standardize protocols, developing electronic methods for data collection, review, transfer, and storage. The program has also submitted data types such as fish passage, redd surveys, and snorkel surveys to approved data repositories such as Data Access in Real Time (DART), Passive Integrated Transponder (PIT) Tag Information System (PTAGIS), and Streamnet. Finally, dissemination of other specific data (GIS layers, EDT reaches, steelhead redd GPS coordinates, and water temperature data) are made available on the OBMEP website at: <https://www.okanoganmonitoring.org/>

Specifically within the Okanogan subbasin, considerable coordination has occurred between monitoring, habitat implementation, and hatchery programs. Due to close organization of these programs within the Colville Confederated Tribes Fish and Wildlife Department, findings from monitoring projects can be effectively communicated to habitat and hatchery programs in an efficient manner. For example, output from the EDT model for summer/fall Chinook is used by the Chief Joseph Hatchery program at the Annual Program Review. Outlined in this document and the accompanying habitat status and trend reports are a number of factors that may be limiting recovery of salmonids within the Okanogan subbasin. Subsequent recommendations to habitat practitioners are included throughout these documents, which were derived from 12 years of monitoring data, analyses, and extensive professional experience working in the field. The OBMEP data are shared following the Coordinated Assessment Data Exchange Standard and are considered critical pieces in the regions salmon recovery activities.

Although results from monitoring can be reported in relatively succinct summaries, it is important to understand that a number of assumptions exist behind many of these studies, which can be difficult to explain in short segments (Salmon Monitoring Advisor 2010). Additionally, fisheries data are frequently complex, and “without manipulative experiments, it is not possible to definitively identify causes that lead to clear actions for mitigating the effects... on salmon ...” (Salmon Monitoring Advisor 2010).

OBMEP was designed to monitor status and trends of abundance, productivity, diversity, and spatial structure of adult and juvenile Upper Columbia River summer steelhead and associated habitat in the Okanogan River and its tributaries. Readers and decision makers are encouraged to ask questions and learn more about relative assumptions and complexities of the data before investing in management decisions (Salmon Monitoring Advisor 2010). Additionally, monitoring staff can be contacted directly if more specific data or analyses are needed.

## 6.0 References

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## **7.0 Appendices**

### **Appendix A. Adult Steelhead Abundance and Distribution**

*For additional information pertaining to adult steelhead spawning estimates in the Washington State portion of the subbasin, refer to the technical report listed below:*

OBMEP. 2022. 2022 Okanogan Subbasin Steelhead Spawning Abundance and Distribution. Colville Confederated Tribes Fish and Wildlife Department, Nespelem, WA. Report submitted to the Bonneville Power Administration, Project No. 2003-022-00. Available online at:  
<https://www.okanaganmonitoring.org/Reports/ViewReportsForType/2>

*Additional information pertaining to adult steelhead in the British Columbia portion of the subbasin:*

#### **Introduction**

In the Canadian portion of the Okanagan subbasin, previous research studies indicate that, historically, steelhead were found throughout the Okanagan subbasin (Ernst and Vedan 2000). Prior to 2009, the upstream barrier for returning anadromous salmonids was McIntyre Dam at the outlet of akspaqmix (Vaseux Lake). During this time, akskʷəkʷant (Inkaneep) and nɬaxʷlqaxʷiya (Vaseux) Creeks were the only major tributaries accessible to anadromous steelhead for spawning and rearing. The ONA fisheries department conducted redd surveys on both streams and operated a counting weir on akskʷəkʷant (Inkaneep Creek) from 2006 until 2011. While anadromous steelhead were documented during these monitoring actions (Audy et al. 2011), the counting weir was discontinued due to difficulties in data collection during spring freshets and low-confidence estimates. McIntyre Dam was refitted in 2009 for upstream migration of salmonids and, currently, migrating steelhead have access to habitat as far upstream as the kłusxnitkʷ (Okanagan Lake) outlet dam at Penticton. This allows steelhead access to at least four more major tributaries for spawning and rearing including Shuttleworth, McLean, snpiňya?tkʷ (Ellis) and akłxʷumina? (Shingle) Creek systems. From 2012-2014, the only enumeration method used was a Passive Integrated Transponder (PIT) antenna array in the ɭawsitkʷ (Okanagan River) mainstem upstream of swiws (Osoyoos Lake) at Vertical Drop Structure (VDS) 3 (OKC). In 2015, three more permanent PIT arrays were also installed in akskʷəkʷant (Inkaneep) (OKI), akłxʷmina? (Shingle) (OKS) and Shuttleworth Creeks (OKW). An additional PIT array was installed in nɬaxʷlqaxʷiya (Vaseux Creek) (OKV) in the Spring of 2018. While seasonal arrays have been used in other tributaries in previous years, none were installed in 2021.

#### **Results**

For the Canadian portion of the Okanagan subbasin, steelhead spawning estimates are based on expanded PIT tag detections on the ɭawsitkʷ (Okanagan River) at VDS 3 (OKC), in the Penticton Channel

and major tributaries to the Okanagan. In all years except 2021, a higher proportion of wild steelhead detected at Zosel Dam continued up the qawsitkʷ (Okanagan River) upriver from swiws (Osoyoos Lake) as compared to hatchery steelhead. However, these proportions were based on relatively small sample sizes.

During the Sockeye Salmon migration of 2012, the detection efficiency at the OKC array was estimated at 88.9% (Fryer et al. 2013); however, the detection rate may change between seasons and years. Between 2019 – 2021, all adult steelhead detected on arrays upstream of that point were previously detected on OKC, so we assumed a 100% detection efficiency for those years. The Washington Department of Fish and Wildlife has conducted a PIT tagging effort at Priest Rapids Dam (PRD), on the Columbia River, since 2011 (Ben Truscott, pers. comm.) and abundance estimates listed below are taken from the tagging rates at PRD during sampling times only. Using a simple expansion factor based on the proportion of tagged to untagged fish at PRD and adjusting for the detection rate, escapement at the OKC PIT antenna array was estimated as follows:

It should be noted that all the estimates listed above are based on extremely low sample numbers at the OKC interrogation site. The fall-back rate was not estimated. Also, PIT detection numbers at OKC are based on a number of assumptions including: (1) PIT tags had no detectable effect on the distribution or survival of individuals, (2) all steelhead had an equal chance of detection, (3) there was no loss of tags, (4) the population was closed, and (5) fish falling back downstream had an equal chance of being detected as fish migrating upstream.

Total spawning estimates for steelhead in British Columbia were calculated the same as in the Washington portion of the subbasin, only using tags from the representitively marked Priest Rapids Dam sample group and expanded by the mark rate of 0.139. Two tagged steelhead were detected in n̄fačʷlqaxʷiya (Vaseux Creek), one of natural-origin and one hatchery steelhead (Table A-1). Only the hatchery fish was part of the mark group and that tag was expanded by the mark rate to 0 natural-origin and 7 hatchery steelhead. Because there was a wild fish detected in the creek, the best spawning estimate for the creek would be 7 hatchery and one natural-origin steelhead. There were no steelhead that were only detected on OKC and only two hatchery fish, not from the mark group, were last detected in the Penticton Channel. Those tags would not be expanded by the mark rate; these fish likely spawned in the mainstem qawsitkʷ (Okanagan River), or potentially in another small stream that did not have a PIT antenna in operation. All adult steelhead detected on arrays upstream of that point were previously detected on OKC, so we assumed a 100% detection efficiency for this brood-year. No tagged steelhead were detected in in akskʷəkʷant (Inkaneep), Shuttleworth or akłxʷuminaʔ (Shingle) Creeks. The total spawning estimate was one natural-origin and nine hatchery steelhead in British Columbia in 2021 (Table A-2). This is the second lowest spawning estimate since 2013, only 2018 has less with nine total steelhead. The average number of steelhead spawning in the British Columbia portion of the subbasin over the last nine years (2013-2021) was 23 natural-origin and 12 hatchery steelhead.

As in previous years, each site had small numbers of detections of juvenile *O. mykiss* which had been tagged locally in previous years. Increased PIT detection efforts in the Canadian portion of the Okanagan

basin has also benefited in information gathering for other salmonids beyond *O.mykiss*, including Sockeye, spring Chinook and Coho.

Table A-1. Brood-year 2021 steelhead detected on PIT tag sites in British Columbia.

Location	Status	Tag Group		
		PRD	Other	Total
akskʷəkʷant (Inkaneeep Creek)	Natural-Origin	0	0	0
	Hatchery	0	0	0
	Total	0	0	0
n̄faχʷlqaxʷiya (Vaseux Creek)	Natural-Origin	0	1	1
	Hatchery	1	0	1
	Total	1	1	2
Shuttleworth Cr	PRD	Other	Total	
	Natural-Origin	0	0	0
	Hatchery	0	0	0
	Total	0	0	0
aklxʷuminaʔ (Shingle Creek)	PRD	Other	Total	
	Natural-Origin	0	0	0
	Hatchery	0	0	0
	Total	0	0	0
Penticton Channel	PRD	Other	Total	
	Natural-Origin	0	0	0
	Hatchery	0	2	2
	Total	0	2	2
OKC Only	PRD	Other	Total	
	Natural-Origin	0	0	0
	Hatchery	0	0	0
	Undetermined	0	0	0
	Total	0	0	0

Table A-2. Estimated distribution of steelhead spawning in British Columbia based on expanded PIT tag detections.

Location	Status	2013	2014	2015	2016	2017	2018	2019	2020	2021	Avg.
akskʷəkʷant (Inkaneep Creek)	Natural-Origin			1	0	0		2	0	0	1
akskʷəkʷant (Inkaneep Creek)	Hatchery			6	1	5		0	0	0	2
akskʷəkʷant (Inkaneep Creek)	Total			7	1	5		2	0	0	3
Shuttleworth Creek	Natural-Origin	0	0	0	0	0	0	0	0	0	0
Shuttleworth Creek	Hatchery	0	0	0	0	0	0	0	0	0	0
Shuttleworth Creek	Total	0	0	0	0	0	0	0	0	0	0
n̄aχʷlqaxʷiya (Vaseux Creek)	Natural-Origin						9	9	19	1	10
n̄aχʷlqaxʷiya (Vaseux Creek)	Hatchery						0	9	5	7	5
n̄aχʷlqaxʷiya (Vaseux Creek)	Total						9	18	24	8	15
akłxʷumina? (Shingle Creek)	Natural-Origin	0	0	0	0	0	0	0	0	0	0
akłxʷumina? (Shingle Creek)	Hatchery	0	0	0	0	0	0	0	0	0	0
akłxʷumina? (Shingle Creek)	Total	0	0	0	0	0	0	0	0	0	0
Mainstem or Other	Natural-Origin	22	23	64	15	10	0	23	5	0	18
Mainstem or Other	Hatchery	2	16	20	14	5	0	14	0	2	8
Mainstem or Other	Total	24	39	84	29	15	0	37	5	2	26
Subtotal BC	Natural-Origin	22	23	65	15	10	9	34	24	1	23
Subtotal BC	Hatchery	2	16	26	15	10	0	23	5	9	12
Subtotal BC	Total	24	39	91	30	20	9	57	29	10	35

## Conclusions

The removal of barriers in the Canadian portion of the Okanagan subbasin allows steelhead to access more tributary habitat for spawning and rearing. While current sample sizes are not sufficient to provide confident abundance estimates, baseline data are needed in order to detect if summer steelhead recolonize newly accessible habitat. Since the installation of the OKP PIT array in late 2017, steelhead may be detected as far north as Penticton. The OKP did not have any detections of steelhead in 2018, four were detected in 2019, none in 2020 and two in 2021. Expanding the PIT program into additional tributaries will provide the improved resolution needed to determine specific use of spawning areas, spawn timing and could be coordinated with reintroduction programs. Adding more arrays in the Canadian Okanagan River subbasin could also improve detection efficiency of downstream arrays. Data

from the n̄āx̄w̄lqax̄wiya (Vaseux Creek) PIT array has already proven to be useful; more detections can be expected in the future as more arrays are added.

## Additional Datasets

Table A-3. Estimated number of hatchery and natural-origin steelhead spawning for each sub-watershed or assessment unit in 2021 compared with long-term averages.

Category	Location/HUC	2021 natural- origin spawner abundance	Average # of natural- origin spawners 2005– 2020	2021 hatchery spawner abundance	Average # of hatchery spawners 2005– 2020
WA Mainstem	Okanogan-Davis Canyon	0	0	0	0
WA Mainstem	Okanogan-Talant Creek	0	1	3	10
WA Mainstem	Okanogan-Swipkin Canyon	0	5	15	46
WA Mainstem	Okanogan-Alkali Lake	0	3	8	27
WA Mainstem	Okanogan-Whitestone Coulee	1	6	18	56
WA Mainstem	Okanogan-Mosquito Creek	0	1	4	13
WA Mainstem	Okanogan-Haynes Creek South	3	37	79	325
WA Mainstem	Similkameen River	2	23	62	193
WA Tributary	Loup Loup Creek	7	10	58	32
WA Tributary	Salmon Creek	38	36	8	103
WA Tributary	Omak Creek	36	64	113	142
WA Tributary	Wanacut Creek	0	1	2	3
WA Tributary	Johnson Creek	0	5	0	19
WA Tributary	Tunk Creek	14	10	50	28
WA Tributary	Aeneas Creek	0	0	9	3
WA Tributary	Bonaparte Creek	9	28	19	57
WA Tributary	Antoine Creek	12	6	37	8
WA Tributary	Wild Horse Spring Creek	0	8	43	34
WA Tributary	Tonasket Creek	14	8	29	21
WA Tributary	Ninemile Creek	0	7	7	15
Area	Washington State Mainstem	6	76	189	670
Area	Washington State Tributaries	130	183	375	465
Area	British Columbia	1	25 <sup>a</sup>	9	12 <sup>a</sup>

<sup>a</sup> Average from British Columbia only contain data from 2013-2020.

Table A-4. PIT tag rates of steelhead released by year in the Priest Rapids Dam release group study (BPA Project # 2010-034-00).

Year	Spawning		PRD Tag Rate*
	Hatchery	Wild	
2011	0.0834	0.0834	
2012	0.1309	0.1311	
2013	0.1343	0.1339	
2014	0.1446	0.1448	
2015	0.1742	0.1744	
2016	0.1940	0.1942	
2017	0.2126	0.2205	
2018	0.2242	0.2237	
2019	0.2218	0.2218	
2020	0.2131	0.2131	
2021	0.1390	0.1390	

\*Data provided by WDFW (Ben Truscott, WDFW, pers com)

## **Appendix B. Juvenile Steelhead Abundance and Distribution**

### **Introduction**

Summer steelhead (*Oncorhynchus mykiss*) are currently listed as threatened in the Upper Columbia River. Monitoring the status and trends of tributary populations in the Upper Columbia allow researchers to track progress towards recovery goals, as outlined in the Monitoring Strategy for the Upper Columbia Basin (Hillman 2006). Until recently, estimating the population size of naturally produced juvenile steelhead in the Okanogan subbasin continued to be a challenging task. Life history strategies and residence time of juvenile steelhead can be highly variable. The timing of outmigration can vary widely, even among the same brood year and between sexes (Peven et al. 1994). Consequently, interpreting migrational movements (i.e. resident vs. anadromous) can be challenging. The Okanogan Basin Monitoring and Evaluation Program operated a rotary screw trap (RST) from 2004 to 2011 on the mainstem Okanogan River, but very few captures of naturally produced steelhead produced highly variable and unreliable estimates of population size.

Snorkel surveys of juvenile salmonids can show changes in relative abundance over time (Schill and Griffith 1984, Thurow 1994). Annual variation in observed abundance is calculable from the current long-term snorkel dataset for the Okanogan subbasin, but it remained unknown how these values related to absolute abundance. Data from snorkel surveys conducted from 2004 through 2017 show very low numbers of juvenile steelhead in the mainstem and considerably higher densities in tributaries. Therefore, to more accurately monitor population status and trends of naturally produced juvenile steelhead in the subbasin, population monitoring efforts are being refocused to the cool water tributaries.

The Washington Department of Fish and Wildlife (WDFW) and the Colville Confederated Tribes (Colville Tribes) installed a series of permanent and temporary PIT tag arrays from 2012–2014 near the mouth of tributaries with known or potential steelhead spawning habitat (BPA Project #2010-034-00). Beginning in 2013, the Okanagan Nation Alliance (ONA) installed a series of temporary and permanent arrays in the Canadian portion of the Okanagan Basin. The arrays were primarily installed to monitor movements of adult steelhead during the spring spawning period and better define annual escapement estimates. These PIT tag interrogation systems also have the capacity to detect PIT tagged juvenile salmonids as they leave the system, allowing for development of outmigration estimates.

This study was designed to assess utilization of tributaries to the Okanogan River by juvenile steelhead, while conforming to existing monitoring frameworks in the subbasin. This task was accomplished with the use of electrofishing, remote PIT tagging, mark-recapture events, and in-stream PIT tag interrogations. The primary study goals were to: (1) estimate abundance of juvenile *O. mykiss* in small streams, (2) calculate precision of estimates, and (3) calculate an independent, stream-based population emigration estimates from PIT tagged fish. These methods allow the program to more accurately monitor annual abundance of juvenile steelhead in the Okanogan, estimate precision and bias

associated with methods, and to determine trends in juvenile abundance, spatial distribution, and diversity through time.

## **Methods**

OBMEP - Juvenile Abundance - Mark-Recapture (ID:194)

<https://www.monitoringresources.org/Document/Protocol/Details/194>

*Study Location and Site Selection*

*Loup Loup Creek*

Loup Loup Creek is a tributary that enters the Okanogan River at RKM 24, in the town of Malott, WA. The lower sections of the creek frequently went dry during mid-summer, until 2010, when the point of diversion was transferred to the Okanogan River and the irrigation diversion on Loup Loup Creek was removed. A noticeable increase in juvenile abundance was noted after 2010 (refer to snorkel survey observations). Loup Loup Creek was divided into three reaches below a naturally occurring falls. Within each of the three reaches, one ~150–200 m site was randomly selected to perform a site based population estimate (Figure B-1). A PIT tag interrogation array (LLC) consists of three pass-over HDPE antennas, configured in three separate rows, is located near the mouth of the creek in the town of Malott, WA.

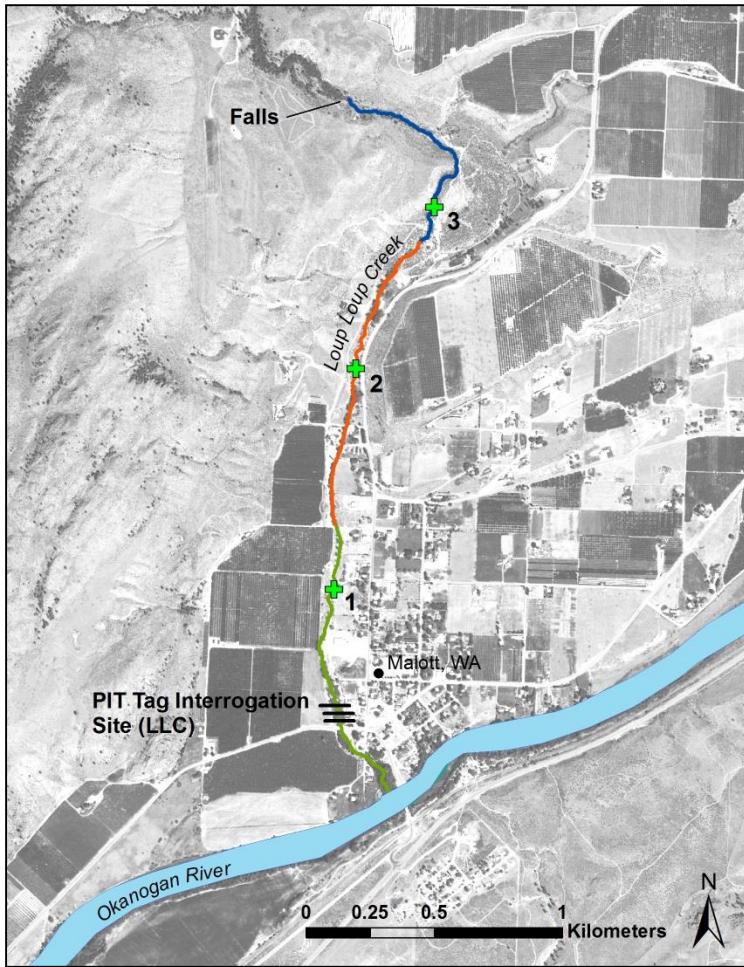


Figure B-1. Loup Loup Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

#### *Salmon Creek*

Salmon Creek is a highly managed, medium sized tributary that enters the Okanogan River at RKM 41.3, in the city of Okanogan, WA. Since the early 1900's, the majority of water from Salmon Creek had been diverted for irrigation usage. The largely dry stream channel extended from the Okanogan Irrigation District (OID) diversion dam (7.2 km) to the confluence with the Okanogan River. Occasionally, uncontrolled spills occurred downstream of the OID diversion dam in high water years. These spills typically occurred in mid-May to June, which is after summer steelhead have already moved into tributaries to spawn. To provide sufficient water during the migration window of spring-spawning steelhead, the Colville Tribes purchased water from the OID and allowed it to flow down the channel to the Okanogan River. After several years of successful evaluations of steelhead passage, the Tribes negotiated a long term water lease agreement with the OID. Since 2006, the long term water lease has

provided a window of water for returning adults and outmigrating juvenile salmonids. The creek has stayed wetted year round since 2019.

Salmon Creek was divided into eight reaches below the anadromous barrier (Conconully Dam) as part of an EDT analysis (Figure B-2). Reach breaks were determined by changes in habitat, gradients, confluence with other streams, or man-made features in the stream that may affect distribution of fish (ex. culverts, irrigation diversion). Within each of the reaches, one ~150–200 m site was randomly selected to perform a site based population estimate. All sites were drawn from a previous General Random Tessellation Stratified (GRTS) sampling effort for habitat monitoring.

A PIT tag interrogation array (SA1) consisting of four pass-over HDPE antennas, configured in two separate rows, is located 2.9 km upstream from the confluence with the Okanogan River. A second PIT tag interrogation site (SA0) is located immediately downstream of the OID diversion dam and consists of five PVC antennas configured in two separate rows.

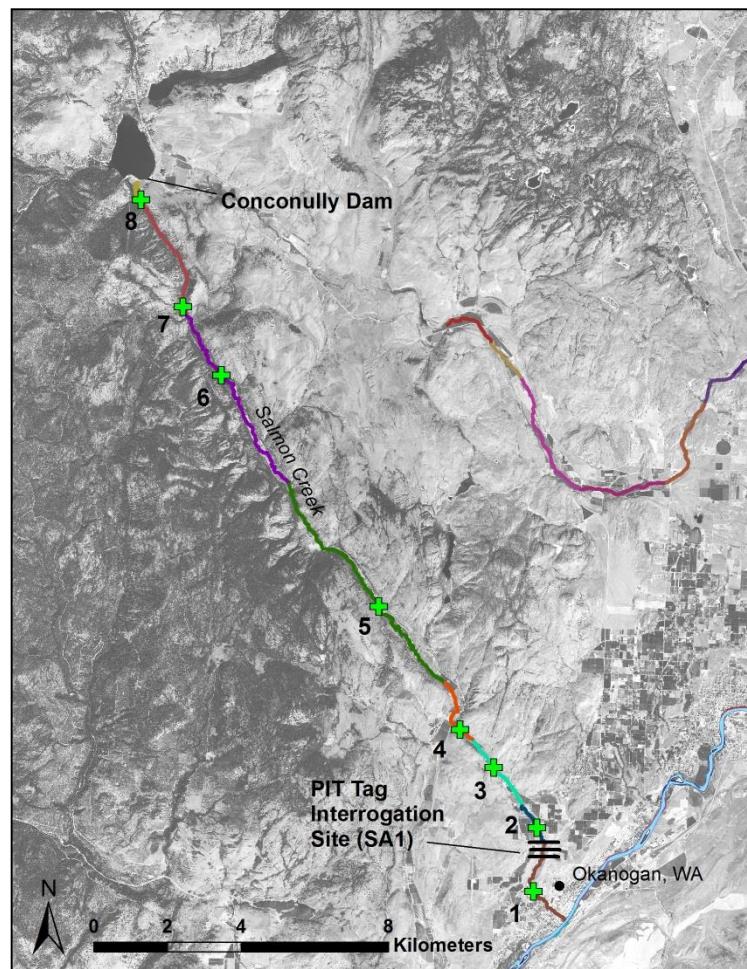


Figure B-2. Salmon Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

## Omak Creek

Omak Creek is characterized as a perennial, medium sized tributary that enters the Okanogan River at RKM 51.5, approximately 1.0 km upstream from the city of Omak, WA. Discharge rates in the creek range from a base flow of 2–4 cfs to over 150 cfs during the spring. During the base flow period, wetted widths range from approximately 2 to 8 m. Omak Creek was divided at Mission Falls to include four reaches below and eight survey reaches above the falls (Figure B-3). Upper Omak Creek was surveyed for the first time in 2016 and 2017 after confirmation or steelhead passage above Mission Falls.

