Okanogan Basin Monitoring and Evaluation Program

2022 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 2022 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 2022, it was estimated that 314 summer steelhead (203 hatchery-origin and 111 natural-origin) spawned in the Okanogan subbasin. The total number of spawners is the lowest on the recent period of record (2005-2023). When specifically looking at natural-origin spawners, 2022 was also the lowest on the period of record. The two previous lowest years occurred in 2017 and 2018, with 115 and 120 natural-origin spawners, respectively. Over the past 18 years of monitoring, the average number of adult steelhead spawners in the Okanogan subbasin was 1,360 (geomean = 1,095). The average number of natural-origin spawning steelhead was 269 (geomean = 234). The number of natural-origin steelhead spawning in the Okanogan River subbasin has a slightly declining trend and remains below the VSP 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 origin (natural- or hatchery-origin), year, survey reach, subwatershed, snowpack and spring discharge patterns.

An estimated 10,223 ± 1,639 (95% CI) natural-origin juvenile steelhead outmigrated from creeks in the Washington State portion of the subbasin in 2022. The majority of these outmigrants were produced in Salmon Creek (8,882 ± 1,148), which represents 87 percent of all sampled tributaries. The total combined number of outmigrants in 2022 produced the second lowest estimate since sampling began in 2013. Each of the ten sampling areas were estimated to have produced fewer outmigrants in 2022 than the previous year, notably the lower section of Omak Creek with only 56 ± 36 outmigrants. The low number of Omak Creek outmigrants represented a ~98% reduction from the 2013-2021 average, largely due to high water temperature based mortality occurring in 2021. Yearling Chinook Salmon *Oncorhynchus tshawytscha* (most likely spring Chinook Salmon) were first observed in small numbers in Okanogan tributaries in 2016 and had increased to a peak total estimated population of 2,352 ± 361 (95% CI) in 2019. Since then, spring Chinook Salmon have maintained a small population within the subbasin with an estimated 628 ± 240 parr in 2021 producing 541 ± 222 outmigrating smolts in 2022. This information will be critical to documenting the success of the experimental reintroduction of spring Chinook Salmon 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 2022 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 2022, peak discharge in the mainstem Okanogan River was both slightly higher and later than the average peak flow. Many

tributaries to the Okanogan River, including Omak, Salmon and Loup Loup Creeks, experienced below average peak flows. The 2022 water year was again punctuated by extended triple-digit heat events in the Okanogan River subbasin that resulted in stream temperatures climbing above 25 degrees Celsius in several tributaries. Weekly average temperature observations in most subwatersheds reached upper quartile values of the period of record. Though above average, these occurrences correlate with a rebound in overall abundance in juvenile salmonids in multiple subwatersheds. This was most noteworthy in Omak Creek below Mission Falls for age-0 juvenile *O. mykiss* when compared to 2021, extreme temperatures likely decreased the instream abundance of *O. mykiss* to only 10% of 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%.

OBMEP staff received the University of Washington based Society for Ecological Restoration Northwest Special Award in 2022 for their work and published article in Fisheries Magazine, entitled: Integrating Ecosystem Models with Long-Term Monitoring to Support Salmon Recovery (Doyle et al. 2022). This award was dedicated to any organization or individual that has demonstrated their commitment to "reconnecting to restoration through the use of innovative tools and techniques in restoration planning or practice in the Cascadia Bioregion." This paper and its applications were presented at the National AFS meeting in Spokane, WA in 2022 along with five other talks ranging from fish population monitoring research to novel methodological approaches in conducting fish and habitat field studies. OBMEP staff were also directly involved in the Columbia Basin Tributary Habitat RM&E Strategy, designed to provide guidance to tributary habitat research, monitoring and evaluation programs "to more consistently document and assess the outcomes and benefits of tributary habitat investments to the Columbia River above Bonneville dam."

Monitoring staff continued to find creative solutions to obstacles, worked 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 Okanogan Basin Monitoring and Evaluation Program will continue to deliver practical status and trend monitoring data for use in more comprehensive broad-scale analyses.

Acknowledgements

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The Okanagan Nation Alliance (ONA) fisheries department would like to acknowledge the Osoyoos Indian Band (OIB), the Penticton Indian Band (PIB), the Townships of Osoyoos, Oliver and Okanagan Falls, the City of Penticton, the Baptiste families (of OIB & PIB), the Gabriel family (of PIB), the Lezard family (of PIB), the E. Kruger family (of PIB), the Thompson family (of OK Falls), The Nature Trust of BC, Bobtail Ranch, and the South Okanagan Rehabilitation Center for Owls. Acknowledgements also go to C. Cassidy, B. Kruger, J. Squakin, S. Squakin, D.Tom, P. Snow, C. Mathieu, C. Welch, K. Alex, S. King, N. Carlile, S. Macleod, A.Clarke, T. Gleboff, L. George, C. Louie and the OIB Fisheries department, T. Jack, T. Shuter, T. Marchand and the PIB Natural Resources department and S. Macleod and the Ntityix Development Corporation for providing technical assistance throughout the 2022 study. Special acknowledgements to R. Armstrong for nsyilxcn[1].

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Okanagan Nation Alliance Disclaimer: Nothing in this report shall be construed as abrogating or derogating from the Aboriginal title or rights of the Syilx Okanagan Nation or limiting or quantifying infringements to the Syilx Okanagan Nation’s Aboriginal title and rights.

[1] 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).

Contents

1.0 Introduction

The Okanogan Basin Monitoring and Evaluation Program (OBMEP) conducted status and trend monitoring from 2004 through 2022 to collect and analyze fisheries data corresponding to adult and juvenile abundance and spatial and temporal distribution throughout the Okanogan[2] 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 Okanagan subbasin, the Colville Confederated Tribes (CCT) and the Okanagan Nation Alliance (ONA) began coordinating on this project for the northern (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.

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^2, 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 gives 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 *O. mykiss*, a small number of spring Chinook Salmon from an experimental reintroduction, increasing observations of Coho Salmon *Oncorhynchus kisutch* and very rare transient use from 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.

[2] Spelled ‘Okanogan’ in the U.S. and ‘Okanagan’ in Canada; used interchangeably in this document.

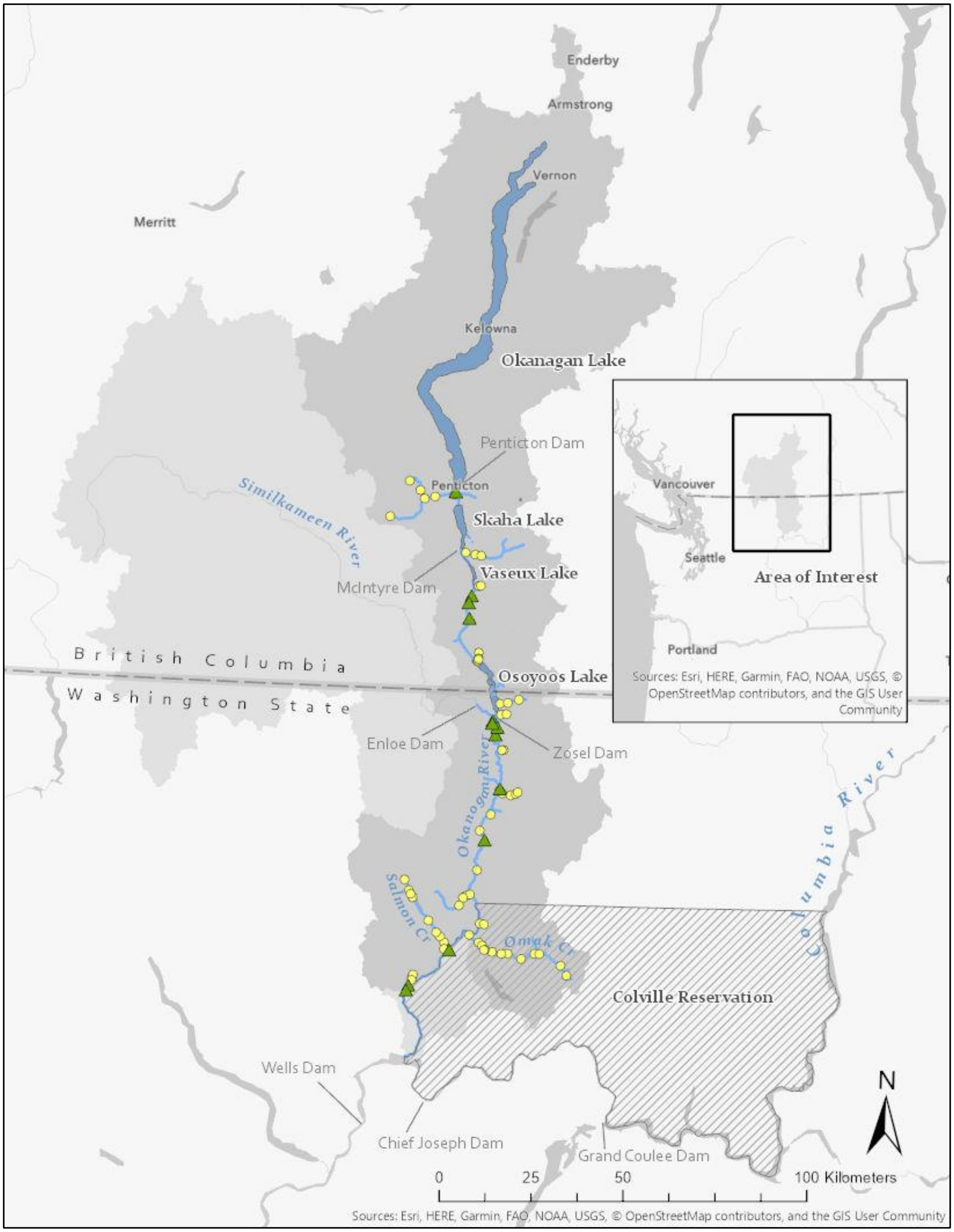


Figure 1. Study area, the Okanogan subbasin in north-central Washington State and southern British Columbia. Markers signify OBMEP monitoring sites: yellow markers represent electrofishing sites, green triangles represent mainstem snorkel sites, stream segments highlighted in blue represent areas likely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

Within the Washington State portion of the Okanogan subbasin, the vast majority of land along the river is under private ownership, and landowner cooperation is essential 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, sẁiẁs (Osoyoos), akspaqmix (Vaseux), t̓uʔcin (Skaha) and kłusxnitkʷ (Okanagan) Lakes. The outlet dam at akspaqmix (Vaseux Lake), known as the McIntyre Dam, was refitted for fish passage in 2009. In 2014, the outlet dam at t̓ucin (Skaha Lake) underwent improvements to further enhance fish passage. Until 2022, the upstream impediment for anadromous salmon species was the Okanagan Lake Dam, at the outlet of the kłusxnitkʷ (Okanagan Lake) in Penticton. Between 2019 and 2022, the ONA manually operated the fish ladder at Okanagan Lake Dam, providing passage to anadromous fall spawners. Anadromous salmonids have previously occupied the entire sq̓awsitkʷ (Okanagan River) system (Ernst and Vedan 2000).

Goals and Objectives

Goal:

To monitor the status and trend of listed salmonids in the Okanogan Subbasin and salmonid habitat in the Okanogan/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 Okanogan River subbasin to evaluate the Upper Columbia River summer steelhead population in support of Bonneville Power Administration (BPA) Fish and Wildlife management sub-strategies[1] with the following objectives:

1. Assess the status and trend of Okanogan 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 Okanogan 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[2] 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 Okanogan (2025, 2035) and Methow (2030, 2040) subbasins.

[1] Fish Population RM&E https://www.cbfish.org/ProgramStrategy.mvc/Summary/1
[2] 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 publicly 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
Method: Instream PIT Tag Detection Array (ID:1076)
https://www.monitoringresources.org/Document/Method/Details/1076
Method: Weirs (ID:145)
https://www.monitoringresources.org/Document/Method/Details/145
Method: Natural Spawner Abundance 2 (ID:6927)
https://www.monitoringresources.org/Document/Method/Details/6927
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 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 2022, 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. Antoine Creek was comprehensively sampled for the first time in 2021 and again in 2022. The remaining two creeks (Johnson and Wildhorse Spring Creeks) were not sampled due to lack of access or time. Five subwatersheds were also sampled in the British Columbia side of the subbasin, including akskʷəkʷant (Inkaneep), nʕax̌ʷlqaxʷiya (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 2022. 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 (ID:3973)
https://www.monitoringresources.org/Document/Method/Details/3973

The data collection protocols and habitat modeling methodology implemented by OBMEP are 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 the US, 67 in Canada) over the four-year data collection cycle with 55 reaches (8 annual and 47 rotating panel reaches) 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, Tribal Nations, First Nations, 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 capacity 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 2022, it was estimated that 314 summer steelhead (203 hatchery-origin and 111 natural-origin) spawned in the Okanogan subbasin in 2022. The total number of spawners is the lowest on the recent period of record (2005-2023). When specifically looking at natural-origin spawners, 2022 was also the lowest on the period of record. The two previous lowest years occurred in 2017 and 2018, with 115 and 120 natural-origin spawners, respectively. Over the past 18 years of monitoring, the average number of adult steelhead spawners in the Okanogan subbasin was 1,360 (geomean = 1,095). The average number of natural-origin spawning steelhead was 269 (geomean = 234). The number of natural-origin steelhead spawning in the Okanogan River subbasin has a fairly level, but slightly declining trend, which remains below the minimum abundance threshold for natural-origin spawners (500 in the US portion of the subbasin) (Figure 2). Steelhead returns in 2022 continued a similar low abundance trend seen recent years.

Table 1. Estimated summer steelhead spawner abundance in the Okanogan subbasin, 2005–2022.

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
2022	314	203	111	234
Average	1,360	1,096	269	273

The proportion of hatchery origin spawners (pHOS) from 2005 through 2013 averaged 0.85, but the average pHOS decreased to 0.71 from 2014 through 2022. The lowest recorded pHOS was 0.31 in 2020. The abundance of hatchery steelhead has been variable, ranging from a low of 203 in 2022 up to 2,768 in 2010.

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 influenced in part by stream discharge, which in turn is 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 has improved with the installation of a PIT tag antenna array (OKC) above sẁiẁs (Osoyoos Lake) and representative marking sessions 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 ten years (2013–2022); however, average pHOS was much lower in British Columbia (0.34) than Washington State (0.74) during that timeframe.

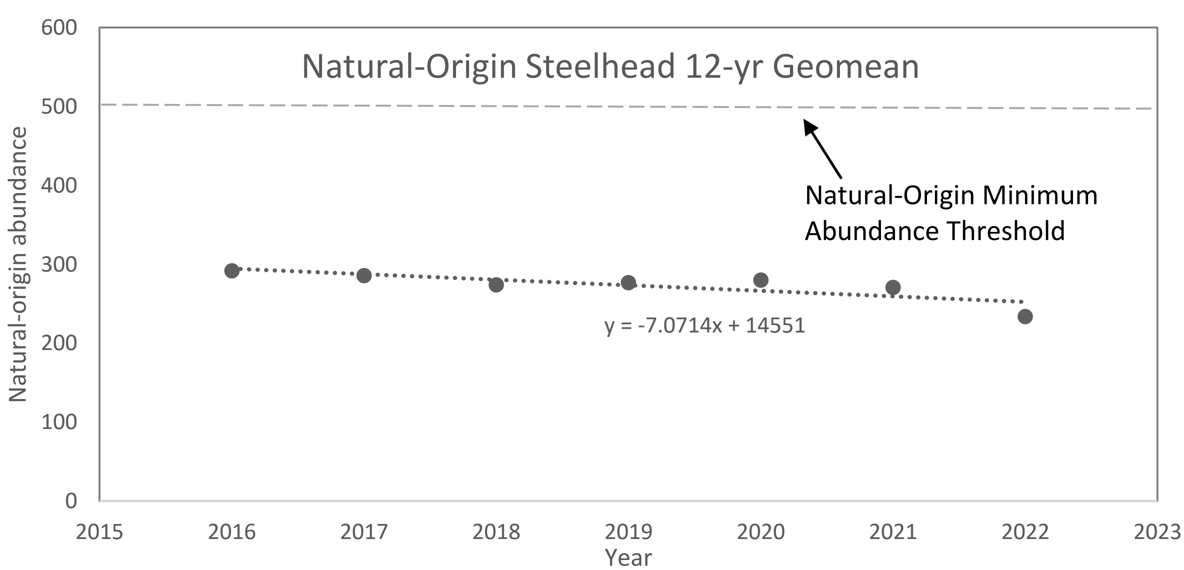


Figure 2. Twelve-year geomean for natural-origin summer steelhead spawners in the Okanogan River subbasin showing the trend (dotted line) and the ESA-recovery objective for the natural-origin minimum abundance thresholds (dashed line).

Juvenile Salmonid Monitoring

Instream Abundance (Electrofishing Method)

In June of 2021, weekly average water 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 (Table 2 and 3). In 2022, age-0 juvenile steelhead returned to numbers similar to what had been documented in the previous four years (2017-2020), although the number of age-1+ fish remained extremely low due to the previous year's cohort recruitment failure (Refer to appendix B, Figure B-15). Beginning in 2016 or 2017, most subwatersheds in the Washington portion of the subbasin began a declining trend in the number of juvenile *O. mykiss* (Figure B-15 – B17).

Four streams in the British Columbia portion of the subbasin akskʷəkʷant (Inkaneep), akłxʷuminaʔ (Shingle), Shatford and Shuttleworth Creeks were sampled in 2016 through 2022 using this method. In addition, nʕax̌ʷlqaxʷiya (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 10,223 ± 1,639 (95% CI) juvenile steelhead outmigrated from nine defined sample areas (Table 4). Each of these sampled tributaries is estimated to have produced fewer outmigrants in 2022 than the previous year. This resulted in the second fewest total estimated outmigrants since current sampling practices began in 2013. Notably the lower section of Omak Creek, which typically ranks as the second leading contributor in the subbasin, produced 56 ± 36 outmigrants. Salmon Creek's estimated production of 8,882 ± 1,148 continues to be the leading contributor to the outmigrant population from the Okanogan subbasin, accounting for 87% of all estimated production of all sampled tributaries from fall 2021 through spring 2022, by far the highest proportion on record. Production from outside the sampling areas, including the mainstem Okanogan River or Similkameen River was not factored into those estimates; therefore, the sum is not a subbasin-wide 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, including discussion about lower Omak Creek production in 2022.

Table 2. Instream population estimates of young-of-year natural-origin *O. mykiss* (±95%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	2018	2019	2020	2021	2022
Salmon Cr	32,646 ± 3,982	36,667 ± 3,378	51,691 ± 6,346	60,414 ± 4,707	25,334 ± 4,952
Lower Omak Cr	9,360 ± 2,147	19,717 ± 1,797	10,818 ± 1,555	921 ± 396	7,907 ± 691
Upper Omak Cr	30,212 ± 6,583	17,905 ± 2,018	23,226 ± 5,658	5,539 ± 1,811	15,946 ± 2,361
Lower Loup Loup Cr	2,014 ± 405	4,979 ± 335	4,839 ± 397	6,435 ± 495	5,150 ± 475
Upper Loup Loup Cr	Not sampled	Not sampled	Not sampled	3,484 ± 1,168	5,282 ± 1,383
Ninemile Cr	3,992 ± 500	11,244 ± 1,150	5,261 ± 1,081	17,109 ± 2,403	3,725 ± 580
Bonaparte Cr	662 ± 108	3,057 ± 1,538	670 ± 124	3,185 ± 463	486 ± 88
Tonasket Cr	1,862 ± 391	2,496 ± 321	3,567 ± 465	1,817 ± 250	3,106 ± 427
Tunk Cr	1,267 ± 167	3,067 ± 229	2,692 ± 217	6 ± 0	1,595 ± 158
Aeneas Cr	728 ± 415	111 ± 18	406 ± 92	488 ± 82	3 ± 0
Wanacut Cr	2,300 ± 344	1,644 ± 351	1,896 ± 230	0 ± 0	0 ± 0
Johnson Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not Sampled
Lower Antoine Cr	Not sampled	Not sampled	Not sampled	493 ± 69	584 ± 96
Upper Antoine Cr	Not sampled	Not sampled	Not sampled	16,152 ± 6,115	6,816 ± 3,940
Wildhorse Sp Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not Sampled
Inkaneep Cr	30,936 ± 6,139	19,856 ± 2,720	14,450 ± 2,810	NA	5,299 ± 1,526
Vaseux Cr	3,543 ± 1,351	8,630 ± 4,274	16,998 ± 6,514	10,312 ± 3,291	4,752 ± 2,223
Shuttleworth Cr	18,239 ± 3,703	17,459 ± 1,786	19,286 ± 2,247	8,796 ± 8,895	610 ± 192
Lower Shingle Cr	2,399 ± 1,286	846 ± 655	686 ± 108	1,783 ± 1,629	2,578 ± 2,427
Upper Shingle Cr	8,086 ± 2,748	33,297 ± 10,368	11,560 ± 1,745	NA	801 ± 624
Shatford Cr	14,419 ± 3,427	53,899 ± 11,865	33,625 ± 5,206	21,953 ± 5,490	32,019 ± 9,032

