Okanogan Basin Monitoring and Evaluation Program

2017 Annual Progress Report

BPA Project # 2003-022-00

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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. The Okanogan Basin Monitoring and Evaluation Program (OBMEP) conducted status and trend monitoring from 2004 through 2017 to evaluate viable salmonid population (VSP) criteria (abundance, productivity, spatial structure, and diversity) and threats to habitat of salmonids 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 2017, it was estimated that 1,044 summer steelhead (929 hatchery origin and 115 natural origin) spawned in the Okanogan subbasin. Over the past 13 years of monitoring (2005 through 2017), the average number of adult steelhead spawners in the Okanogan subbasin was 1,711 (geomean = 1,592). The average number of natural-origin spawning steelhead was 311 (geomean = 272). The abundance of natural-origin steelhead spawning in the Okanogan River subbasin has increased since data collection began in 2005; unfortunately the minimum abundance threshold for ESA-recovery for natural origin spawners (1,000) in the combined transboundary population was not reached. Distribution of adult steelhead spawning within the subbasin has varied by survey reach, subwatershed, origin (natural or hatchery), and year, and was largely influenced by snowpack and spring discharge patterns.

An estimated 28,991 (95%CL=19,919 to 38,063) juvenile steelhead outmigrated from creeks in the Washington State portion of the subbasin in 2017. The majority of juvenile steelhead outmigrants were produced in Salmon Creek (20,730 ± 6,700), Lower Omak Creek (4,590 ± 1,359), and Loup Loup Creek (1,984 ± 433). Estimates of outmigrants in 2017 were more than 2-fold higher than the three previous years.

Habitat monitoring included collection of eight physical habitat metrics at 25 fixed and 25 rotating panel sites. This protocol was complemented with a rapid assessment protocol, designed to quickly collect the most essential inputs for the Ecosystem Diagnosis and Treatment (EDT) model in reaches that were not covered by the fixed or rotating panel sites. Data collection also included water quality (1 metric), surface water temperature (22 locations), stream discharge (11 gaging stations), and benthic macroinvertebrates (285 metrics) at sites throughout the subbasin corresponding with fixed/rotating panel and rapid assessment monitoring locations. In 2017, peak discharge in the mainstem Okanogan River was relatively large compared with historic averages. Many tributaries to the Okanogan River, including Omak, Salmon, and Loup Loup Creeks, experienced extremely large runoffs, which washed out PIT tag antennas, bridges and roads. Later in the summer, weekly average temperature observations in subwatersheds and the mainstem were generally 'normal' (within the 12 year Q2-Q3 range). 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 2015 and includes data collected through 2013. Status and trend results suggest relatively stable habitat capacity and abundance performance for both adults and juveniles. Between 2009 and 2013, modeled adult habitat capacity decreased by 2% and adult abundance decreased by 19%. However, because the

quality and quantity of available data changed between model runs, the results do not necessarily indicate that habitat condition has degraded.

Since 2004, OBMEP has successfully delivered on all of its contractual obligations and beyond, expanding into areas such as action effectiveness inference and methods for standardizing spatial scale currency. Data collection includes pertinent data useful for in-season decisions regarding harvest, hatchery management, and habitat action implementation. 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 have 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 and make those data readily available to agencies for use in more comprehensive, broad-scale analyses.

Acknowledgements

The Colville Confederated Tribes would like to acknowledge Edward Berrigan, Oly Zacherle, Mike Miller, Jack Roy, Oliver Pakootas, Jordan Pakootas, Wes Tibbits, and Brooklyn Hudson who helped in collecting, entering, or compiling field data for this report. Additionally, this document benefitted from insightful reviews from Casey Baldwin. Thanks also to ICF, Sitka Technology Group, Washington State Department of Ecology, Washington Department of Fish and Wildlife, and the United States Geological Survey (USGS) for their collaboration on projects and data collection efforts. Acknowledgements also go to Richard Townsend and John Skalski from the University of Washington Columbia Basin Research for reviewing, providing comments, and assisting in the development of juvenile abundance monitoring statistics. This work would not be possible without the cooperation of the many private landowners who have provided river access and enabled us to collect data within the Okanogan subbasin.