A permanent PIT tag array (OMK) consisting of four pass-over HDPE antennas, configured in two separate rows, is located 0.24 km upstream from the confluence with the Okanogan River. A 5' rotary screw trap (RST) is operated in the spring, 225 m upstream of the PIT tag array. However, due to site and flow-based restrictions, operation of the trap is limited to discharges between 25 and 75 cfs. Captures and releases of PIT tagged juvenile steelhead at the RST will be used to determine detection efficiency at the downstream PIT antenna sites at various discharge rates. Two additional PIT tag interrogation sites are also operated below (OBF) and above (OMF) Mission Falls to monitor passage rates.

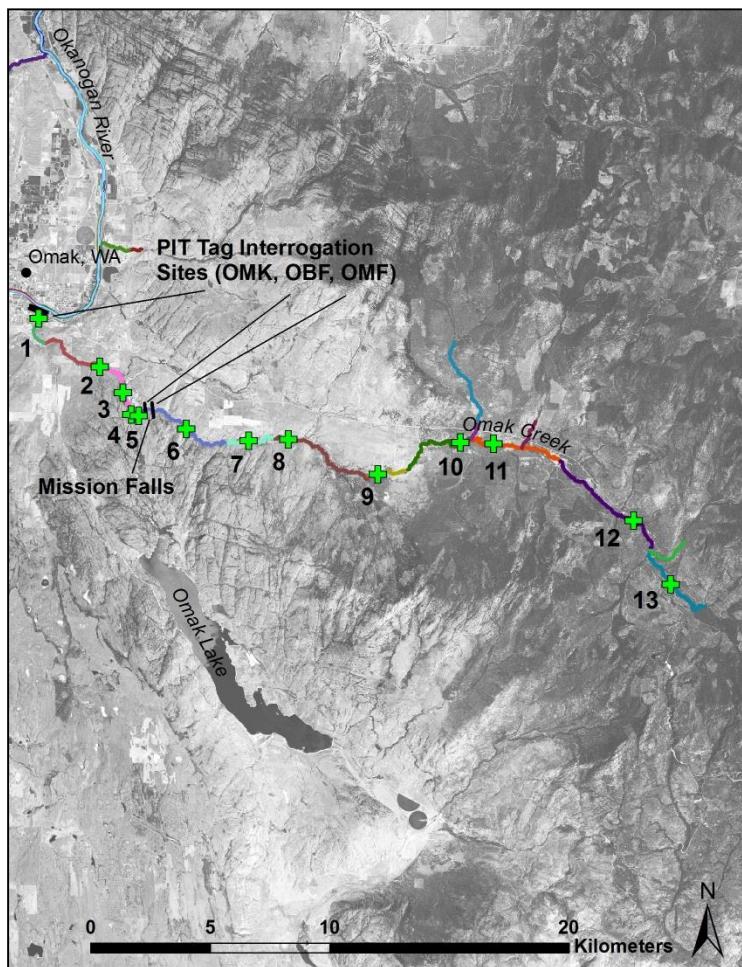


Figure B-3. Omak Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

#### Wanacut Creek

Wanacut Creek is a small stream that meets the Okanogan River at approximately RKM 56, between Omak and Riverside, WA (Figure B-4). The 51 km<sup>2</sup> Wanacut Creek drainage stems from Omak Mountain, located on the Colville Reservation. A large natural falls exists a short distance from the confluence with the Okanogan River and the creek frequently flows subsurface in the lower most reaches. A handful of adult steelhead have been documented spawning in Wanacut Creek, particularly on years where sufficient runoff occurs in March through May. A single PIT tag antenna (WAN) is placed seasonally near the mouth of the creek to document PIT tagged steelhead movements. The creek was divided into two survey reaches for subsampling.

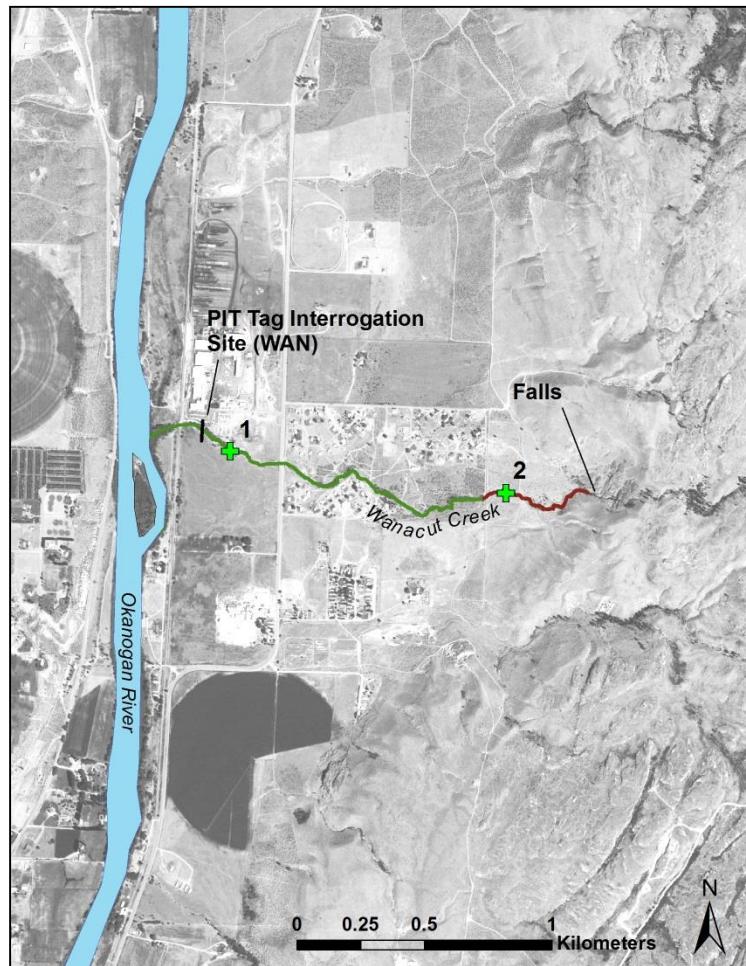


Figure B-4. Wanacut Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

### Tunk Creek

Tunk Creek is a small tributary that meets the Okanogan River at RKM 72, upstream of Riverside, WA. Although the drainage area of Tunk Creek is approximately 186 km<sup>2</sup>, only the lower ~1.2 KM are accessible to anadromous fish, due to a natural falls (Figure B-5). The creek frequently flows subsurface in the lower reaches during mid-summer, although efforts are being made to improve instream flow. A single PIT tag antenna (TNK) is installed seasonally near the mouth of the creek. Tunk Creek was surveyed as one reach below the falls.

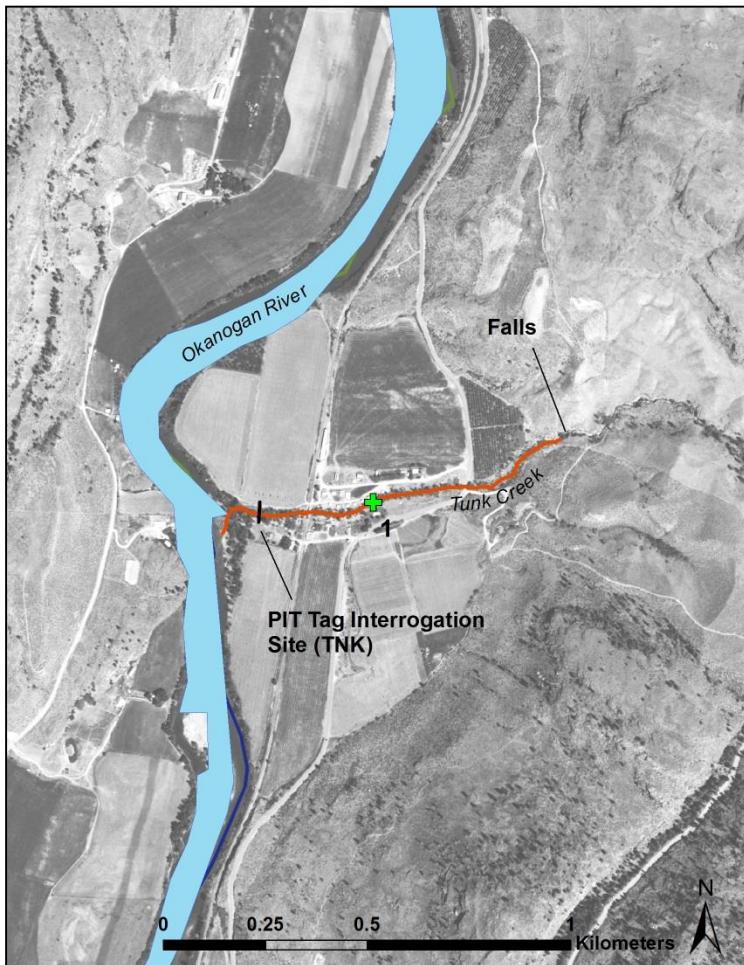


Figure B-5. Tunk Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

### Aeneas Creek

Aeneas Creek is a small creek that enters the Okanogan River just south of the town of Tonasket, WA (RKM 85). The lower section of the creek was impounded with a series of very large beaver dams that were cemented in with calcified clay. In 2012, many of these structures were removed, allowing adult steelhead passage at the mouth of the creek. The total habitat accessible to anadromous fish is limited by a culvert and steep gradient, although potential passage has not been specifically examined at that location (Figure B-6). A single permanent PIT tag antenna (AEN) is located near the mouth of the creek to document utilization by adult steelhead. The first adults were detected in the creek in the spring of 2014. Aeneas Creek was surveyed as one reach for juvenile salmonids.

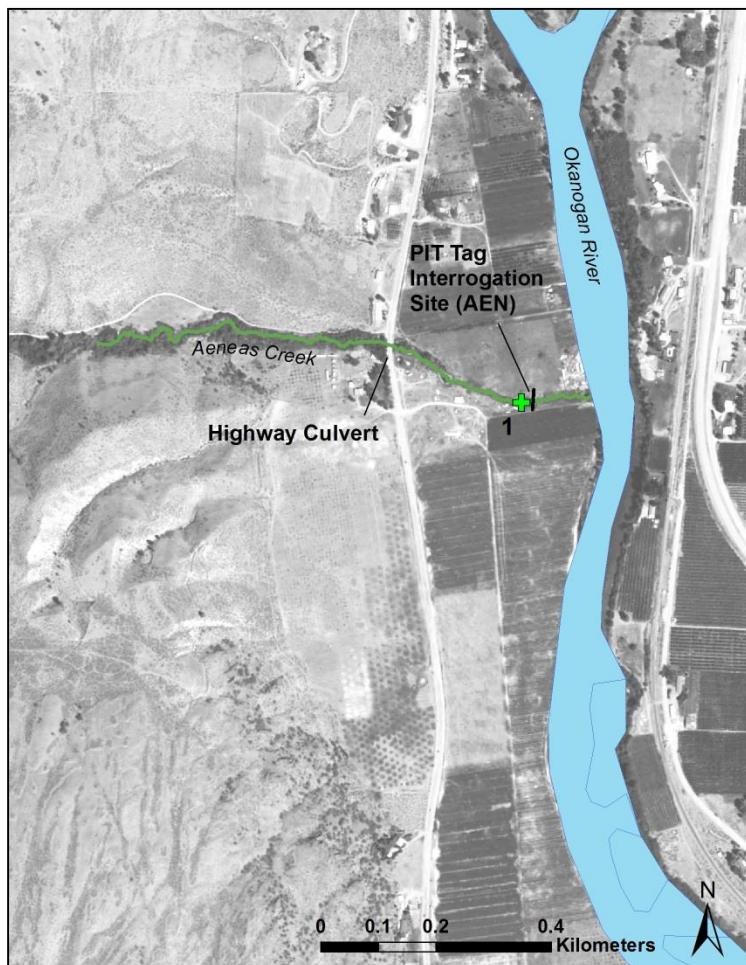


Figure B-6. Aeneas Creek juvenile *O. mykiss* mark-recapture study site (green numbered markers) and strata (colored stream lines).

### Bonaparte Creek

Bonaparte Creek flows out of Bonaparte Lake, near Wauconda, WA, and enters the Okanogan River at RKM 91. The Bonaparte Creek watershed has a drainage area of 396 km<sup>2</sup>; discharge ranges from 1 cfs during low flow conditions and may reach 20 to over 40 cfs during peak runoff. During summer base flow, wetted widths range from 1.5 m to 3 m. The total stream kilometers available to anadromous fish is short, totaling only 1.6 km below a natural falls.

Bonaparte Creek was sampled as one reach, from the confluence with the Okanogan River, 1.6 km upstream to the anadromous barrier (natural falls). A PIT tag interrogation site (BPC) consisting of three pass-over HDPE antennas, configured in three separate rows, is located just upstream from the confluence with the Okanogan River (Figure B-7).

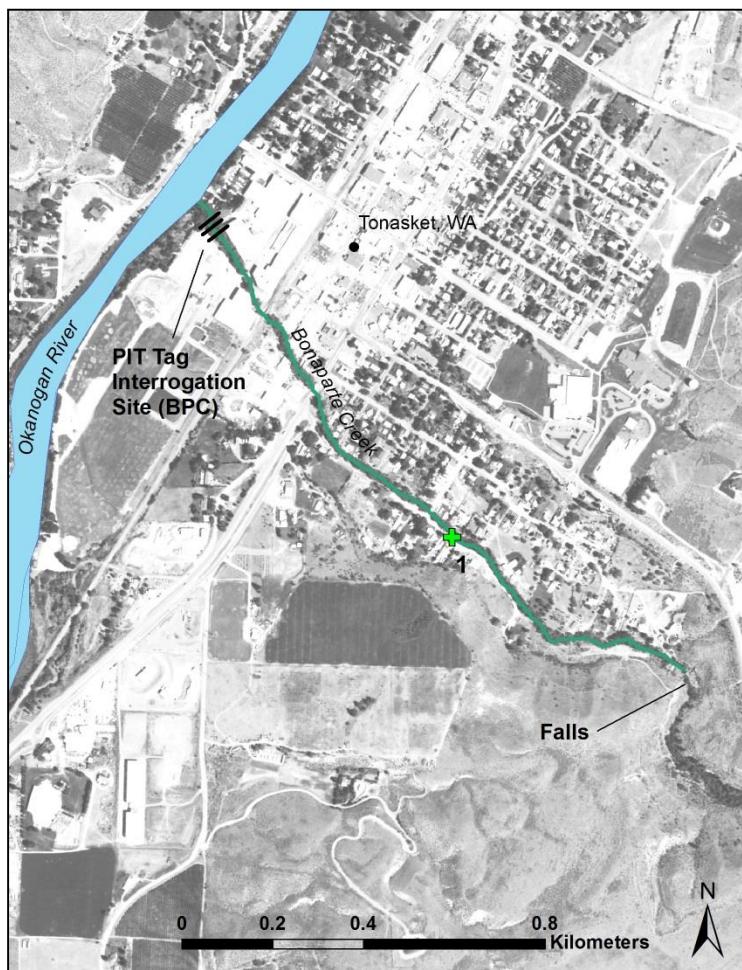


Figure B-7. Bonaparte Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

## Antoine Creek

Antoine Creek flows out of Fancher Reservoir (controlled by Fancher Dam) near Havillah, WA and enters the Okanogan River at RKM 98. The Antoine Creek watershed has a drainage area of 189 km<sup>2</sup>; discharge is often less than 1 cfs during low flow conditions and ranges from 10 to 40+ cfs during peak runoff. During summer base flow, wetted widths generally range from 1 m to 3 m. A PIT tag interrogation site (ANT) consisting of three pass-through HDPE antennas, configured in three separate rows, is located just upstream from the confluence with the Okanogan River (Figure B-7). Antoine Creek has a long history of being managed for irrigation usage. Most years, while the reservoir was being filled in early spring, the creek would go dry in the lower reaches, blocking adult steelhead access into the creek. In recent years, flow has been uninterrupted. The total stream kilometers available to anadromous fish significantly increased in 2013, with the removal of a diversion structure at RKM 1.5 and the construction of concrete step pools within a bed-rock chute.

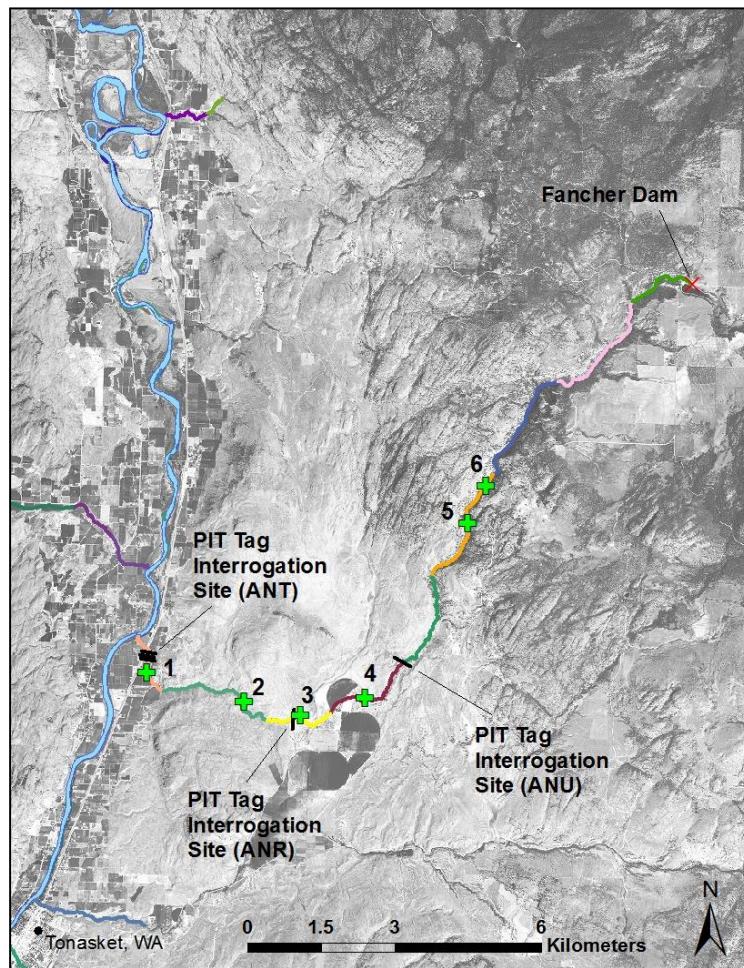


Figure B-7. Antoine Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

With the removal of the diversion structure, fish can access to at least RKM 8.8, where an impediment was documented just upstream of the Antoine Valley Ranch property. Potential passage at that location is being monitored by a seasonally operated PIT tag antenna (ANU). Upstream of that impediment, exists 12.2 km of high quality habitat.

#### Tonasket Creek

Tonasket Creek is a third order stream that has a drainage area of 153 km<sup>2</sup>. The confluence is located at Okanogan River RKM 125, just upstream from Zosel Dam, at the tail end of Lake Osoyoos. The lower reach is known to go dry on an annual basis; however, there is typically some flow in the upper most reach, below the natural falls (Figure B-9). A single temporary PIT tag antenna (TON) is operated near the confluence of the creek with the Okanogan River.

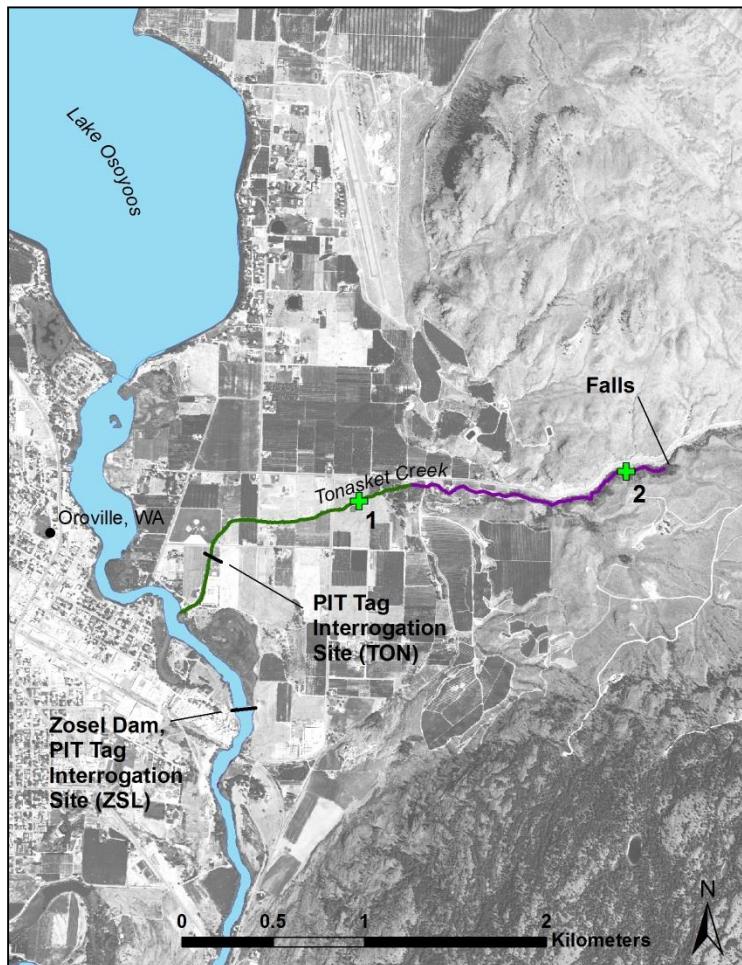


Figure B-9. Tonasket Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

### Ninemile Creek

The drainage area of Ninemile Creek is approximately 122 km<sup>2</sup>. Ninemile Creek is known to flow subsurface annually in the middle reach, but surface flows are usually present in the upper and lower reach. The creek was divided into three survey reaches for analysis (Figure B-10). A permanent PIT tag array (NMC) consisting of three pass-through HDPE antennas, configured in three separate rows, is located near the mouth of the creek, which enters into the east side of Lake Osoyoos.

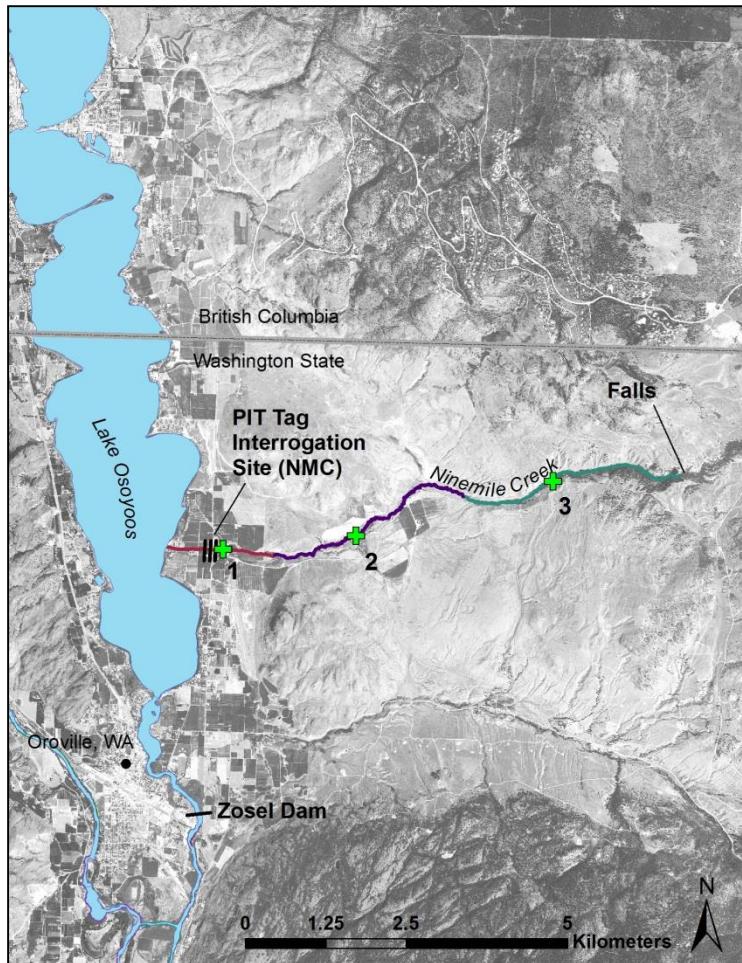


Figure B-10. Ninemile Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

### *Additional Washington State Watersheds*

A number of creeks draining into the Washington State portion of the Okanogan subbasin may not have been sampled due to lack of landowner permissions, insufficient funding or field staff time, or monitoring strategies were not yet defined. Tributaries not sampled, but may be included in future study years include Chilliwit, Johnson, and/or Whitestone Creeks.