Table 3. Instream population estimates of age-1+ natural-origin *O. mykiss* (±95%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	2018	2019	2020	2021	2022
Salmon Cr	28,203 ± 2,058	27,284 ± 1,603	31,715 ± 1,979	32,827 ± 1,938	32,221 ± 2,222
Lower Omak Cr	3,101 ± 1,335	4,163 ± 325	5,284 ± 641	224 ± 50	281 ± 47
Upper Omak Cr	13,330 ± 1,839	11,300 ± 917	17,040 ± 2,217	7,675 ± 1,236	8,186 ± 1,052
Lower Loup Loup Cr	1,214 ± 185	556 ± 86	1,681 ± 86	1,223 ± 55	1,604 ± 152
Upper Loup Loup Cr	Not sampled	Not sampled	Not sampled	8,229 ± 705	7,475 ± 634
Ninemile Cr	3,519 ± 361	4,524 ± 367	2,847 ± 153	1,814 ± 201	5,709 ± 372
Bonaparte Cr	348 ± 36	423 ± 60	1,279 ± 87	538 ± 115	635 ± 53
Tonasket Cr	3,652 ± 338	340 ± 43	596 ± 62	144 ± 0	589 ± 34
Tunk Cr	109 ± 23	80 ± 15	318 ± 45	61 ± 24	68 ± 9
Aeneas Cr	105 ± 11	36 ± 5	24 ± 0	13 ± 0	14 ± 4
Wanacut Cr	1,762 ± 62	1,151 ± 61	609 ± 46	659 ± 32	70 ± 28
Johnson Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Lower Antoine Cr	Not sampled	Not sampled	Not sampled	298 ± 123	528 ± 76
Upper Antoine Cr	Not sampled	Not sampled	Not sampled	12,930 ± 1,281	16,653 ± 2,062
Wildhorse Sp Cr	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
Inkaneep Cr	149 ± 56	4,351 ± 452	3,333 ± 311	1,211 ± 319	2,071 ± 330
Vaseux Cr	3,588 ± 1,405	3,424 ± 978	6,374 ± 2,693	3,110 ± 1,120	3,770 ± 1,156
Shuttleworth Cr	3,696 ± 776	10,830 ± 981	4,906 ± 828	1,261 ± 404	2,277 ± 505
Lower Shingle Cr	8,136 ± 1,125	6,284 ± 3,277	5,679 ± 715	2,189 ± 813	1,048 ± 217
Upper Shingle Cr	5,071 ± 498	7,169 ± 1,517	5,930 ± 528	1,391 ± 787	868 ± 390
Shatford Cr	4,182 ± 664	3,718 ± 839	8,460 ± 916	3,770 ± 3,583	3,857 ± 1,339

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	2022
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	8,882 ± 1,148
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	56 ± 36
Upper Omak Cr				20,954 ± 18,841	2,235 ± 1,669	236 ± 208	455 ± 243	NA	36 ± 70
Loup Loup Cr		1,193 ± 255	600 ± 112	1,984 ± 433	980 ± 432	501 ± 125	323 ± 84	946 ± 125	685 ± 102
Ninemile Cr		0	655 ± 250	836 ± 387	1,918 ± 444	2,382 ± 3,771	511 ± 215	942 ± 235	339 ± 164
Bonaparte Cr	201 ± 71	112 ± 0	195 ± 62	767 ± 151	211 ± 103	174 ± 65	224 ± 78	671 ± 132	374 ± 113
Tonasket Cr		24 ± 0	2 ± 2	30 ± 26	441 ± 129	1,178 ± 296	159 ± 64	343 ± 98	12 ± 23
Tunk Cr		131 ± 119	NA	NA	0	NA	49 ± 23	264 ± 52	14 ± 17
Aeneas Cr		198 ± 103	32 ± 32	54 ± 16	78 ± 24	80 ± 18	18 ± 11	14 ± 9	7 ± 6
Wanacut Cr		0	0	0	1,610 ± 843	818 ± 231	270 ± 103	110 ± 59	39 ± 37
Sum[1]	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	10,223 ± 1,639

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

[1]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 Okanagan 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 27 fish/ha across survey years. Detailed results showing general trends in observed abundance from annual monitoring sites are presented in Appendix C.

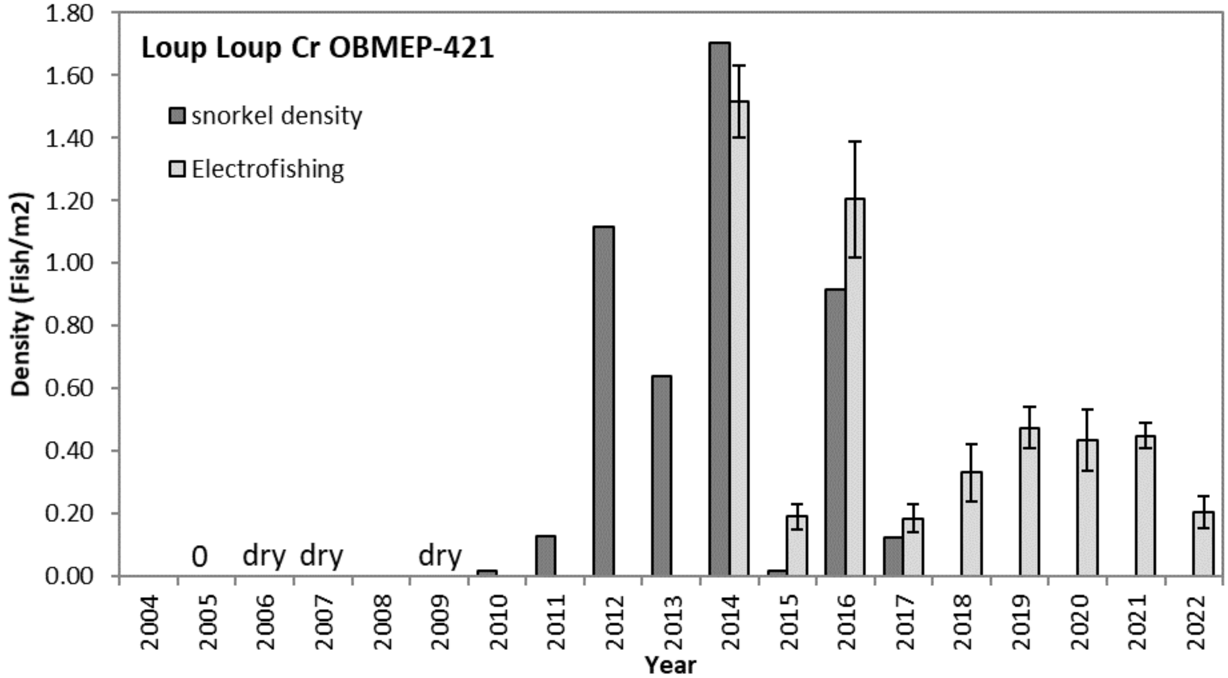
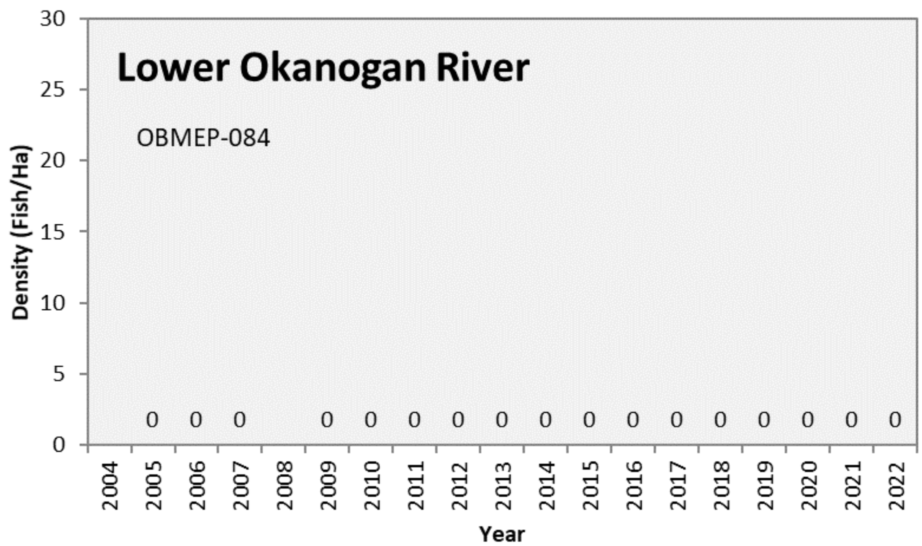


Figure 3. Observed densities of juvenile (< 300 mm) *O. mykiss* in Loup Loup Creek.



Year	# Obs.
2004	0
2005	0
2006	0
2007	0
2008	NA
2009	0
2010	0
2011	0
2012	0
2013	0
2014	0
2015	0
2016	0
2017	0
2018	0
2019	0
2020	0
2021	0
2022	0

Figure 4. Observed densities of juvenile (< 300 mm) *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 reflect 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[1]
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

[1]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 (2005–2022) 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 Beitinger et al. 2000), high water temperature represents a limiting factor for rearing summer steelhead fry and parr in the Okanogan River. Overall, temperature observations in 2022 were above 'normal' (within the 14 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.

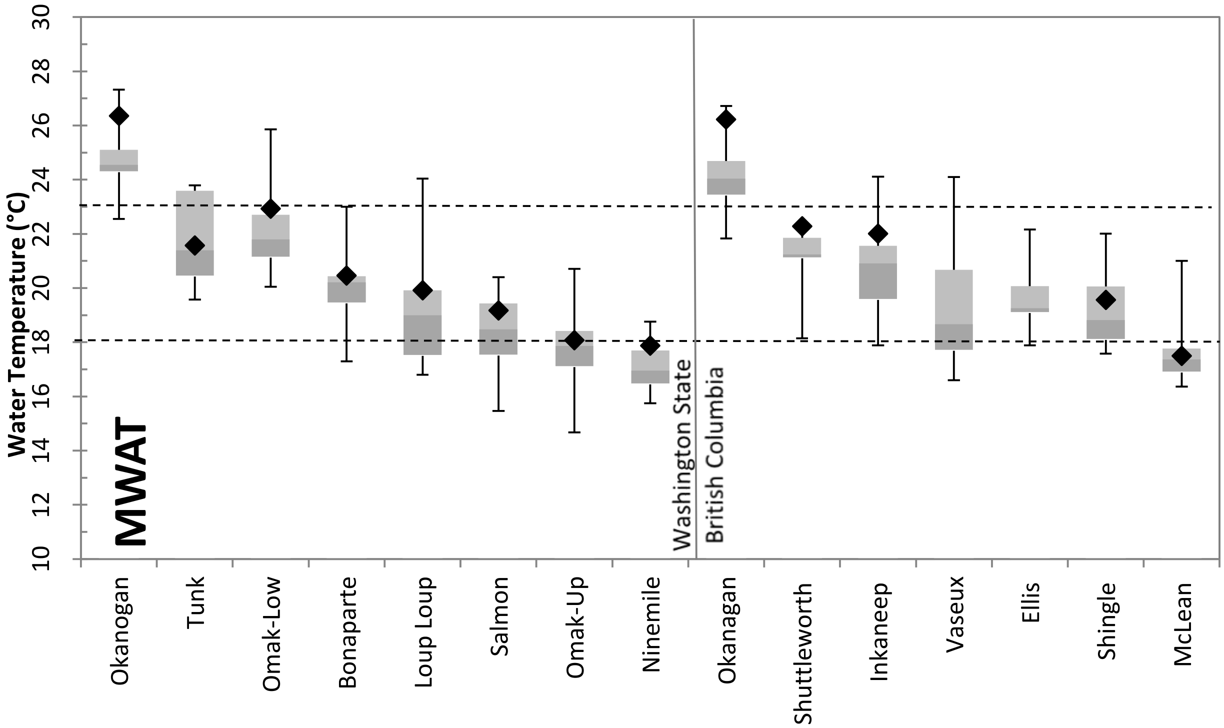


Figure 5. Maximum weekly average water temperatures (MWAT) in the Okanogan subbasin from 2005–2022. Black diamonds are 2022 MWAT values. Boxes represent 50–75th (Q3, light grey) and 25–50th (Q2, dark grey) quartiles of the MWAT distribution during 2005–2022 while whiskers display the maximum and minimum 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 93 years. Historic average monthly discharge at this location is displayed by averaging two decades per hydrograph (Figure 6) and highlights the current water year 2022. In the 2022 water year, a rare fall flood event occurred causing the highest annual peak discharge ever recorded outside the normal high flow months of April to June for the 93-year period of record.

All precipitation that caused the Similkameen to flood originated in the Cascade Mountains of southern British Columbia and northern Washington, while none of it fell in the Okanogan River subbasin. Below-normal precipitation and snowpack in the United States portion of the Okanogan River subbasin resulted in a reduced spring 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 2014-2022. Maximum daily mean flows for these tributaries were all below the ‘normal’ (9 years of data) range, as shown in Figure 7. Base flows were also below the ‘normal’ range (Figure 8). Additional trends in water quantity are presented in Appendix E.

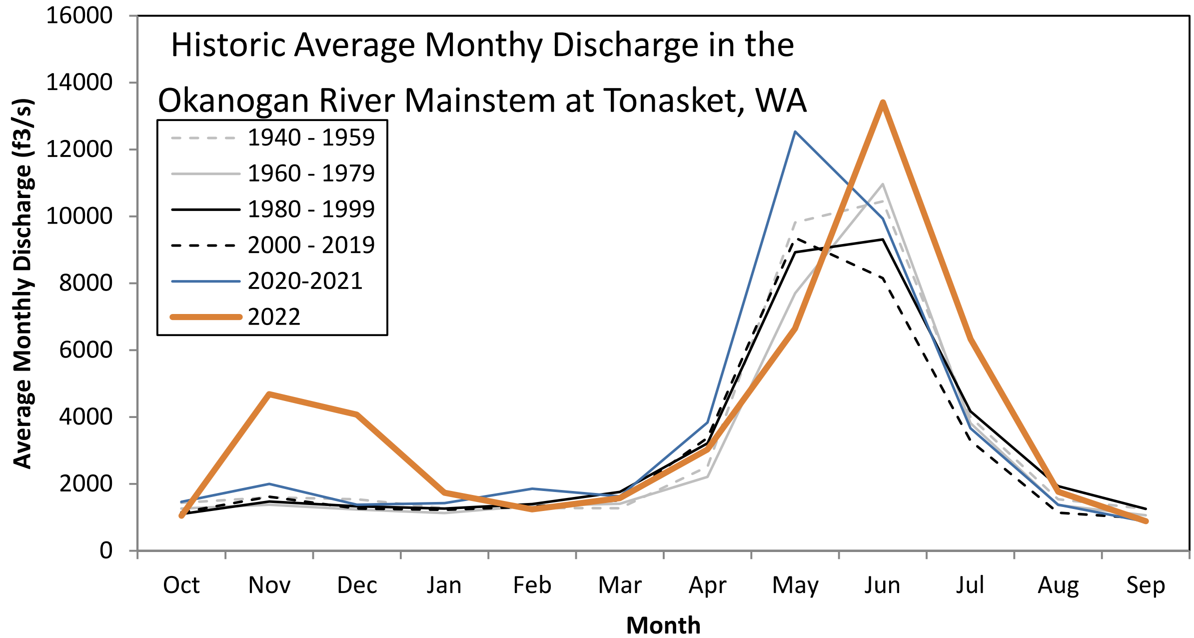


Figure 6. Average monthly discharge of the Okanogan River at Tonasket, WA (USGS Station 12445000, Okanogan River near Tonasket, WA).

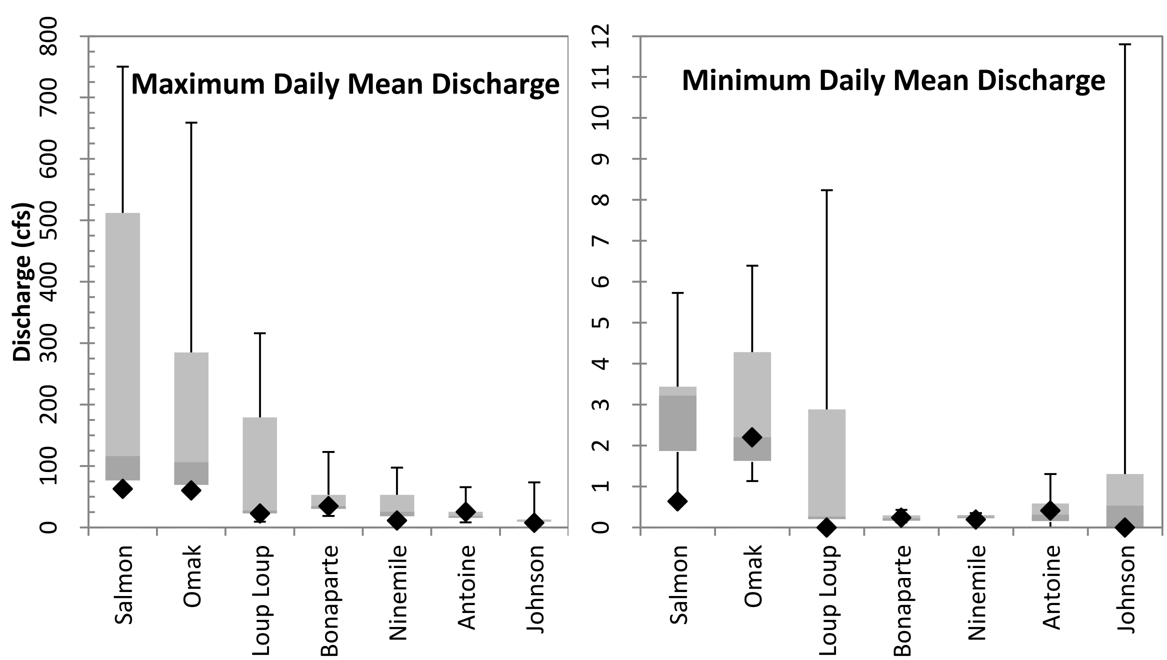


Figure 7. Maximum and Minimum Daily Mean Discharge of seven tributaries to the Okanogan River, or the mean discharge for the highest peak and lowest flow day of the year. Black diamonds are 2022 MDMD values. Boxes represent 50–75th (Q3, light grey) and 25–50th (Q2, dark grey) quartiles of the MDMD distribution during 2014–2022 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, First Nations, 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 representative marking of returning adults at Priest Rapids Dam (Project # 2010-034-00) has allowed managers additional means to estimate abundance on years with poor water visibility, to validate redd survey efficiency, and to 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 Creeks) 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 Creeks) 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 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 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 are 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 protection, restoration and water managers. 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/

OBMEP staff received the University of Washington based Society for Ecological Restoration Northwest Special Award in 2022 for their work and published article in Fisheries Magazine, entitled: Integrating Ecosystem Models with Long-Term Monitoring to Support Salmon Recovery (Doyle et al. 2022). This award was dedicated to any organization or individual that has demonstrated their commitment to "reconnecting to restoration through the use of innovative tools and techniques in restoration planning or practice in the Cascadia Bioregion." This paper and its applications were presented at the National AFS meeting in Spokane, WA in 2022 along with five other talks ranging from fish population monitoring research to novel methodological approaches in conducting fish and habitat field studies. OBMEP staff were also directly involved in the Columbia Basin Tributary Habitat RM&E Strategy, designed to provide guidance to tributary habitat research, monitoring and evaluation programs "to more consistently document and assess the outcomes and benefits of tributary habitat investments to the Columbia River above Bonneville dam."

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 restoration programs 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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Zydlewski, G., C. Winter, E. McClanahan, J. Johnson, and J. Zydlewski. 2003. Evaluation of fish movements, migration patterns, and population abundance with stream width PIT tag interrogation systems. Bonneville Power Administration, Report 00005464, Portland, Oregon Appendix A. Adult Steelhead Abundance and Distribution

7.0 Appendices

Appendix A. Adult Steelhead Abundance and Distribution

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

OBMEP 2023. 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.okanoganmonitoring.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, Inkaneep and 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 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 which allowed for migrating steelhead to access habitat as far upstream as the kłusxnitkʷ (Okanagan Lake) outlet dam at Penticton. This allowed steelhead access to at least four more major tributaries for spawning and rearing including Shuttleworth, McLean, snpiṅyaʔtkʷ (Ellis) and akłxʷuminaʔ (Shingle) Creek systems. Fish passage trials are currently underway at kłusxnitkʷ (Okanagan Lake) outlet.

From 2012-2014, the only enumeration method used was a Passive Integrated Transponder (PIT) antenna array in the sq̓awsitkʷ (Okanagan River) mainstem (OKC) upstream of sw̓iw̓s (Osoyoos Lake) at Vertical Drop Structure (VDS) 3. In 2015, three more permanent PIT arrays were also installed in akskʷəkʷant (Inkaneep) (OKI), akłxʷminaʔ (Shingle) (OKS) and Shuttleworth Creeks (OKW). An additional PIT array was installed in nʕax̌ʷlqaxʷiya (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. In 2022, a PIT array was installed at Okanagan (Lake outlet) Dam fishway (OKD) in Penticton, B.C.

Results

For the Canadian portion of the Okanagan subbasin, steelhead spawning estimates are based on expanded PIT tag detections on the sq̓awsitkʷ (Okanagan River) at VDS 3 (OKC), in the Penticton Channel (OKP) and major tributaries to the Okanagan. In all years except 2021, a higher proportion of wild steelhead detected at Zosel (Osoyoos Lake outlet) Dam continued up the sq̓awsitkʷ (Okanagan River) upriver from sw̓iw̓s (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 – 2022, 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. Representative PIT tagging efforts have been conducted at Priest Rapids Dam (PRD) on the Columbia River, since 2011 (Katy Shelby, 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 0.107. Within the entire Canadian Okanagan, only one tagged natural-origin steelhead from the mark group was detected on site OKC, located just above Lake Osoyoos. One additional tag, not from the representitively sampled PRD group was detected on OKV in nʕax̌ʷlqaxʷiya (Vaseux Creek), (Table 7). That tag was not expanded, but at least represented a single hatchery steelhead. In the interest of best describing total spawning distribution of steelhead based on a very small sample size, we added this fish to that respective creek segments (not expanding those tags). Any fish detected on OKC or in other years in the Penticton Channel, likely spawned in the mainstem sq̓awsitkʷ (Okanagan River), or potentially in another small stream that did not have a PIT antenna in operation, although would be considered more unusual. 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 akɬxʷuminaʔ (Shingle) Creeks. The total spawning estimate in the British Columbia portion of the Okanagan subbasin for 2022 was 9 natural-origin and one hatchery steelhead (Table 8). The average number of steelhead spawning upstream of Lake Osoyoos over the last nine years (2013-2022) was 21 natural-origin and 11 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 2022 steelhead detected on PIT tag sites in British Columbia.