The Okanagan Nation Alliance Fisheries Department would like to acknowledge the Osoyoos Indian Band (OIB), the Penticton Indian Band (PIB), the townships of Oliver, Okanagan Falls and Penticton, the Lezard family (of PIB), the Baptiste family (of OIB), the Thompson family (of OK Falls), The Nature Trust of BC, Elkink Ranch, Bobtail Ranch and the South Okanagan Rehabilitation Center for Owls for access granted to sites of this ongoing study. Acknowledgements also go to Jamison Squakin, Molly Teather, Natasha Lukey, Camille Rivard-Sirois, Dave Tom, Zoe Eyjolfson, Sheena Hooley, Colette Louie, Chelsea Mathieu, Nick Yanew, Paul Snow, Belinda Kruger, and Kari Alex for providing valuable technical assistance throughout the 2017 study.

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Contents

1.0 Introduction

The Okanogan Basin Monitoring and Evaluation Program (OBMEP) conducted status and trend monitoring from 2004 through 2017 to collect and analyze fisheries data corresponding to adult and juvenile abundance, as well as, spatial and temporal distribution throughout the Okanogan[1] subbasin. Much of 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 Okanagan Nation Alliance (ONA) began coordinating on this project in the Canadian portion of the subbasin in 2005. Continuing effort is put into maintaining consistent sampling programs on both sides of the border through frequent meetings and cross-training to maintain methodologies for collecting biological and habitat data.

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 give way to a low gradient mainstem river before entering the Columbia River near the town of Brewster, WA.

The subbasin supports a stable population of summer-fall Chinook Salmon *Oncorhynchus tshawytscha*, a greatly expanding number of Sockeye Salmon *Oncorhynchus nerka*, a threatened population of summer steelhead, and occasional observations of spring Chinook Salmon, Bull Trout *Salvelinus confluentus* and Coho Salmon *Oncorhynchus kisutch*. 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, cooler water tributaries to the Okanogan offer additional habitat for steelhead, but access is often limited by insufficient discharge, natural barriers and man-made

[1] Spelled 'Okanogan' in the U.S. and 'Okanagan' in Canada; may be used interchangeably in this document.