### *British Columbia*

#### *akskʷəkʷant (Inkaneep Creek)*

The akskʷəkʷant (Inkaneep Creek) drainage area is approximately 227 km<sup>2</sup>. It is a 5th order stream at the mouth where it drains into the north basin of swiws (Osoyoos Lake) at RKM 139. At present there are 68 water extraction licenses within the watershed; however, the actual volume extracted annually is unknown. The lowest permanent barrier to adult anadromous fish migration is approximately 4.5 km from the mouth. The creek downstream of the barrier was divided into 3 survey reaches (Figure B-10). In 2015, a permanent 3 antenna PIT tag array (OKI) was installed 1 km from the mouth. This array was damaged in 2018 when the Creek experienced an extremely high spring runoff and a large landslide. The array was repaired in 2019 as a 2 antenna system (consisting of one upstream and one downstream antenna. The upstream antenna was not in operation during 2021 due to the breakdown of wiring.

In 2018, a landslide occurred roughly 14km upstream from the confluence with swiws (Osoyoos Lake) that directly impacted akskʷəkʷant (Inkaneep Creek). The 14km of creek had been altered from pool riffle habitats to a thick mud bottomed beds and banks. The mud slide covered spawning gravels during the spring run, but the sediments were fine enough that the creek cleared itself of most of the sediments by the mid-summer (of 2018). The long-term impacts of the mud slide are yet to be determined.



Figure B- 11. akskw̓ək̓want (Inkaneep Creek) juvenile *O. mykiss* mark-recapture study sites (green numbered dots) and strata (colored stream lines).

#### *Shuttleworth Creek*

The Shuttleworth Creek drainage area is approximately 90 km<sup>2</sup>. It is a 3rd order stream at the mouth where it drains into the qawsitkw̓ (Okanagan River) at RKM 175 just downstream of the t'u?cin (Skaha Lake) outlet dam at Okanagan Falls, BC. At present there are 13 water extraction licenses within the watershed; however, the actual volume extracted is unknown. The lowest permanent barrier to adult anadromous fish migration is believed to be 8.5 km from the mouth (long cascade of high gradient in the canyon). For the purposes of EDT modeling, the length of the creek downstream of the barrier was divided into 4 survey reaches (Figure B-12). A permanent 2 antenna PIT tag array (OKW) was installed in 2015. This array is located 0.5 km from the mouth. This array sustained heavy damage in 2018 during spring runoff, which rendered it inoperable. The PIT array was replaced in 2019 with a temporary pass-through system that can be removed (for example, should flows become extremely high).



Figure B- 12. Shuttleworth Creek juvenile *O. mykiss* mark-recapture study sites (green numbered dots) and strata (colored stream lines).

#### *aklxʷuminaʔ (Shingle Creek)*

The *aklxʷuminaʔ* (Shingle Creek) drainage area is approximately 308 km<sup>2</sup>. It is a 6th order stream at the mouth where it drains into the *tuʔcin* (Okanagan River) at RKM 195 downstream of the *kłusxnitkʷ* (Okanagan Lake) outlet dam at Penticton, BC. The main tributary to *aklxʷuminaʔ* (Shingle Creek) is Shatford Creek (Figure B-13). At present there are 191 water extraction licenses within the watershed; however, the actual volume extracted is unknown. It is believed that approximately 32 km of stream are available to anadromous salmonids. The entire lengths of *aklxʷuminaʔ* (Shingle Creek) and Shatford Creek were divided into 18 survey reaches (Figure B-13). A permanent 4 antenna PIT tag array (OKS) was installed in 2015, 1km from the mouth. This array also sustained damage during the extreme freshet of 2018, was inoperable for the majority of 2017, and was replaced in 2019 with a 1 antenna system.

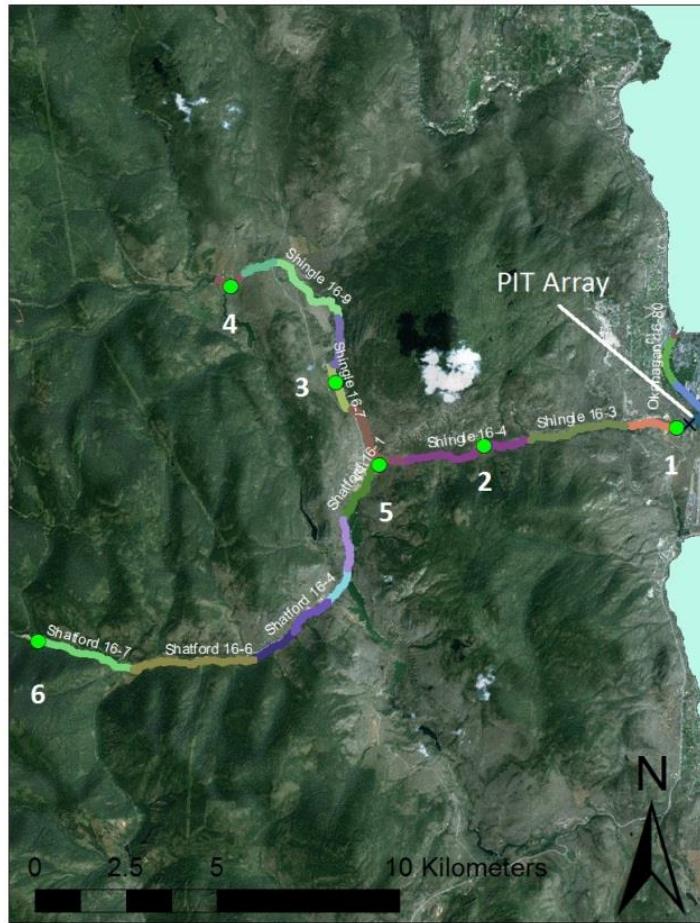


Figure B- 13. Shingle and Shatford Creek juvenile *O. mykiss* mark-recapture study sites (green numbered dots) and strata (colored stream lines).

#### *n̄axʷlqaxʷiya (Vaseux Creek)*

The *n̄axʷlqaxʷiya* (Vaseux Creek) drainage area from the mouth is approximately 296 km<sup>2</sup>. There are 26 current water extraction licenses within the watershed; however, the actual volume extracted is unknown. A permanent 5-antenna PIT Array (OKV) was installed in *n̄axʷlqaxʷiya* (Vaseux Creek) in 2018, less than 1 km from the mouth. This array sustained damage in 2018 but remained partially operable throughout spring and summer until the Creek ran dry. The damage was repaired in 2018. The system has been functional since April 2019.

### *Site Based Abundance Estimate*

To estimate site abundance of juvenile steelhead within each site, a two-pass Lincoln-Petersen mark-recapture study was performed. Block nets were placed at the bottom and top extent of each site to create a closed population. Fish were sampled with a Smith Root LR-24 backpack electrofisher. Captured fish were anesthetized with MS-222 to reduce injury during handling and render fish immobile for tagging. During the first pass, *O. mykiss* greater than 95 mm were marked with a PIT tag and *O. mykiss* less than 95 mm were marked with a top caudal fin clip. All other fish species handled had lengths measured and received a top caudal mark. Marked fish were released and evenly distributed throughout the sample site close to capture locations.

A closed population is maintained during sampling with the use of block nets with a three hour wait period between the first and second passes (Temple and Pearson 2006). During the second pass, all captured fish were examined for a mark. If the fish was unmarked, the length was recorded and the fish released again near the location of capture. Additionally, unmarked *O. mykiss* greater than 95 mm also received a PIT tag to increase the number of PIT tagged fish available for later interrogation (i.e. when emigrating from the creek).

During mark-recapture sampling events, it was assumed that: (1) the population remained closed with the use of block nets, (2) sampling effort remained the same on the first and second pass, (3) marking of fish did not affect the likelihood of recapture, (4) marked fish were randomly distributed with unmarked fish, and (5) no marks were lost and all marks were detected upon recapture. Given those assumptions, site based abundance estimates were calculated using the Lincoln-Peterson mark-recapture model, as modified by Chapman (1951):

$$N = \frac{(M + 1)(C + 1)}{R + 1} - 1 \quad (\text{eq. 1})$$

where N = Estimate of site abundance size for *O. mykiss*,

M = Number of *O. mykiss* captured and marked on the first pass,

C = Total number of *O. mykiss* captured on the second pass,

R = Number of marked *O. mykiss* captured on the second pass.

The site abundance (N) variance was estimated as:

$$\text{var}(N) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)(R+1)(R+2)}. \quad (\text{eq. 2})$$

### *Expanding Site Abundance to Reach and Tributary Population Estimates*

The site-based abundance N was expanded to estimate the population of juvenile *O. mykiss* in each of the strata (ex. Omak Creek,  $\hat{N}_i$  for  $i = 1, \dots, 7$ ). It was assumed that each site was representative of the

reach in which it is located and that fish were evenly distributed throughout the reach. Each reach has an expansion factor for the area not sampled (i.e.,  $R_i$ ),

$$R_i = \frac{\text{Reach Length } i}{\text{Sample Site Length } i}. \quad (\text{eq. 3})$$

The expansion factor  $R_i$  was used to expand site based abundance estimates to individual reaches as follows,

$$\hat{N}_i = N_i R_i. \quad (\text{eq. 4})$$

Therefore, the total population estimate across all seven strata was calculated as:

$$\hat{N} = \sum_{i=1}^7 \hat{N}_i R_i, \quad (\text{eq. 5})$$

with a variance of

$$\widehat{\text{Var}}(\hat{N}) = \sum_{i=1}^7 R_i^2 \times \widehat{\text{Var}}(\hat{N}_i), \quad (\text{eq. 6})$$

and a 95% confidence interval (CI) of

$$\hat{N} \pm 1.96 \sqrt{\widehat{\text{Var}}(\hat{N})}. \quad (\text{eq. 7})$$

The coefficient of variation (CV) was calculated as:

$$\text{CV}(\hat{N}) = \frac{\sqrt{\widehat{\text{Var}}(\hat{N})}}{\hat{N}}. \quad (\text{eq. 8})$$

#### *Outmigration Estimates Based on PIT Tagged Fish*

The location of PIT tag interrogation sites near the mouth of each creek may allow for determination of an emigration estimate. Assuming that marked fish are representative of the total population of juvenile *O. mykiss*, the estimated proportion of tags from the study that pass the array will be applied to the population estimate to determine a total yearly emigration estimate. Two methods may be used to estimate outmigration. The first is based on the Chapman (1951) modification of the Lincoln index (1930), where outmigration of fish is estimated at a double-PIT tag array site. However, many of the interrogation sites within the Okanogan subbasin were installed in a lay-down orientation, rather than a pass-through system. While the lay-down configuration allows the PVC and HDPE antennas to persist through larger flood events, an unknown number of tagged fish may miss both rows of antennas by passing above the detection range. To reduce this inherent bias of lay-down antennas, a second method

based on the Cormack-Jolly-Seber (CJS) estimator may be used. This method involves pooling all detections at the in-creek site as one detection site and using a second pooled downstream detection site which includes all down-river detections (ex. mainstem dams, juvenile bypass systems, estuary trawl, etc.). This method is further detailed below.

*Method 1:*

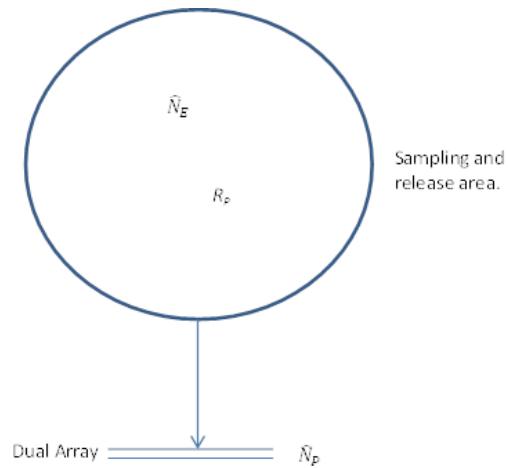


Figure B- 14. Diagram of the study.

where  $n_{10}$ = total PIT-tagged steelhead detected at the first site only,  
 $n_{01}$ = total PIT-tagged steelhead detected at the second site only,  
 $n_{11}$ = total PIT-tagged steelhead detected at both detection sites, and  
 $R_p$  = total PIT-tagged steelhead released.

The total outmigration abundance is estimated in three steps.

*Step 1. Estimate the total outmigration abundance of PIT-tagged steelhead at the dual array.*

The Lincoln Index (Lincoln 1930) is asymptotically unbiased as sample size approaches infinity, but is biased at small sample sizes. The Chapman (1951) modification to the Lincoln Index is less biased, therefore is used to estimate the abundance ( $\hat{N}_P$ ) of PIT-tagged steelhead outmigrating past the dual array.

$$\hat{N}_P = \frac{(n_1+1)(n_2+1)}{(m+1)} - 1 \quad (\text{eq. 9})$$

Where n1= total PIT-tagged steelhead detected at the first array,  
 n2= total PIT-tagged steelhead detected at the second array, and  
 m = total PIT-tagged steelhead detected at both arrays.

With the variance estimate (Seber 1982)

$$\widehat{Var}(\hat{N}_P) = \frac{(n_1+1)(n_2+1)(n_1-m)(n_2-m)}{(m+1)^2(m+2)}. \quad (\text{eq. 10})$$

*Step 2. Estimate the proportion of PIT-tagged steelhead outmigrating.*

The proportion of the PIT-tagged steelhead ( $\hat{P}$ ) outmigrating from the creek is simply the estimated abundance at the dual array divided by the total PIT-tagged steelhead.

$$\hat{P} = \frac{\hat{N}_P}{R_p} \quad (\text{eq. 11})$$

with a variance of

$$\widehat{Var}(\hat{P}) = \left(\frac{1}{R_p}\right)^2 * \widehat{Var}(\hat{N}_P) + \frac{\left(\frac{\hat{N}_P}{R_p}\right)\left(1-\frac{\hat{N}_P}{R_p}\right)}{R_p}. \quad (\text{eq. 12})$$

*Step 3. Estimate the total abundance of the steelhead population outmigrating from the creek.*

Assuming that the proportion of outmigrating PIT-tagged steelhead is the same as the untagged steelhead, the total abundance of outmigrating steelhead ( $\hat{N}_{all}$ ) is estimated by

$$\hat{N}_{all} = \hat{N}_E * \hat{P} \quad (\text{eq. 13})$$

with a variance of

$$\widehat{Var}(\hat{N}_{all}) = \hat{P}^2 * \widehat{Var}(\hat{N}_E) + \hat{N}_E^2 * \widehat{Var}(\hat{P}) - \widehat{Var}(\hat{N}_E) * \widehat{Var}(\hat{P}) \quad (\text{eq. 14})$$

*Method 2:*

An alternative method is to estimate the proportion of PIT-tagged steelhead outmigrating from a creek is to use the pooled detections at the dual array as a single detection site and the pooled detections anywhere after the dual array as a second detection site. This may be desirable in cases where the dual array appears to be biased (higher than expected number of tags not detected at either array, but are detected downriver).

*Alternative Step 1. Estimate the total outmigration abundance of PIT-tagged steelhead at the dual array.*

Cormack (1964), Jolly (1965), and Seber (1965) developed closed-form estimates of the parameters of a multinomial likelihood (CJS model) describing a release-recapture study with survival (S) processes occurring between detection events (p). The probability of detection at an interrogation site is estimated by the proportion of detections at the array of the total known to have passed the array. Based on methods described in Burnham (1987), the equations below were simplified to a two-detection site analysis. Using the pooled, unique detection count at the array and the pooled detections downriver of the dual array, the probability of detection ( $\hat{p}_1$ ) is:

$$\hat{p}_1 = \left( \frac{n_{11}}{n_{11} + n_{01}} \right) \quad (\text{eq. 15})$$

where  $n_{01}$ = total PIT-tagged steelhead detected at the second site only, and  
 $n_{11}$ = total PIT-tagged steelhead detected at both detection sites.

With the variance estimate

$$\widehat{Var}(\hat{p}_1) = (\hat{p}_1 * (1 - \hat{p}_1))^2 * \left( \frac{1}{n_{11}} + \frac{1}{n_{01}} \right). \quad (\text{eq. 16})$$

The abundance ( $\hat{N}_P$ ) of PIT-tagged steelhead outmigrating past the dual array is then

$$\hat{N}_P = \frac{n_{1*}}{\hat{p}_1} \quad (\text{eq. 17})$$

where  $n_{1*}$ = total unique PIT-tagged steelhead detected at the dual array.

Using the delta method, the variance estimate is

$$\widehat{Var}(\hat{N}_P) = \widehat{Var}(\hat{p}_1) * \frac{n_{1*}^2}{\hat{p}_1^4}. \quad (\text{eq. 18})$$

#### *Alternative Step 2. Estimate the proportion of PIT-tagged steelhead outmigrating.*

Continuing with the CJS model, the probability of survival for the period from release to detection at the dual array (S1) can be interpreted as the proportion of PIT-tagged steelhead that are outmigrating from the creek. Though this proportion can be obtained by dividing the total abundance of outmigrating PIT-tagged steelhead ( $\hat{N}_P$ ) estimated earlier, by the total number released, estimating S1 directly from the CJS model results in a slightly smaller variance by removing a step.

$$\hat{S}_1 = \frac{n_{11} + n_{10}}{R_p} * \left( 1 + \frac{n_{01}}{n_{11}} \right) \quad (\text{eq. 19})$$

where  $n_{10}$ = total PIT-tagged steelhead detected at the first site only,  
 $n_{01}$ = total PIT-tagged steelhead detected at the second site only,  
 $n_{11}$ = total PIT-tagged steelhead detected at both detection sites, and  
 $R_p$  = total PIT-tagged steelhead released.

With the variance estimate

$$\widehat{Var}(\hat{S}_1) = \hat{S}_1^2 * \left[ \left( \frac{1}{n_{11} + n_{10} + n_{01}} - \frac{1}{R_p} \right) + (1 - \hat{p}_1)^2 * \left( \frac{1}{n_{11}} - \frac{1}{n_{11} + n_{10}} \right) + \hat{p}_1 * (1 - \hat{p}_1) * \left( \frac{n_{10}^2}{n_{11} * (n_{11} + n_{10}) * (n_{11} + n_{10} + n_{01})} \right) \right]. \quad (\text{eq. 20})$$

The process then continues to Step 3, as described previously, with  $\hat{S}_1$  from the CJS model in place of the proportion outmigrating estimated in the 1st method.

#### *Estimating age breaks*

When designing and implementing this field study, it was initially necessary to define arbitrary breaks in length; 95 mm was selected as the general break point between “age-0” and “age-1+”, primarily for regulatory permits and PIT tagging potential steelhead outmigrants. However, actual age breaks by length are oftentimes more blurred in reality, which can vary among location and between years. In the absence of sufficient scale data for linking length to age within the subbasin, it may be feasible to coarsely estimate age breaks visually from obvious bi-modal distributions. Length frequency distributions are much more distinct at the site-level, before rolling data up to the sub-watershed-level. In this document and in the early years of this study, we may refer to fry (age-0) and parr/juvenile+ (age-1+) age classes, but it is important to note that those divisions came from professional judgement based on length frequency distributions rather than scale aging. In future years, if time and funding allow, scale data or statistical analysis of length frequency distributions may be used to more precisely define length by age-class.

## **Results**

### *O. mykiss Instream Abundance*

Between 2014 and 2021, ten tributaries were representatively sampled in Washington State to determine abundance of juvenile *O. mykiss* in stream reaches accessible to anadromous fish. The first year of this work in the British Columbia portion of the Subbasin was 2016. Estimated abundance with 95% confidence intervals are presented in Table B-1. The largest number of fry and juvenile *O. mykiss* in the Okanogan subbasin were found in Salmon Creek, followed by lower and upper Omak, and Ninemile Creeks. A number of small creeks in the Okanogan subbasin contain flowing water in the upper reaches, but water flows sub-surface before entering the mainstem Okanogan River in late-summer, including Salmon, Wanacut, Tunk, and Tonasket Creeks. Salmon Creek historically went sub-surface during late summer due to the construction of Conconully Dam and associated irrigation practices. However, since 2007, the Colville Confederated Tribes through a lease agreement with the Okanogan Irrigation District (OID), purchased water to provide sufficient flows for migration and emigration downstream of the OID diversion (RM 4.3), but the volume of water purchased was not enough to provide year round flow.

From 2019 through 2021, additional water was purchased through a drought relief fund thereby allowing water to flow downstream of the diversion through the whole year.

Spatial distribution of juvenile *O. mykiss* varied within and between sub-watersheds, both by density and length distribution. Abundance of juvenile *O. mykiss* also varied by reach and year. Although not presented in this document, detailed length frequency data are available for all individual reaches in all sampled streams, which can be provided upon request by contacting OBMEP staff. Additional trends in spatial distribution of *O. mykiss* by length and age will be presented as further years of data become available for the subbasin.

Table B-1. Instream population estimates of young-of-year natural-origin *O. mykiss* ( $\pm 95\%CI$ ) in tributaries to the Okanogan River in Washington State and British Columbia.

Tributary	2014	2015	2016	2017	2018
Salmon Cr	46,434 $\pm$ 8,602	56,501 $\pm$ 5,945	61,234 $\pm$ 7,383	27,717 $\pm$ 3,065	32,646 $\pm$ 3,982
Lower Omak Cr	29,136 $\pm$ 2,145	27,671 $\pm$ 3,921	29,243 $\pm$ 4,321	4,064 $\pm$ 1,755	9,360 $\pm$ 2,147
Upper Omak Cr	Not sampled	Not sampled	13,104 $\pm$ 1,811	10,510 $\pm$ 4,311	30,212 $\pm$ 6,583
Lower Loup Loup Cr	19,787 $\pm$ 1,643	6,597 $\pm$ 593	13,191 $\pm$ 1,713	728 $\pm$ 181	2,014 $\pm$ 405
Upper Loup Loup Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Ninemile Cr	6,177 $\pm$ 1,289	3,030 $\pm$ 965	6,705 $\pm$ 1,613	5,304 $\pm$ 1,763	3,992 $\pm$ 500
Bonaparte Cr	3,149 $\pm$ 396	989 $\pm$ 362	2,532 $\pm$ 582	208 $\pm$ 125	662 $\pm$ 108
Tonasket Cr	2,192 $\pm$ 716	0	7,911 $\pm$ 745	5,684 $\pm$ 497	1,862 $\pm$ 391
Tunk Cr	0	0	1,412 $\pm$ 358	212 $\pm$ 131	1,267 $\pm$ 167
Aeneas Cr	111 $\pm$ 18	15 $\pm$ 2	1,204 $\pm$ 131	697 $\pm$ 102	728 $\pm$ 415
Wanacut Cr	0	0	501 $\pm$ 95	3,407 $\pm$ 793	2,300 $\pm$ 344
Johnson Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Lower Antoine Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Upper Antoine Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Wildhorse Sp Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Inkaneeep Cr	Not sampled	Not sampled	21,304 $\pm$ 7,284	2,327 $\pm$ 1,480	30,936 $\pm$ 6,139
Vaseux Cr	Not sampled	Not sampled	Not sampled	Not sampled	3,543 $\pm$ 1,351
Shuttleworth Cr	Not sampled	Not sampled	9,207 $\pm$ 2,190	16,078 $\pm$ 7,211	18,239 $\pm$ 3,703
Lower Shingle Cr	Not sampled	Not sampled	15,293 $\pm$ 7,485	7,112 $\pm$ 4,639	2,399 $\pm$ 1,286
Upper Shingle Cr	Not sampled	Not sampled	13,989 $\pm$ 9,632	6,593 $\pm$ 1,703	8,086 $\pm$ 2,748
Shatford Cr	Not sampled	Not sampled	53,022 $\pm$ 16,235	104,611 $\pm$ 30,251	14,419 $\pm$ 3,427

Table B-1 cont. Instream population estimates of young-of-year natural-origin *O. mykiss* ( $\pm 95\% \text{CI}$ ) in tributaries to the Okanogan River in Washington State and British Columbia.