Location	Status	Tag Group		
akskʷəkʷant (Inkaneep Creek)		PRD	Other	Total
	Natural-Origin	0	0	0
	Hatchery	0	0	0
	Total	0	0	0
nʕax̌ʷlqaxʷiya (Vaseux Creek)		PRD	Other	Total
	Natural-Origin	0	0	0
	Hatchery	0	1	1
	Total	0	1	1
Shuttleworth Cr		PRD	Other	Total
	Natural-Origin	0	0	0
	Hatchery	0	0	0
	Total	0	0	0
akłxʷminaʔ (Shingle Creek)		PRD	Other	Total
	Natural-Origin	0	0	0
	Hatchery	0	0	0
	Total	0	0	0
Pentincton Channel		PRD	Other	Total
	Natural-Origin	0	0	0
	Hatchery	0	0	0
	Total	0	0	0
OKC Only		PRD	Other	Total
	Natural-Origin	1	0	1
	Hatchery	0	0	0
	Total	1	0	1

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	2022	Avg.
akskʷəkʷant (Inkaneep Creek)	Natural-Origin			1	0	0		2	0	0	0	0
akskʷəkʷant (Inkaneep Creek)	Hatchery			6	1	5		0	0	0	0	2
akskʷəkʷant (Inkaneep Creek)	Total			7	1	5		2	0	0	0	2
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
nʕax̌ʷlqaxʷiya (Vaseux Creek)	Natural-Origin						9	9	19	1	0	8
nʕax̌ʷlqaxʷiya (Vaseux Creek)	Hatchery						0	9	5	7	1	4
nʕax̌ʷlqaxʷiya (Vaseux Creek)	Total						9	18	24	8	1	10
akɬxʷminaʔ (Shingle Creek)	Natural-Origin			0	0	0	0	0	0	0	0	0
akɬxʷminaʔ (Shingle Creek)	Hatchery			0	0	0	0	0	0	0	0	0
akɬxʷminaʔ (Shingle Creek)	Total			0	0	0	0	0	0	0	0	0
Mainstem or Other	Natural-Origin	22	23	64	15	10	0	23	5	0	9	17
Mainstem or Other	Hatchery	2	16	20	14	5	0	14	0	2	0	4
Mainstem or Other	Total	24	39	84	29	15	0	37	5	2	9	24
Subtotal BC	Natural-Origin	22	23	65	15	10	9	34	24	1	9	21
Subtotal BC	Hatchery	2	16	26	15	10	0	23	5	9	1	11
Subtotal BC	Total	24	39	91	30	20	9	57	29	10	10	32

Conclusions

The removal of barriers in the Canadian portion of the Okanagan subbasin allows steelhead and other salmonids access to 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, two in 2021 and none in 2022. 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 nʕax̌ʷlqaxʷiya (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 2022 compared with long-term averages.

Category	Location/HUC	2022 natural-origin spawner abundance	*Average # of natural-origin spawners 2005–2021*	2022 hatchery spawner abundance	*Average # of hatchery spawners 2005–2021*
WA Mainstem	Okanogan-Davis Canyon	0	*0*	0	*0*
WA Mainstem	Okanogan-Talant Creek	0	*1*	0	*10*
WA Mainstem	Okanogan-Swipkin Canyon	0	*5*	0	*44*
WA Mainstem	Okanogan-Alkali Lake	0	*3*	0	*25*
WA Mainstem	Okanogan-Whitestone Coulee	0	*6*	0	*54*
WA Mainstem	Okanogan-Mosquito Creek	0	*1*	0	*13*
WA Mainstem	Okanogan-Haynes Creek South	0	*35*	47	*310*
WA Mainstem	Similkameen River	0	*22*	0	*185*
WA Tributary	Loup Loup Creek	0	*10*	14	*33*
WA Tributary	Salmon Creek	18	*36*	9	*97*
WA Tributary	Omak Creek	19	*68*	53	*156*
WA Tributary	Wanacut Creek	0	*0*	2	*2*
WA Tributary	Johnson Creek	0	*5*	2	*17*
WA Tributary	Tunk Creek	19	*10*	1	*30*
WA Tributary	Aeneas Creek	0	*0*	0	*3*
WA Tributary	Bonaparte Creek	9	*27*	37	*55*
WA Tributary	Antoine Creek	0	*6*	0	*10*
WA Tributary	Wild Horse Spring Creek	9	*7*	0	*34*
WA Tributary	Tonasket Creek	19	*8*	9	*22*
WA Tributary	Ninemile Creek	9	*7*	28	*15*
Area	Washington State Mainstem	**0**	**73**	**47**	**641**
Area	Washington State Tributaries	**102**	**183**	**155**	**474**
Area	British Columbia	**9**	**23**	**1**	**12**

[a] Average from British Columbia only contain data from 2013-on.

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

Spawning	PRD Tag Rate*	
Year	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
2022	0.1070	0.1070

*Data provided by WDFW (Katy Shelby, 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.

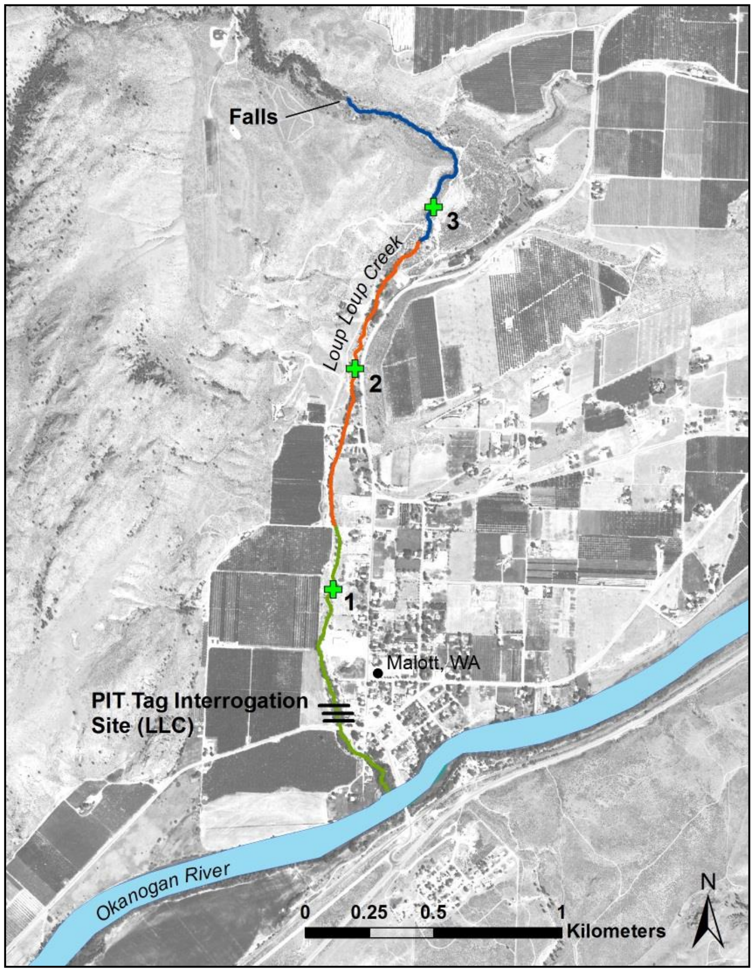


Figure B-1. Loup Loup Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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. A third interrogation site (SAD) was installed upstream of the diversion in 2022 to assess adult passage, as well as enumerating downstream-migrating juveniles above the diversion. Located approximately 9 rkm from the confluence, it consists of one row with two 10 foot HDPE antennas.

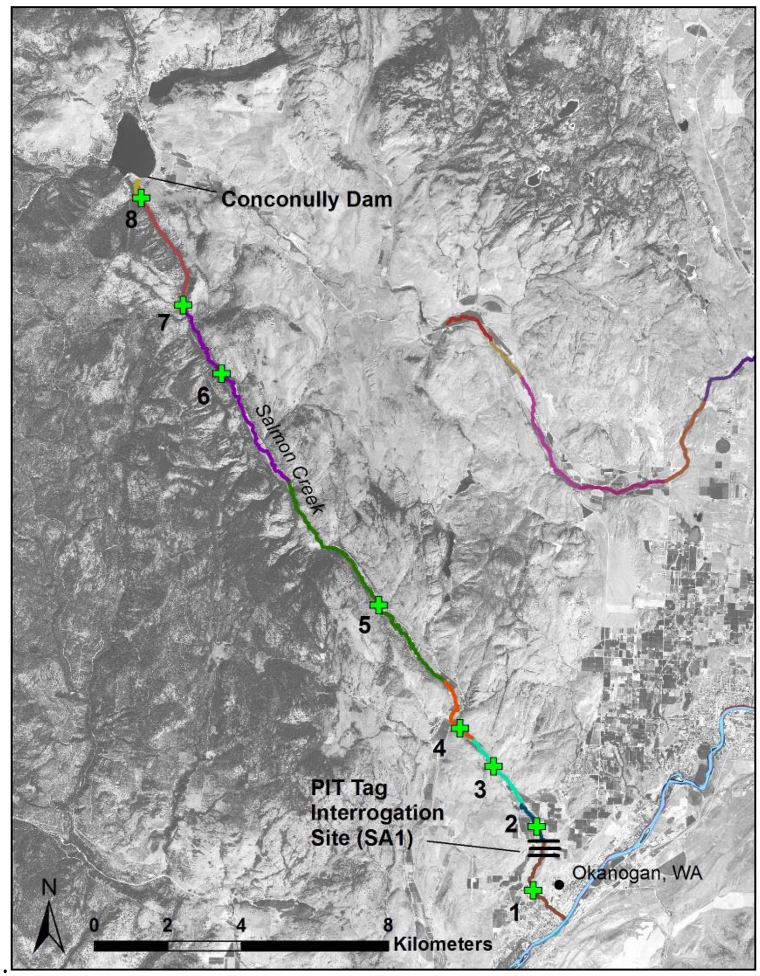


Figure B-2. Salmon Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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 antennas at various discharge rates. Two additional PIT tag interrogation sites are also operated below (OBF) and above (OMF) Mission Falls to monitor passage rates.

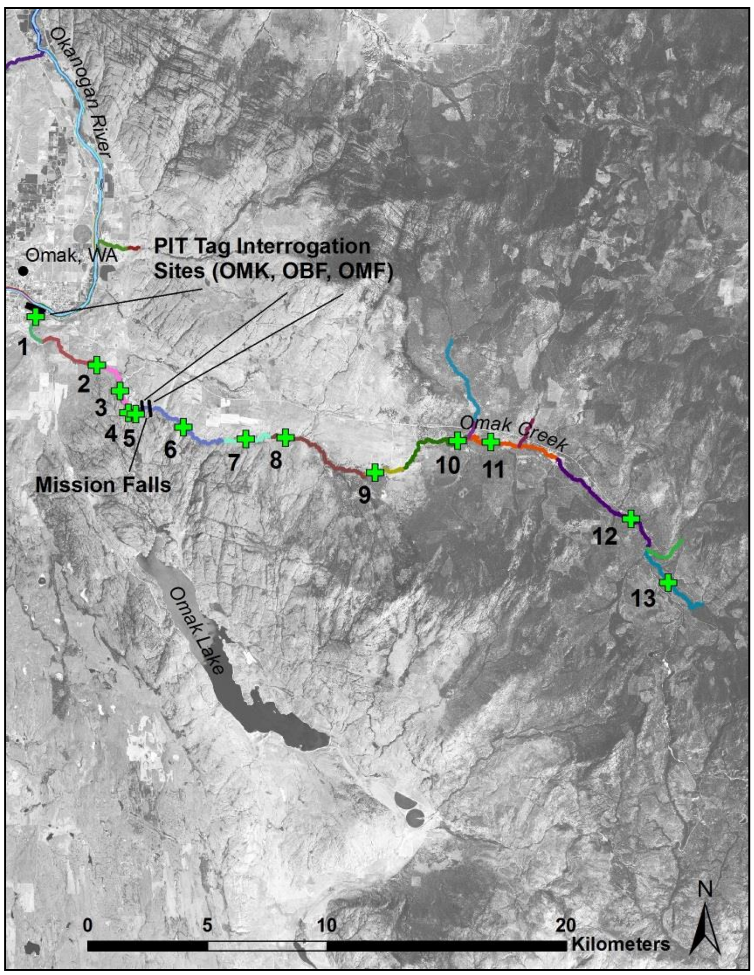


Figure B-3. Omak Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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^2 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.

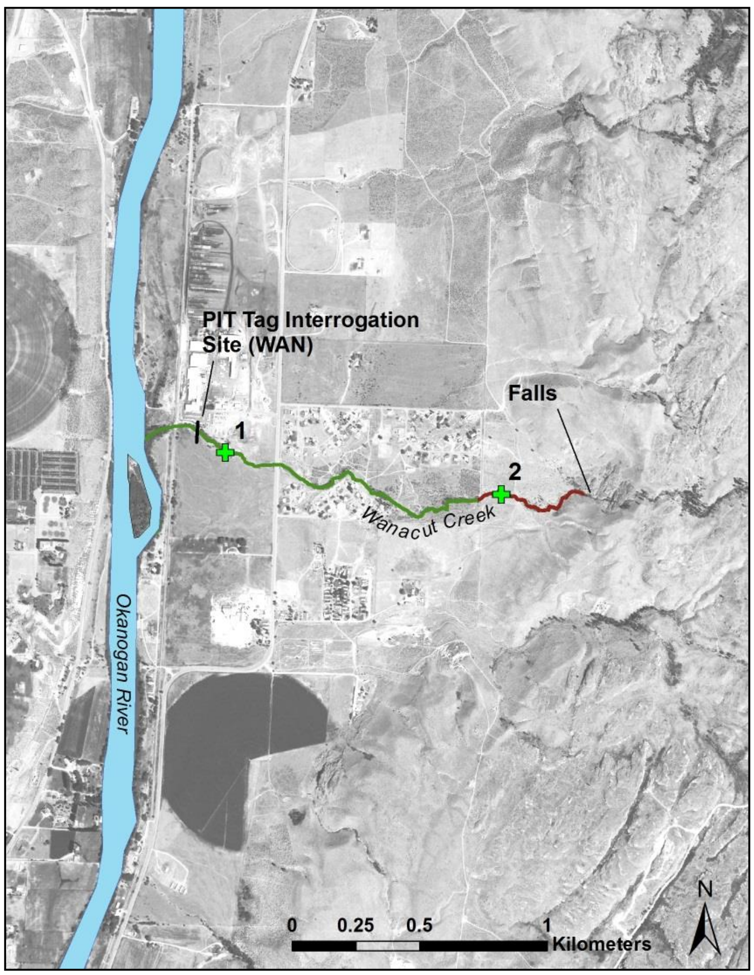


Figure B-4. Wanacut Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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^2, 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.

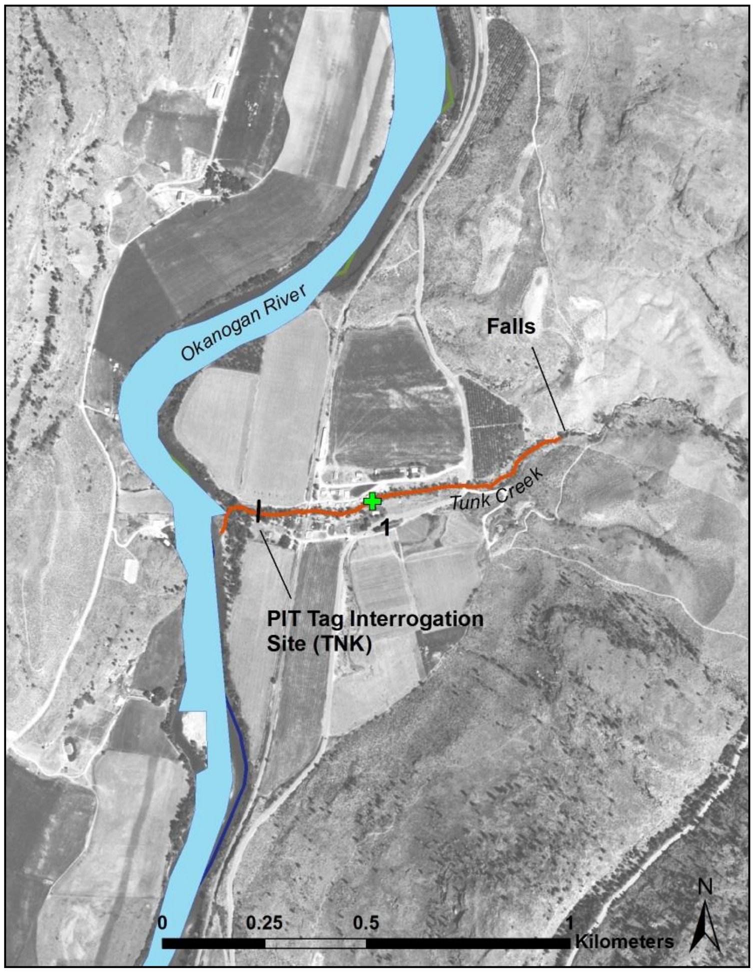


Figure B-5. Tunk Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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.

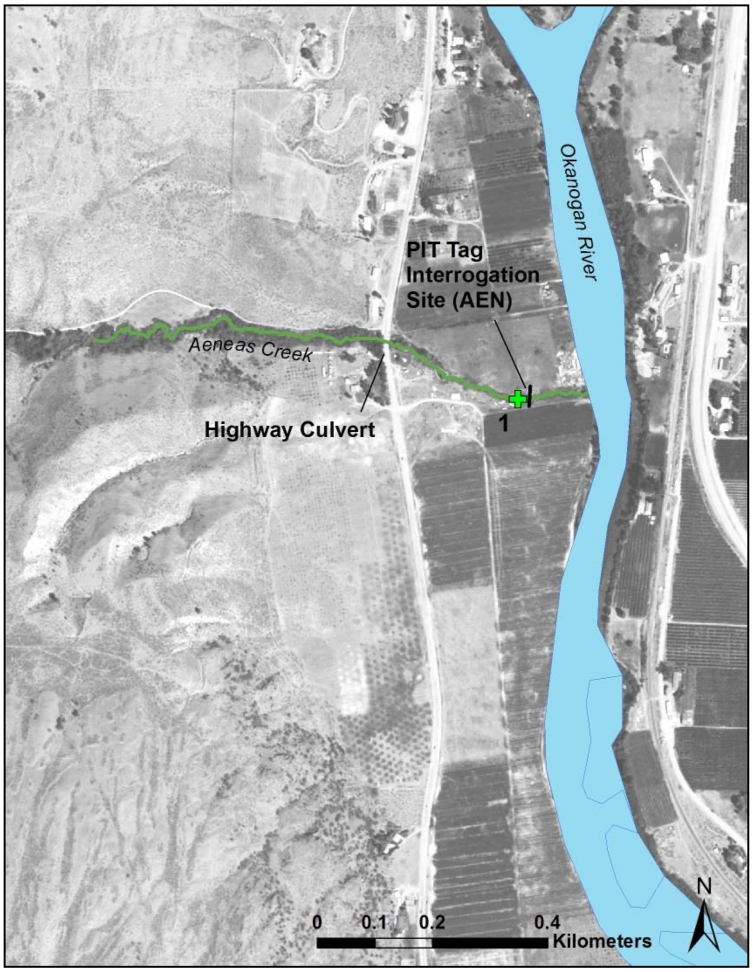


Figure B-6. Aeneas Creek juvenile *O. mykiss* mark-recapture study site (green numbered markers) and strata (colored stream lines).

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^2; 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).

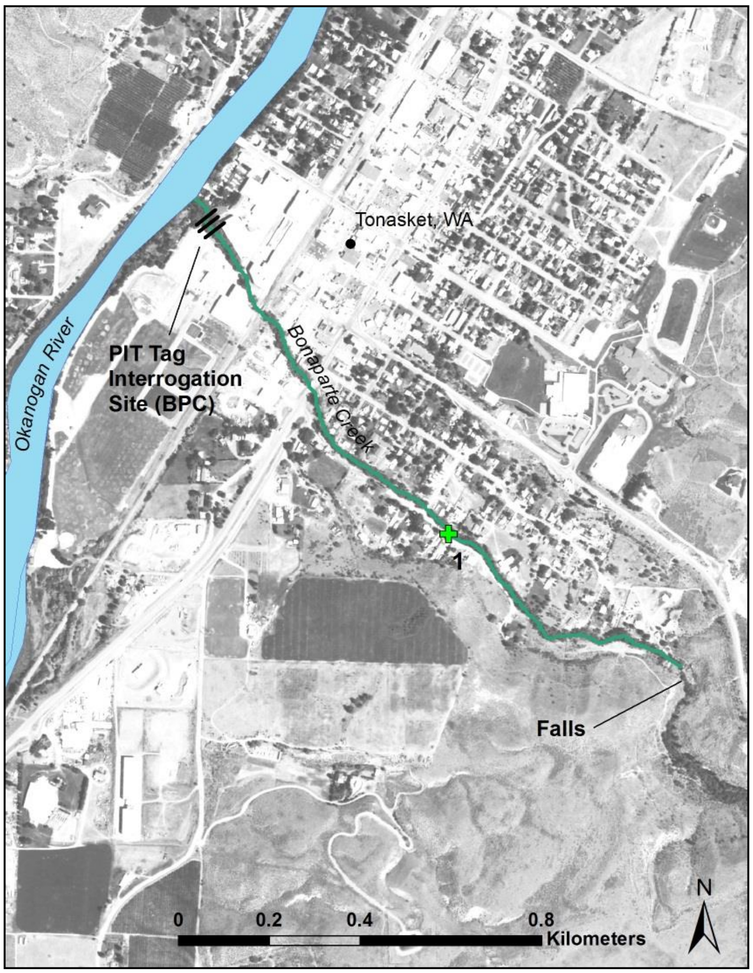


Figure B-7. Bonaparte Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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^2; 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 perennial. 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.