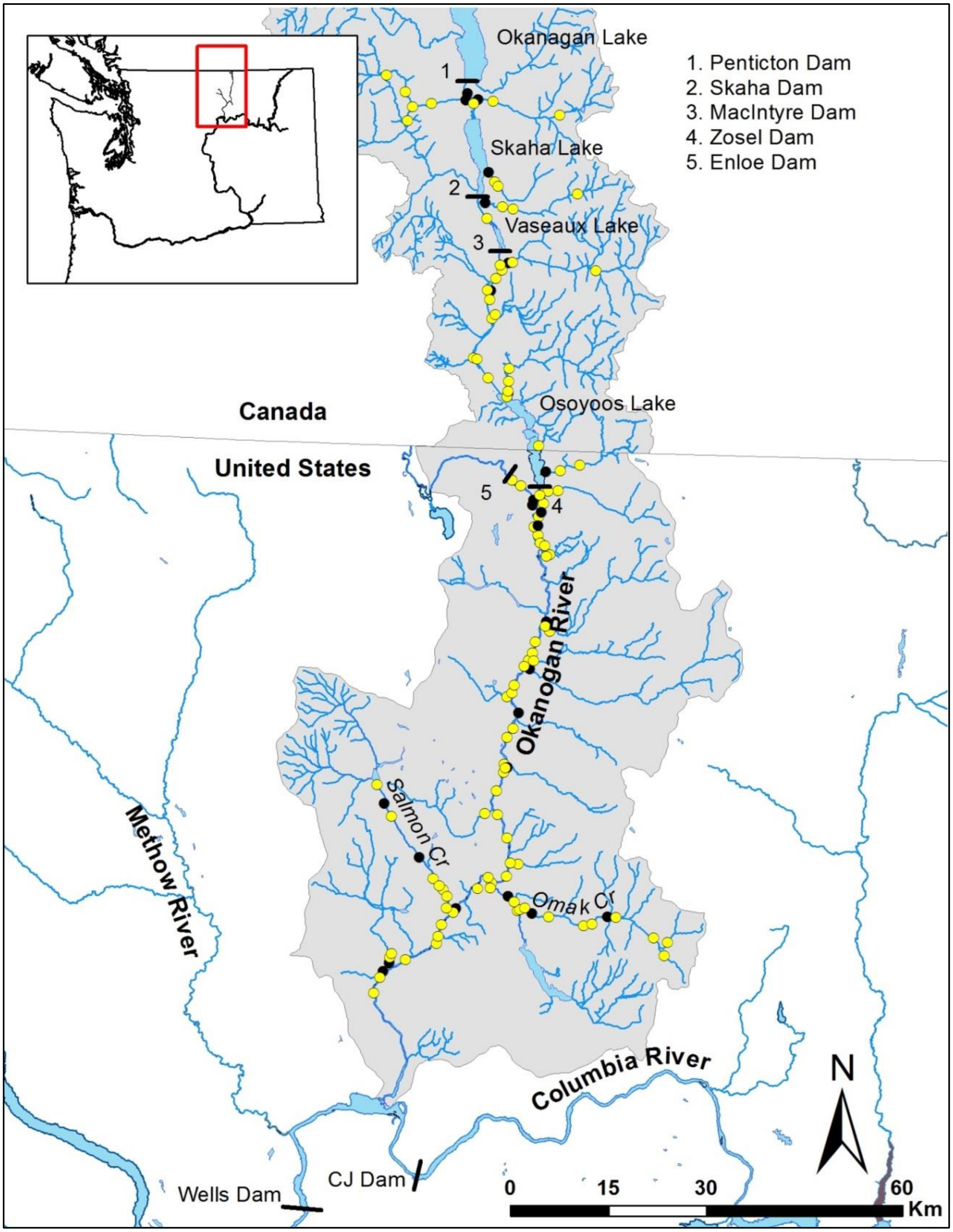


Figure 1. Study area, the Okanogan subbasin in north-central Washington State and southern British Columbia. Markers signify OBMEP habitat monitoring sites; black markers represent annual panel sites sampled every year and yellow markers represent rotating panel sites sampled every four years.

impediments. 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 required for fisheries research activities to occur. Economic activity in the subbasin is centered on fruit crops, ranching, agriculture, tourism, mining, and timber harvest. In this relatively arid environment, a complex system of fisheries and water management requires coordination between many local stakeholders, state (provincial) agencies, federal agencies, Tribes and First Nations, from both the United States and Canada.

In the Canadian portion of the Okanagan subbasin, man-made barriers are major constraints to current salmonid migrations. Dams exist at the outlets of Canadian Okanagan mainstem lakes including, suwiẇs (Osoyoos Lake), np'əxƚpiw' (Vaseux Lake), q̇awstik̓ʷt (Skaha Lake), and kƚusxnitkʷ (Okanagan Lake). In 2009, the outlet dam at np'əxƚpiw' (Vaseux Lake), known as McIntyre Dam, was refitted to allow fish passage. Currently, the kƚusxnitkʷ (Okanagan Lake) outlet dam at snpintktn (Penticton) is the upstream barrier for all anadromous salmon species and the q̇awstik̓ʷt (Skaha Lake) outlet underwent improvements for fish passage in 2014. Anadromous salmonids have previously occupied the entire q̇awsitkʷ (Okanagan River) system (Ernst and Vedan 2000).

Goals and Objectives

The OBMEP conducted status and trend monitoring in the Okanogan River subbasin to evaluate Upper Columbia River summer steelhead population in support of the following Bonneville Power Administration (BPA) Fish and Wildlife management sub-strategies[2]:

1. Assess the status and trend of natural and hatchery origin abundance of fish populations for various life stages.
2. Assess the status and trend of juvenile abundance and productivity of natural origin fish populations.
3. Assess the status and trend of spatial distribution of fish populations.
4. Assess the status and trend of diversity of natural and hatchery origin fish populations.

This project also conducted status and trends monitoring to evaluate habitat in the Okanogan subbasin used by Endangered Species Act (ESA) Listed Upper Columbia River steelhead and summer/fall Chinook in support of the following BPA Fish and Wildlife sub-strategy[3]:

5. Monitor and evaluate tributary habitat conditions that may be limiting achievement of biological performance objectives.

OBMEP was designed to monitor status and trends of both biological and physical habitat parameters. Protocols were developed to assess viable salmonid population (VSP) criteria (abundance, productivity, diversity, and spatial structure) of adult and juvenile Upper Columbia River summer steelhead in the Okanogan River and its tributaries. Although data and analysis derived from OBMEP may help to address effectiveness of habitat or hatchery projects, identifying causal mechanisms was not the intent of the original program research questions.