Tributary	2019	2020	2021
Salmon Cr	$36,667 \pm 3,378$	$51,691 \pm 6,346$	$60,414 \pm 4,707$
Lower Omak Cr	$19,717 \pm 1,797$	$10,818 \pm 1,555$	$921 \pm 396$
Upper Omak Cr	$17,905 \pm 2,018$	$23,226 \pm 5,658$	$5,539 \pm 1,811$
Lower Loup Loup Cr	$4,979 \pm 335$	$4,839 \pm 397$	$6,435 \pm 495$
Upper Loup Loup Cr	Not sampled	Not sampled	$3,484 \pm 1,168$
Ninemile Cr	$11,244 \pm 1,150$	$5,261 \pm 1,081$	$17,109 \pm 2,403$
Bonaparte Cr	$3,057 \pm 1,538$	$670 \pm 124$	$3,185 \pm 463$
Tonasket Cr	$2,496 \pm 321$	$3,567 \pm 465$	$1,817 \pm 250$
Tunk Cr	$3,067 \pm 229$	$2,692 \pm 217$	$6 \pm 0$
Aeneas Cr	$111 \pm 18$	$406 \pm 92$	$488 \pm 82$
Wanacut Cr	$1,644 \pm 351$	$1,896 \pm 230$	$0 \pm 0$
Johnson Cr	Not sampled	Not sampled	Not sampled
Lower Antoine Cr	Not sampled	Not sampled	$493 \pm 69$
Upper Antoine Cr	Not sampled	Not sampled	$16,152 \pm 6,115$
Wildhorse Sp Cr	Not sampled	Not sampled	Not sampled
Inkaneep Cr	$19,856 \pm 2,720$	$14,450 \pm 2,810$	NA
Vaseux Cr	$8,630 \pm 4,274$	$16,998 \pm 6,514$	$10,312 \pm 3,291$
Shuttleworth Cr	$17,459 \pm 1,786$	$19,286 \pm 2,247$	$8,796 \pm 8,895$
Lower Shingle Cr	$846 \pm 655$	$686 \pm 108$	$1,783 \pm 1,629$
Upper Shingle Cr	$33,297 \pm 10,368$	$11,560 \pm 1,745$	NA
Shatford Cr	$53,899 \pm 11,865$	$33,625 \pm 5,206$	$21,953 \pm 5,490$

Table B-2. Instream population estimates of age-1+ natural-origin *O. mykiss* ( $\pm 95\% \text{CI}$ ) in tributaries to the Okanogan River in Washington State and British Columbia.

Tributary	2014	2015	2016	2017	2018
Salmon Cr	$31,498 \pm 2,379$	$31,630 \pm 2,461$	$50,621 \pm 3,931$	$38,556 \pm 2,136$	$28,203 \pm 2,058$
Lower Omak Cr	$7,581 \pm 836$	$4,488 \pm 387$	$7,252 \pm 779$	$7,264 \pm 812$	$3,101 \pm 1,335$
Upper Omak Cr	Not sampled	Not sampled	$25,697 \pm 1,633$	$16,820 \pm 1,642$	$13,330 \pm 1,839$
Lower Loup Loup Cr	$2,177 \pm 267$	$1,282 \pm 111$	$2,422 \pm 683$	$2,722 \pm 295$	$1,214 \pm 185$
Upper Loup Loup Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Ninemile Cr	$2,136 \pm 333$	$3,017 \pm 367$	$2,141 \pm 683$	$6,971 \pm 673$	$3,519 \pm 361$
Bonaparte Cr	$137 \pm 22$	$273 \pm 46$	$913 \pm 88$	$437 \pm 104$	$348 \pm 36$
Tonasket Cr	$526 \pm 51$	$9 \pm 0$	$69 \pm 0$	$1,423 \pm 71$	$3,652 \pm 338$
Tunk Cr	$164 \pm 26$	0	$142 \pm 53$	$138 \pm 19$	$109 \pm 23$
Aeneas Cr	$138 \pm 26$	$56 \pm 29$	$74 \pm 37$	$112 \pm 23$	$105 \pm 11$
Wanacut Cr	0	0	$21 \pm 0$	$2,113 \pm 177$	$1,762 \pm 62$
Johnson Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Lower Antoine Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Upper Antoine Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Wildhorse Sp Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Inkaneeep Cr	Not sampled	Not sampled	$2,200 \pm 1,457$	$4,556 \pm 2,368$	$149 \pm 56$
Vaseux Cr	Not sampled	Not sampled	Not sampled	Not sampled	$3,588 \pm 1,405$
Shuttleworth Cr	Not sampled	Not sampled	$3,314 \pm 1,165$	$2,658 \pm 798$	$3,696 \pm 776$
Lower Shingle Cr	Not sampled	Not sampled	$6,532 \pm 3,322$	$13,515 \pm 6,622$	$8,136 \pm 1,125$
Upper Shingle Cr	Not sampled	Not sampled	$2,797 \pm 1,105$	$2,286 \pm 366$	$5,071 \pm 498$
Shatford Cr	Not sampled	Not sampled	$4,756 \pm 148,309$	$9,465 \pm 3,863$	$4,182 \pm 664$

Table B-2 cont. Instream population estimates of age-1+ natural-origin *O. mykiss* ( $\pm 95\% \text{CI}$ ) in tributaries to the Okanogan River in Washington State and British Columbia.

Tributary	2019	2020	2021
Salmon Cr	27,284 $\pm$ 1,603	31,715 $\pm$ 1,979	32,827 $\pm$ 1,938
Lower Omak Cr	4,163 $\pm$ 325	5,284 $\pm$ 641	224 $\pm$ 50
Upper Omak Cr	11,300 $\pm$ 917	17,040 $\pm$ 2,217	7,675 $\pm$ 1,236
Lower Loup Loup Cr	556 $\pm$ 86	1,681 $\pm$ 86	1,223 $\pm$ 55
Upper Loup Loup Cr	Not sampled	Not sampled	8,229 $\pm$ 705
Ninemile Cr	4,524 $\pm$ 367	2,847 $\pm$ 153	1,814 $\pm$ 201
Bonaparte Cr	423 $\pm$ 60	1,279 $\pm$ 87	538 $\pm$ 115
Tonasket Cr	340 $\pm$ 43	596 $\pm$ 62	144 $\pm$ 0
Tunk Cr	80 $\pm$ 15	318 $\pm$ 45	61 $\pm$ 24
Aeneas Cr	36 $\pm$ 5	24 $\pm$ 0	13 $\pm$ 0
Wanacut Cr	1,151 $\pm$ 61	609 $\pm$ 46	659 $\pm$ 32
Johnson Cr	Not sampled	Not sampled	Not sampled
Lower Antoine Cr	Not sampled	Not sampled	298 $\pm$ 123
Upper Antoine Cr	Not sampled	Not sampled	12,930 $\pm$ 1,281
Wildhorse Sp Cr	Not sampled	Not sampled	Not sampled
Inkaneeep Cr	4,351 $\pm$ 452	3,333 $\pm$ 311	1,211 $\pm$ 319
Vaseux Cr	3,424 $\pm$ 978	6,374 $\pm$ 2,693	3,110 $\pm$ 1,120
Shuttleworth Cr	10,830 $\pm$ 981	4,906 $\pm$ 828	1,261 $\pm$ 404
Lower Shingle Cr	6,284 $\pm$ 3,277	5,679 $\pm$ 715	2,189 $\pm$ 813
Upper Shingle Cr	7,169 $\pm$ 1,517	5,930 $\pm$ 528	1,391 $\pm$ 787
Shatford Cr	3,718 $\pm$ 839	8,460 $\pm$ 916	3,770 $\pm$ 3,583

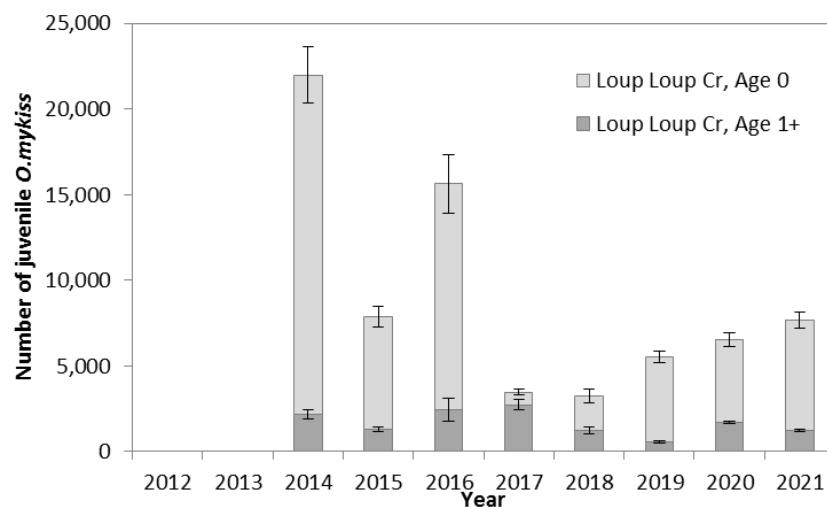
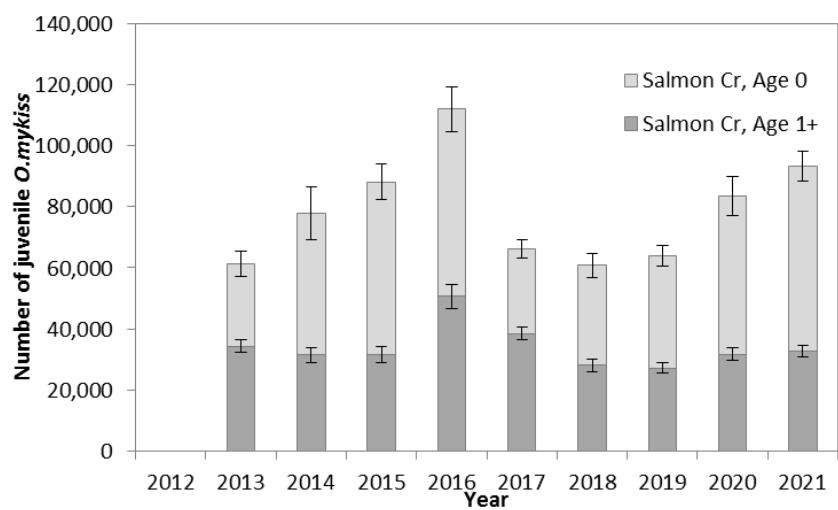
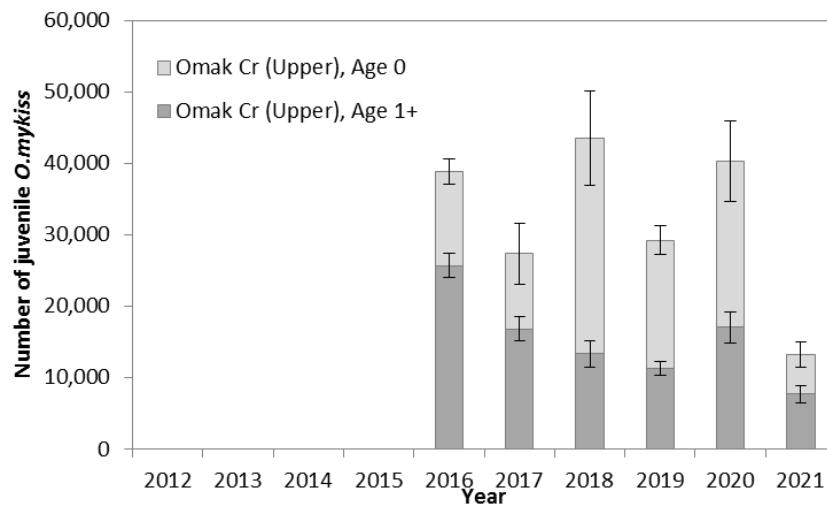
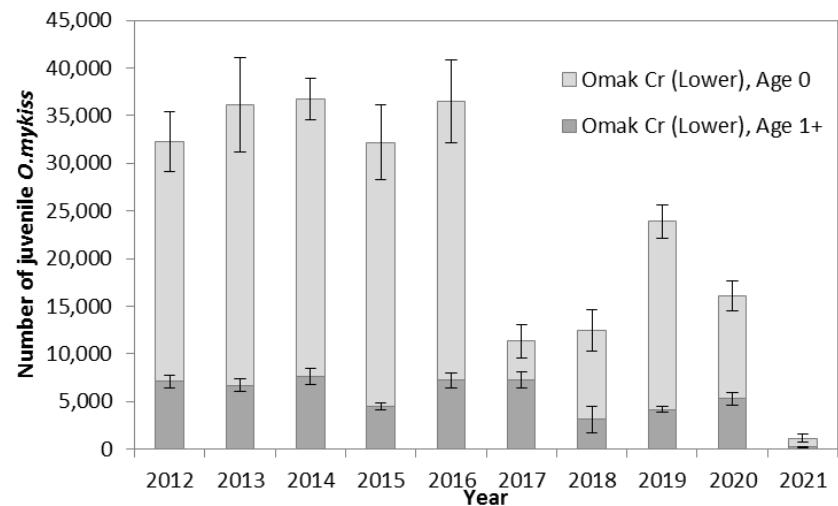


Figure B-15. Total estimated abundance of juvenile *O. mykiss* by age class in lower Omak, upper Omak, Salmon and Loup Loup Creeks.

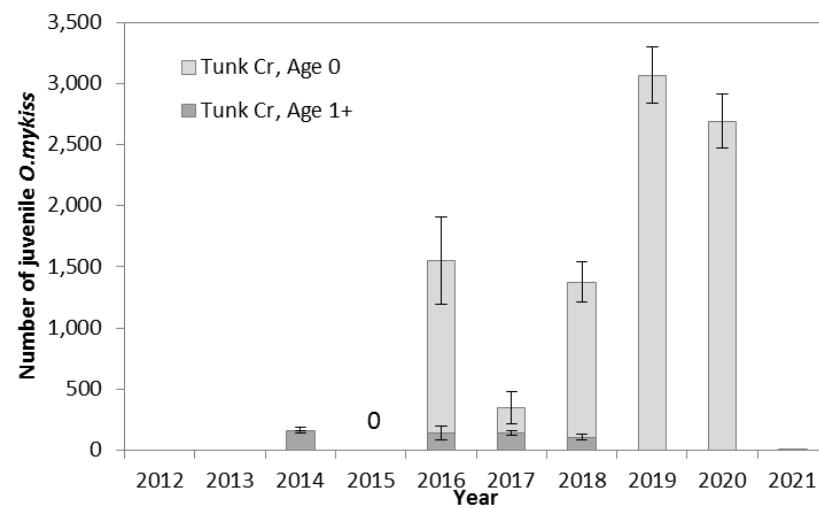
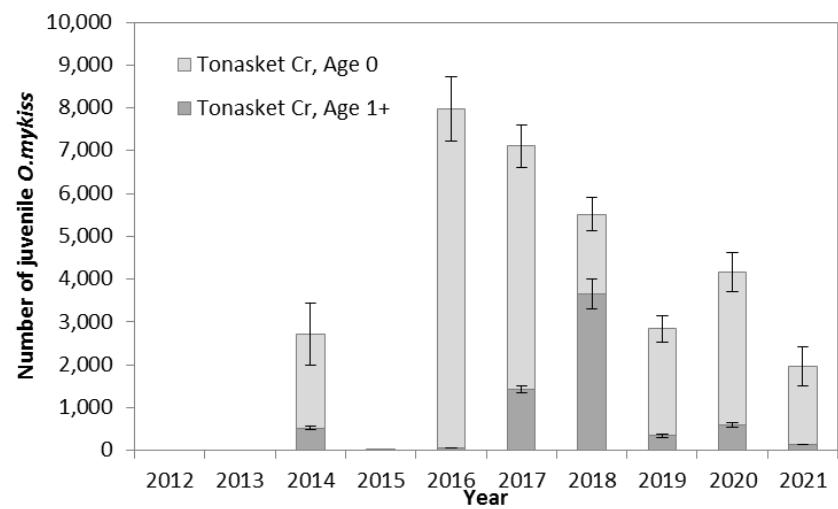
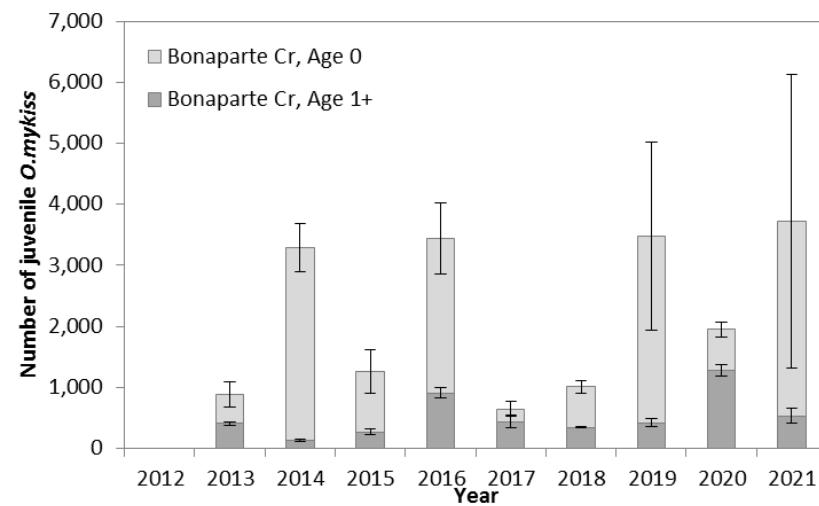
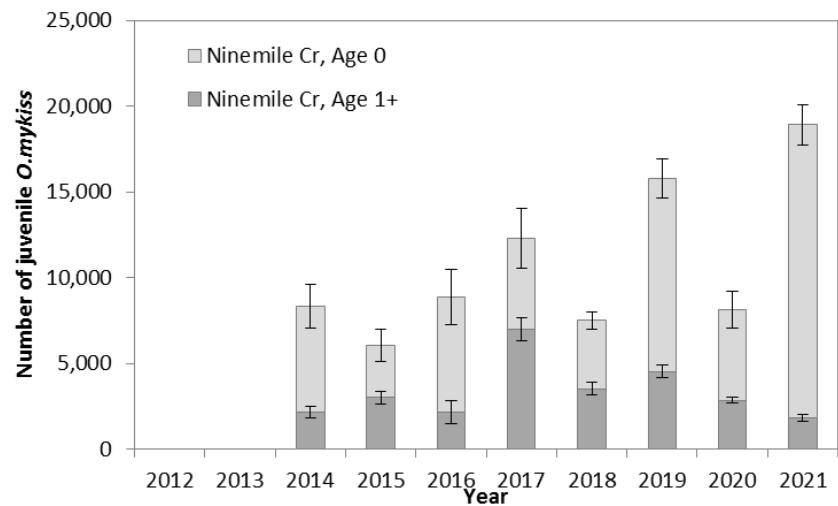


Figure B-16. Total estimated abundance of juvenile *O.mykiss* by age class in Ninemile, Bonaparte, Tonasket and Tunk Creeks.

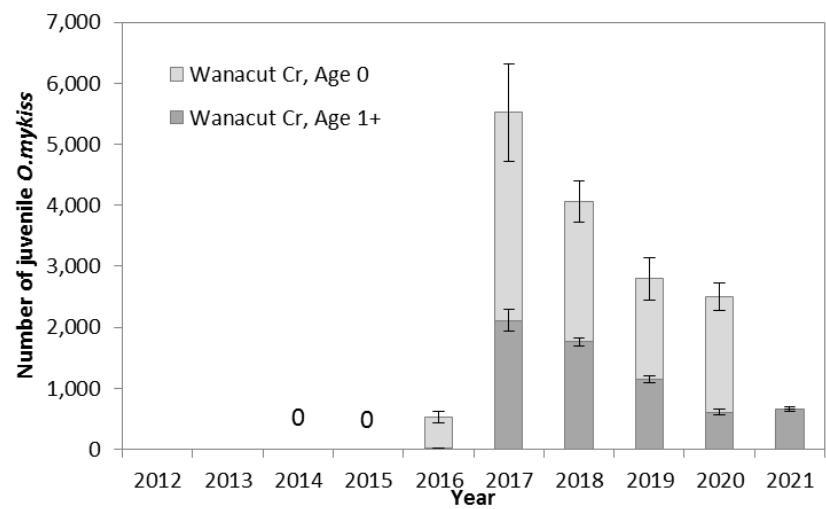
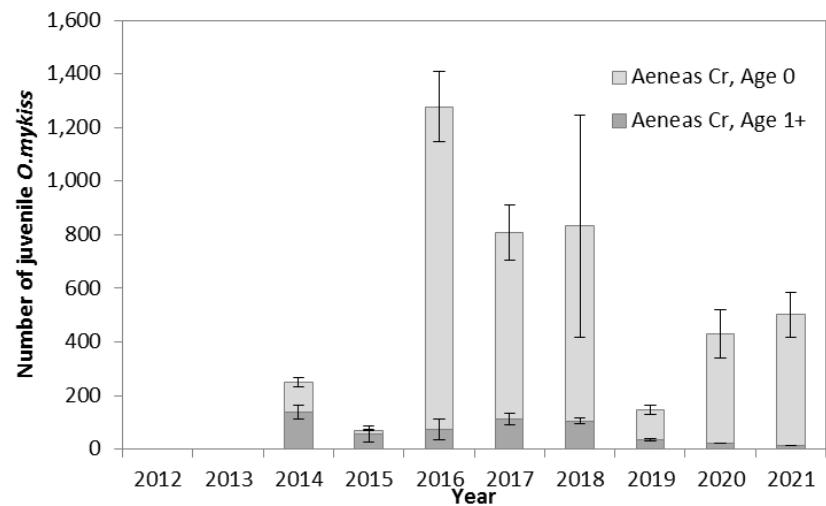


Figure B-17. Total estimated abundance of juvenile *O. mykiss* by age class in Aeneas and Wanacut Creeks.

### *O. mykiss Outmigration*

PIT tag detection and calculation of outmigration estimates occur in the year following the marking season, and thus, total emigration results are reported one year after the mark-year. For example, the data presented in Table B-3 column 2021 represent outmigration of juvenile steelhead from that year, derived from fish PIT tagged and released in the fall of 2020 and detected from September 2020 through August 2021. Based on combined detections of PIT tagged fish from within and downstream of the Okanogan subbasin, a total of  $15,349 \pm 2,226$  juvenile steelhead outmigrated from the defined strata, reversing a general downward trend observed since peak estimated outmigration in 2017. The reduced number of smolts correlates and is likely explained by the limited number of adult Steelhead spawning seen since 2018 (Table-1 in Results). The proportion of outmigrants varied by survey reach and distance from the confluence with the Okanogan River. A higher proportion of the total age-1 and older juvenile steelhead outmigrated in the lower reaches of Omak creek compared with the upper reaches (Figure B-18). A similar trend was documented in Salmon Creek (Figure B-19), where a larger proportion of fish outmigrated from the lower reaches, compared with higher in the watershed. Cumulative proportion of downstream observations were calculated from each tributary since outmigration estimates began in 2014 to help explain wide confidence intervals in certain tributaries, as well as to illuminate which are most successful at producing true outmigrating steelhead (Figure B-20). f note is Ninemile Creek, where cumulatively only 11.7% of the tags detected at the mouth were subsequently detected at observations sites located downstream (i.e. OKL, RRJ, etc), which is substantially less than the next numerically closest tributary of Aeneas Creek (21.5%) and the subwatershed mean of 37.3%. This would suggest a greater likelihood that *O. mykiss* which originate from Ninemile Creek exhibit a residential or adfluvial life history type, and/or greater chance of mortality before emigrating from the subbasin, therefore their numbers are excluded from the total outmigrant populations reported in Table B-3. Conversely, tagged *O. mykiss* from Omak Creek located above Mission Falls had a 68.1% downstream detection rate of fish that had been observed at the mouth array (OMK).

In the Canadian portion of the Okanagan subbasin, outmigration estimates can only be attributed to each individual tributary due to the proximity of lakes within this area of the mainstem Okanagan. Outmigrating *O. mykiss* from tributaries cannot always be predicted to make up anadromous stocks as they may be adfluvial Rainbow Trout from the lake systems. Detections downstream of suwiw's (Osoyoos Lake) in following years will indicate the migratory life histories of tagged *O. mykiss*. Tagged *O.mykiss* from akskw'ək'w'ant (Inkaneep) and Shuttleworth creeks have been detected in juvenile bypass facilities in the Columbia River (John Day Dam and Rocky Reach Dam).

Table B-3. Juvenile steelhead outmigration estimates (95%CI) by year from subwatersheds within the Okanogan subbasin.