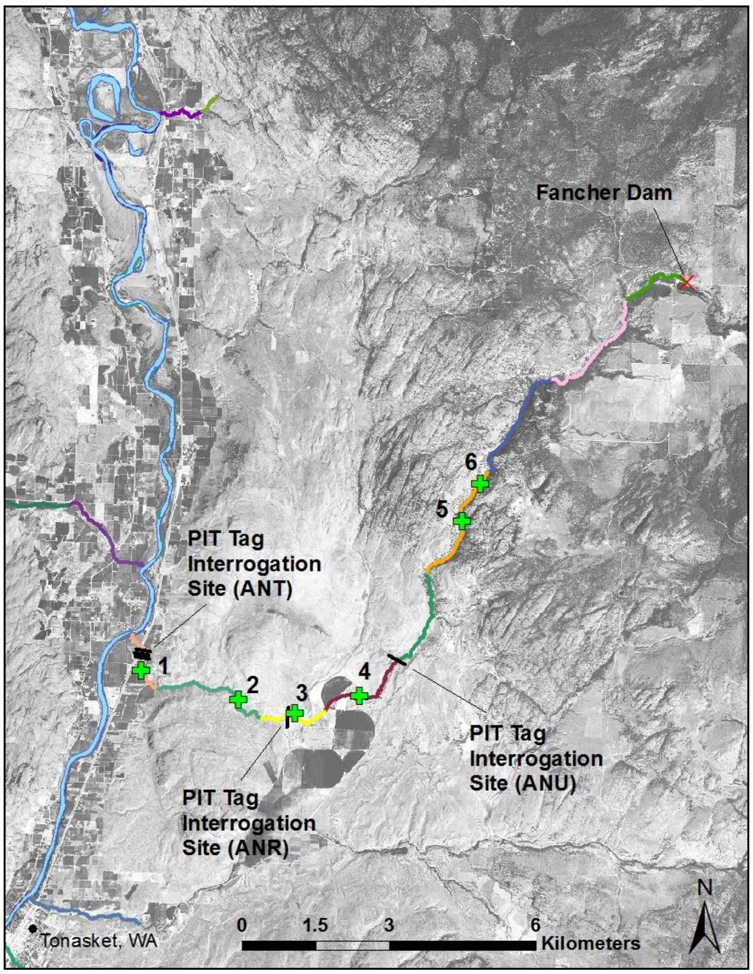


Figure B-7. Antoine Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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^2. 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.

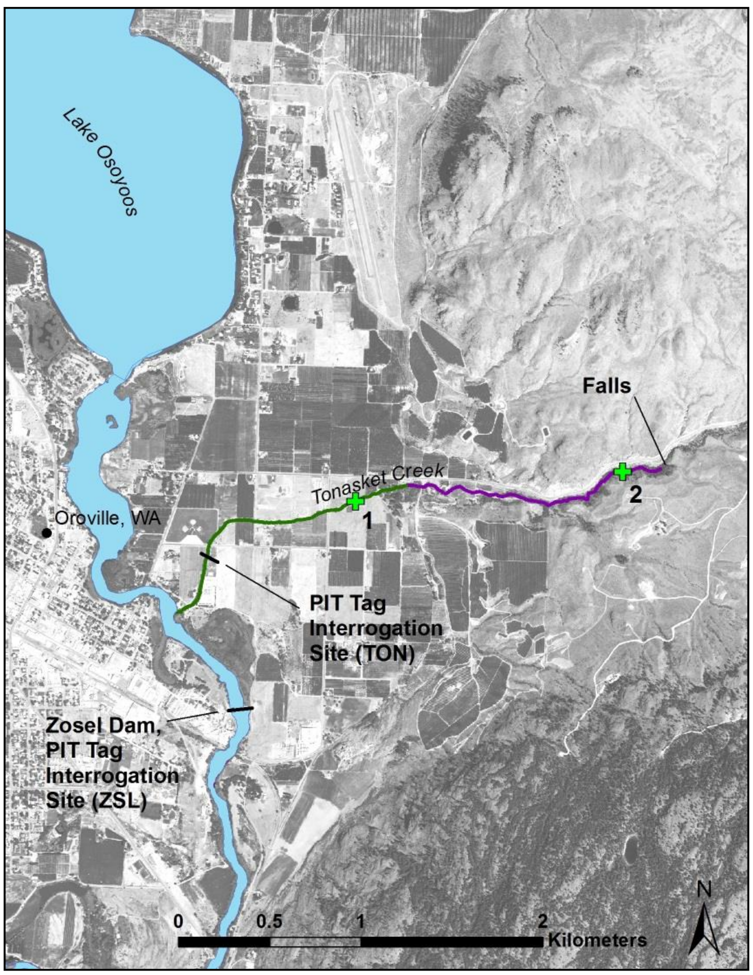


Figure B-9. Tonasket Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

Ninemile Creek

The drainage area of Ninemile Creek is approximately 122 km^2. Ninemile Creek is known to flow sub-surface 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.

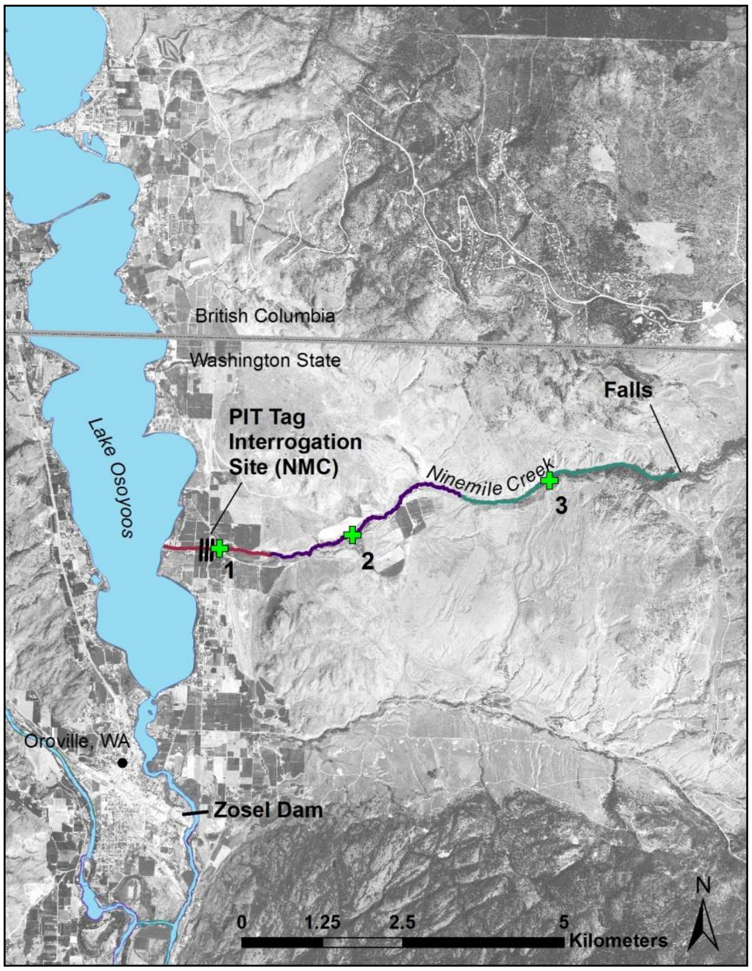


Figure B-10. Ninemile Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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 Chilliwist, Johnson, Wildhorse and/or Whitestone Creeks.

British Columbia

akskʷəkʷant (Inkaneep Creek)

The akskʷəkʷant (Inkaneep Creek) drainage area is approximately 227 km^2. It is a 5th order stream at the mouth where it drains into the north basin of sw̓iw̓s (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 14 km upstream from the confluence with sw̓iw̓s (Osoyoos Lake) that directly impacted akskʷəkʷant (Inkaneep Creek). The 14 km 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.

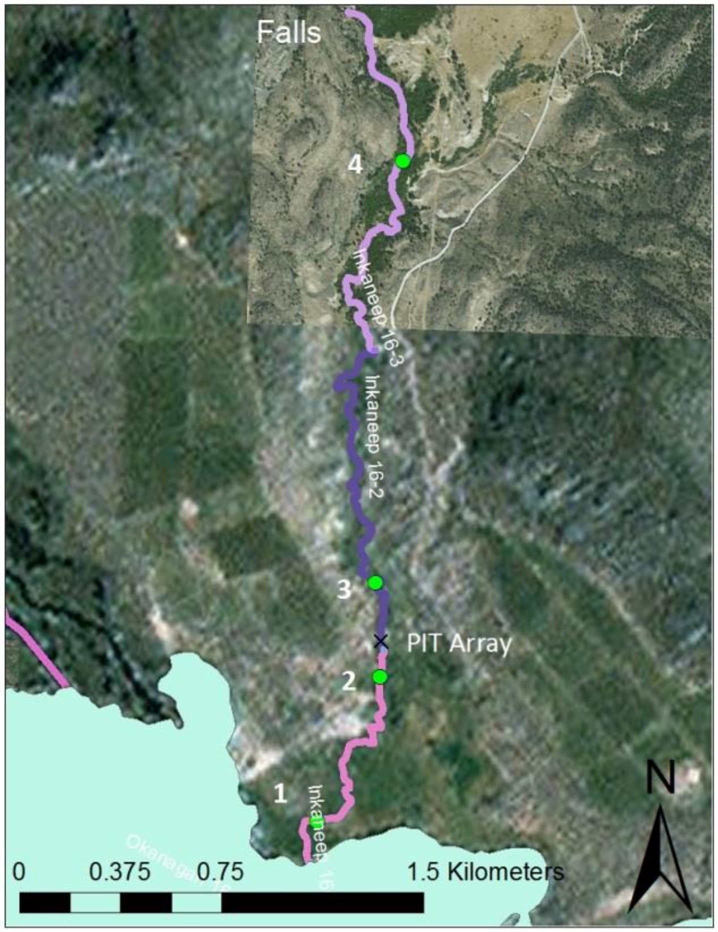


Figure B- 11. akskʷəkʷant (Inkaneep Creek) juvenile *O. mykiss* mark-recapture study sites (green numbered dots) and strata (colored stream lines).

Shuttleworth Creek

The Shuttleworth Creek drainage area is approximately 90 km^2. It is a 3rd order stream at the mouth where it drains into the sq̓awsitkʷ (Okanagan River) at RKM 175 just downstream of the t̓uʔcin (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).

akłxʷuminaʔ (Shingle Creek)

The akłxʷuminaʔ (Shingle Creek) drainage area is approximately 308 km^2. It is a 6th order stream at the mouth where it drains into the sq̓awsitkʷ (Okanagan River) at RKM 195 downstream of the kłusxnitkʷ (Okanagan Lake) outlet dam at Penticton. The main tributary to akłxʷuminaʔ (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 akłxʷuminaʔ (Shingle) and Shatford Creeks are divided into 18 survey reaches (Figure B-13). In 2015 a permanent 4 antenna PIT tag array (OKS) was installed 1 km upstream from the mouth. This array was inoperable for the majority of 2017, sustained damage during the extreme freshet of 2018, and was replaced in 2019 with a 1 antenna system. This PIT array was not in operation during the fall of 2022 due to a breakdown of wiring.

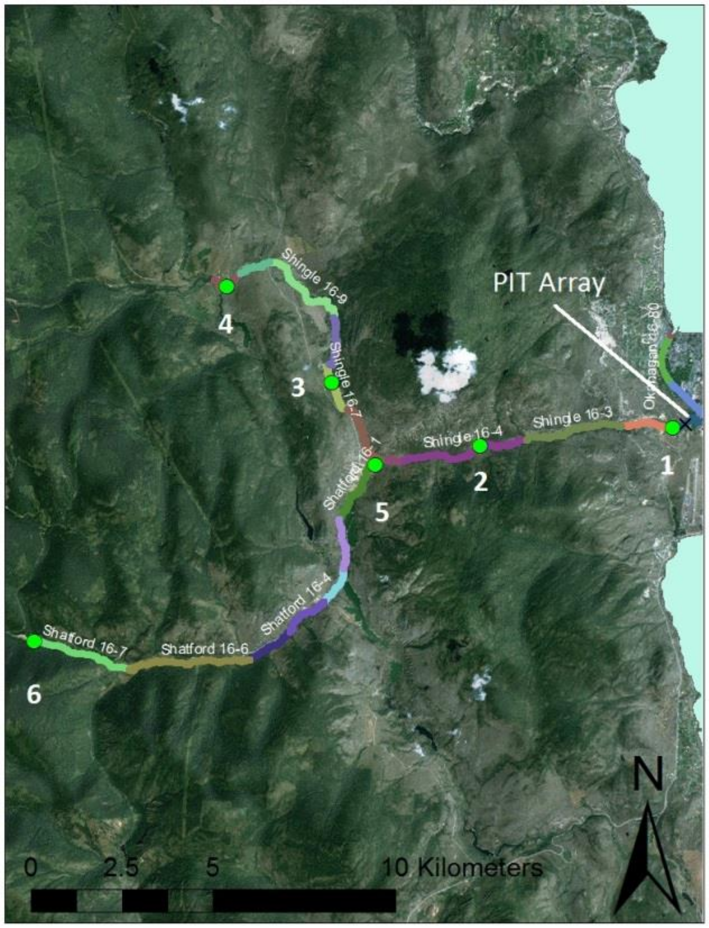


Figure B- 13. Shingle and Shatford Creek juvenile *O. mykiss* mark-recapture study sites (green numbered dots) and strata (colored stream lines).

nʕax̌ʷlqaxʷiya (Vaseux Creek)

The nʕax̌ʷlqaxʷiya (Vaseux Creek) drainage area from the mouth is approximately 296 km^2. 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 nʕax̌ʷlqaxʷiya (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, until a breakdown of wiring in 2022 caused the downstream array to be inoperable.

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* age-1+ or greater than ~80 mm were marked with a PIT tag and smaller *O. mykiss* were marked with a top caudal fin clip. All other salmonid 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 Pearsons 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 ~80 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):

$$N = \frac{(M+1)(C+1)}{R+1} - 1$$

(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:

$$var(N) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)(R+1)(R+2)}.$$ (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, $\widehat{N}_i$ for $i = 1, \ldots, 7$). 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., Ri),

$$R_i = \frac{Reach\ Length_{\ i}}{Sample\ Site\ Length_{\ i}}. \tag{eq. 3}$$

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

$$\hat{N}_i = N_i R_i\ . \tag{eq. 4}$$

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

$$\hat{N} = \sum_{i=1}^{7} \hat{N}_i R_i\ , \tag{eq. 5}$$

with a variance of

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

and a 95% confidence interval (CI) of

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

The coefficient of variation (CV) was calculated as:

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

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 are 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:

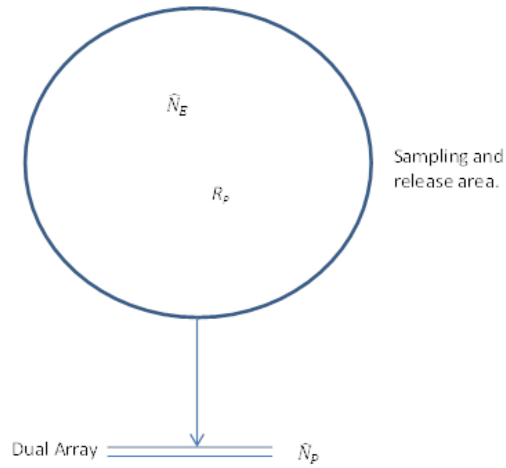


Figure B- 14. Diagram of the study.

where n10= total PIT-tagged steelhead detected at the first site only,
n01= total PIT-tagged steelhead detected at the second site only,
n11= total PIT-tagged steelhead detected at both detection sites, and
Rp = 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.

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

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)

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

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

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

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

with a variance of

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

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 ($\widehat{N}_{all}$) is estimated by

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

with a variance of

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

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 (p1) is:

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

where n01= total PIT-tagged steelhead detected at the second site only, and
n11= total PIT-tagged steelhead detected at both detection sites.

With the variance estimate

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

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

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

where n1*= total unique PIT-tagged steelhead detected at the dual array.

Using the delta method, the variance estimate is

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

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 ($\widehat{N}$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.

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

where n10= total PIT-tagged steelhead detected at the first site only,
n01= total PIT-tagged steelhead detected at the second site only,
n11= total PIT-tagged steelhead detected at both detection sites, and
Rp = 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 often times 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. Since age breaks are now determined through length frequency distributions, 80 mm was chosen as the cut-off for PIT tagging to ensure marking of all age-1+ specimens. 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 2022, 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 populations 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 transitions to 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 2022, 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* (±95%CI) in tributaries to the Okanogan River in Washington State and British Columbia.

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

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

Tributary	2019	2020	2021	2022
Salmon Cr	36,667 ± 3,378	51,691 ± 6,346	60,414 ± 4,707	25,334 ± 4,952
Lower Omak Cr	19,717 ± 1,797	10,818 ± 1,555	921 ± 396	7,907 ± 691
Upper Omak Cr	17,905 ± 2,018	23,226 ± 5,658	5,539 ± 1,811	15,946 ± 2,361
Lower Loup Loup Cr	4,979 ± 335	4,839 ± 397	6,435 ± 495	5,150 ± 475
Upper Loup Loup Cr	Not sampled	Not sampled	3,484 ± 1,168	5,282 ± 1,383
Ninemile Cr	11,244 ± 1,150	5,261 ± 1,081	17,109 ± 2,403	3,725 ± 580
Bonaparte Cr	3,057 ± 1,538	670 ± 124	3,185 ± 463	486 ± 88
Tonasket Cr	2,496 ± 321	3,567 ± 465	1,817 ± 250	3,106 ± 427
Tunk Cr	3,067 ± 229	2,692 ± 217	6 ± 0	1,595 ± 158
Aeneas Cr	111 ± 18	406 ± 92	488 ± 82	3 ± 0
Wanacut Cr	1,644 ± 351	1,896 ± 230	0 ± 0	0 ± 0
Johnson Cr	Not sampled	Not sampled	Not sampled	Not Sampled
Lower Antoine Cr	Not sampled	Not sampled	493 ± 69	584 ± 96
Upper Antoine Cr	Not sampled	Not sampled	16,152 ± 6,115	6,816 ± 3,940
Wildhorse Sp Cr	Not sampled	Not sampled	Not sampled	Not Sampled
Inkaneep Cr	19,856 ± 2,720	14,450 ± 2,810	NA	5,299 ± 1,526
Vaseux Cr	8,630 ± 4,274	16,998 ± 6,514	10,312 ± 3,291	4,752 ± 2,223
Shuttleworth Cr	17,459 ± 1,786	19,286 ± 2,247	8,796 ± 8,895	610 ± 192
Lower Shingle Cr	846 ± 655	686 ± 108	1,783 ± 1,629	2,578 ± 2,427
Upper Shingle Cr	33,297 ± 10,368	11,560 ± 1,745	NA	801 ± 624
Shatford Cr	53,899 ± 11,865	33,625 ± 5,206	21,953 ± 5,490	32,019 ± 9,032

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

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

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

Tributary	2019	2020	2021	2022
Salmon Cr	27,284 ± 1,603	31,715 ± 1,979	32,827 ± 1,938	32,221 ± 2,222
Lower Omak Cr	4,163 ± 325	5,284 ± 641	224 ± 50	281 ± 47
Upper Omak Cr	11,300 ± 917	17,040 ± 2,217	7,675 ± 1,236	8,186 ± 1,052
Lower Loup Loup Cr	556 ± 86	1,681 ± 86	1,223 ± 55	1,604 ± 152
Upper Loup Loup Cr	Not sampled	Not sampled	8,229 ± 705	7,475 ± 634
Ninemile Cr	4,524 ± 367	2,847 ± 153	1,814 ± 201	5,709 ± 372
Bonaparte Cr	423 ± 60	1,279 ± 87	538 ± 115	635 ± 53
Tonasket Cr	340 ± 43	596 ± 62	144 ± 0	589 ± 34
Tunk Cr	80 ± 15	318 ± 45	61 ± 24	68 ± 9
Aeneas Cr	36 ± 5	24 ± 0	13 ± 0	14 ± 4
Wanacut Cr	1,151 ± 61	609 ± 46	659 ± 32	70 ± 28
Johnson Cr	Not sampled	Not sampled	Not sampled	Not sampled
Lower Antoine Cr	Not sampled	Not sampled	298 ± 123	528 ± 76
Upper Antoine Cr	Not sampled	Not sampled	12,930 ± 1,281	16,653 ± 2,062
Wildhorse Sp Cr	Not sampled	Not sampled	Not sampled	Not sampled
Inkaneep Cr	4,351 ± 452	3,333 ± 311	1,211 ± 319	2,071 ± 330
Vaseux Cr	3,424 ± 978	6,374 ± 2,693	3,110 ± 1,120	3,770 ± 1,156
Shuttleworth Cr	10,830 ± 981	4,906 ± 828	1,261 ± 404	2,277 ± 505
Lower Shingle Cr	6,284 ± 3,277	5,679 ± 715	2,189 ± 813	1,048 ± 217
Upper Shingle Cr	7,169 ± 1,517	5,930 ± 528	1,391 ± 787	868 ± 390
Shatford Cr	3,718 ± 839	8,460 ± 916	3,770 ± 3,583	3,857 ± 1,339

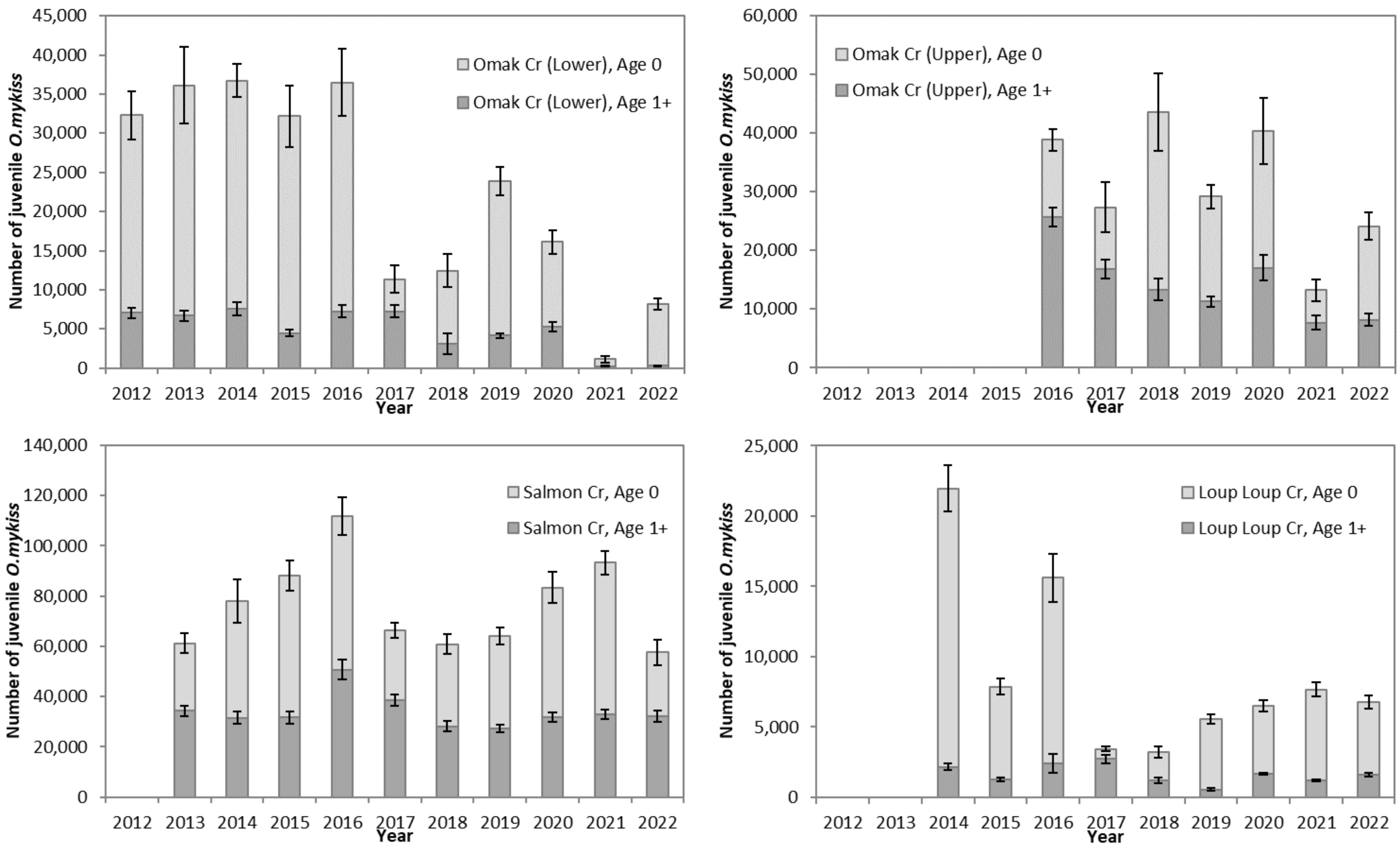


Figure B-15. Total estimated abundance of juvenile *O.mykiss* by age class in lower Omak, upper Omak, Salmon and Loup Loup Creeks.