[2] Fish Population RM&E https://www.cbfish.org/ProgramStrategy.mvc/Summary/1
[3] Tributary Habitat RM&E https://www.cbfish.org/ProgramStrategy.mvc/Summary/3

2.0 Methods

2.1 Fish Population Status and Trend Monitoring

Adult Steelhead Monitoring

OBMEP - Adult Abundance - Redd Surveys (ID:192)
https://www.monitoringresources.org/Document/Protocol/Details/192
OBMEP - Adult Abundance - Adult Weir and Video Array (ID:6)
https://www.monitoringresources.org/Document/Protocol/Details/6
Estimate the abundance and origin of Upper Columbia steelhead (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, including redd surveys, underwater video observations, Passive Integrated Transponder (PIT) tag interrogation sites, and adult weir traps. Spawner abundance estimates were determined for each unique 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

In recent years, instream juvenile abundance monitoring occurred through the implementation of an Okanogan tributary-focused electrofishing and PIT tag mark-recapture study in the Washington State portion of the subbasin. To estimate outmigration, OBMEP operated a rotary screw trap from 2004 through 2011 on the mainstem Okanogan River, however, very few captures of naturally produced steelhead yielded highly variable and unreliable estimates for that species. Challenges to derive meaningful outmigration estimates required a shift in methodology. From 2014 onward, outmigration was calculated from natural-origin juvenile steelhead PIT tagged instream during mark-recapture events and subsequently detected within the subbasin and downriver. In 2017, 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. These creeks represent ~85% of all tributary steelhead spawners. The remaining three creeks (Johnson, Wildhorse Spring, and Antoine Creeks) were not sampled due to lack of access, time, or available staff. Three subwatersheds were also sampled in the British Columbia side of the subbasin, including Inkaneep, Shuttleworth, and 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 2017. In this document, snorkel survey metrics have been presented as density of juvenile *O. mykiss*/m^2, 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

OBMEP - Habitat Monitoring (ID:9)
https://www.monitoringresources.org/Document/Protocol/Details/9
OBMEP – Rapid Habitat Assessment (ID:8)
https://www.monitoringresources.org/Document/Protocol/Details/8
Method: Ecosystem Diagnosis and Treatment (EDT) v1.0
https://www.monitoringresources.org/Document/Method/Details/3973

Two data collection protocols and a habitat modeling methodology are utilized by OBMEP on a four-year data collection and analysis cycle. The supporting protocols and methods are detailed in the web links listed above. The transect-based OBMEP Habitat Monitoring protocol is applied at 50 habitat monitoring sites (25 annual panel sites, 25 rotating panel sites) per year for the entire Okanogan subbasin and covers 125 sites including 128 reaches in the U.S. portion of the Okanogan subbasin in each four-year sampling cycle. The GIS mapping-based OBMEP Rapid Habitat Assessment protocol is applied at reaches not sampled using the OBMEP Habitat Monitoring protocol and should occur at least once within each four year cycle.

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

3.0 Results

3.1 Fish Population Status and Trend Monitoring

Adult Steelhead Monitoring

OBMEP 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 2017, it was estimated that 1,044 summer steelhead (929 hatchery origin and 115 natural origin) spawned in the Okanogan subbasin (Table 1). From 2005-2017, the average estimated number of steelhead spawners in the subbasin was 1,711 (geomean=1,592). The average number of natural-origin spawning steelhead was 311 (geomean=272).

The abundance of natural-origin steelhead spawning in the Okanogan River subbasin has increased since data collection began in 2005, unfortunately the minimum abundance threshold for ESA-recovery for natural origin spawners (1,000) in the combined transboundary population was not reached (Figure 2). The proportion of hatchery origin spawners (pHOS) from 2005 through 2013 averaged 0.85, but decreased to 0.74 for 2014 through 2017. The 13-year (2005-2017) average pHOS was higher for the mainstem Okanogan River (0.90) compared with tributaries (0.73).

Table 1. Estimated summer steelhead spawner abundance in the Okanogan subbasin, 2005-2017.