Tributary	2014	2015	2016	2017	2018	2019	2020	2021
Salmon Cr	9,077 ± 1,130	7,918 ± 1,159	8,831 ± 1,902	20,730 ± 6,700	9,593 ± 3,781	6,578 ± 990	5,357 ± 1,003	10,580 ± 1,249
Lower Omak Cr	3,063 ± 415	3,156 ± 466	1,688 ± 272	4,590 ± 1,359	4,934 ± 1,392	1,376 ± 638	1,251 ± 298	2,421 ± 502
Upper Omak Cr				20,954 ± 18,841	2,235 ± 1,669	236 ± 208	455 ± 243	N/A
Loup Loup Cr		1,193 ± 255	600 ± 112	1,984 ± 433	980 ± 432	501 ± 125	323 ± 84	946 ± 125
Ninemile Cr		0	655 ± 250	836 ± 387	1,918 ± 444	2,382 ± 3,771	511 ± 215	942 ± 235
Bonaparte Cr	201 ± 71	112 ± 0	195 ± 62	767 ± 151	211 ± 103	174 ± 65	224 ± 78	671 ± 132
Tonasket Cr		24 ± 0	2 ± 2	30 ± 26	441 ± 129	1,178 ± 296	159 ± 64	343 ± 98
Tunk Cr		131 ± 119	N/A	N/A	0	N/A	49 ± 23	264 ± 52
Aeneas Cr		198 ± 103	32 ± 32	54 ± 16	78 ± 24	80 ± 18	18 ± 11	14 ± 9
Wanacut Cr		0	0	0	1,610 ± 843	818 ± 231	270 ± 103	110 ± 59
Sum	12,341 ± 1,616	12,732 ± 2,102	11,348 ± 2,382	49,109 ± 27,526	20,082 ± 8,373	10,941 ± 2,234	8,106 ± 1,907	15,349 ± 2,226

N/A = could not calculate outmigration estimate due to an insufficient number of PIT tag detections

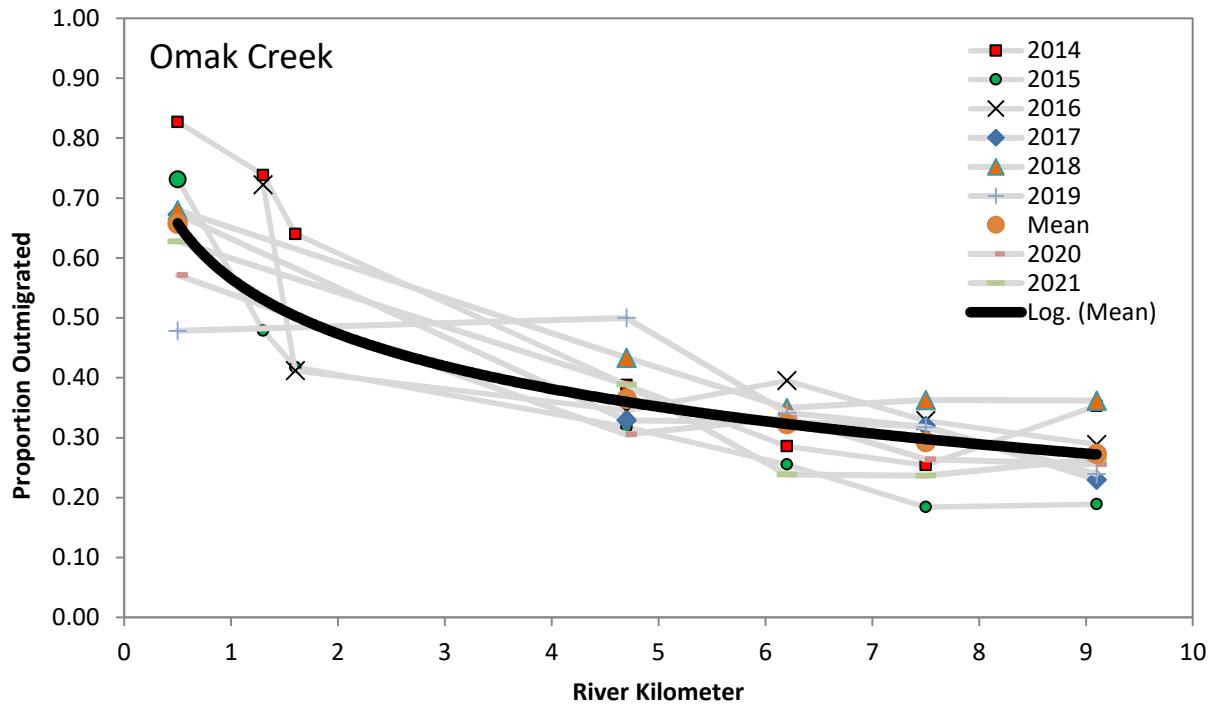


Figure B- 18. Proportion of PIT tagged natural-origin juvenile steelhead that outmigrated in Omak Creek by river kilometer (distance upstream from the confluence with the Okanogan River).

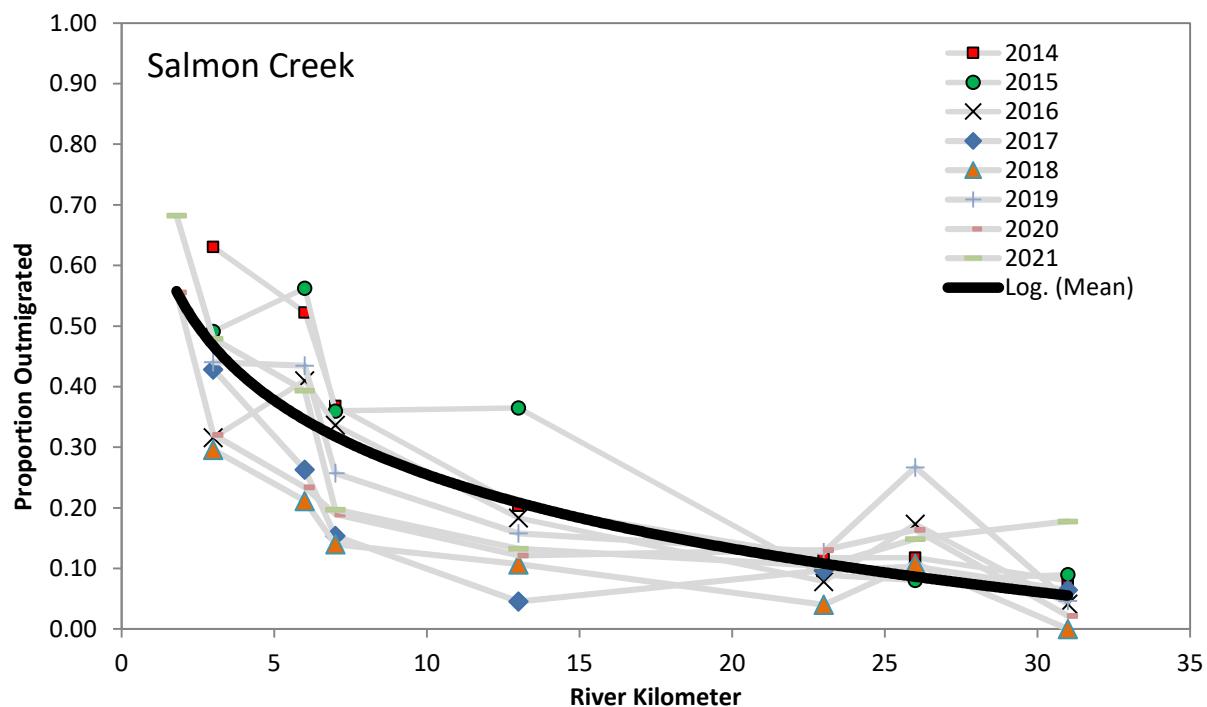


Figure B- 19. Proportion of PIT tagged natural-origin juvenile steelhead that outmigrated in Salmon Creek by river kilometer (distance upstream from the confluence with the Okanogan River).

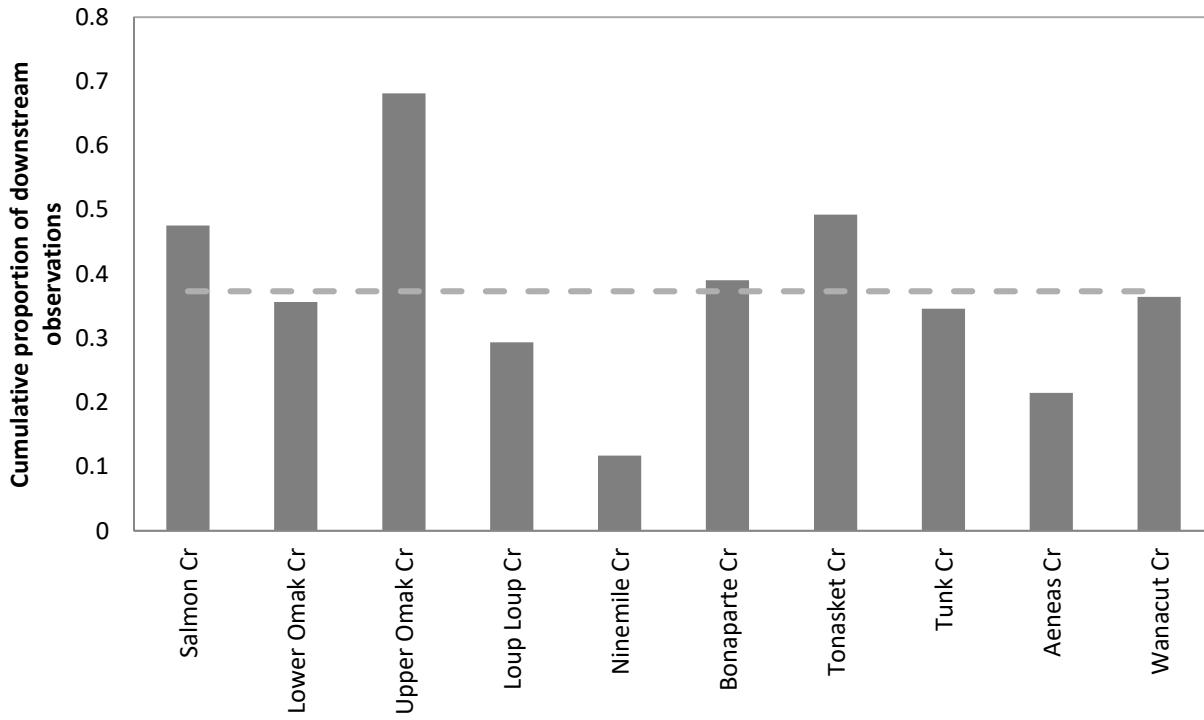


Figure B- 20. Proportion of PIT tagged natural-origin steelhead that, after being detected at the mouth of a tributary, were subsequently detected downriver. Dashed line represents the mean of all creeks.

#### *Juvenile Chinook*

The estimated instream abundance of juvenile natural-origin Chinook (*O. tshawytscha*) in the fall had been increasing in recent years, however estimates in 2020 and 2021 only produced 158 and 655 individuals, respectively (Table B-4). The dominant tributaries vary from year to year, however Salmon, Loup Loup and Lower Omak Creeks appear to be the consistent key contributors to the subbasin population. In order to investigate the origin of these fish, tissue samples were collected for DNA analysis in 2018 and of the 71 samples that returned results, 70 came back as Spring Chinook, all of them being of natural-origin. Although Spring Chinook were considered extirpated from the Okanogan subbasin, adults from adjacent subbasins (particularly the Methow River) are occasionally detected on instream PIT tag arrays. In 2017, the first adults of an experimental reintroduction of Spring Chinook returned to the Okanogan Subbasin (adult Chinook are monitored as part of the Chief Joseph Hatchery monitoring and evaluation project. Results can be found at <https://www.cct-fnw.com/reports/>). The juvenile Chinook observed in the fall of 2018 may be offspring of natural spawning adults returning from the experimental reintroduction, which is supported by DNA analysis. However, the presence of juvenile

Chinook in the fall of 2016 and 2017 suggest that stray hatchery Spring Chinook (or remnant natural-origin fish) may also be contributing to production (Table B-4).

In 2021 an estimated  $89 \pm 36$  (95%CI) juvenile Spring Chinook outmigrated from Loup Loup and Salmon Creeks, with about 92% of those attributed to Loup Loup Creek. The estimated number of fish that outmigrated in the spring was roughly half of the estimated population present in the fall (Table B-4). It is likely that the reduced numbers could be attributed to a combination of overwinter mortality and development of the precocial life history type that remain within the system to spawn with returning adults the next fall.

Table B-4. Instream population estimates of natural-origin *O. tshawytscha* ( $\pm 95\%CI$ ) in tributaries to the Okanogan River in Washington State and British Columbia.

Tributary	Juvenile Chinook							
	2014	2015	2016	2017	2018	2019	2020	2021
Salmon Cr	0	0	0	18 ± 0	1,893 ± 519	219 ± 57	21 ± 0	553 ± 241
Lower Omak Cr	0	0	64 ± 0	187 ± 57	48 ± 0	570 ± 185	24 ± 0	0
Upper Omak Cr	0	0	0	0	0	0	0	0
Loup Loup Cr	0	0	0	0	295 ± 43	1,474 ± 100	94 ± 0	34 ± 0
Ninemile Cr	0	0	0	0	0	0	0	0
Bonaparte Cr	0	0	24 ± 0	0	0	0	0	62 ± 13
Tonasket Cr	0	0	0	0	0	0	0	0
Tunk Cr	0	0	0	0	0	11 ± 0	0	0
Aeneas Cr	0	0	0	3 ± 0	7 ± 0	45 ± 3	0	6 ± 0
Wanacut Cr	0	0	0	0	28 ± 26	33 ± 16	19 ± 0	0
Johnson Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Antoine Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	0
Wildhorse Sp Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Shingle Cr	Not sampled	Not sampled	0	0	0	0	0	38 ± 0
Inkaneep Cr	Not sampled	Not sampled	0	0	0	0	0	0
Shuttleworth Cr	Not sampled	Not sampled	0	0	0	0	0	0
Total	0	0	88 ± 0	208 ± 57	2,271 ± 589	2,352 ± 361	158 ± 0	639 ± 254

## **Conclusions**

This study demonstrated that it was possible to determine a population estimate of juvenile steelhead in small creeks with a defined measure of precision. While this technique might not be an optimal approach in larger systems, such as the mainstem Okanogan River, it was shown to be fairly precise in smaller watersheds. With multiple years of data collection, it may be possible to detect change in status and trends in the population of juvenile steelhead in relatively small, spatially distinct watersheds. Expanding these methods to additional tributaries within the Okanogan subbasin will allow for further examination of juvenile steelhead production in this system and increase the number of PIT tagged fish available for interrogation to estimate outmigration for the subbasin as a whole.

Many of the stated assumptions used in this study appeared to be adequate, but remained untested. Block nets were meticulously placed in small trenches and back filled with substrate in attempts to anchor nets to create a closed population during mark-recapture events, detections of marks were easily distinguishable with the use of PIT tags and top caudal fin clips, sampling effort was monitored to remain consistent between the first and second pass, and fish were evenly distributed throughout the site upon release in the mark-recapture sampling close to their initial capture location. Assumptions that may contribute to more bias include that handling and marking of fish did not affect the likelihood of recapture and that no PIT tag marks were lost prior to outmigration detections. In this study, no fish were recaptured that had a tag puncture wound and were found without a tag. Studies have shown that short term retention of PIT tags to be quite high, near 100% (Prentice et al. 1990, Zytlewski et al. 2003).

One factor that may warrant further consideration is the assumption that fish are evenly distributed throughout the reach, or more specifically, that the sample site was representative of the reach as a whole. Violation of this assumption may lead to less certainty in the accuracy of abundance of fish within that reach. Some studies have shown that spatial variation in fish density across a watershed may be considerable (Bisson et al. 1988, Kiffney et al. 2006). This bias may be inflated in longer reaches such as lower Omak Creek Reach 3 and Salmon Creek Reach 6, where the sample site only covered 3.8% and 1.8% of the reach length, respectively. However, this bias was minimized overall by randomly sampling all reaches in each sub-watershed. Additionally, the relatively large site length-to-wetted width ratio (ex. Omak Creek, 150 m / ~5 m) may accommodate habitat variation within this small system. If time and budget allow, the placement of multiple randomly selected sites within a reach will allow us to quantify inter-site variability of fish density within each reach.

Spatial distribution of fish throughout the creek may vary by age and size class (Roper et al. 1994). For example, density of steelhead fry may be linked to spawning location of adults the previous spring. Distribution of juvenile salmonids may also be linked to specific habitat variables, such as water velocity and substrate (Bisson et al. 1988, Everest and Chapman 1972, Nielsen et al. 1994), log/beaver jams (Roni and Quinn 2001), and overhead cover (Fausch 1993), among others. While the distribution of fish in relation to specific habitat variables was not examined in this study period, it may be possible to explore the hypotheses in the future, due to the fact that these abundance data were collected at existing long-term habitat monitoring sites. Determining abundance of fish in respect to specific habitat

characteristics may help to further describe variables favored in this system and assist in focusing habitat restoration efforts.

All naturally produced juvenile *O. mykiss* that were 95 mm and larger were PIT tagged. Additional years of outmigration data may be able to show if naturally produced *O. mykiss* in streams contribute to returns of adult steelhead, or if contribution from certain small watersheds is minimal, relative to the number of adults that spawn in these streams. Representatively marking a known proportion of the population upstream of the PIT tag array enabled the program to estimate emigration, even in the absence of a rotary screw trap. This method can also be applied to small watersheds where monitoring of juvenile production was previously infeasible. Dividing the creek into biologically distinct reaches allowed for subsampling to occur at a finer scale and site-based abundance of juvenile steelhead were only expanded within similar habitat types. Outmigration trend analyses will expand with further years of data. Although the methods outlined in this report might not be applicable for larger systems, the representative fish sampling approach was shown to provide an estimate of juvenile steelhead in small watersheds with a high degree of precision.

## **Appendix C. Mainstem Snorkel Surveys**

Follow the link below to view and download snorkel data from all sites and years. At the bottom of the webpage, click on the ‘maps’ link. From there, one can select a site on the map and retrieve all years of available data. Data are presented in table and graph form.

<https://www.okanoganmonitoring.org/>

A representative subset of snorkel sites from mainstem reaches throughout the subbasin are presented in the following pages. Refer to Figure C-1 for survey sites in Washington State and Figure C-7 for sites located in British Columbia. Snorkel surveys have been conducted during the base flow period, typically late summer to early fall. During this time, *O. mykiss* and other juvenile salmonids (<300mm) have rarely been detected in the Washington State portion of the subbasin (Figures C-2 to C-5). Densities increase slightly in the lower reaches of the Similkameen River (Figure C-6) below Enloe Dam, the barrier to anadromy (near Oroville, WA). In British Columbia, there is a noticeable increase in the number of juvenile *O. mykiss* in the ‘natural section’ of the mainstem river (Figure C-9) when compared with other channelized reaches.

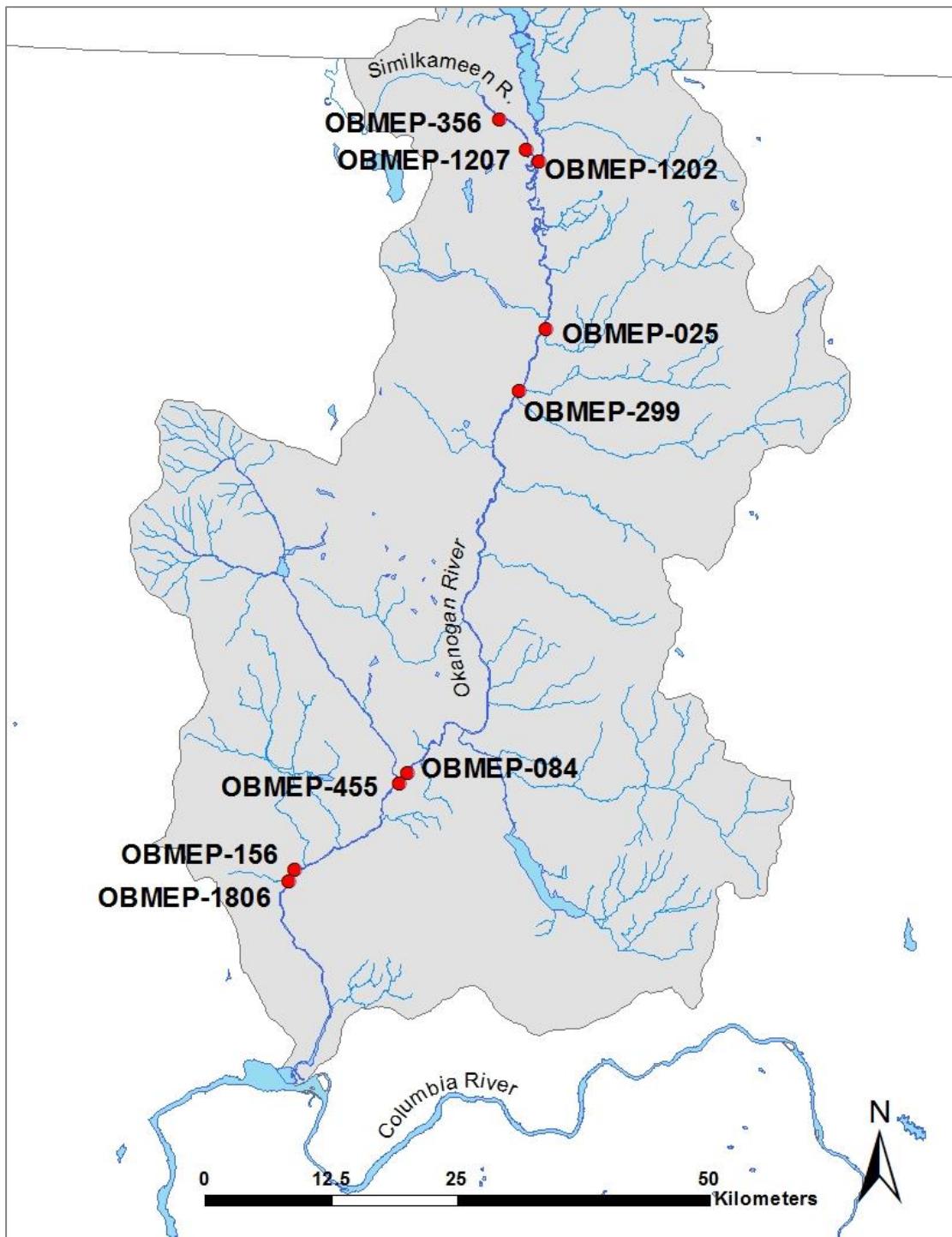


Figure C-1. Location annual snorkel survey sites on the mainstem Okanogan and Similkameen Rivers. Rotating panel sites are not shown due to fewer years of data.

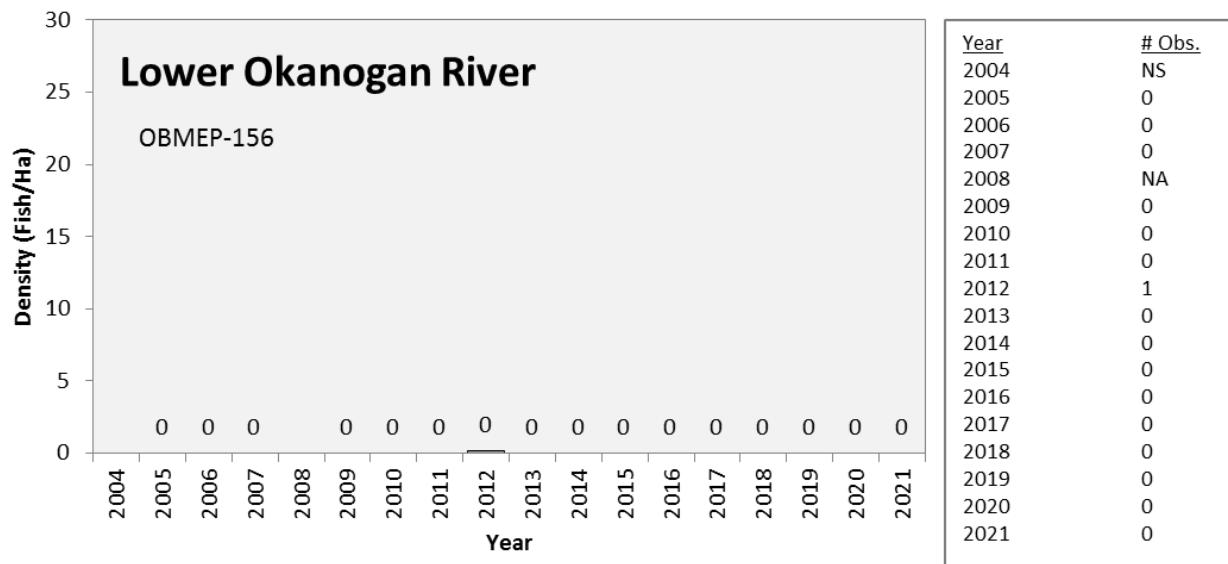


Figure C-2. Observed densities of juvenile (< 300mm) *O. mykiss* in the Okanogan River, downstream of the confluence with Loup Loup Creek.

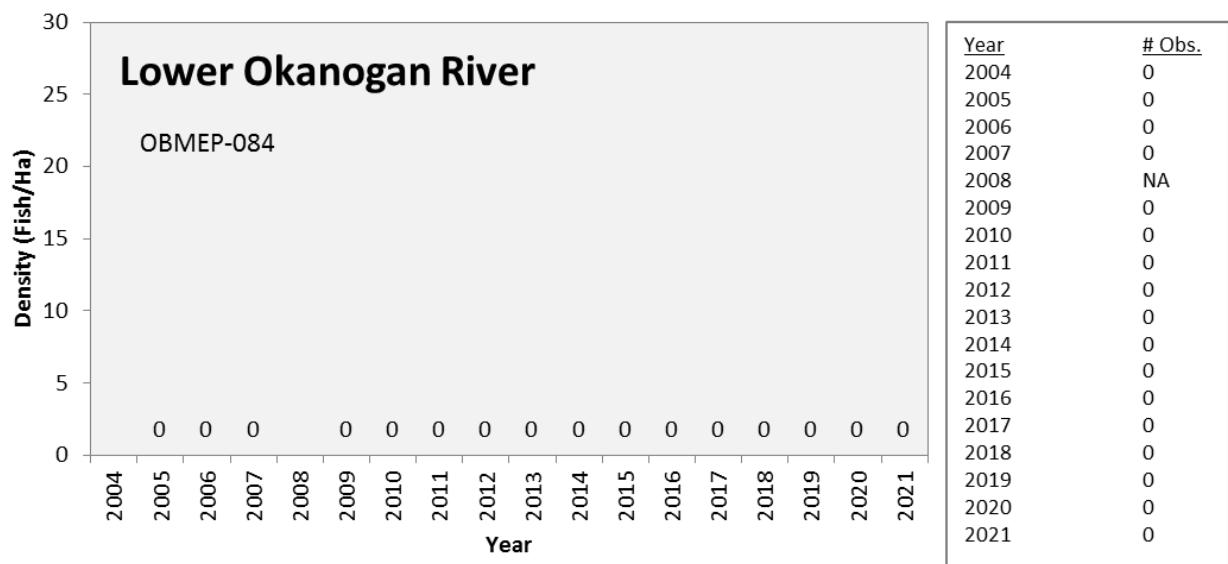


Figure C-3. Observed densities of juvenile (< 300mm) *O. mykiss* in the Okanogan River, upstream of the confluence with Salmon Creek.