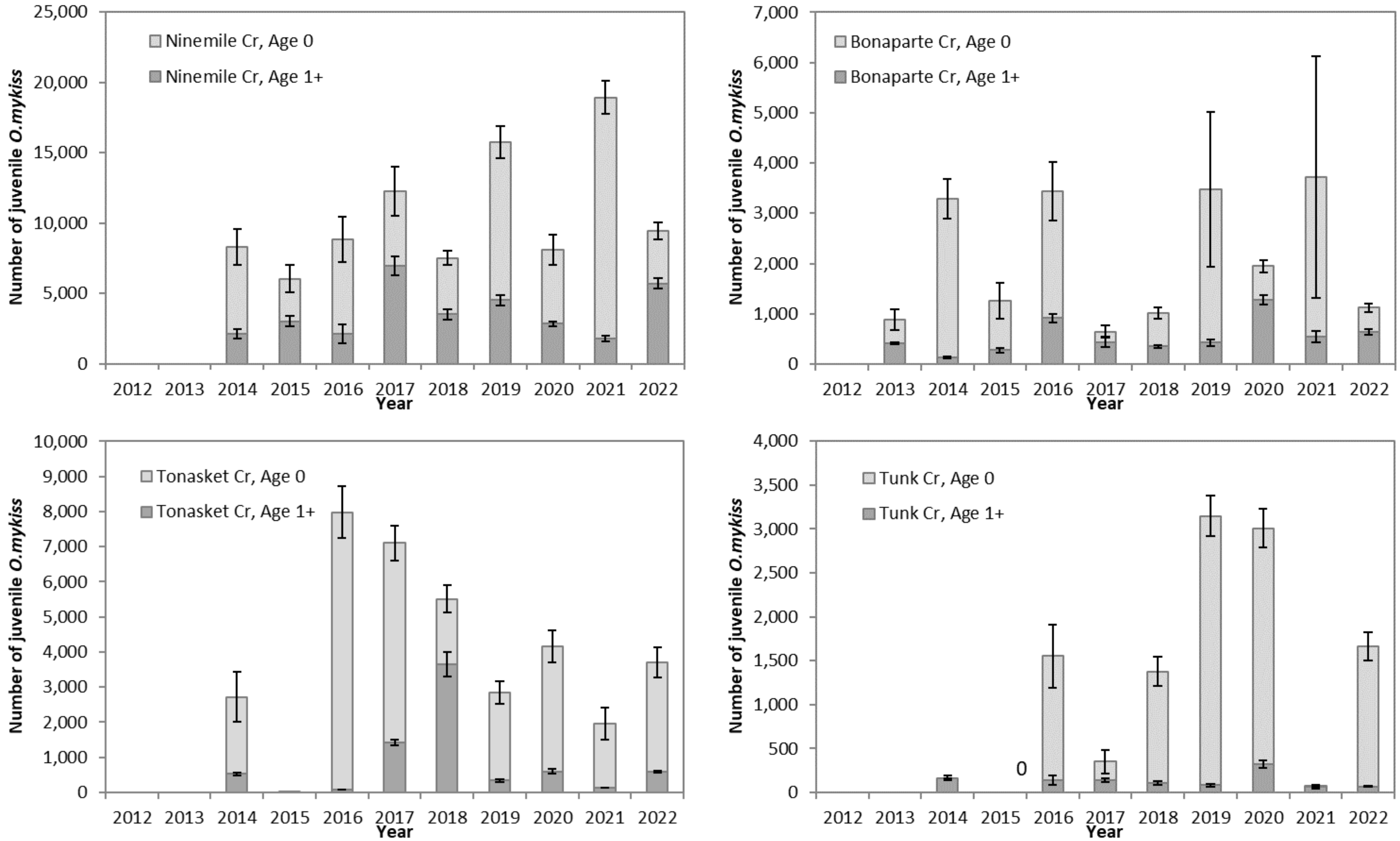


Figure B-16. Total estimated abundance of juvenile *O.mykiss* by age class in Ninemile, Bonaparte, Tonasket and Tunk Creeks.

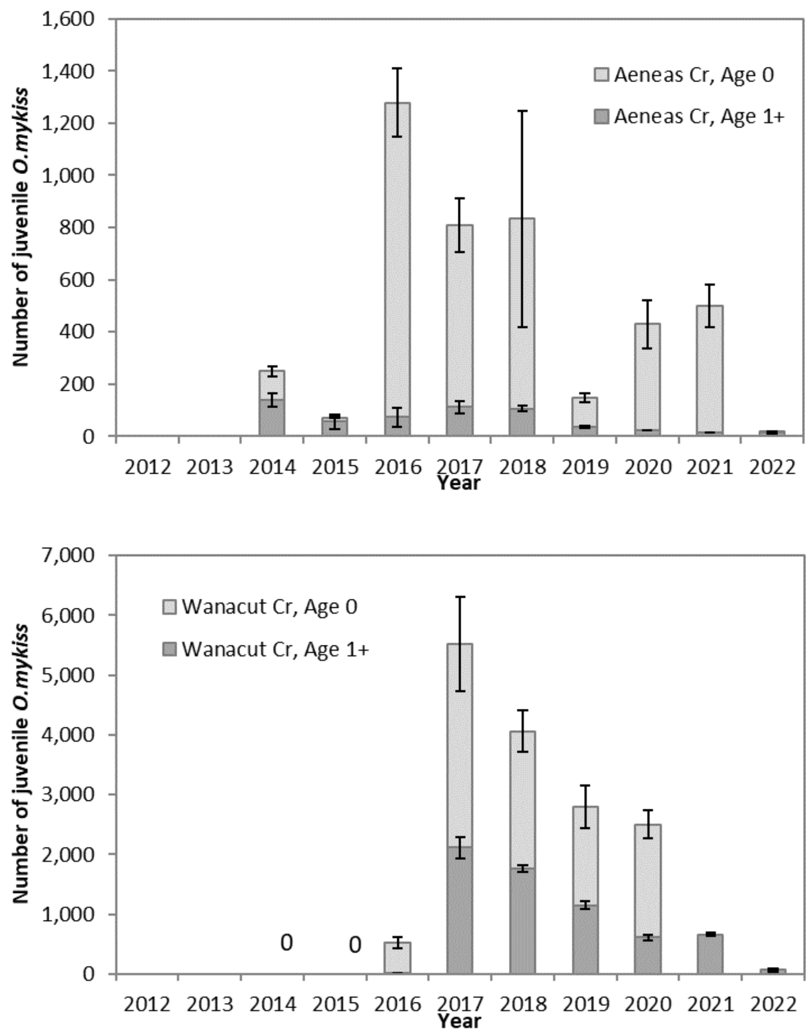


Figure B-17. Total estimated abundance of juvenile *O.mykiss* by age class in Aeneas and Wanacut Creeks.

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 2022 represent outmigration of juvenile steelhead from that year, derived from fish PIT tagged and released in the fall of 2021 and detected from September 2022 through August 2022. Based on combined detections of PIT tagged fish from within and downstream of the Okanogan subbasin, a total of 10,223 ± 1,639 juvenile steelhead outmigrated from the defined strata, the second lowest since current enumeration practices began in 2013. Each of the ten sampling areas produced a lower estimate in 2022 than in 2021. Notably in the lower portion of Omak Creek, typically the second leading producer of steelhead outmigrants in the subbasin, produced only an estimated 56 ± 36 outmigrants. Upper Omak creek has also has been a significant contributor in previous years, however only produced 36 ± 70 outmigrants in 2022. Omak Creek in particular experienced extended extreme temperatures during the summer months of 2021 and 2022 (Figure-5, p. 15), which likely induced stress and mortality to cold water salmonids and is validated by the reduced populations observed in-stream (Figure B-15).

One effect of the reduced population densities (likely due to increased water temperatures) appears to have a positive effect on growth rates. Observations at the Omak Creek rotary screw trap operated by CCT's Broodstock, Acclimation, and Monitoring (BAM) program indicated a higher rate of age 1 steelhead chose to outmigrate in 2022 (Brooklyn Hundson CCT BAM Biologist, pers. comm.). Scale data collected at the screw trap collaborated that age-1fish grew to smolt size up to 185 mm. Age-1 outmigrating *O. mykiss* historically were not deemed to be a significant enough contributor to the population under this project to PIT tag during the fall mark-recap sessions however, so data is incomplete for this life-history and not represented in Table B-3. This was decided based on scale data collected at Priest Rapids Dam (PRD) during representative marking sessions for returning steelhead, where nearly all adults were determined to be of age 2+ at the time of smoltification. This project's protocols will be reevaluated once further data analysis of the 2022 outmigration cohort is completed.

Water temperatures in 2021 did not appear to be as significant of a factor in the Okanogan's most significant steelhead producer, Salmon Creek where 8,882 ± 1,148 juvenile steelhead outmigrants were estimated in 2022, accounting for 87 percent of the combined sum of sampled strata, eclipsing the previous high of 78 percent in 2016.

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 proportions 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). Of note is Ninemile Creek, where cumulatively only 11.0% of the tags detected at the mouth were subsequently detected at observation sites located downstream (i.e. OKL, RRJ, etc), which is substantially less than the next numerically closest tributary of Aeneas Creek (21.1%) and the subwatershed mean of 37.3%. This would suggest a greater likelyhood that *O. mykiss* which originate from Ninemile Creek exhibit a residential or adfluvial life history type, and/or a greater chance of mortality before emigrating from the subbasin, therefore their numbers are excluded from the sum of outmigrant populations reported in Table B-3. Conversely, tagged *O. mykiss* from Omak Creek located above Mission Falls had a 68.3% downstream detection rate of those 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 suwiẁs (Osoyoos Lake) in following years will indicate the migratory life histories of tagged *O. mykiss*. Tagged *O.mykiss* from akskʷəkʷant (Inkaneep) and Shuttleworth creeks have been detected in juvenile bypass facilities in the Columbia River (John Day Dam and Rocky Reach Dam), though very few to date.

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	2022
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	8,882 ± 1,148
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	56 ± 36
Upper Omak Cr				20,954 ± 18,841	2,235 ± 1,669	236 ± 208	455 ± 243	NA	36 ± 70
Loup Loup Cr		1,193 ± 255	600 ± 112	1,984 ± 433	980 ± 432	501 ± 125	323 ± 84	946 ± 125	685 ± 102
Ninemile Cr		0	655 ± 250	836 ± 387	1,918 ± 444	2,382 ± 3,771	511 ± 215	942 ± 235	339 ± 164
Bonaparte Cr	201 ± 71	112 ± 0	195 ± 62	767 ± 151	211 ± 103	174 ± 65	224 ± 78	671 ± 132	374 ± 113
Tonasket Cr		24 ± 0	2 ± 2	30 ± 26	441 ± 129	1,178 ± 296	159 ± 64	343 ± 98	12 ± 23
Tunk Cr		131 ± 119	NA	NA	0	NA	49 ± 23	264 ± 52	14 ± 17
Aeneas Cr		198 ± 103	32 ± 32	54 ± 16	78 ± 24	80 ± 18	18 ± 11	14 ± 9	7 ± 6
Wanacut Cr		0	0	0	1,610 ± 843	818 ± 231	270 ± 103	110 ± 59	39 ± 37
Sum[1]	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	10,223 ± 1,639

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

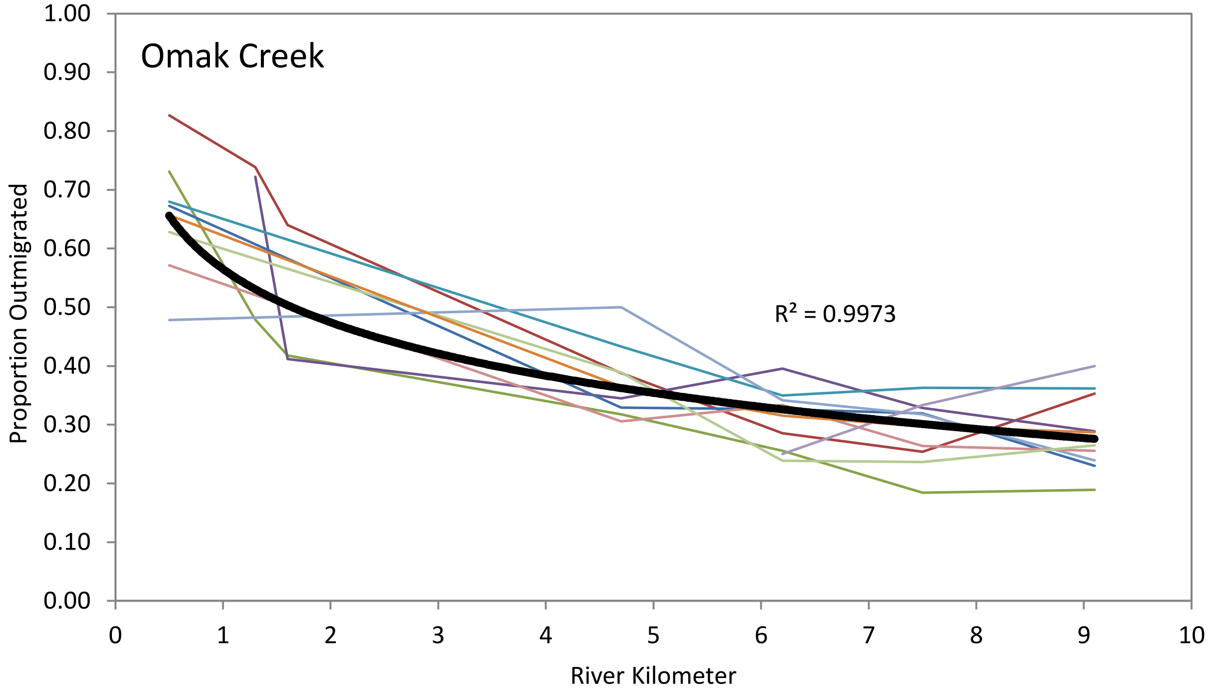


Figure B- 18. Proportion of PIT tagged natural-origin juvenile steelhead that outmigrated in lower Omak Creek by river kilometer (distance upstream from the confluence with the Okanogan River) in each unique year, 2014-2022. Trend of mean shown in bold black.

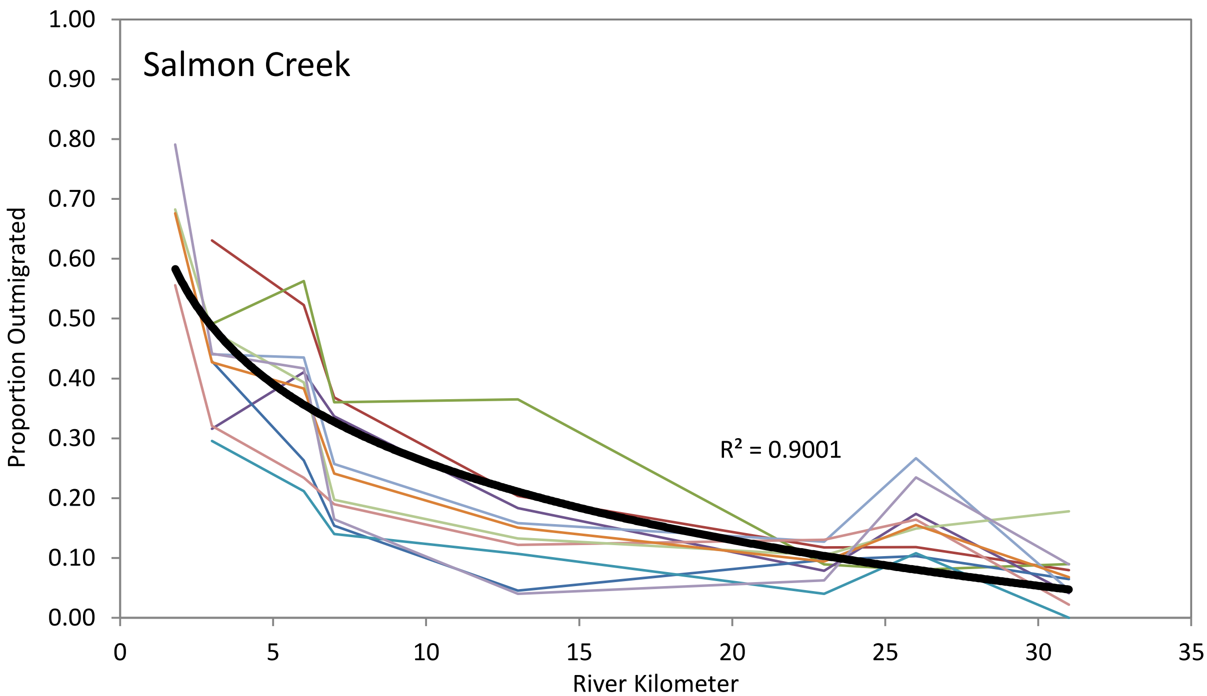


Figure B- 19. Proportion of PIT tagged natural-origin juvenile steelhead that outmigrated in Salmon Creek by river kilometer (distance upstream from the confluence with the Okanogan River) in each unique year, 2014-2022. Trend of mean shown in bold black.

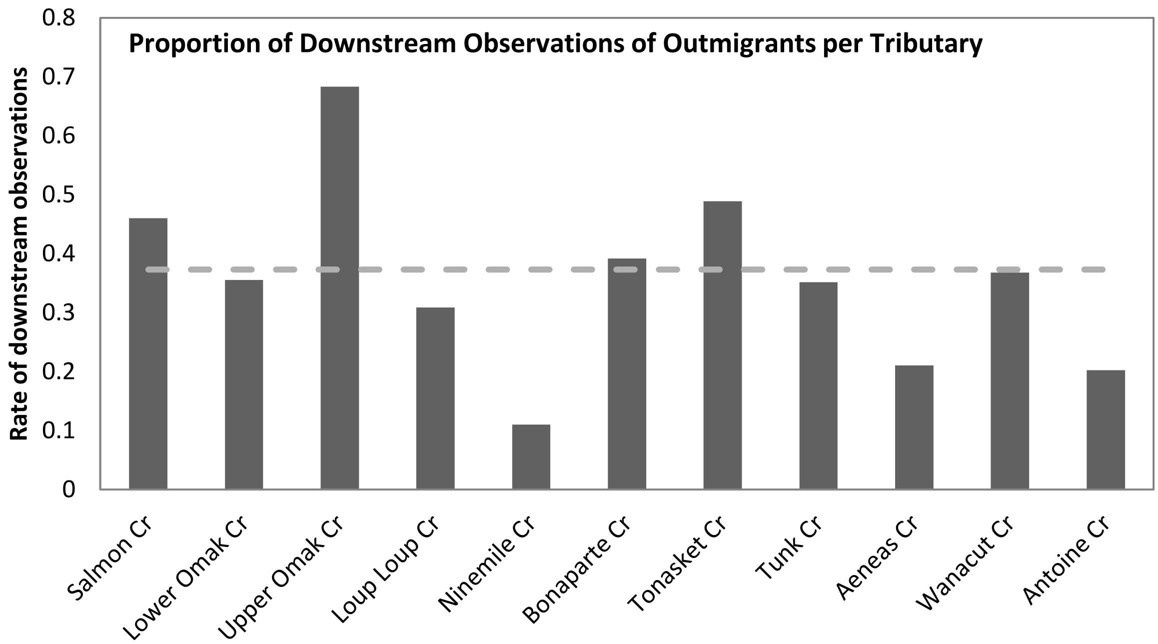


Figure B- 20. Cumulative proportion of PIT tagged natural-origin steelhead that, after being detected at the mouth of a tributary, were subsequently detected downriver. Dashed line represents the mean of all creeks.