Year	Hatchery-Origin	Natural-Origin	Total	pHOS
2005	1,080	146	1,226	0.88
2006	702	197	899	0.78
2007	1,116	152	1,268	0.88
2008	1,161	225	1,386	0.84
2009	1,921	212	2,133	0.90
2010	2,768	728	3,496	0.79
2011	1,341	333	1,674	0.80
2012	2,475	327	2,802	0.88
2013	1,687	250	1,937	0.87
2014	838	518	1,356	0.62
2015	1,009	452	1,461	0.69
2016	1,175	391	1,566	0.75
2017	929	115	1,044	0.89
Geomean	1,289	311	1,711	0.75
Mean	1,400	272	1,592	0.88

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, such as the reach below Zosel Dam near the town of Oroville, WA (see Table A-3, Appendix A). On average, Omak (228) and Salmon (163) creeks host the most spawners followed by Bonaparte Creek (96) (Table A-3). The proportion of steelhead spawning in many of the tributaries to the Okanogan River appeared to be regulated in part by stream discharge, which in turn was influenced by winter snowpack, spring precipitation in small creeks, runoff timing, and surface water diversions. Detailed spawning distribution data in the British Columbia portion of the subbasin is limited. Determining total abundance of spawners remains difficult, but improved with the installation of a PIT tag antenna array (OKC) above suwiw̓s (Osoyoos Lake) and representative marking of returning adults at Priest Rapids Dam (Project # 2010-034-00). A relatively small proportion of the total adult steelhead pass into British Columbia, averaging 2.7% for the past five years (2013-2017); however, average pHOS was much lower in British Columbia (0.34) than Washington State (0.78) during that timeframe.

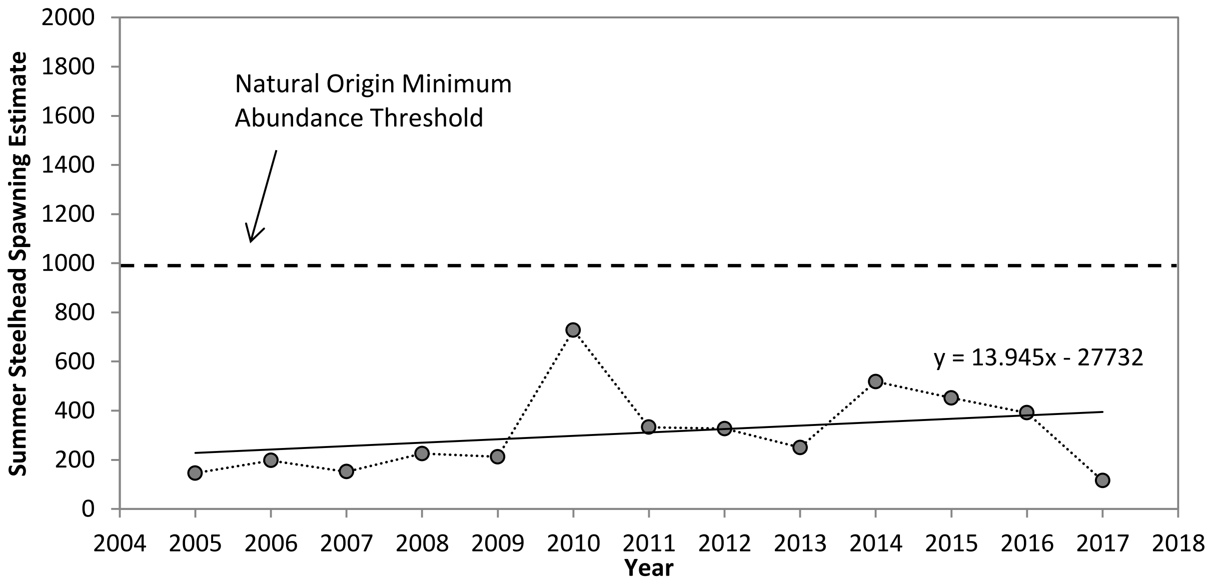


Figure 2. Estimated number of natural-origin summer steelhead spawning in the Okanogan River subbasin, 2005 - 2017.

Juvenile Salmonid Monitoring

Instream Abundance (Electrofishing)

During sampling in the fall of 2017, the majority of juvenile *O. mykiss* were found in Salmon Creek, lower and upper Omak Creek, Loup Loup and Ninemile Creeks. Similar results were found across past sample years (2014-2017). Three streams in the British Columbia portion of the subbasin akskʷəkʷant (Inkaneep Creek), akɬxʷminaʔ (Shingle Creek), and Shuttleworth Creek) were sampled in 2016 and 2017 using this method. Subwatershed abundance metrics and trend information are presented in Table 2 and further detailed 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.