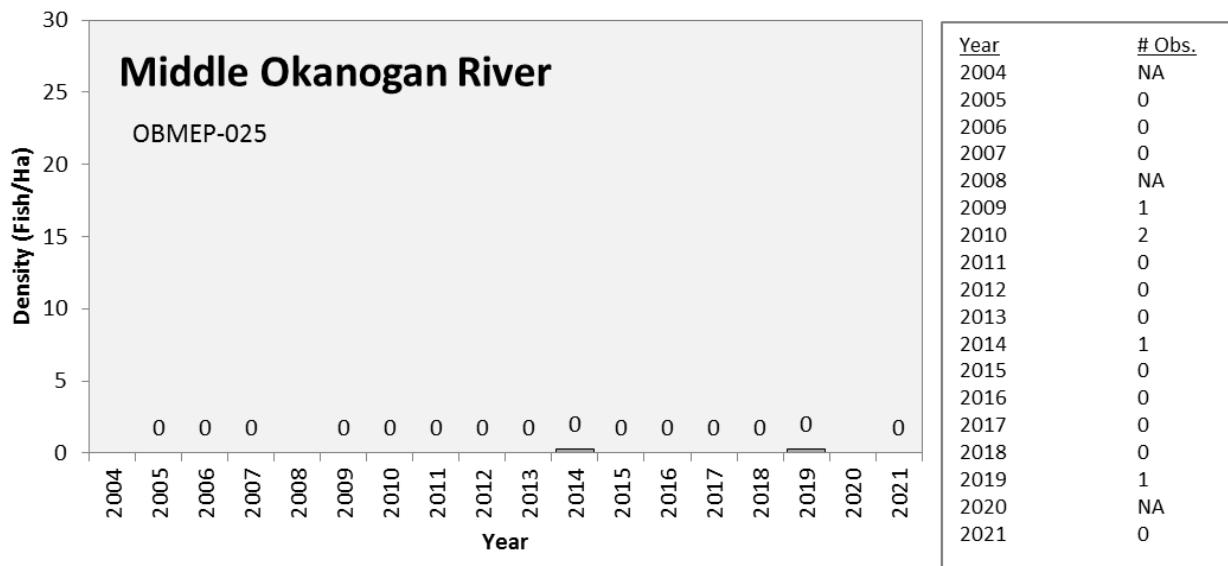


Figure C-4. Observed densities of juvenile (< 300mm) *O. mykiss* in the Okanogan River, upstream of the confluence with Antoine Creek.

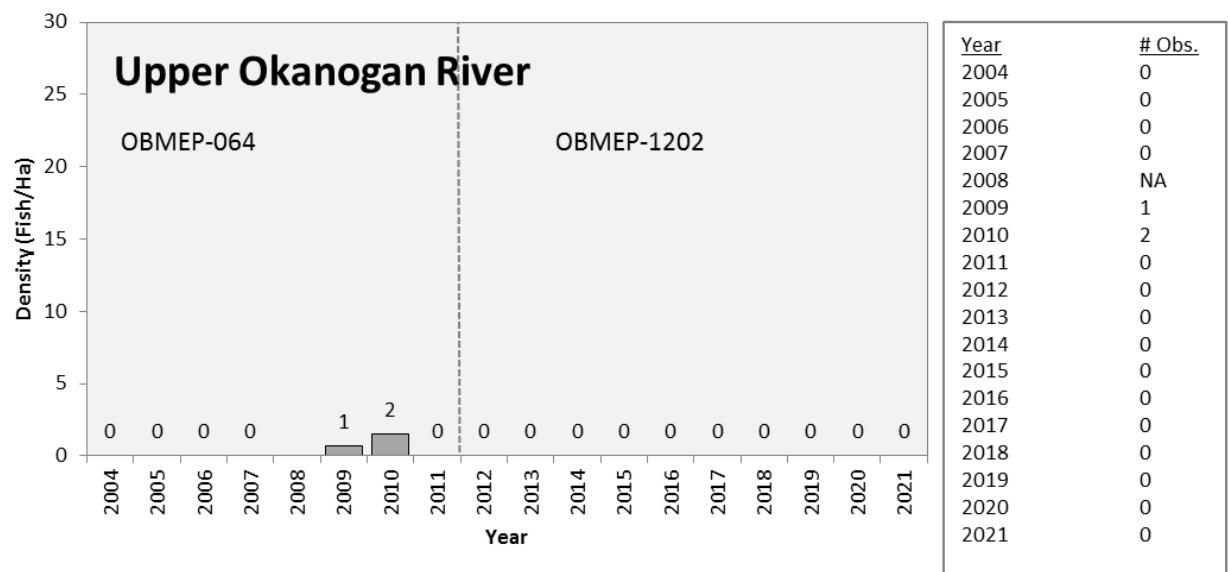


Figure C-5. Observed densities of juvenile (<300mm) *O. mykiss* in the Okanogan River. Site 1202 was moved two transects downstream of previous annual site 064 which overlapped the upper cross-channel with the Similkameen.

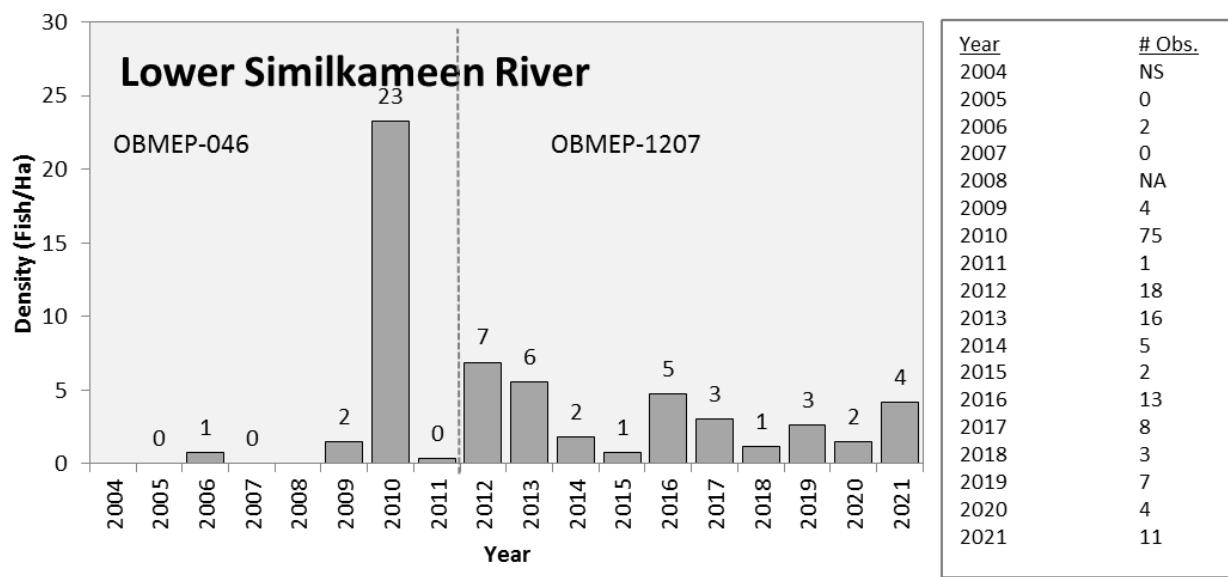


Figure C-6. Observed densities of juvenile (< 300mm) *O. mykiss* in the Similkameen River, near the city of Oroville, WA.

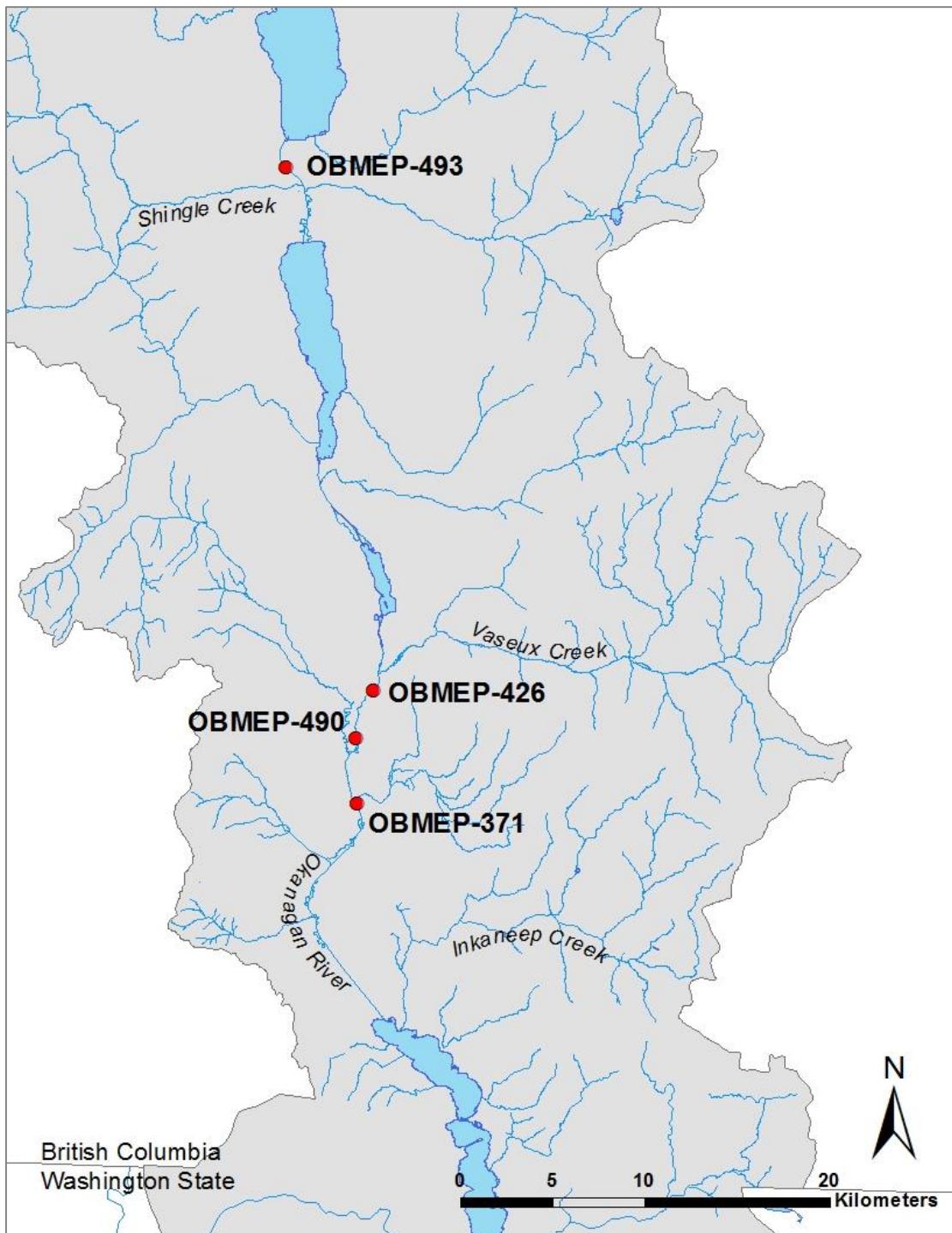


Figure C-7. Location of annual snorkel survey sites on the British Columbia portion of the Okanagan subbasin. Rotating panel sites are not shown due to fewer years of data.

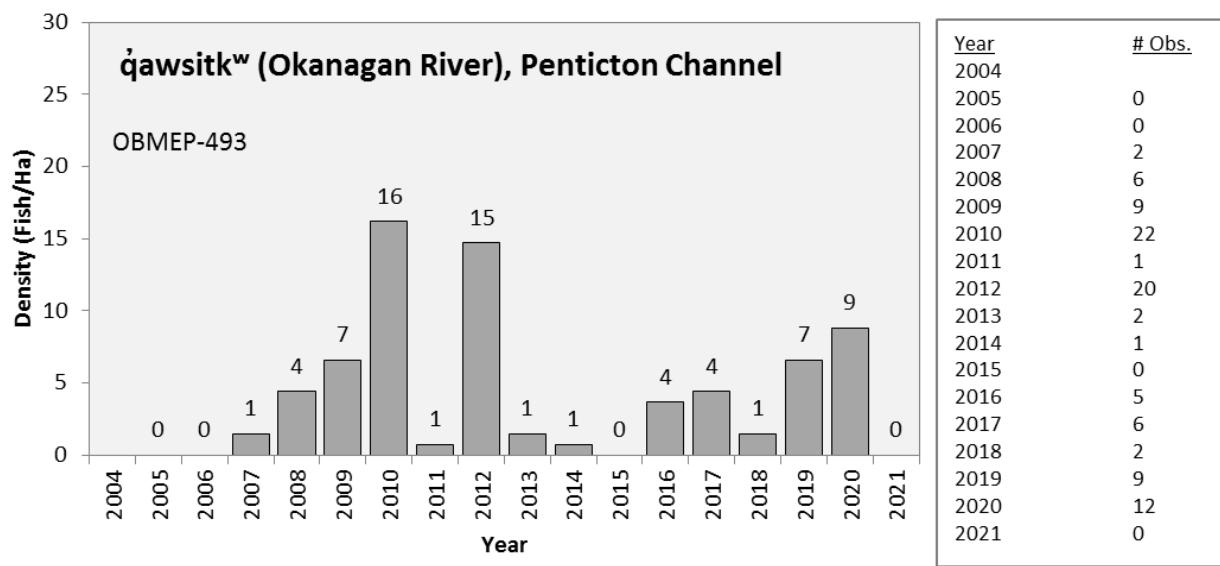


Figure C-8. Observed densities of juvenile (< 300mm) *O. mykiss* in the qawsitkw (Okanagan River) at site 493 located in the Penticton channel.

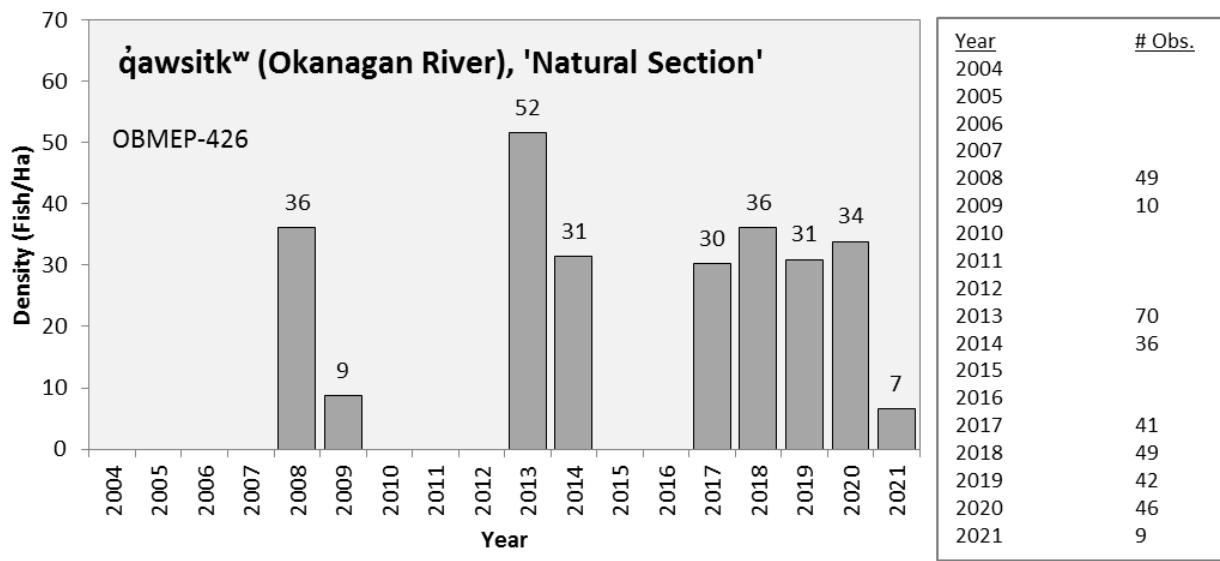


Figure C-9. Observed densities of juvenile (< 300mm) *O. mykiss* in the qawsitkw (Okanagan River) at site 426 in the 'natural section' of the river. Data from 2009 and 2014 are from nearby and similar site 383.

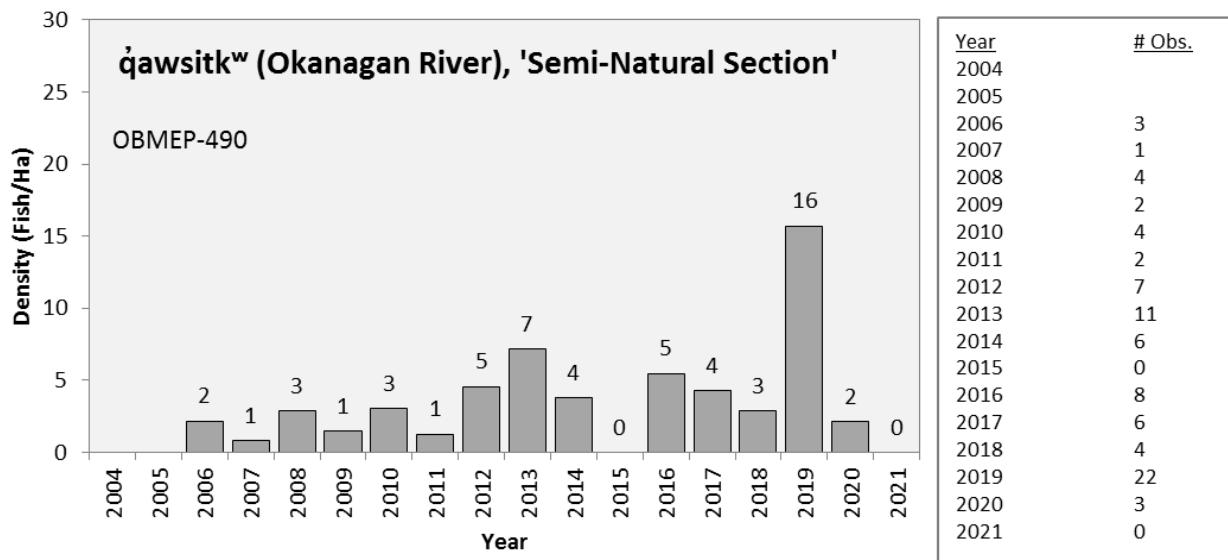


Figure C-10. Observed densities of juvenile (< 300mm) *O. mykiss* in the qawsitkw (Okanagan River) at site 490 in the 'semi-natural section' of the river.

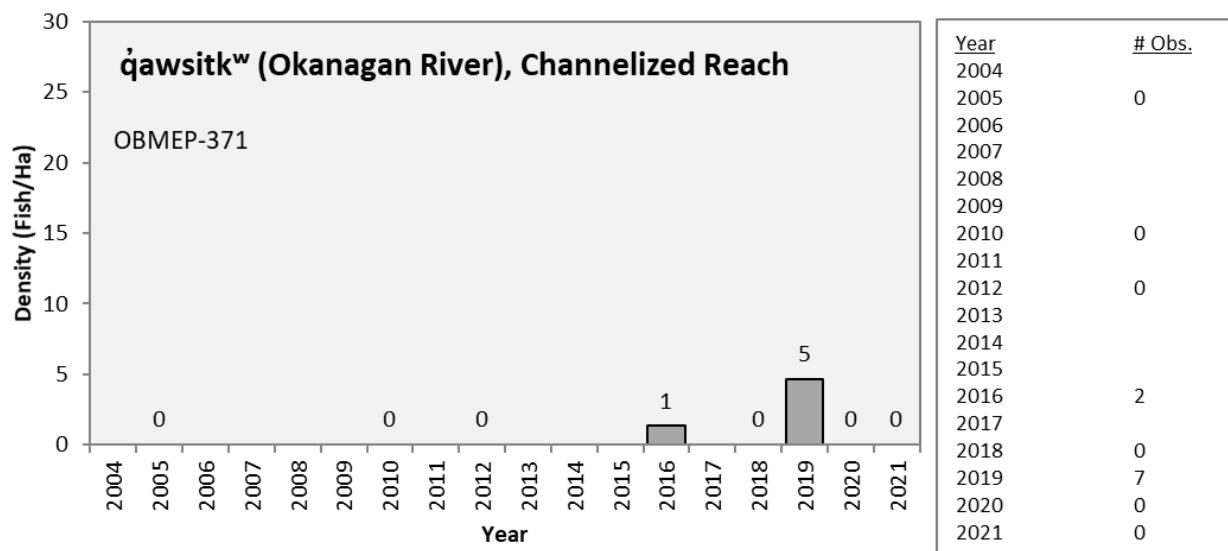


Figure C-11. Observed densities of juvenile (< 300mm) *O. mykiss* in the qawsitkw (Okanagan River) at site 371 in a channelized section of the river.

## **Appendix D. Water Temperature**

### **Introduction**

Water temperature plays a fundamental role in dictating the distribution and abundance of salmonids in the Columbia River Basin, particularly in the Okanogan subbasin where steelhead are exposed to a challenging thermal environment. Migratory adults enter the subbasin in late-fall through early-spring and spawn from late-March through early-May, with peak spawning occurring in mid-April. Steelhead eggs typically hatch at around 300 accumulated temperature units (ATU °C) or approximately 30–50 days at temperatures from 10–15°C (Wydoski and Whitney 2003, Moyle 2002). Alevin may remain in the gravels for 2 to 3 weeks longer before emergence (Moyle 2002). Based on spawn-timing data from the Okanogan subbasin over the past 10 years (OBMEP 2015), steelhead eggs and alevin may be present in the gravels from March through June. Juvenile steelhead parr rear in the subbasin from one to two years or more before outmigrating to the ocean. Resident life histories of *O. mykiss* (Rainbow Trout) can be found in the Okanogan River subbasin year-round.

When examining potential effects of water temperature on salmonids, it is useful to establish ranges and thresholds of chronic and acute exposure at each stage of development and rearing. However, applying these thresholds is tenuous in a complex thermal landscape, especially when fish may be able to seek refuge from extreme temperatures. The presence and processes of these refugia are poorly understood across large landscapes and are only within the last two decades beginning to gain notoriety. Widely implemented methods of monitoring water temperature do not detect most thermal complexity when monitoring occurs at a relatively coarse resolution and is targeted at surface waters. As such, describing effects on the fitness of salmonids is difficult if the actual thermal experience of a given life stage is not well understood. Similarly, it is essential to understand the background methods by which thresholds were obtained and in the absence of location-specific tolerance information, to treat regulatory temperature considerations (Table D-1) as generalizations when describing any potential effect.

The values presented in Table D-1 are considered appropriate for the preliminary analysis presented in due to a lack of specific data to suggest that *O. mykiss* in the Okanogan River have developed adaptations to temperature regimes at the extremes of published tolerances. Extensive review and discussion of on lethal and sub-lethal temperature effects on juvenile salmonids have been completed in Myrick and Cech 2001, U.S. Environmental Protection Agency (USEPA) 2003, and Carter 2005, among others. Studies of acute lethal effects of temperature on steelhead egg survival (see Myrick and Cech 2001 identify 15°C as a temperature threshold of increased mortality during egg incubation while Velsen (1987) cited poor survival (< 7%) above 16°C. For juvenile rearing, 18°C and below represents a preferred rearing temperature and above may represent a high risk for disease (Table D-1). Although this temperature alone may not be deleterious, noting that increased growth rates occur in this range (USEPA 2001c), it represents a threshold where increased stressors and negative effects have been documented. Additionally, elevated stream temperatures may compound intra- and interspecific

species competition for resources or rearing space (USEPA 2001a), particularly during summer low flows.

Table D-1. Summary of temperature considerations for incubating eggs and juvenile salmon and trout (adapted from USEPA 2003, Table 1, p.16).