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). No population estimate was produced for the 2022 cohort, only 5 individuals were encountered throughout the subbasin during mark-recap sessions. Loup Loup Creek was the only tributary where more than one individual was found. 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, were determined to be 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 2022 an estimated 541 ± 222 (95%CI) juvenile spring Chinook outmigrated from Loup Loup, Aeneas, Bonaparte and Salmon Creeks. Of the 25 Chinook detected on tributary mouth arrays, 17 of them originated from Salmon Creek.

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

Tributary	2014	2015	2016	2017	2018	2019	2020	2021	2022
Salmon Cr	0	0	0	18 ± 0	1,893 ± 519	219 ± 57	21 ± 0	553 ± 240	20 ± 0
Lower Omak Cr	0	0	64 ± 0	187 ± 57	48 ± 0	570 ± 185	24 ± 0	0	0
Upper Omak Cr	0	0	0	0	0	0	0	0	0
Loup Loup Cr	0	0	0	0	295 ± 43	1,474 ± 100	94 ± 0	34 ± 0	57 ± 53
Ninemile Cr	0	0	0	0	0	0	0	0	0
Bonaparte Cr	0	0	24 ± 0	0	0	0	0	36 ± 0	13 ± 0
Tonasket Cr	0	0	0	0	0	0	0	0	0
Tunk Cr	0	0	0	0	0	11 ± 0	0	0	0
Aeneas Cr	0	0	0	3 ± 0	7 ± 0	45 ± 3	0	6 ± 0	0
Wanacut Cr	0	0	0	0	28 ± 26	33 ± 16	19 ± 0	0	0
Johnson Cr	Not sampled	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	15 ± 0
Wildhorse Sp Cr	Not sampled	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		
Inkaneep Cr	Not sampled	Not sampled	0	0	0	0	0		
Shuttleworth Cr	Not sampled	Not sampled	0	0	0	0	0		
Total	0	0	88 ± 0	208 ± 57	2,271 ± 589	2,352 ± 361	158 ± 0	629 ± 240	105 ± 53

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 has 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. Studies have shown that short term retention of PIT tags to be quite high, near 100% (Prentice et al. 1990, Zydlewski 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 80 mm and larger were PIT tagged. Additional years of outmigration data will show to what extent 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 (<300 mm) 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.

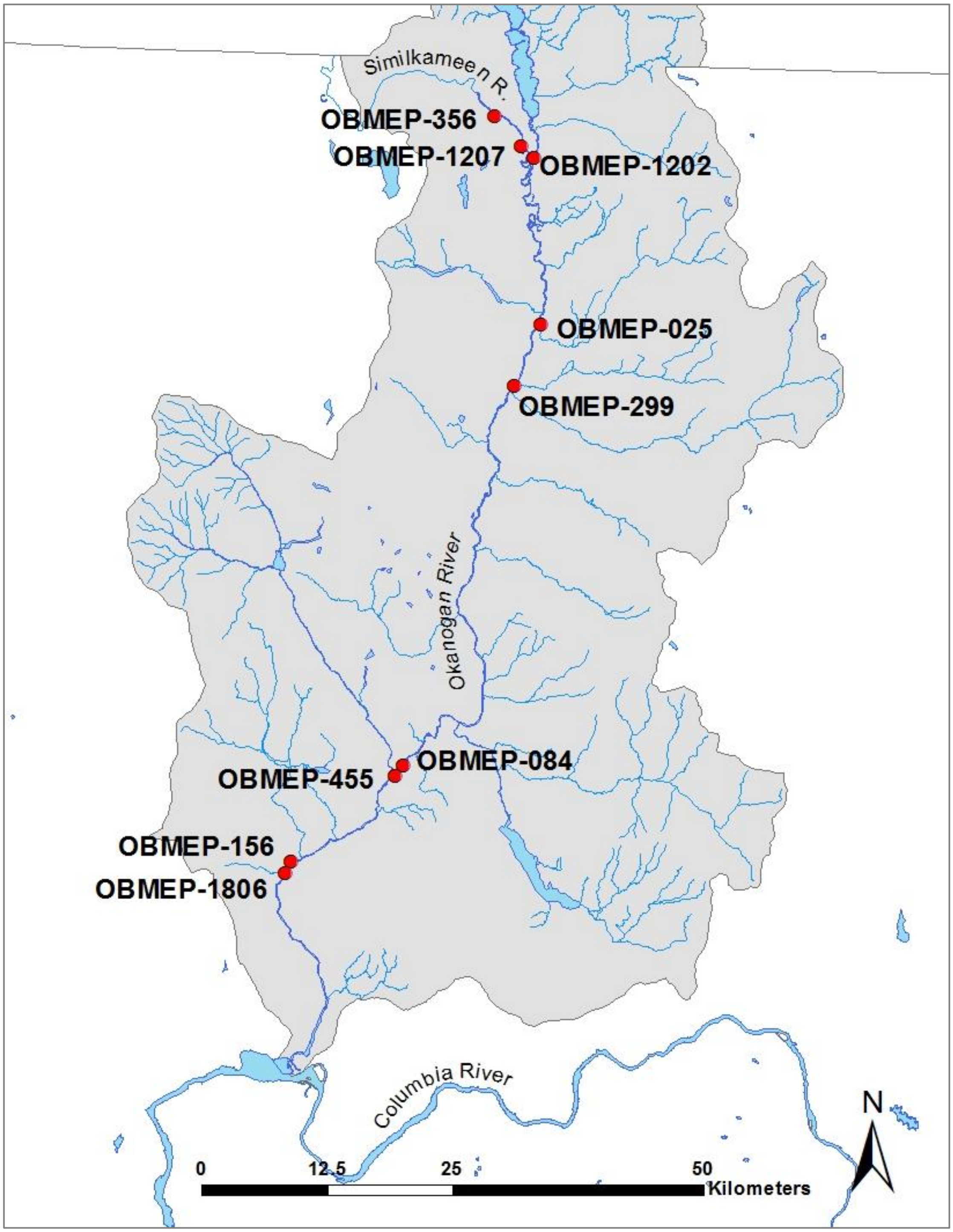
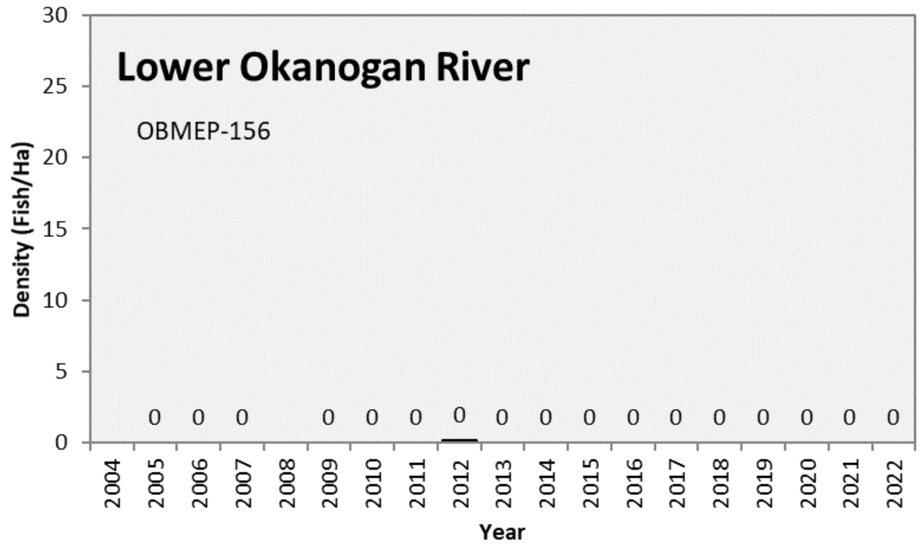
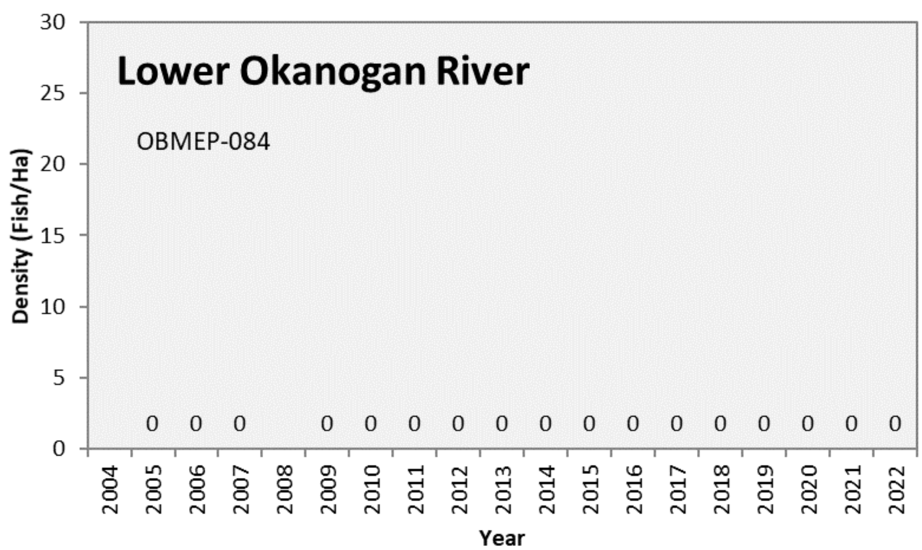


Figure C-1. Locations of annual snorkel survey sites on the mainstem Okanogan and Similkameen Rivers. Rotating panel sites are not shown due to fewer years of data.



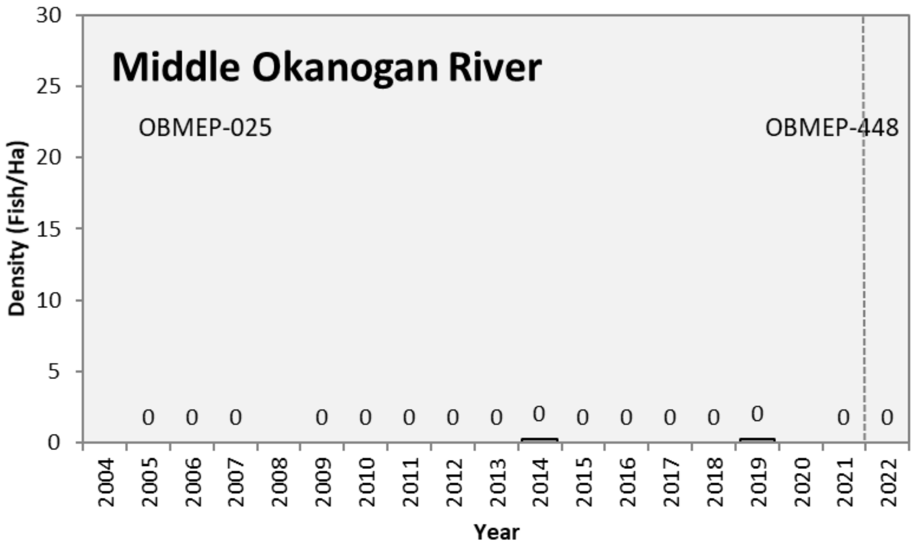
Year	# Obs.
2004	NS
2005	0
2006	0
2007	0
2008	NA
2009	0
2010	0
2011	0
2012	1
2013	0
2014	0
2015	0
2016	0
2017	0
2018	0
2019	0
2020	0
2021	0
2022	0

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



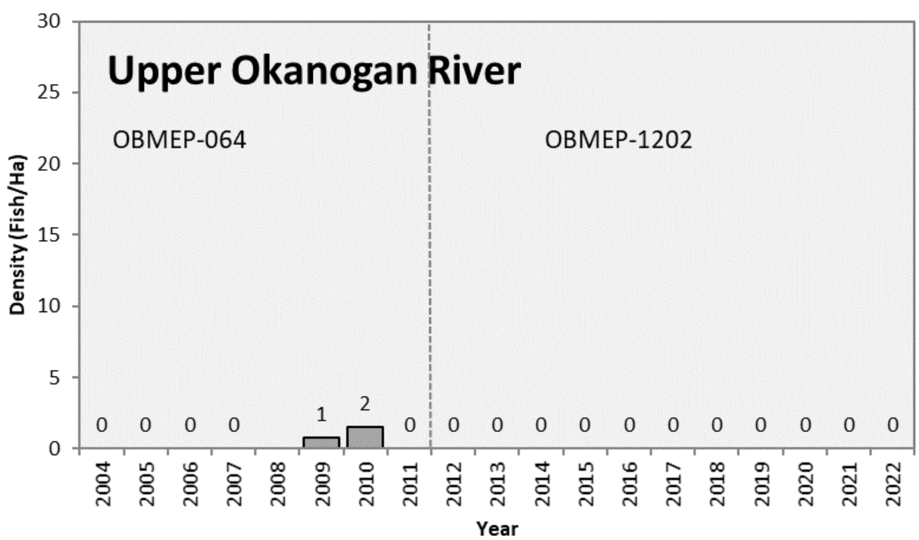
Year	# Obs.
2004	0
2005	0
2006	0
2007	0
2008	NA
2009	0
2010	0
2011	0
2012	0
2013	0
2014	0
2015	0
2016	0
2017	0
2018	0
2019	0
2020	0
2021	0
2022	0

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



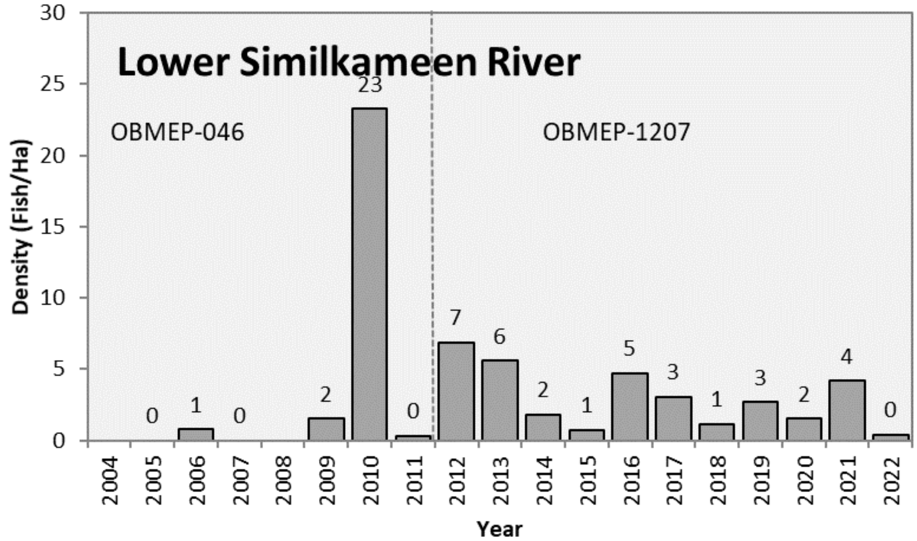
Year	# Obs.
2004	NA
2005	0
2006	0
2007	0
2008	NA
2009	1
2010	2
2011	0
2012	0
2013	0
2014	1
2015	0
2016	0
2017	0
2018	0
2019	1
2020	NA
2021	0
2022	0

Figure C-4. Observed densities of juvenile (< 300 mm) *O. mykiss* in the Okanogan River, upstream of the confluence with Antoine Creek. Sample site was moved to OBMEP-448 in 2022 due to frequent issues with turbidity at OBMEP-025.



Year	# Obs.
2004	0
2005	0
2006	0
2007	0
2008	NA
2009	1
2010	2
2011	0
2012	0
2013	0
2014	0
2015	0
2016	0
2017	0
2018	0
2019	0
2020	0
2021	0
2022	0

Figure C-5. Observed densities of juvenile (<300 mm) *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 River.



Year	# Obs.
2004	NS
2005	0
2006	2
2007	0
2008	NA
2009	4
2010	75
2011	1
2012	18
2013	16
2014	5
2015	2
2016	13
2017	8
2018	3
2019	7
2020	4
2021	11
2022	1

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

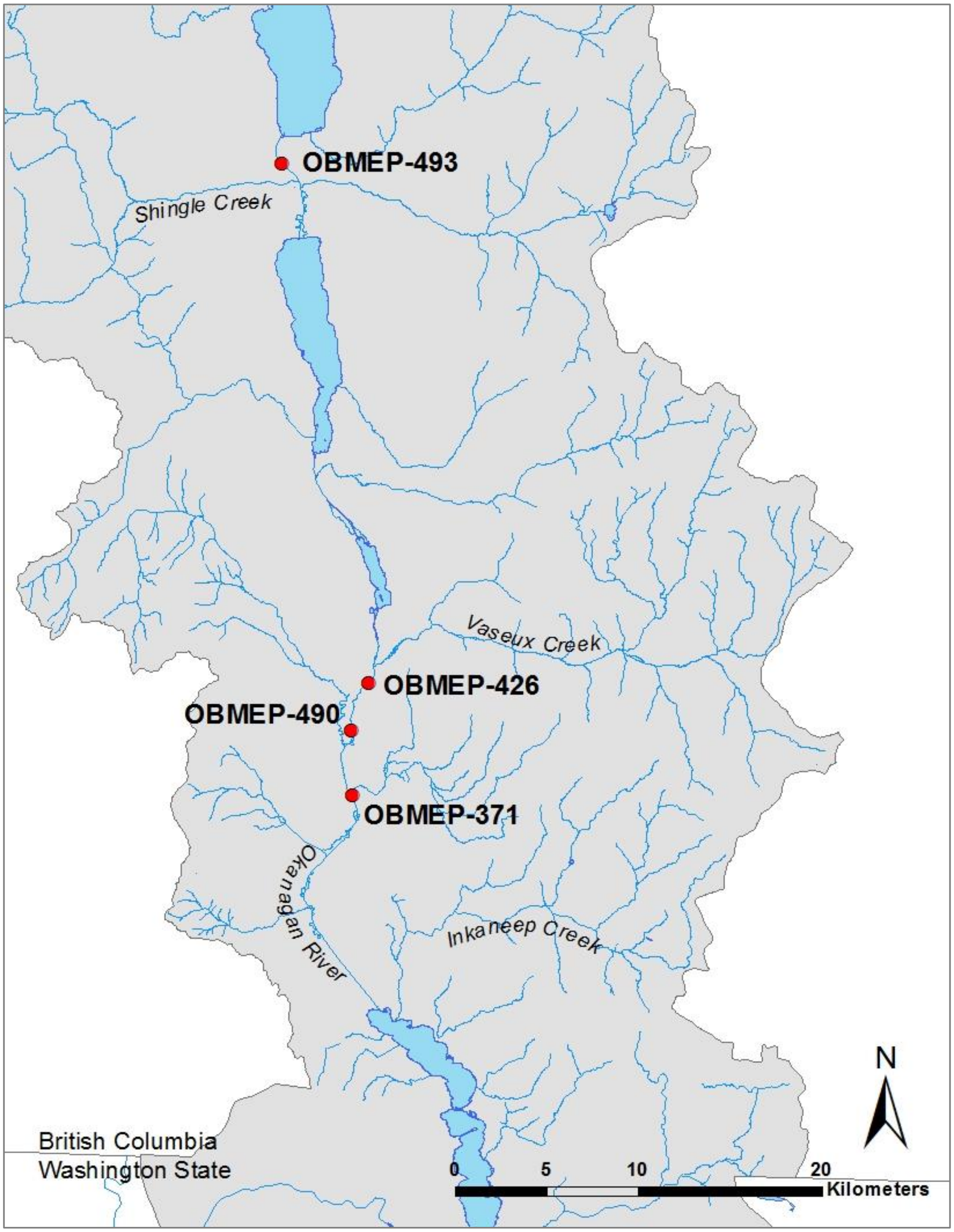
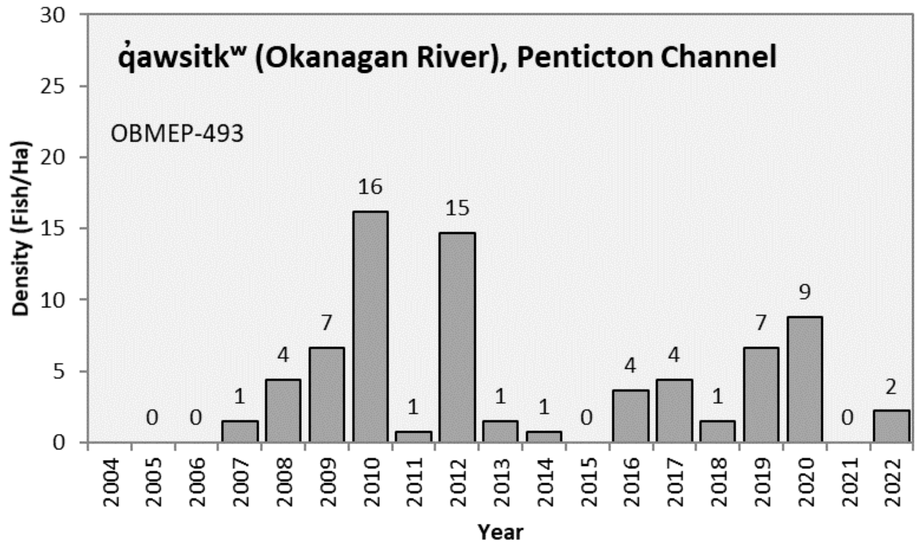
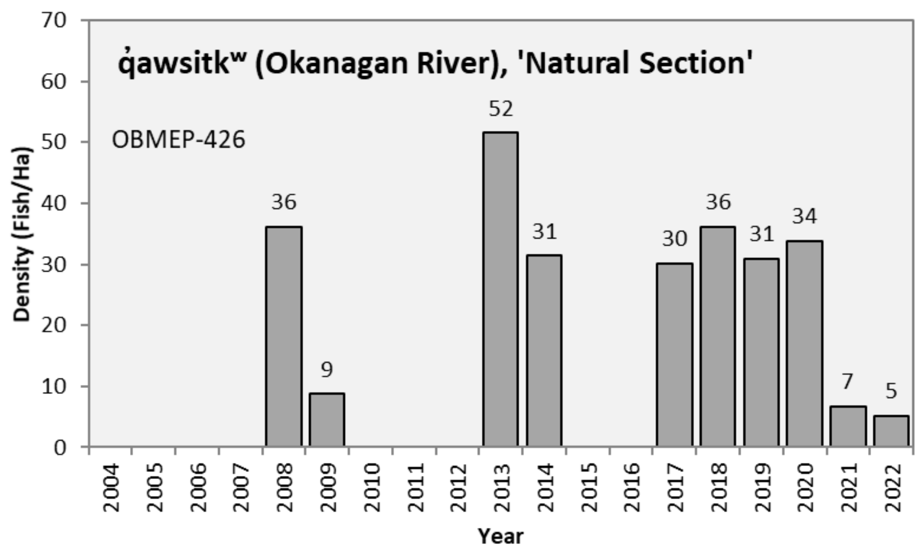


Figure C-7. Locations of annual snorkel survey sites on the British Columbia portion of the Okanagan subbasin. Rotating panel sites are not shown due to fewer years of data.