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

Age-0 *O. mykiss*				
Tributary	2014	2015	2016	2017
Salmon Cr	46,434 ± 8,602	56,501 ± 5,945	61,234 ± 7,383	27,717 ± 3,065
Lower Omak Cr	29,136 ± 2,145	27,671 ± 3,921	29,243 ± 4,321	4,064 ± 1,755
Upper Omak Cr	-	-	13,104 ± 1,811	10,510 ± 4,311
Loup Loup Cr	19,787 ± 1,643	6,597 ± 593	13,191 ± 1,713	728 ± 181
Ninemile Cr	6,177 ± 1,289	3,030 ± 965	6,705 ± 1,613	5,304 ± 1,763
Bonaparte Cr	3,149 ± 396	989 ± 362	2,532 ± 582	208 ± 125
Tonasket Cr	2,192 ± 716	0	7,911 ± 745	5,684 ± 497
Tunk Cr	0	0	1,412 ± 358	212 ± 131
Aeneas Cr	111 ± 18	15 ± 2	1,204 ± 131	697 ± 102
Wanacut Cr	0	0	501 ± 95	3,407 ± 793
Johnson Cr	-	-	-	-
Antoine Cr	-	-	-	-
Wildhorse Sp Cr	-	-	-	-
Lower Shingle Cr	-	-	15,293 ± 7,485	7,112 ± 4,639
Upper Shingle Cr	-	-	13,989 ± 9,632	6,593 ± 1,703
Shatford Cr	-	-	53,022 ± 16,235	104,611 ± 30,251
Inkaneep Cr	-	-	21,304 ± 7,284	2,327 ± 1,480
Shuttleworth Cr	-	-	9,207 ± 2,190	16,078 ± 7,211

Age-1+ *O. mykiss*				
Tributary	2014	2015	2016	2017
Salmon Cr	31,498 ± 2,379	31,630 ± 2,461	50,621 ± 3,931	38,556 ± 2,136
Lower Omak Cr	7,581 ± 836	4,488 ± 387	7,252 ± 779	7,264 ± 812
Upper Omak Cr	-	-	25,697 ± 1,633	16,820 ± 1,642
Loup Loup Cr	2,177 ± 267	1,282 ± 111	2,422 ± 683	2,722 ± 295
Ninemile Cr	2,136 ± 333	3,017 ± 367	2,141 ± 683	6,971 ± 673
Bonaparte Cr	137 ± 22	273 ± 46	913 ± 88	437 ± 104
Tonasket Cr	526 ± 51	9 ± 0	69 ± 0	1,423 ± 71
Tunk Cr	164 ± 26	0	142 ± 53	138 ± 19
Aeneas Cr	138 ± 26	56 ± 29	74 ± 37	112 ± 23
Wanacut Cr	0	0	21 ± 0	2,113 ± 177
Johnson Cr	-	-	-	-
Antoine Cr	-	-	-	-
Wildhorse Sp Cr	-	-	-	-
Lower Shingle Cr	-	-	6,532 ± 3,322	13,515 ± 6,622

Upper Shingle Cr	-	-	2,797 ± 1,105	2,286 ± 366
Shatford Cr	-	-	4,756 ± 148,309	9,465 ± 3,863
Inkaneep Cr	-	-	2,200 ± 1,457	4,556 ± 2,368
Shuttleworth Cr	-	-	3,314 ± 1,165	2,658 ± 798

Outmigration

Based on remote PIT tagging, an estimated total of 28,991 (95%CL=19,919 to 38,063) juvenile steelhead outmigrated from defined sample areas. The number of outmigrants in 2017 was more than 2-fold higher in 2017 than for previous years (Table 3). Production from outside the sampling area, including the mainstem Okanogan River, Similkameen River, or British Columbia was not factored into those estimates; therefore the sum is not a population-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.