Temperature Consideration	Temperature (unit)	Reference
Incubation and Emergence		
Optimal Range	6 - 10°C (constant)	USEPA 2001c
Good survival	4 - 12°C (constant)	USEPA 2001c
Increased mortality	> 15°C	Myrick and Cech 2001
Poor survival (< 7%)	> 16°C	Velsen 1987
Rearing Preference	10 - 17°C (constant) < 18°C (7DADM)	USEPA 2001a Welsh et al. 2001
Optimal Growth		
Unlimited food	13 - 20°C (constant)	USEPA 2001c
Limited food	10 - 16°C (constant)	USEPA 2001c
Disease Risk		
Minimized	12 - 13°C (constant)	USEPA 2001b
Elevated	14 - 17°C (constant)	USEPA 2001b
High	> 18 - 20°C (constant)	USEPA 2001b
Lethal Temp		
1 Week	23 - 26°C (constant)	USEPA 2001c

## Methods

OBMEP - Water Quality Sampling (ID:5)

<https://www.monitoringresources.org/Document/Protocol/Details/5>

OBMEP - Habitat Monitoring (ID:9)

<https://www.monitoringresources.org/Document/Protocol/Details/9>

OBMEP collected hourly water temperature data in the Okanogan subbasin from 2005 through 2021, in both the mainstem and tributary reaches. Water temperature was collected at annual tributary habitat sites using Onset HOBO® temperature loggers. Additionally, real time temperature data were collected at three USGS sites on the Okanogan River in the United States at Malott, Tonasket, and Oroville under this project. Additional USGS sites are located on important tributaries to the Okanogan River. Data have been assimilated into the archives available on the USGS website, which provides access to the public and other agencies. In the British Columbia portion of the subbasin, monitoring on tributaries and the q̄awsitkʷ (Okanagan River) mainstem was also conducted through Water Survey of Canada

(Environment Canada 2021). Web links for water temperature and discharge monitoring site data, within the Washington portion of the Okanogan subbasin, are provided in Appendix E. Water temperature data can be accessed at <https://www.okanoganmonitoring.org/>.

Maximum weekly maximum temperature (MWMT) values were calculated by averaging daily maximum water temperatures for each seven-day period from June through September and selecting the highest seven-day average value. Maximum weekly average temperatures (MWAT) were determined by calculating daily mean temperature values during the summer period and selecting the highest seven-day average.

In 2015, additional investigations began to characterize variation between surface and hyporheic water temperatures at select major spawning areas in the Okanogan subbasin. During the initial study year, four sites were selected, two on the Okanogan mainstem below Zosel dam, one on the Similkameen mainstem, and one on Omak Creek. Two piezometers were installed at each site, one to monitor surface water temperature and one to monitor hyporheic temperature at egg-pocket depth ~20cm below the river surface. Temperature data were recorded hourly. The variation between surface and hyporheic temperatures was simply the difference in daily average. Projections of hatch and emergence timing were made using daily average hyporheic temperatures from the monitoring locations for spawning timing two weeks before and after peak spawning in the Okanogan subbasin (April 15). Accumulated temperature units to hatch were assumed to be approximately 300 with emergence occurring at 450.

## Results

### *Subbasin-Wide Temperature Monitoring*

Maximum weekly maximum temperature (MWMT) and maximum weekly average temperature (MWAT) values were calculated for all streams in Washington and British Columbia that had complete data sets for the months of June, July, August, and September. Median MWAT values for the current dataset (2005–2021) were above 23°C for the Okanogan River in Washington State and British Columbia; median MWAT values for most tributaries were between 18 and 23°C (Figure D-1). Summer 2021 MWAT values generally trended near median throughout the Okanogan subbasin.

MWMT values were calculated for all streams in the US and Canada that had complete data sets for the months of June, July, August, and September. From 2005 through 2021, the MWMT in the mainstem, most of the tributaries in the US, and all of the tributaries in Canada exceeded the 18 °C threshold (Figure D-2). Weekly maximum stream temperature trended similarly to MWAT, as the majority of high temperatures in summer 2021 exceeded the 23 °C threshold. While most tributaries were at the high end of whiskers in the summer of 2021, the MWMT Okanogan River (USGS site, Malott, WA 12447200) only reached Q3. The USGS, Okanogan River (Malott), water temperature is influenced by the cooler water input from the Similkameen River (Figure D-3).

Daily average water temperatures in lower Omak Creek reached 27°C by the end of June, with diel fluctuations between 23 and 26°C for more than a week (Table D-1).

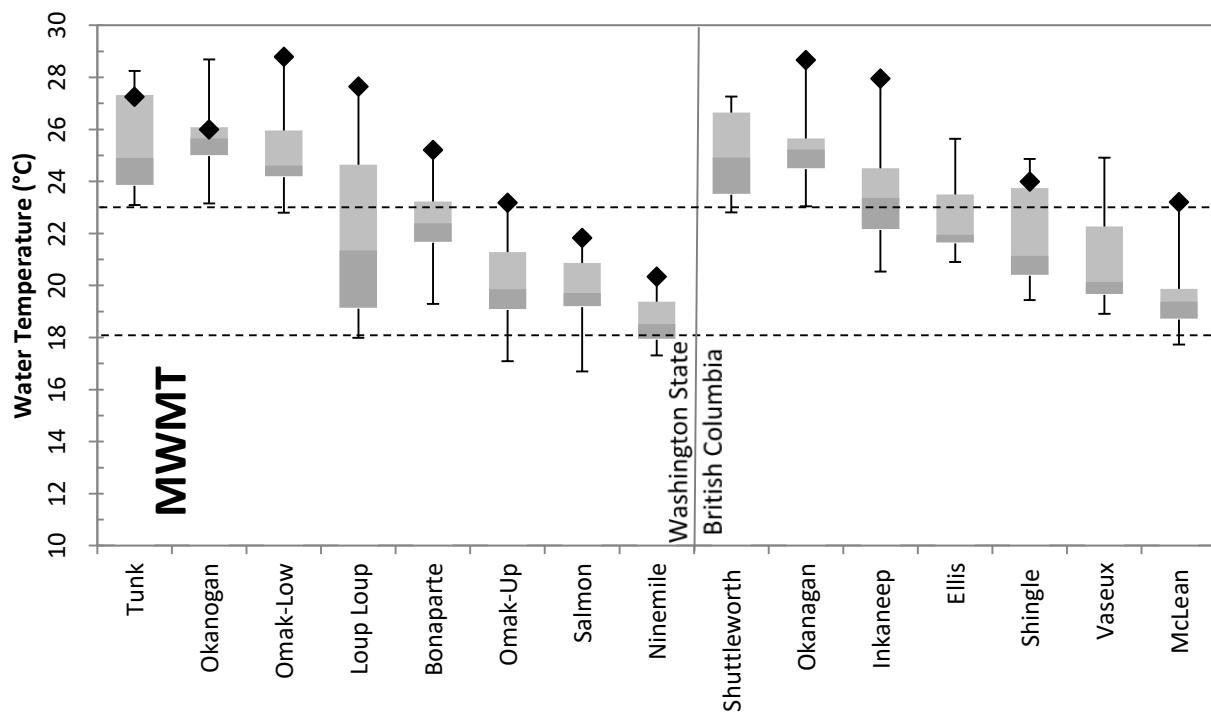


Figure D-2. Maximum weekly maximum water temperatures (MWMT) in the Okanagan subbasin from 2005–2021. Black markers are 2021 data; dashed line represents 18 and 23°C exceedance (EPA 2003).

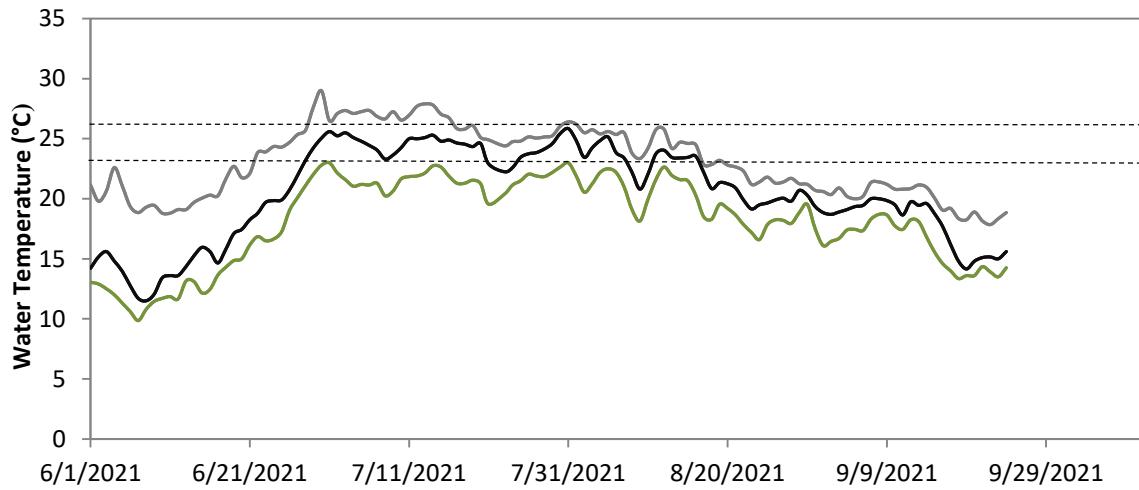


Figure D-3. USGS discharge stations mean daily temperature. Black line represents Okanogan River (Malott) 12447200, gray line represents Okanogan River (Oroville) 12439000, and green line represents Similkameen River (Nighthawk) 12442500. Dashed lines represent 23 and 26°C exceedance (EPA 2003).

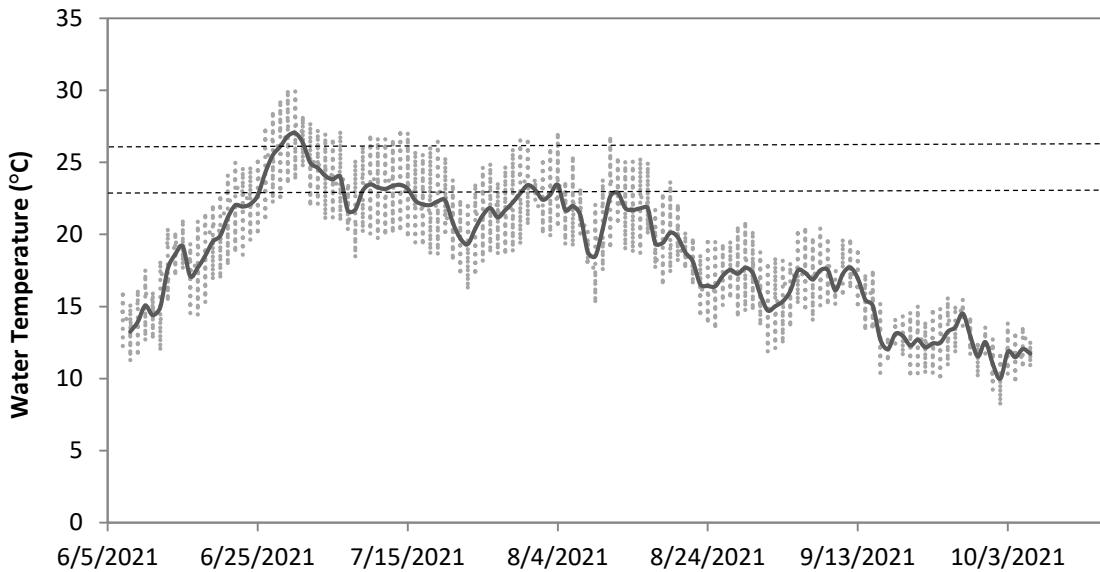


Figure D-4. Omak Creek (Omak – Low on MWMT), black line represents average daily temperature, gray dotted line represents diel fluctuations. Dashed lines represent 23 and 26°C exceedance (EPA 2003).

## Discussion

Water temperature in the Okanogan River and tributaries remains an important variable affecting spatial and temporal distribution, growth rates, abundance, and survival of juvenile salmonids. In bioenergetics models, temperature directly affects metabolic responses by determining what portion of an organism's energy budget is available to either support basal and active metabolism or contribute to somatic growth, reproduction, or high-energy lipid storage (Beauchamp et al. 2007). Although temperature tolerances in laboratory studies depend on initial acclimation temperatures, peer-reviewed literature suggests the preferred temperature of rearing juvenile *O. mykiss* is approximately 18°C, incipient upper lethal temperature (IULT) is approximately 24°C and critical thermal maximum (CTMax) temperature is approximately 28°C (Wagner et al. 1997, Myrick and Cech 2000, Galbreath et al. 2004, and reviews in Currie et al. 1998, Beitingen et al. 2000, and Spina 2007). Results from the Okanogan showed that high summer temperatures in the mainstem, and to a lesser extent in some tributaries, could be adversely affecting salmonids directly, or indirectly causing behavior modifications and altering spatial distribution.

Many laboratory and field studies have quantified the acute and chronic effects of temperature on salmonids (reviews by Currie et al. 1998 and Beitingen et al. 2000). When temperatures exceed salmonids' biological tolerance, acute effects such as migration blockages, avoidance behavior, or death may occur. The EPA uses the maximum weekly maximum temperature (MWMT, the highest 7-day average of maximum daily temperature in a given year) to regulate against acute effects because MWMT is not overly influenced by a single daily maximum, but it still describes maximum temperatures in a stream over a week-long period (USEPA 2003). Salmonids may tolerate temperatures higher than their optimal range, but sublethal effects may occur such as impacts to growth, increased incidence of disease, increased risk of predation, and potential delay of smoltification.

Although high summer water temperatures occur in the tributaries, acclimation and diel temperature fluctuations most years help buffer salmonids against many of the negative impacts of high water temperature documented in the literature (reviews by Currie et al. 1998 and Beitingen et al. 2000). According to Bjornn and Reiser (1991), the effects of acutely or chronically lethal and sub-lethal temperatures depend on acclimation temperature, duration of temperature increase, daily fluctuations, and ecological adaptations. When daily maximum temperatures approach lethal values in small streams but only for short durations, salmonids can still thrive if temperatures decline back to optimal ranges (Bjornn and Reiser 1991). Salmonids can also respond to high temperatures by moving upstream or downstream (Mabbott 1982), or seeking cold water refugia (reviews in USEPA 2001a). Daily behavioral movements and use of thermal refugia are not well understood and have not been specifically studied in the Okanogan subbasin to date.

As shown in the subset of snorkel sites from mainstem reaches throughout the subbasin (Appendix C), juvenile salmonids are infrequently observed. Thermal tolerances for juvenile salmonids suggest there should be few or no juvenile salmonids in the mainstem during high summer temperatures. However, concern exists over this apparent absence because approximately 50% of steelhead spawning occurs in the mainstem on a given year (OBMEP 2015). It is unknown if high summer water temperatures cause direct mortality to juveniles or alter their behavior by avoiding high temperatures, or if both are occurring, and to what degree. Juveniles may seek refuge in interstitial spaces between the gravels and snorkeling may not be as efficient for observing juveniles in the mainstem. Although summer water temperatures may limit use of certain habitats for a few months these same habitats can be utilized for many months when water temperatures are not limiting but this seasonal use is still not well studied. Monitoring temperature in the mainstem Okanogan River and its tributaries will continue to play an important role in understanding life histories and seasonal habitat use of steelhead in the Okanogan subbasin.

## **Appendix E. Water Quantity/Discharge**

### **Introduction**

The Okanogan subbasin consists of two large mainstem rivers, the Okanogan and Similkameen, which combined have a substantial catchment area, roughly 21,000 km<sup>2</sup>, more than twice the size of the Methow, Entiat, and Wenatchee subbasins combined (NPCC 2004, Morrison and Smith 2007). In the areas accessible to anadromous salmonids, additional habitat is found in relatively small tributaries, which in general, have a flashy runoff period, followed by very low base flow periods throughout the rest of the year. Many small tributaries flow subsurface in the lower reaches in mid-summer, which may result in disconnection of streams from the mainstem river. Primary causes may be attributed to the semi-arid climate and geology of the Okanogan subbasin, minimal catchment area for some small watersheds, and water diversion/withdrawals for irrigation usage.

### **Methods**

OBMEP - Water Quality Sampling (ID:5)

<https://www.monitoringresources.org/Document/Protocol/Details/5>

OBMEP - Habitat Monitoring (ID:9)

<https://www.monitoringresources.org/Document/Protocol/Details/9>

Discharge data were collected on the mainstem by the USGS and Water Survey of Canada. Many of these monitoring sites were operated with funding from OBMEP, through the CCT Fish and Wildlife Program. Tributary discharge monitoring in the U.S. was done cooperatively with the USGS and OBMEP employees and tributary discharge data were collected on Canadian tributaries through OBMEP. Discharge data collection included field visits to measure the stage (surface water elevation), and discharge (volume of water passing a point per unit time). Some sites have automated water level data loggers (pressure transducers located at the stream gage site that upload continuous water level data to the internet in real-time), however some Canadian sites have archiving water level data loggers that require downloading periodically during field visits. Data analysis comprises of creating stage-discharge rating curves, applying rating curves to continuous water level data to estimate continuous discharge, and quality control. Stage height data and discharge curves were incorporated into the EDT model to estimate suitability, carrying capacity, and fish abundance in the Okanogan subbasin.

### **Results**

Discharge in the Canadian Okanagan mainstem is influenced by the Okanagan Basin Lake Regulation System, a series of regulated dams located along the British Columbia portion of the river. Discharge in the U.S. Okanagan mainstem is highly influenced by the Similkameen River, an unregulated, snowmelt-fed river, which contributes approximately three quarters of the flow to the US portion of the Okanagan River, and explains the different quantity of discharge in the US Okanagan mainstem (Figure E-1) compared to the Canadian mainstem (Figure E-2). The USGS has continuously operated an Okanagan

mainstem stream gage at Tonasket for the last 92 years. Similarly the WSC has operated a mainstem stream gage near Oliver, British Columbia for 77 years.

Historic average monthly discharges for both locations are displayed in Figure E-1 and Figure E-2. The historic time periods are represented in 20-year divisions for the entire span of operation. Figure E-1 averages the monthly discharge for the years 2020 and 2021 resulting in a hydrograph with a relatively higher peak in May due to the above normal peak discharge in 2020. In 2021, the spring freshet peak flow at the USGS Okanogan mainstem stream gage at Tonasket was only 85% of the average peak flow for the 92 year period of record. Below-normal precipitation and snowpack in the Canadian and United States portion of the Okanogan River subbasin resulted in a reduced runoff period for small streams as observed at the cooperatively operated USGS stream gages in tributaries to the Okanogan River. There were lower peak flows and reduced summer flows for all the seven tributaries monitored with USGS stream gages. Peak flows for these tributaries were all at or below the ‘normal’ (7 years of data) range, as shown in Figure E-4. Base flows were all below the ‘normal’ range (E-3).

Website links for temperature and discharge monitoring sites within the US Okanogan subbasin include:

- Okanogan River at Malott: [http://waterdata.usgs.gov/nwis/uv?site\\_no=12447200](http://waterdata.usgs.gov/nwis/uv?site_no=12447200)
- Okanogan River near Tonasket: [http://waterdata.usgs.gov/nwis/uv?site\\_no=12445000](http://waterdata.usgs.gov/nwis/uv?site_no=12445000)
- Okanogan River at Oroville: [http://waterdata.usgs.gov/nwis/uv?site\\_no=12439500](http://waterdata.usgs.gov/nwis/uv?site_no=12439500)
- Ninemile Creek: [https://waterdata.usgs.gov/nwis/uv?site\\_no=12438905](https://waterdata.usgs.gov/nwis/uv?site_no=12438905)
- Similkameen River near Nighthawk: [http://waterdata.usgs.gov/wa/nwis/uv?site\\_no=12442500](http://waterdata.usgs.gov/wa/nwis/uv?site_no=12442500)
- Antoine Creek near Ellisforde: [http://waterdata.usgs.gov/nwis/uv/?site\\_no=12444290](http://waterdata.usgs.gov/nwis/uv/?site_no=12444290)
- Bonaparte Creek at Tonasket: [http://waterdata.usgs.gov/nwis/uv/?site\\_no=12444550](http://waterdata.usgs.gov/nwis/uv/?site_no=12444550)
- Johnson Creek near Riverside: [http://waterdata.usgs.gov/nwis/uv/?site\\_no=12445500](http://waterdata.usgs.gov/nwis/uv/?site_no=12445500)
- Omak Creek near Omak: [http://waterdata.usgs.gov/nwis/uv/?site\\_no=12445900](http://waterdata.usgs.gov/nwis/uv/?site_no=12445900)
- Salmon Creek above diversion near Okanogan:  
[http://waterdata.usgs.gov/nwis/uv?site\\_no=12446995](http://waterdata.usgs.gov/nwis/uv?site_no=12446995)
- Loup Loup Creek at Malott: [http://waterdata.usgs.gov/nwis/uv?site\\_no=12447285](http://waterdata.usgs.gov/nwis/uv?site_no=12447285)

Water Survey Canada (WSC) website link for temperature and discharge monitoring sites within the Canadian Okanagan subbasin:

- [https://wateroffice.ec.gc.ca/search/real\\_time\\_e.html](https://wateroffice.ec.gc.ca/search/real_time_e.html)

WSC Station Names and Numbers include:

- INKANEEP CREEK NEAR THE MOUTH: 08NM200
- OKANAGAN RIVER NEAR OLIVER: 08NM085
- SHATFORD CREEK NEAR PENTICTON: 08NM037
- VASEUX CREEK ABOVE SOLCO CREEK: 08NM171

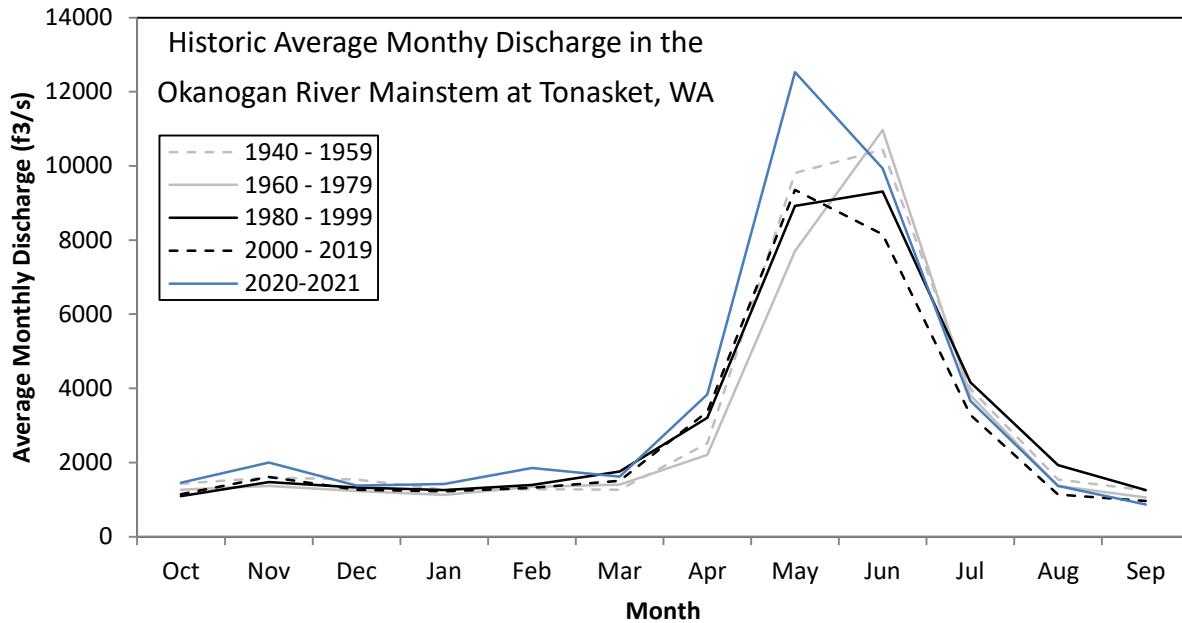


Figure E-1. Average monthly discharge of the Okanogan River at Tonasket, WA (USGS Station 12445000, Okanogan River near Tonasket, WA).