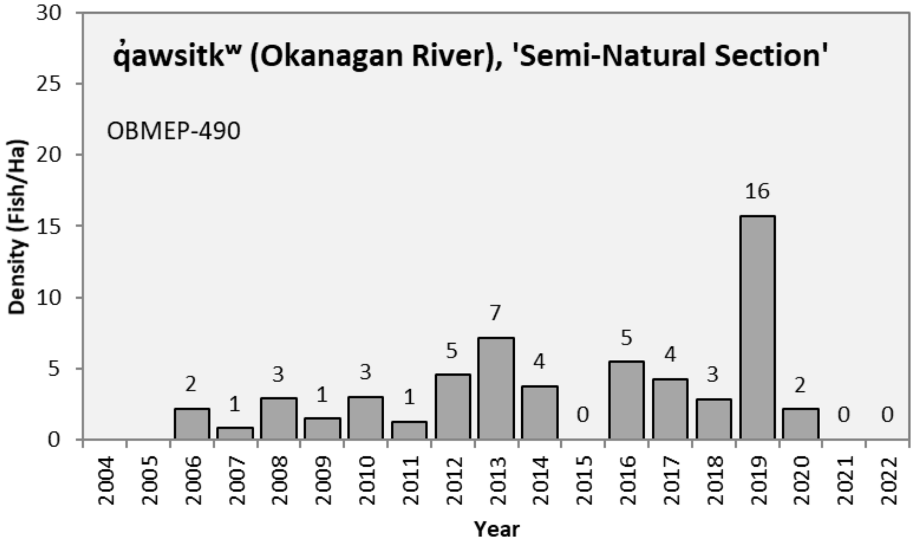
Year	# Obs.
2004	
2005	0
2006	0
2007	2
2008	6
2009	9
2010	22
2011	1
2012	20
2013	2
2014	1
2015	0
2016	5
2017	6
2018	2
2019	9
2020	12
2021	0
2022	3

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



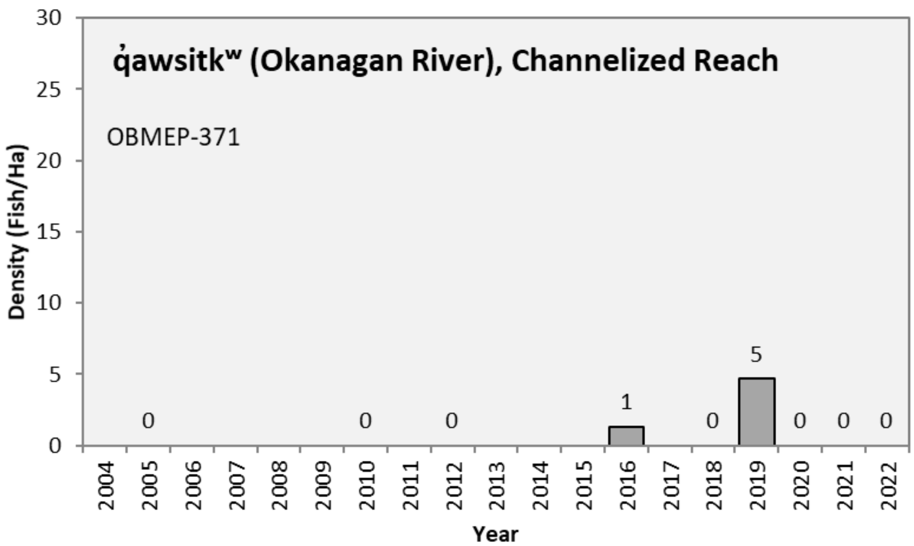
Year	# Obs.
2004	
2005	
2006	
2007	
2008	49
2009	10
2010	
2011	
2012	
2013	70
2014	36
2015	
2016	
2017	41
2018	49
2019	42
2020	46
2021	9
2022	5

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



Year	# Obs.
2004	
2005	
2006	3
2007	1
2008	4
2009	2
2010	4
2011	2
2012	7
2013	11
2014	6
2015	0
2016	8
2017	6
2018	4
2019	22
2020	3
2021	0
2022	0

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



Year	# Obs.
2004	
2005	0
2006	
2007	
2008	
2009	
2010	0
2011	
2012	0
2013	
2014	
2015	
2016	2
2017	
2018	0
2019	7
2020	0
2021	0
2022	0

Figure C-11. Observed densities of juvenile (< 300 mm) *O. mykiss* in the sq̓awsitkʷ (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)	USEPA 2001a
	< 18°C (7DADM)	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
Okanogan Basin Monitoring and Evaluation Program- Habitat Status and Trend (ID:3366)
https://www.monitoringresources.org/Document/Protocol/Details/3366

OBMEP collected hourly water temperature data in the Okanogan subbasin from 2005 through 2022, 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 sq̓awsitkʷ (Okanagan River) mainstem was also conducted through Water Survey of Canada (Environment Canada 2022). 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 ~20 cm 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 hyphorheic 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 (2005–2022) 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 2022 MWAT values generally trended above 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 2022, 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, D-3). Weekly maximum stream temperature trended similarly to MWAT, as many of high temperatures in summer 2022 exceeded the 23 °C threshold.

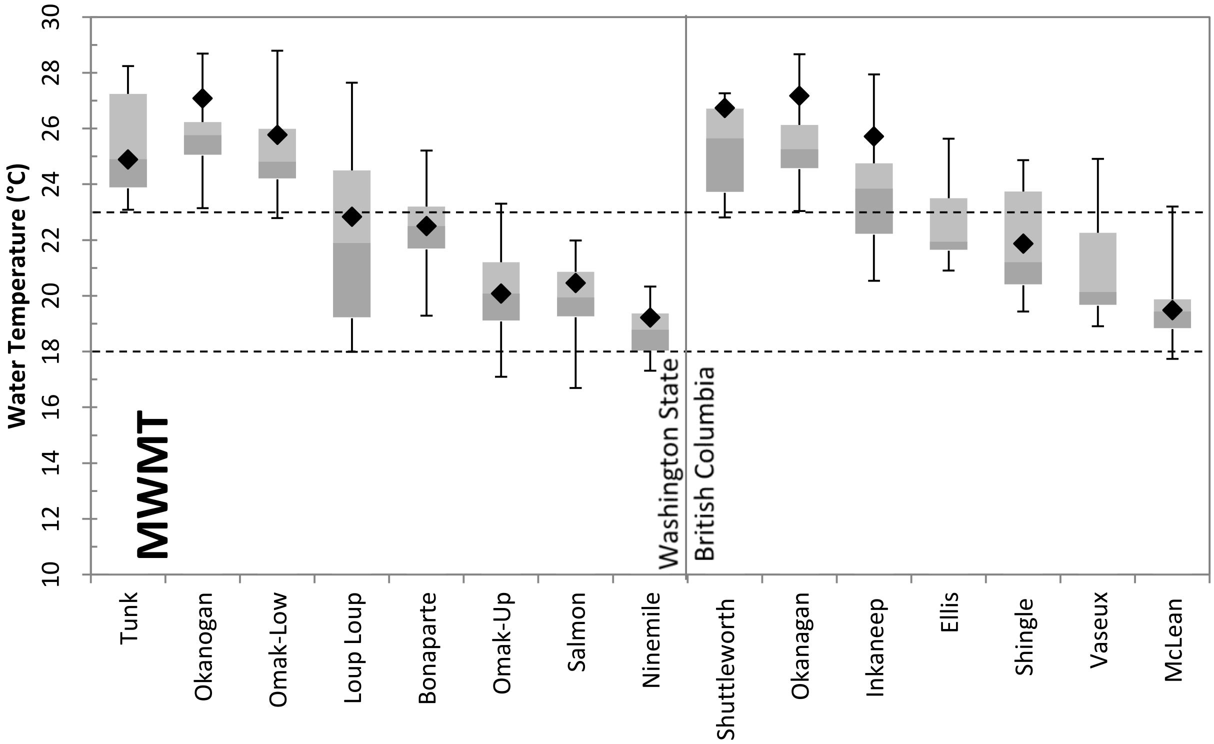


Figure D-1. Maximum weekly maximum water temperatures (MWMT) in the Okanogan subbasin from 2005–2022. Black markers are 2022 data; dashed line represents 18 and 23°C exceedance (EPA 2003).

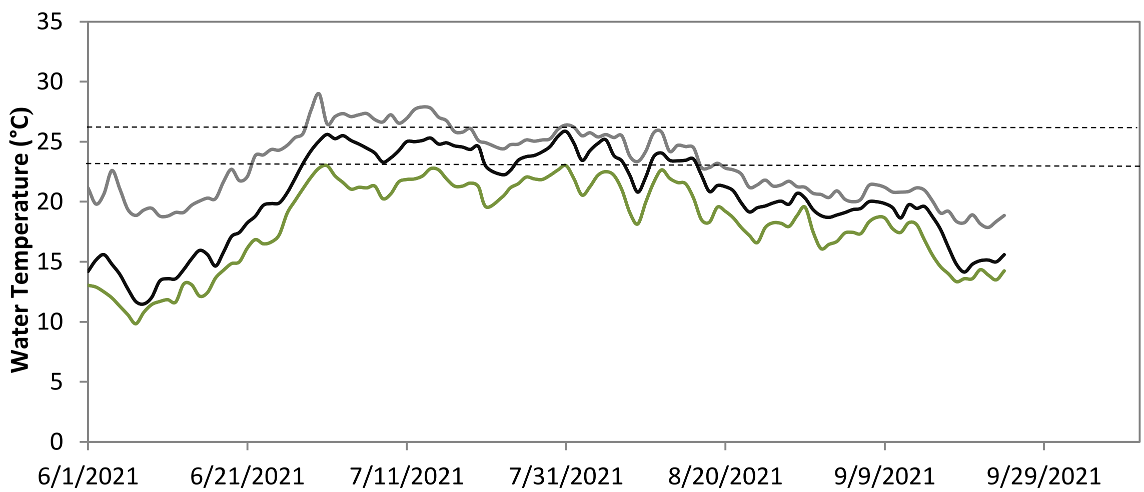


Figure D-2. USGS discharge stations mean daily temperature. Black line represents Okanogan River (Malott) 12447200, gray line represents Okanogan River (Oroville) 12439000, and green line represents Similkameen River (Nighthawk) 12442500. Dashed lines represent 23 and 26°C exceedance (EPA 2003).

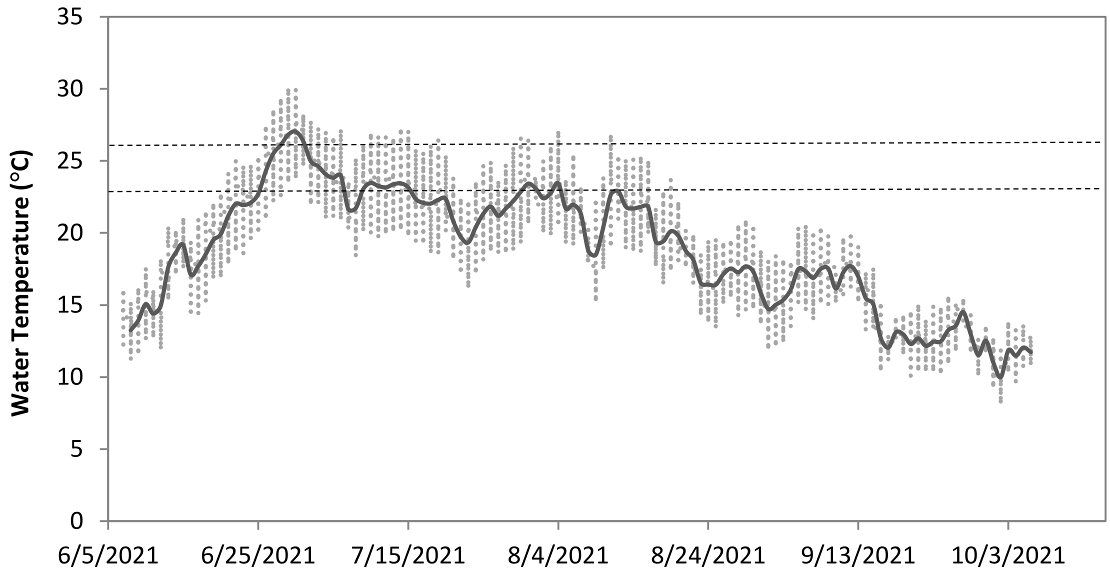


Figure D-3. Omak Creek (Omak – Low on MWMT), black line represents average daily temperature, gray dotted line represents diel fluctuations. Dashed lines represent 23 and 26°C exceedance (EPA 2003).

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, Beitinger 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 Beitinger 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 Beitinger 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 steelhead life histories and seasonal habitat use 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^2, 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 spring 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
Okanogan Basin Monitoring and Evaluation Program- Habitat Status and Trend (ID:3366)
https://www.monitoringresources.org/Document/Protocol/Details/3366

Discharge data were collected on the mainstem by the USGS and Water Survey of Canada (WSC). 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 remote servers in real-time), however some Canadian sites have archiving water level data loggers that require downloading periodically during field visits. Data analysis steps include 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. Okanogan 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 Okanogan River, and explains the different quantity of discharge in the US Okanogan mainstem (Figure E-1) compared to the Canadian mainstem (Figure E-2). The USGS has continuously operated an Okanogan mainstem stream gage at Tonasket for the last 93 years. Similarly, the WSC has operated the mainstem stream gage (or gauge) near Oliver, British Columbia for 78 years.

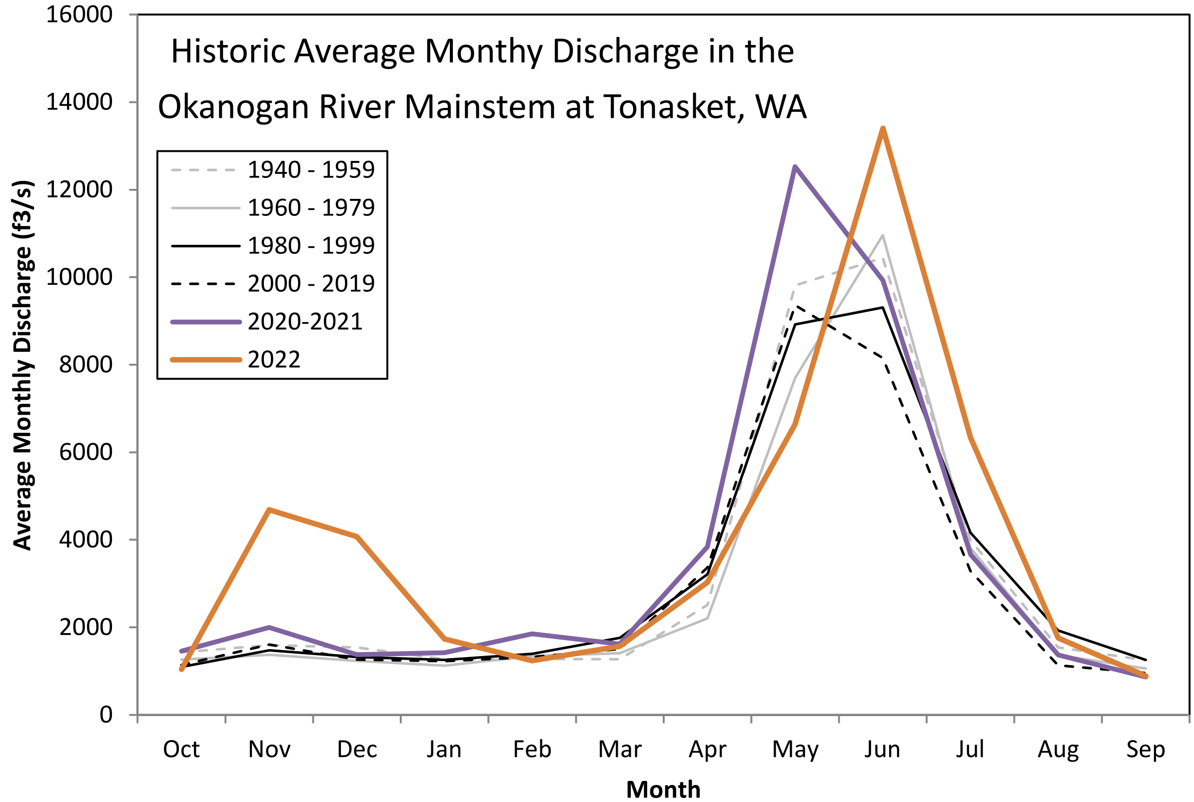


Figure E-1. Average monthly discharge of the Okanogan River at Tonasket, WA (USGS Station 12445000, Okanogan River near Tonasket, WA).

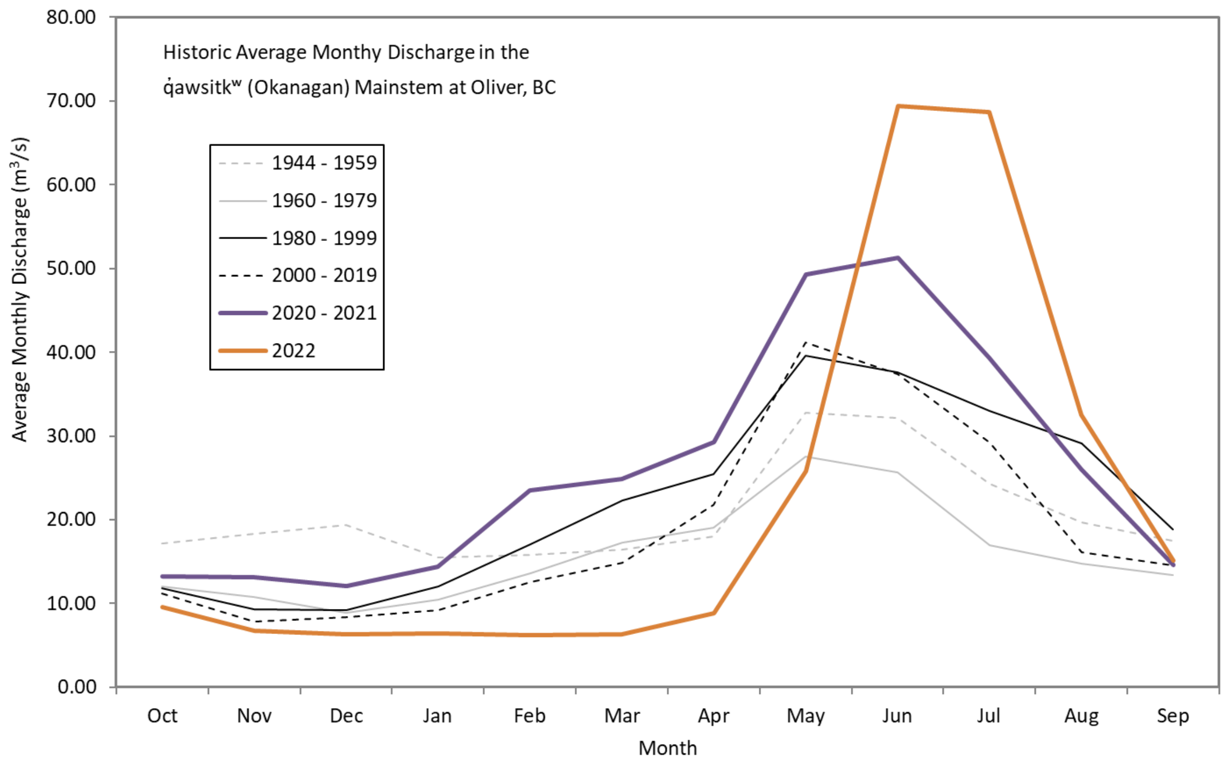


Figure E-2. Average monthly discharge of the sq̓awsitkʷ (Okanagan River) recorded near Oliver (Water Survey of Canada station 08NM085 (Environment Canada 2022).