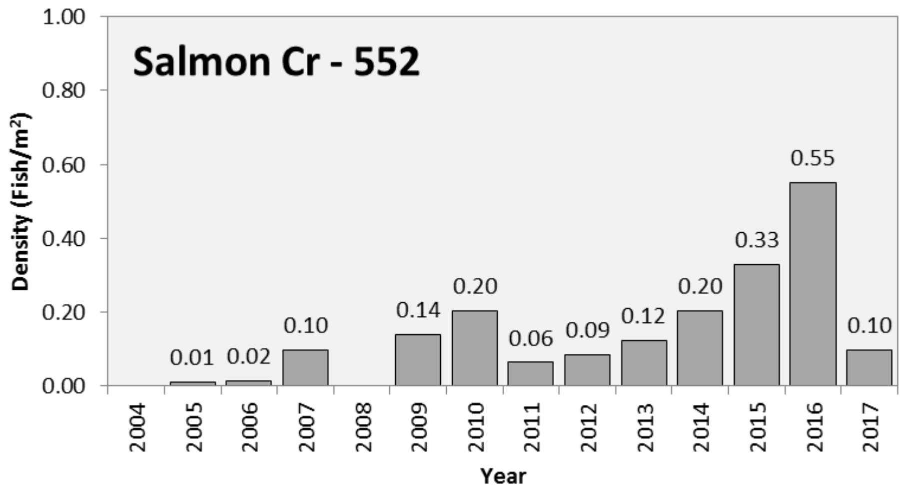
Table 3. Estimated juvenile steelhead outmigration (±95%CI) by subwatershed and outmigration year. Dashes indicate that no empirical estimate was measured.

Tributary	2014	2015	2016	2017
Salmon Cr	9,077 ± 1,130	7,918 ± 1,159	8,831 ± 1,902	20,730 ± 6,700
Lower Omak Cr	3,063 ± 415	3,156 ± 466	1,688 ± 272	4,590 ± 1,359
Upper Omak Cr	-	-	-	25,697 ± 23,584
Loup Loup Cr	-	1,193 ± 255	600 ± 112	1,984 ± 433
Ninemile Cr	-	0	655 ± 250	836 ± 387
Bonaparte Cr	201 ± 71	112 ± 0	195 ± 62	767 ± 151
Tonasket Cr	-	24 ± 0	2 ± 2	30 ± 26
Tunk Cr	-	131 ± 119	0	0
Aeneas Cr	-	198 ± 103	32 ± 32	54 ± 16
Wanacut Cr	-	0	0	0
Sum	12,341 ± 1,616	12,732 ± 2,102	12,003 ± 2,632	28,991 ± 9,072[a]

[a]Does not include estimates from Upper Omak Creek for consistency and due to wide confidence bounds

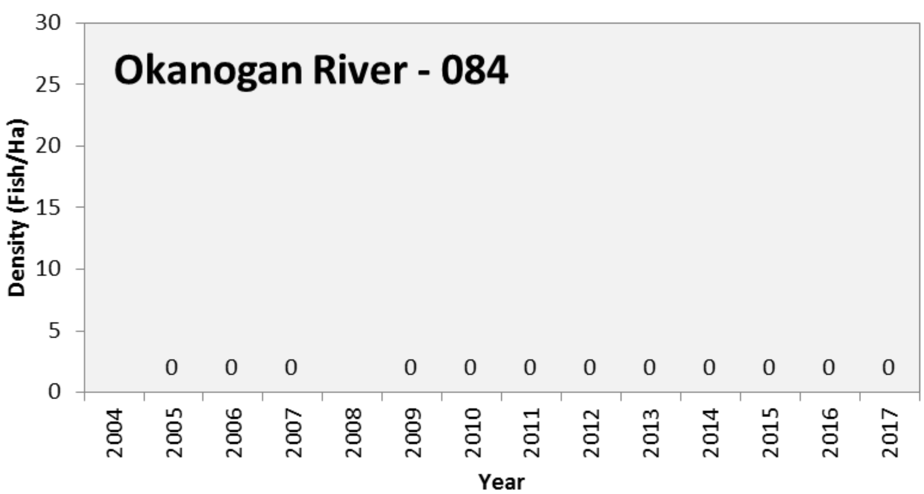
Snorkel Surveys

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 over the past 13 years. Although observed densities of fish do vary by sample site and between subwatersheds, an example data set from Salmon Creek and the mainstem Okanogan River are presented in Figure 3 and 4. In the U.S. portion of the Okanogan from 2004 to 2017, the trend in total abundance of juvenile *O. mykiss* at annual monitoring sites generally increased in tributaries (Loup Loup, Omak, and Salmon Creeks). However, observations from 2017 had relatively low numbers. Mainstem Okanogan River abundance estimates remained near or at zero for nearly all mainstem survey sites. Density of salmonids at annual survey sites in the British Columbia mainstem Okanagan River also remained low when compared to tributaries, averaging 3.45 fish/ha. Detailed results showing general trends in observed abundance from annual habitat monitoring sites are presented in Appendix C.