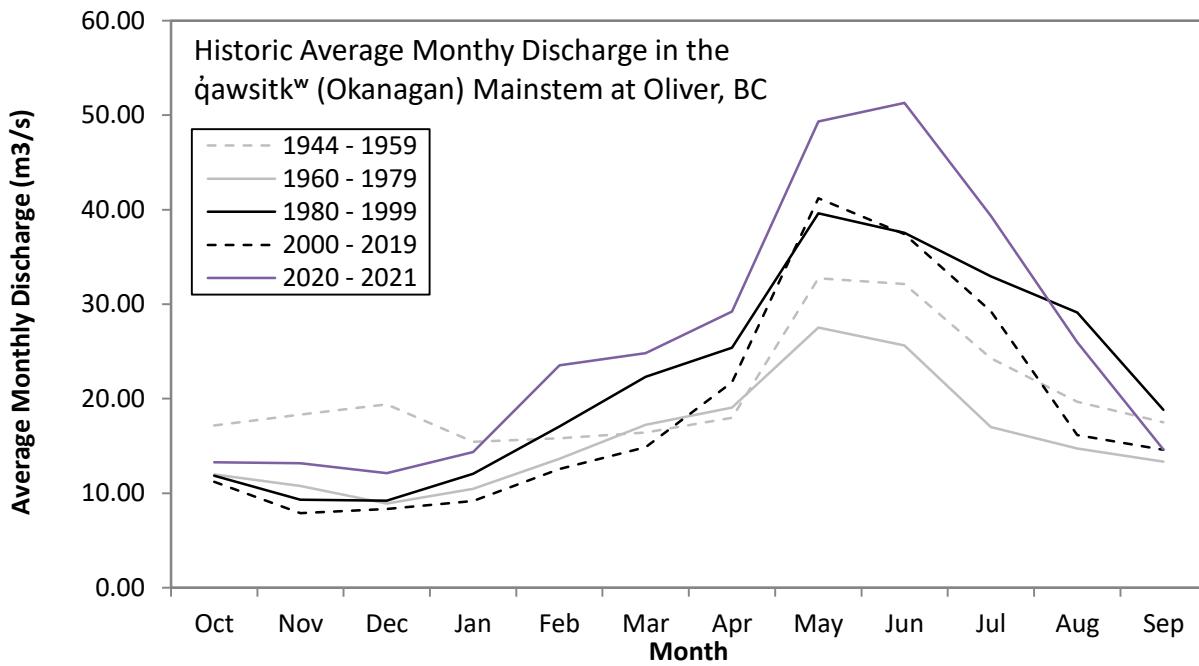


Figure E-2. Average monthly discharge of the qawsitkʷ (Okanagan River) recorded near Oliver (Water Survey of Canada station 08NM085 (Environment Canada 2021)).

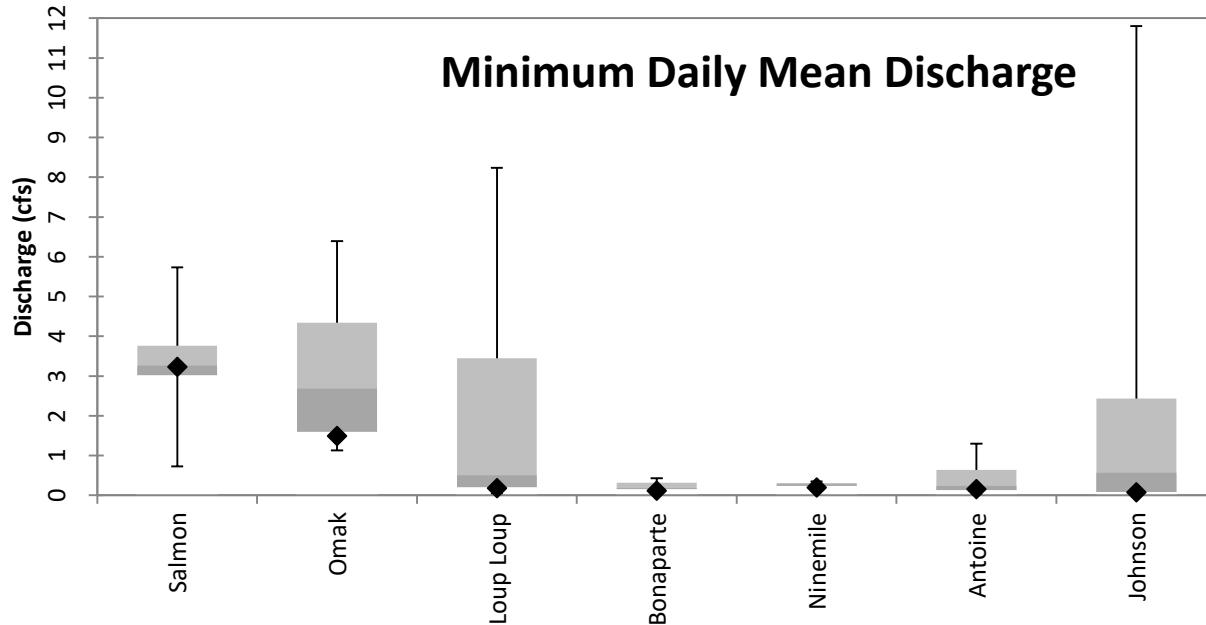


Figure E-3. Minimum Daily Mean Discharge of seven tributaries to the Okanogan River, or the mean discharge for the lowest low flow day of the year. Black diamonds are 2021 MDMD values. Boxes represent 50-75<sup>th</sup> (Q3, light grey) and 25-50<sup>th</sup> (Q2, dark grey) quartiles of the MDMD distribution during 2014-2021 while whiskers display the maximum and minimum range of low flow values.

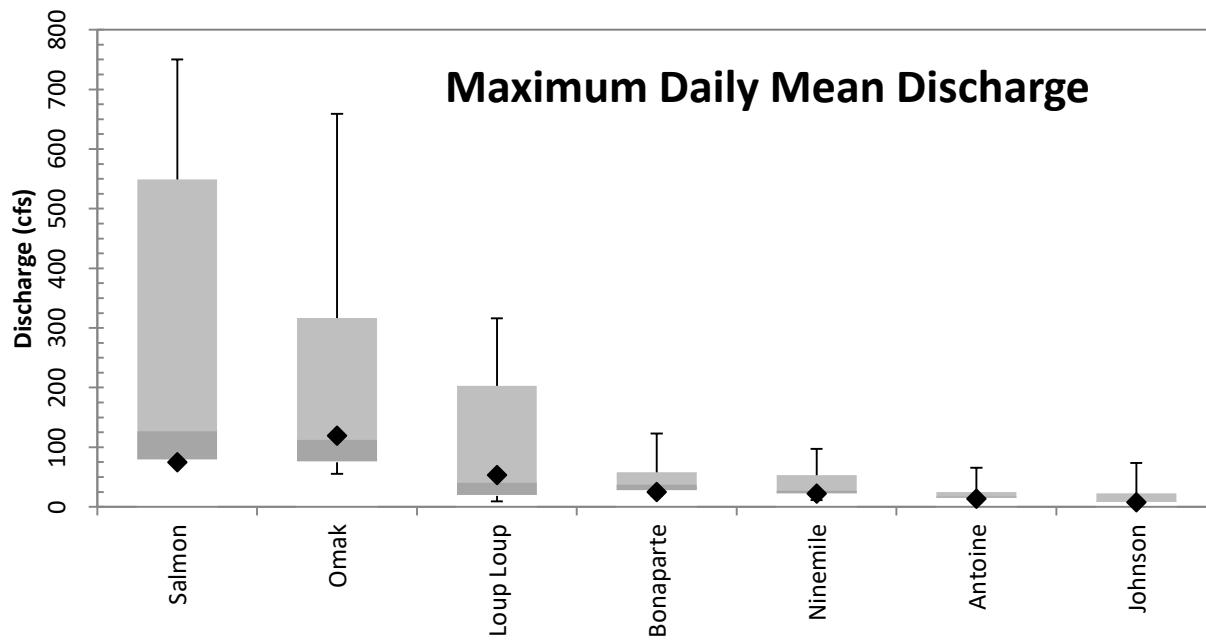


Figure E-4. Maximum Daily Mean Discharge of seven tributaries to the Okanogan River, or the mean discharge for the highest high flow day of the year. Black diamonds are 2021 MDMD values. Boxes represent 50-75<sup>th</sup> (Q3, light grey) and 25-50<sup>th</sup> (Q2, dark grey) quartiles of the MDMD distribution during 2014-2021 while whiskers display the maximum and minimum range of high flow values.

## **Conclusions**

Habitat projects focusing on quantity of water in streams will continue to be an important focus, particularly during the summer base flow period and maintaining connectivity of tributaries with the mainstem Okanogan River. Projects should focus on tributaries that have a sufficient biological capacity to support juvenile rearing. Although additional analyses have not specifically quantified effects outside of the EDT model, quantity of water in tributaries to the Okanogan River has been observed to have effects on various life stages of steelhead. In particular, adult steelhead migration into tributaries is often limited until the spring freshet begins (OBMEP 2015). This is particularly evident in streams with large, wide alluvial fans at the confluence with the Okanogan River, most notably Salmon, Antoine and Bonaparte creeks. Once spring flows increase water depth in the creek, or the mainstem Okanogan River rises to a level to submerge the broad alluvial fans, adult steelhead can enter those systems. For the juvenile life stage, winter low flows can constrain juvenile production and survival; such is the case in Salmon Creek. Results of stream flow are further discussed in the habitat status and trend reports, where specific instances that water quantity may be limiting by life stage are clearly defined.

## Appendix F. Fine Sediment Analyses

### Introduction

During most of their lives, salmonids are mobile and can adapt to changes in stream flow via emigration and displacement. However, after salmonids spawn, eggs and developing embryos are buried beneath the surface of streams for protracted periods, and do not have this option (Reiser and White 1990). During this largely immobile life stage, a variety of habitat factors can greatly effect survival. Previous studies on egg-to-fry survival of salmonids have indicated that factors influencing survival include disease, scour, water temperature, dissolved oxygen (DO), metabolic waste transport and the presence of fine sediments (Rubin 1995).

Fine sediment infiltration into redds reduces egg-to-fry survival when fine sediments (< 2.0 mm in diameter) constitute 4–20% of the gravel framework (Chapman 1988; Soulsby et al. 2001; Greig et al. 2005a) or when sediments < 1.0 mm constitute 12–15% by weight (Garrett and Bennett 1996; Julien and Bergeron 2006; Jensen et al. 2009). Survival of steelhead (*Oncorhynchus mykiss*) and Chinook salmon (*Oncorhynchus tshawytscha*) embryos, when exposed to varying size classes of fine sediment (< 0.84 and 0.84 to 4.6 mm), showed a similar relationship (Reiser and White 1988). Fine sand (0.125–0.250 mm), very fine sand (0.063–0.125 mm), and silt (< 0.063 mm) have also been shown to be negatively correlated with survival of Atlantic salmon (*Salmo salar*) embryos when a threshold of approximately 18% silt and very fine sand by weight is reached (Levasseur et al. 2006). Embryo survival to hatched stages was approximately 30% lower when small amounts of silt were present in redds (Julien and Bergeron 2006). In addition to size and percent composition of fine sediments in redds, the origin of sediment may also have an effect. Greig et al. (2005b) provided evidence that clay particles restrict oxygen uptake by Atlantic salmon embryos by either creating low permeability layers around egg pockets or physically blocking micropores used in embryo respiration.

Studies show that small changes in the percentages of silt and very fine sediments contained within medium and coarse sands can have relatively large impacts on the early immobile life stages of salmonids (Tappel and Bjornn 1983; Lapointe et al. 2004; Louhi et al. 2011). Survival of trout embryos to emergence was significantly reduced when they were exposed to fine organic sediments (< 0.074 mm) even when infiltration was at a maximum of 1.5% of the total sample mass and generally near 0.5% (Louhi et al. 2011). Lapointe et al. (2004) found that silt loadings > 0.5% were detrimental to survival for all substrate mixtures, excepting mixtures that were very sparse in sands (< 5%). Additionally, when sand constituted over 10% of fine sediment by mass, an incremental increase of 1% silt had over three times the effect on survival as a 1% increase of sand.

Monitoring protocols for substrate conditions in the Upper Columbia have lacked the precision to make meaningful correlations with the published research discussed in this section. Many published protocols (AREMP, EMAP, ODFW, etc.) are based on the Wolman pebble count method (Wolman 1954) and thereby attempt to infer fine sediment loading from an estimate of surficial coverage by sands and silt. This creates a known bias against accurate descriptions of sediment composition and inference of

potential limiting factors. In identifying a need for a more rigorous assessment of substrate conditions, the OBMEP found that a bulk-sediment sampling methodology would reduce observational bias and allow for more direct inference of the role of sediment conditions in summer steelhead recruitment.

## Methods

### Bulk Streambed Sediment Sampling (ID:6698)

<https://www.monitoringresources.org/Document/Method/Details/5479>

In 2017, OBMEP implemented a protocol to gather bulk sediments samples in order to better quantify the composition of streambed sediment in spawning habitat. Bulk sediment sampling was focused on known spawning areas for salmonids, defined by detections of redds from previous years spawning surveys. In 2021, 35 samples were collected in 6 tributaries to the Okanogan River with 15 taken in the Okanogan itself. Six previous years of bulk sediment sampling were also included in the analysis, as the basic protocol has remained unchanged, excepting for increasing the volume of the sample taken relative to the apparent grain size distribution. Bulk samples were collected according to the 1% sample error target in Church et al. (1987). After collection, samples were wet sieved through 64, 32, and 16 mm sieves in the field. The portion of the sample finer than 16mm was homogenized and subsampled in the field. Subsamples were processed in the lab by drying for 24 hours at 105°C and passed through a single-phi interval sieve stack on a Rotap sieve shaking table for 10 minutes. A 0.850 mm screen sieve was included in the sieve set to provide consistency with existing sediment research. Each fraction was then weighed to the nearest 0.01g.

In order to examine the effects of sediment conditions on the early developing life stages of salmonids, we used a relationship developed by Tappel and Bjornn (1983) that uses the percent of sample finer than both 9.5 mm and 0.85 mm. The estimate of egg-to-fry survival was estimated by:

$$\text{Percent survival} = 94.7 - 0.116S_{9.5}S_{0.85} + 0.007S_{9.5}$$

where  $S_{0.85}$  and  $S_{9.5}$  are the percent of sediment in the sample less than 0.85 and 9.5 mm.

## Results

The percentage of fine sediment binned in commonly cited size classes which have been shown to have effects on egg-to-fry survival are presented in Table F-1. Approximately half of all samples and tributary average values met or exceeded the upper threshold of effective values for “fines” i.e. a maximum size of 1.0 or 2.0mm.

Table F-1. Okanogan River tributary, sample size  $n$ , and average percent substrate finer than specified size class for the period 2015-2021. Values that meet or exceed cited thresholds of effect are in bold. Average estimated egg-to-fry survival  $S$  was calculated according to Tappel and Bjornn (1983).

	$n$	2.00	1.00	0.850	0.125	$S$
Omak Creek	88	0.17	0.12	0.11	0.01	60
Okanogan River	49	0.17	0.13	0.12	0.00	52
Salmon Creek	21	0.18	0.11	0.10	0.00	56
Tunk Creek	17	<b>0.25</b>	<b>0.18</b>	<b>0.17</b>	0.01	28
Antoine Creek	12	<b>0.27</b>	<b>0.20</b>	<b>0.18</b>	0.02	22
Ninemile Creek	12	0.14	0.09	0.08	0.00	62
Loup Loup Creek	11	0.19	0.12	0.10	0.01	54
Bonaparte Creek	10	<b>0.33</b>	<b>0.25</b>	<b>0.21</b>	0.01	30
Similkameen River	8	0.12	0.10	0.09	0.00	65
Aeneas Creek	7	<b>0.47</b>	<b>0.41</b>	<b>0.39</b>	<b>0.05</b>	2
Stapaloop Creek	6	0.17	0.12	0.11	0.01	56
Trail Creek	6	<b>0.22</b>	0.17	<b>0.15</b>	0.01	32
Wanacut Creek	3	<b>0.20</b>	0.14	0.13	0.01	41
Swimpkin Creek	2	<b>0.20</b>	0.13	0.12	0.01	37
Tonasket Creek	1	0.15	0.08	0.07	0.00	71

Tributary average estimated egg-to-fry survival ranged from two to 71%. Locations with an estimate of zero percent survival were strongly skewed towards relatively large fractions of fine sand and silt (Aeneas, Antoine and Tunk Creek) or had relatively high fractions of medium and coarse sand (Bonaparte Creek). With the exception of the samples from Aeneas and Antoine Creek, the proportion of sediment less than 0.125 mm (fine sand) was generally less than 1% of the total sample mass. Of 274 total samples, 36 had a median diameter (D50) of less than approximately 30 mm (Figure F-1) resulting in an estimated 100% egg mortality.

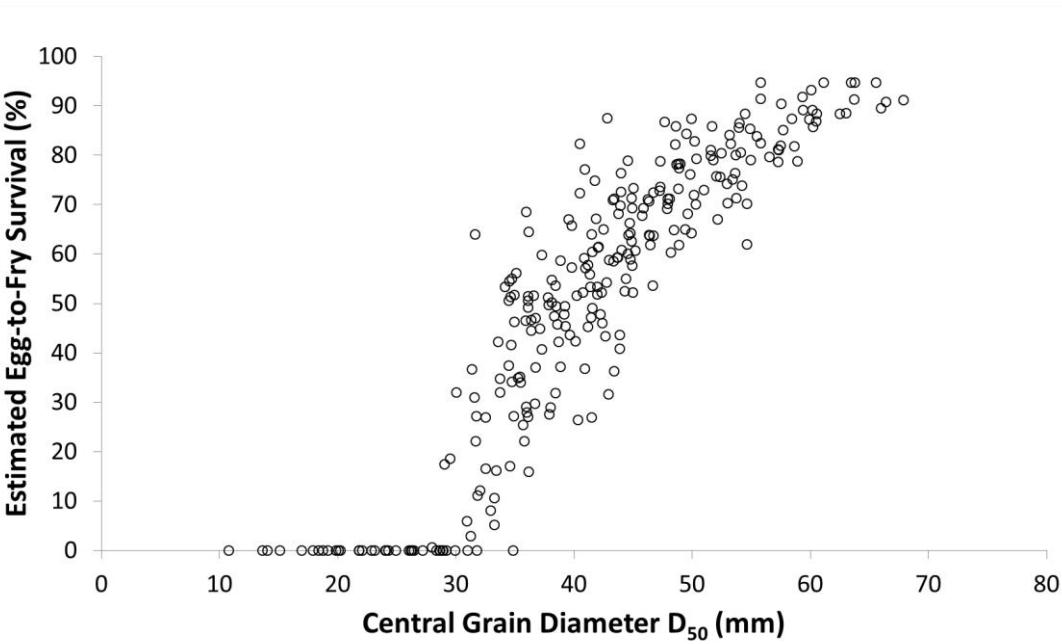


Figure F-1. Estimated egg-to-fry survival and central grain diameter ( $D_{50}$ ). Note that 36 of 274 samples (15%) have an estimated survival of 0%.

Median egg-to-fry survival was approximately 50% in several subwatersheds including Omak, Loup Loup, Salmon, Ninemile and Wanacut Creeks in addition to the mainstem Okanogan and Similkameen Rivers (Figure F-2). Substrate-based survival estimates from Tunk, Bonaparte and Aeneas Creek indicate that substrate conditions may be challenging for incubation and early rearing, though the sample size in Aeneas Creek consists of only one sample to date.

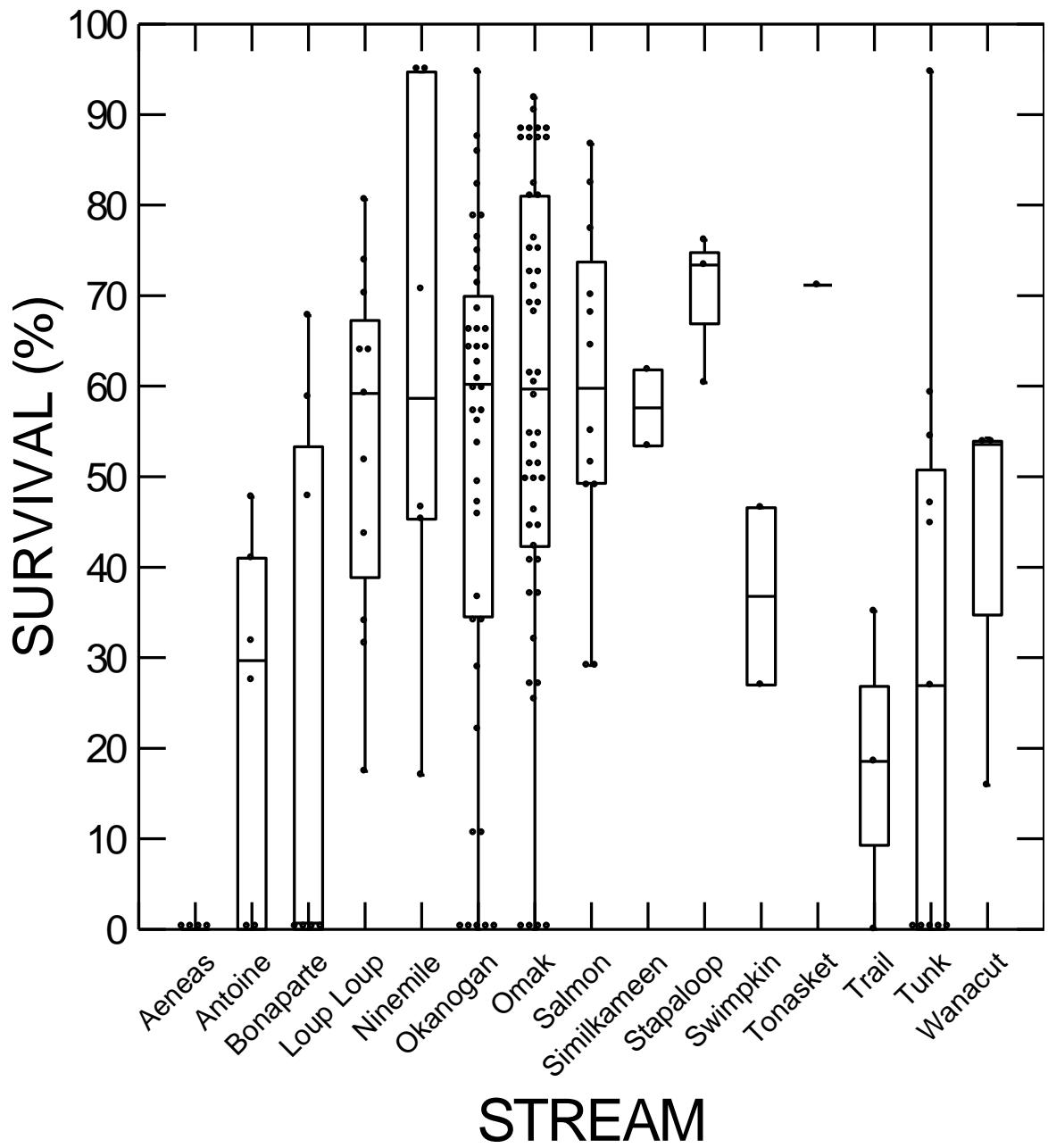


Figure F-2. Estimated egg-to-fry survival by named watershed. Horizontal bars are the median value, upper and lower bound of the boxed are the 25<sup>th</sup> and 75 percentile and whiskers are maximum and minimum values. Individual sample values are displayed as hollow dots.

### Discussion

The relative amount of fine sediment present in spawning substrate plays a fundamental role in determining egg-to-fry survival for many salmonids. Improvements in methodology were made that greatly enhanced the ability to quantify potential effects of sediment on the early life stages of these

fish. Although this sediment study is still in the early phases, the baseline data allows for a characterization of steelhead spawning habitat in tributaries throughout the Okanogan subbasin. Additionally, effects of fine sediment on egg-to-fry survival can be inferred using empirical functions in existing literature.

In most samples from the Okanogan Subbasin taken to date, the relative proportions of “fine” sediment were near, or in excess of, published thresholds throughout a range of size classes (e.g. 12–20% fines by weight < 0.85mm). Previous habitat status and trend monitoring in the Okanogan subbasin indicated that sediment conditions were likely a limiting factor in most tributaries and mainstem reaches of the Okanogan River. Preliminary analyses of data from the newly implemented methods corroborated those findings. The data derived from these methods describe prevailing conditions with greater precision and can be subset for comparison to a greater proportion of published literature.

As previously noted, substrate conditions in 36 of the 274 samples resulted in an estimated survival rate of zero percent. The median grain diameter in these locations was below approximately 30.0 mm and had a D<sub>84</sub> of 33–62mm, which is similar to the optimal spawning substrate size range of summer steelhead. Since sampling was targeted at known spawning locations, it follows that substrate conditions may be limiting recruitment of summer steelhead at early life stages in these locations and in un-sampled locations with similar substrate conditions. Further observations during redd surveys indicate that steelhead in some areas of the Okanogan subbasin are commonly utilizing substrate which is somewhat smaller and more densely laden with fines than published values. This relationship illustrates that assessment of the quality of spawning gravels (and observations of “good” spawning habitat) need to specify what constitutes desirable sediment admixtures in addition to central tendencies of the substrate. Considering that some Okanogan steelhead are building redds in locations with physical indicators that may predispose poor egg survival, a more direct attempt to assess early life stage mortality in select locations may be advisable.

These methods have greatly enhanced the ability for OBMEP to characterize spawning habitat throughout the Okanogan subbasin. In future years, we recommend that this methodology be expanded in the Okanogan mainstem below Zosel Dam and the Similkameen River, which account for approximately one-third of the total steelhead redds on an annual basis as well as increasing the spatial distribution of samples in Salmon Creek.