Historic average monthly discharges for both locations are displayed by water year in Figure E-1 and Figure E-2. The historic time periods are represented in 20-year divisions for the entire span of operation and the 2022 water year is represented as a lone year beginning on October 1, 2021. In November of 2021, the Okanogan River experienced a rare fall flood event. An early snowpack in the Cascade Mountains suddenly melted after multiple strong atmospheric rivers impacted northern Washington and Southern British Columbia. The sudden run-off caused flooding in several rivers in British Columbia including the Similkameen River and consequently, the Okanogan River. Though the Okanogan River subbasin itself did not receive any precipitation from these weather events, the Okanogan River at Tonasket peaked on November 17, 2021 at 19,200 cfs, which was significant in a few ways. This fall peak was higher than either of the 2021 and 2022 spring freshet peaks as shown in Figure E-3.

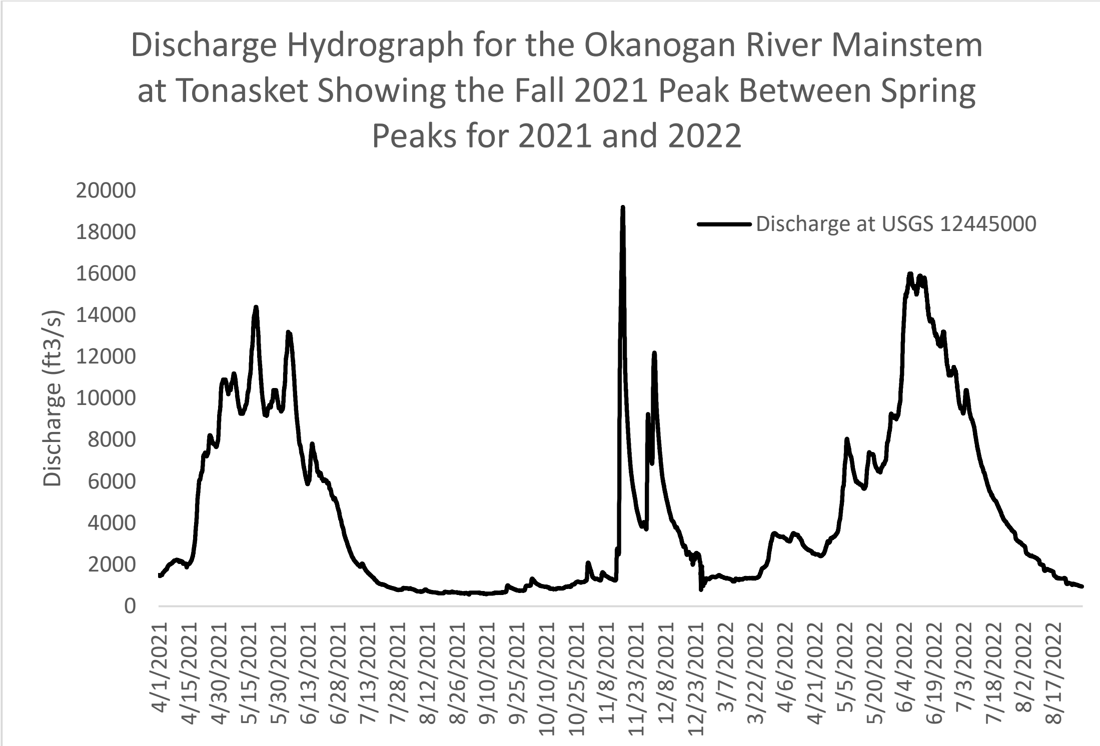


Figure E-3. Discharge hydrograph for the Okanogan River from April 1, 2021 through August 31, 2022 showing the fall 2021 peak was higher than either spring peak from 2021 or 2022 (USGS Station 12445000, Okanogan River near Tonasket, WA).

In 93 years of record, this was the highest peak ever recorded outside the normal high flow months of April to June. Only one previous year in the 93-year period experienced its annual peak in the fall, and that was 2003. In 2003, the peak was about half the magnitude as the fall peak in 2021. In the 2021 event, the upstream Canadian section of the Similkameen River had approximately double the discharge of the U.S. section. During high flow events, the Similkameen River backs up into to Palmer Lake just south of the Canadian border. Drought conditions of the last few years meant the water level in Palmer Lake was low, therefore a large portion of the Similkameen River's flood magnitude was absorbed by Palmer Lake. The fall 2021 flood event had unknown effects on summer/fall chinook and Coho spawning at that time period. The floodwaters were sediment laden and were a milky, light brown color, contrasting with the normal faint blue base flow color of the Okanogan River (Figure E-4). In August 2022, snorkel surveyors in the Okanogan and Similkameen Rivers observed an increased presence of light colored silt deposits on riverbed substrates throughout the Okanogan River basin and an increased presence of algae in the Similkameen River.

Figure E-4a. The milky, light brown color of the Similkameen flood waters backing up into the Okanogan River at the mouth of Osoyoos Lake, Oroville WA on November 18, 2021.

Figure E-4b. Flood waters in the Similkameen River canyon, Oroville, WA on November 18, 2021.

Figure E-4c. Flood waters in the town of Omak, WA on November 18, 2021.

Although the precipitation that caused the Similkameen to flood landed in the Cascade Mountains of southern British Columbia and northern Washington, none of it fell in the Okanogan River subbasin. Below-normal precipitation and snowpack in the Okanogan River subbasin resulted in a reduced spring 2022 runoff period for small streams as observed at the cooperatively operated USGS stream gages in tributaries to the Okanogan River. There were lower maximum daily mean flows and reduced summer flows for all the seven tributaries monitored with USGS stream gages. Johnson and Loup Loup Creeks each dropped to zero flow for some time during the summer. Maximum daily mean flows for these tributaries were below the 'normal' (9 years of data) range, as shown in Figure E-6. Base flows were all below the 'normal' range (E-5).

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

- Okanogan River at Malott: https://waterdata.usgs.gov/monitoring-location/12447200/
- Okanogan River near Tonasket: https://waterdata.usgs.gov/monitoring-location/12445000/
  Okanogan River at Oroville: https://waterdata.usgs.gov/monitoring-location/12439500/
  Ninemile Creek: https://waterdata.usgs.gov/monitoring-location/12438905/
- Similkameen River near Nighthawk: https://waterdata.usgs.gov/monitoring-location/12442500/
- Antoine Creek near Ellisforde: https://waterdata.usgs.gov/monitoring-location/12444290/
- Bonaparte Creek at Tonasket: https://waterdata.usgs.gov/monitoring-location/12444550/
- Johnson Creek near Riverside: https://waterdata.usgs.gov/monitoring-location/12445500/
- Omak Creek near Omak: https://waterdata.usgs.gov/monitoring-location/12445900/
- Salmon Creek above diversion near Okanogan:
- https://waterdata.usgs.gov/monitoring-location/12446995/
- Loup Loup Creek at Malott: https://waterdata.usgs.gov/monitoring-location/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

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

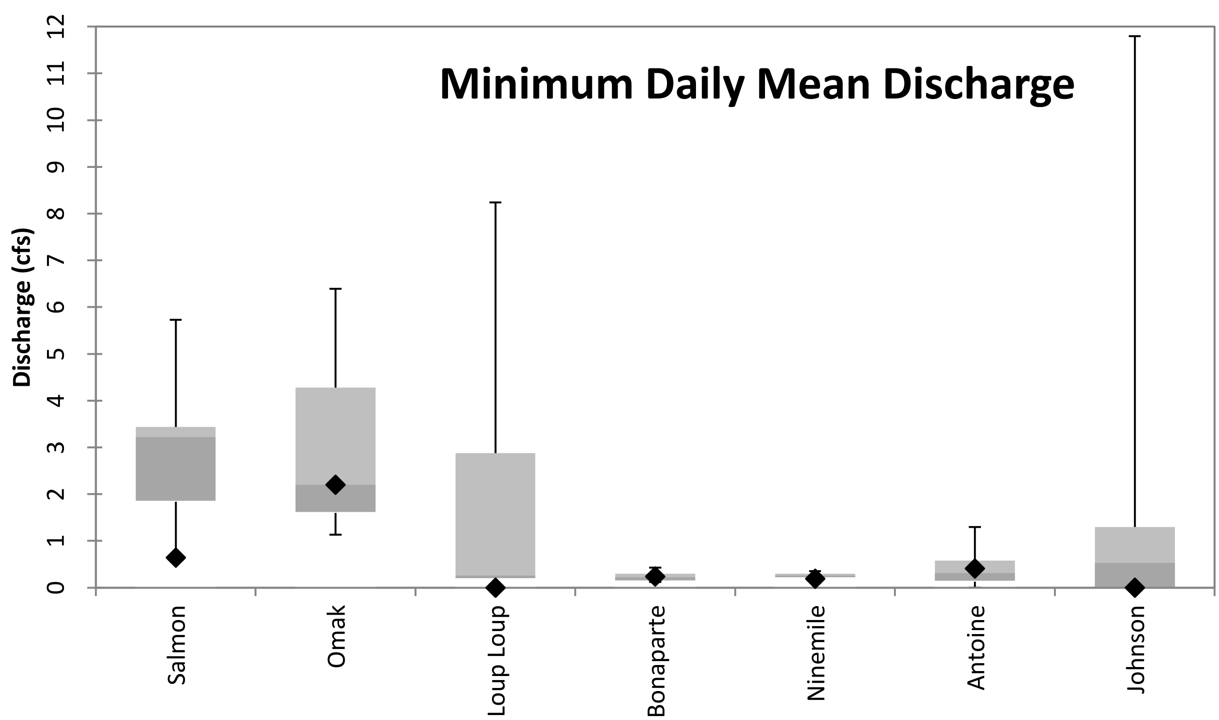


Figure E-5. Minimum Daily Mean Discharge of seven tributaries to the Okanogan River, or the mean discharge for the lowest low flow day of the year. Black diamonds are 2022 MDMD values. Boxes represent 50-75th (Q3, light grey) and 25-50th (Q2, dark grey) quartiles of the MDMD distribution during 2014-2022 while whiskers display the maximum and minimum range of low flow values.

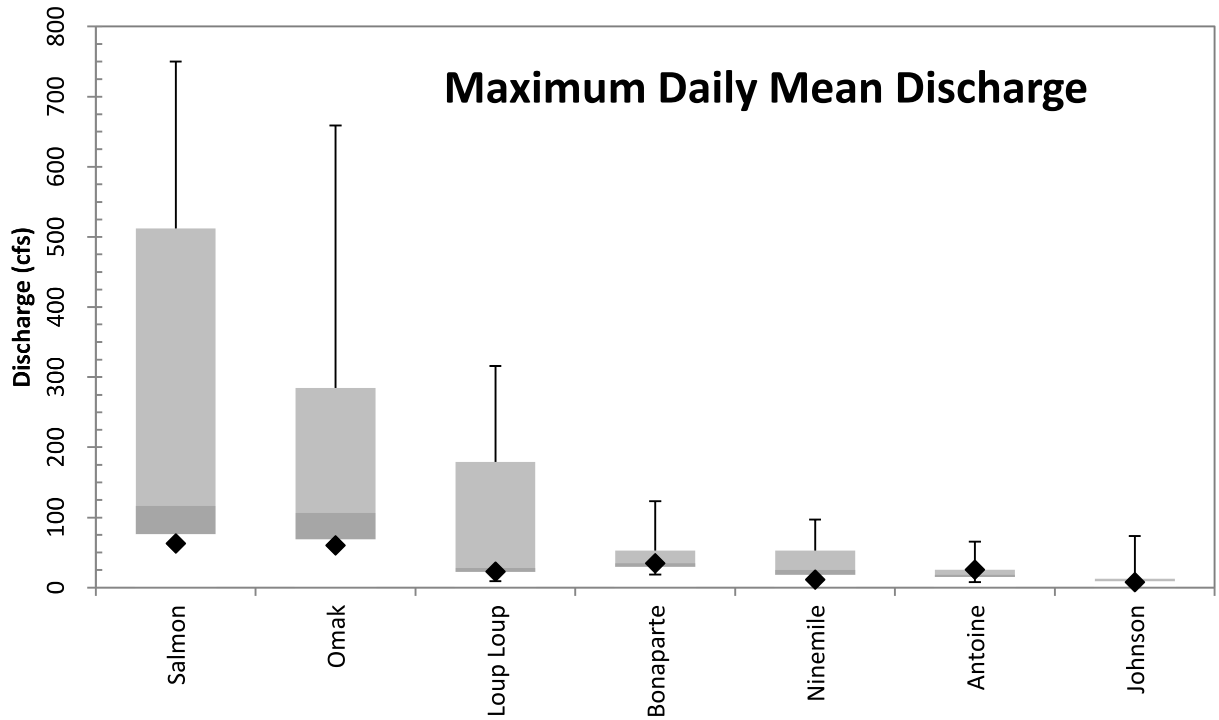


Figure E-6. Maximum Daily Mean Discharge of seven tributaries to the Okanogan River, or the mean discharge for the highest high flow day of the year. Black diamonds are 2022 MDMD values. Boxes represent 50-75th (Q3, light grey) and 25-50th (Q2, dark grey) quartiles of the MDMD distribution during 2014-2022 while whiskers display the maximum and minimum range of high flow values.

Conclusions

The climate in the Okanogan River subbasin is a cold semi-arid steppe featuring hot dry summers and cold winters. Annual precipitation ranges from 9 inches in the valley to 16 inches in higher elevations. The precipitation that falls as snow and accumulates in the higher elevations of the subbasin during the winter months is the primary source of surface water available for salmonids. During the last 10 years, drought conditions, wildfires and floods have impacted stream ecology within this region. In addition, stream restoration practitioners have worked to increase in-stream flows by developing alternatives to surface water diversions. Streamflow monitoring is critical to understanding how climate and human use variables impact water availability.

Habitat improvement projects focusing on the quantity of water in streams will continue to be an important focus, particularly during the summer base flow period. Maintaining connectivity of smaller tributaries with the mainstem Okanogan River will allow for increased accessibility, survival and production. 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, summer base flows can constrain juvenile production and survival; such is the case in Ninemile and Tonasket Creeks and surface water diversions can exacerbate this condition as is the case in Bonaparte, Johnson and Loup Loup Creeks. 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 course 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

Okanogan Basin Monitoring and Evaluation Program- Habitat Status and Trend (ID: 3366)
https://www.monitoringresources.org/Document/Protocol/Details/3366
Method: Bulk Streambed Sediment Sampling – Field (ID:5479)
https://www.monitoringresources.org/Document/Method/Details/5479
Method: Bulk Streambed Sediment Sampling – Lab (ID:6918)
https://www.monitoringresources.org/Document/Method/Details/6918

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 2022, 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 16 mm 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 2.0 mm.

Table F-1. Okanogan River tributary, sample size *n*, and average percent substrate finer than specified size class for the period 2015-2022. 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	106	0.17	0.12	0.11	0.01	60
Okanogan River	49	0.17	0.13	0.12	0.00	52
Salmon Creek	24	0.18	0.12	0.11	0.00	53
Tunk Creek	17	**0.25**	**0.18**	**0.17**	0.01	28
Antoine Creek	12	**0.27**	**0.20**	**0.18**	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	**0.33**	**0.25**	**0.21**	0.01	30
Similkameen River	8	0.12	0.10	0.09	0.00	65
Aeneas Creek	7	**0.47**	**0.41**	**0.39**	**0.05**	2
Stapaloop Creek	6	0.17	0.12	0.11	0.01	56
Trail Creek	6	**0.22**	0.17	**0.15**	0.01	32
Wanacut Creek	3	**0.20**	0.14	0.13	0.01	41
Swimpkin Creek	2	**0.20**	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 Creeks) or had relatively high fractions of medium and coarse sand (Bonaparte Creek). With the exception of the samples from Aeneas and Antoine Creeks, 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.

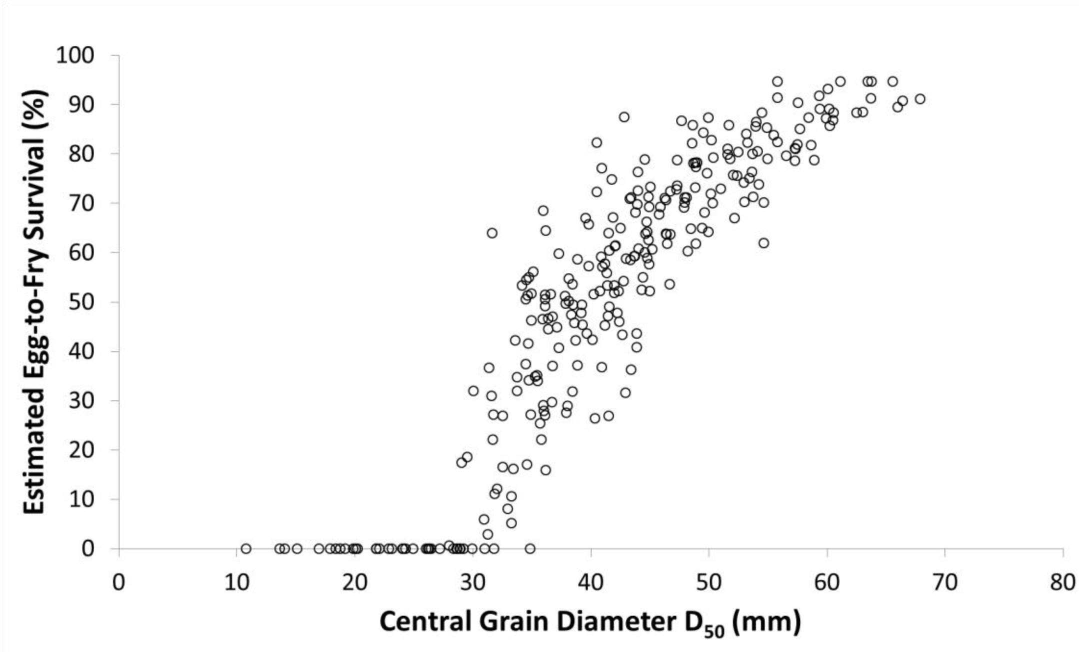


Figure F-1. Estimated egg-to-fry survival and central grain diameter (D50). Note that 36 of 274 samples (15%) have an estimated survival of 0%.

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 Creeks 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.

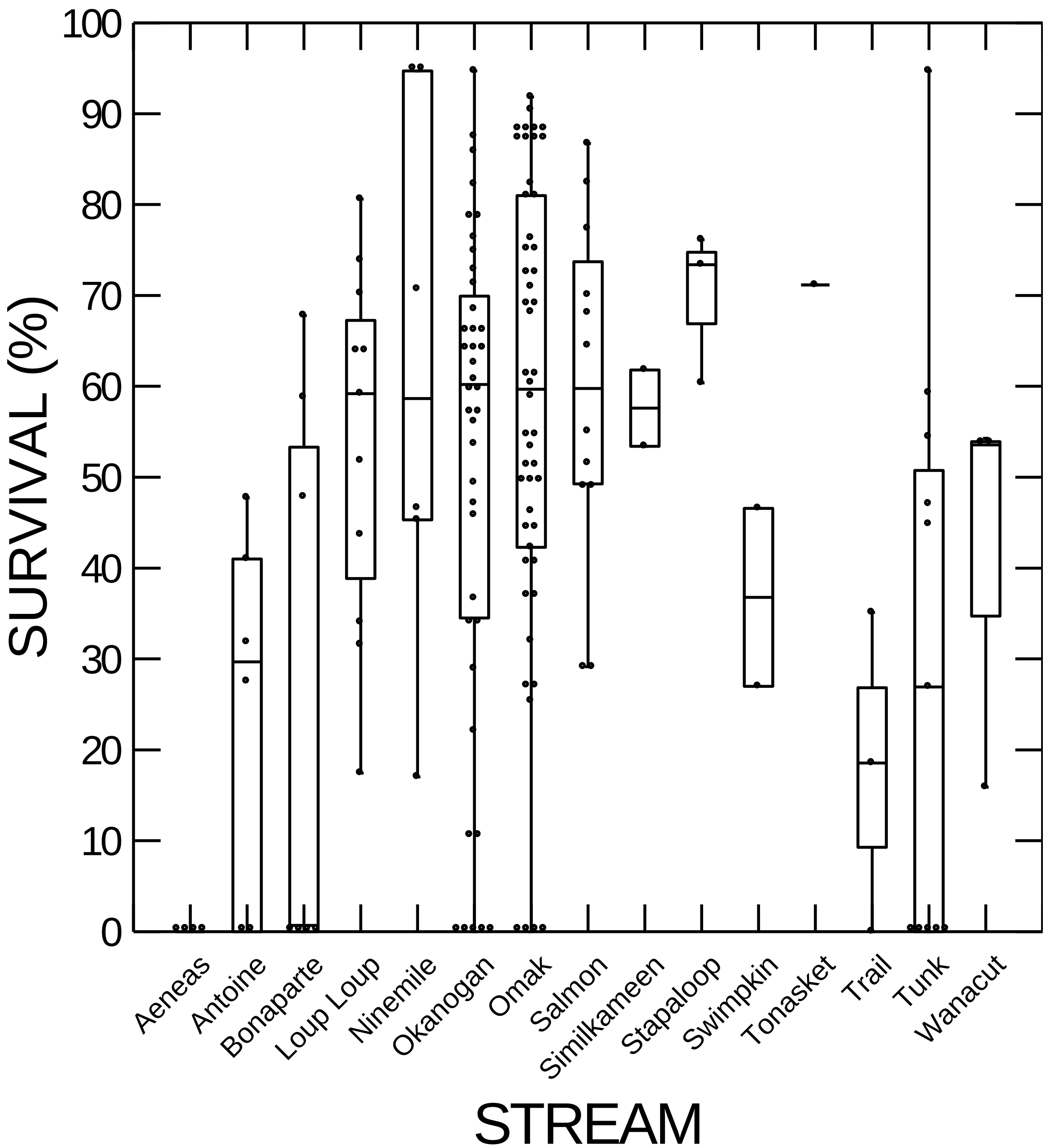


Figure F-2. Estimated egg-to-fry survival by named watershed. Horizontal bars are the median value, upper and lower bound of the boxed are the 25th and 75 percentile and whiskers are maximum and minimum values. Individual sample values are displayed as hollow dots.

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 < 0.85 mm). 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_{84} of 33–62 mm, 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.