Year	# Obs.
2004	NS
2005	10
2006	18
2007	107
2008	NA
2009	103
2010	214
2011	75
2012	85
2013	126
2014	173
2015	267
2016	500
2017	95

Figure 3. Observed densities of juvenile (< 300mm) *O. mykiss* in Salmon Creek, the upper most annual site on the creek, near the historical townsite of Ruby.



Year	# Obs.
2004	NS
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

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

3.2 Habitat Status and Trend Monitoring

The Okanogan subbasin habitat status and trends analyses are presented in two reports, one for summer steelhead and one for summer/fall Chinook. The most recent status and trends reports, delivered in 2015, and containing data collected through 2013 can be accessed at the web links below.

Summer Steelhead:
https://www.okanoganmonitoring.org/Reports/EcosystemDiagnosisandTreatment
Summer/Fall Chinook:
https://www.okanoganmonitoring.org/Reports/EcosystemDiagnosisandTreatment

Results are presented in a series of hierarchically arranged 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 in the reports listed above. The trends in habitat condition in the 2013 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 quality of information that was used in the 2013 model runs was a substantial improvement when compared to 2009.

Updates to the 2010-2013 summer/fall Chinook report were made in 2016 to reflect modifications to out-of-subbasin survival estimates adopted for the 2014-2017 modeling cycle that were retroactively applied to the 2010-2013 modeling cycle. The 2014-2017 status and trends report is due in February of 2018.

Summer Steelhead Population (US)

The trend shown in the population report card (available in 2014-2016 annual reports or link above) for Okanogan (U.S.) steelhead suggests a relatively stable habitat capacity and abundance performance even though habitat performance for steelhead declined slightly between the 2009 and 2013 scenarios for both adults and juveniles. Between 2009 and 2013, modeled adult habitat capacity showed a 2% decrease and adult abundance fell by 19%, however, results indicate that current habitat conditions have the capacity to support a viable population of summer steelhead (> 500) in the U.S. portion of the Okanogan. Additionally, because the quality and quantity of habitat data changed between model runs, the results do not necessarily indicate that habitat condition has degraded.

Upper Salmon Creek was the highest priority for protection because it had the highest potential for reductions in productivity if habitat conditions were to degrade. Priority habitats in both lower and upper Salmon Creek also showed some of the largest potential gains for increased population productivity if restored. Steelhead habitat potential in both upper and lower Salmon Creek show a positive trend in all parameters except the habitat capacity which decreased more than 5% in lower Salmon Creek between 2009 and 2013.

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 2013 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 2013, with capacity increasing by 53% during this period. Juvenile habitat capacity increased substantially during this period to 94% of template, while modeled juvenile abundance increased 43%. Habitat productivity is similar between the 2009 and 2013 scenarios, but the proportion of self-sustaining trajectories drops from 29% to 20% during this period, indicating that the 2013 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 2010-2013 modeling cycle were relatively consistent with 2014-2017 mark-recapture outmigrant estimates from tributary diagnostic units (Table 4). However, model results and mark-recapture outmigrant estimates have not overlapped temporally with the exception of the 2014 outmigrant year, which did rear under conditions reported on during the 2010-2013 modeling cycle and are available for Salmon, Lower Omak and Bonaparte Creeks.

Table 4. OBMEP/EDT integration juvenile outmigration abundance estimates from the 2010-2013 modeling cycle and estimated juvenile steelhead outmigration by subwatershed and outmigration year.

Tributary	2010-2013 Model Abundance	Actual Estimated Outmigration 2014-2017 Mean[1]
Salmon Cr	11,267	11,639
Lower Omak Cr	2,859	3,124
Loup Loup Cr	1,054	1,259
Ninemile Cr	1,574	497
Bonaparte Cr	0	319
Tonasket Cr	749	19
Tunk Cr	41	44
Aeneas Cr	0	95
Wanacut Cr	48	0
Sum	17,592	16,517

[1]Values averaged from data presented in Table 3.

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 - 2017) 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). Although similar daily maximum values were being reached in the tributaries, the minimum daily values were also much lower resulting in a lower average. 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 parr in the Okanogan River. Overall, temperature observations in 2017 were 'normal' (within the 12 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.

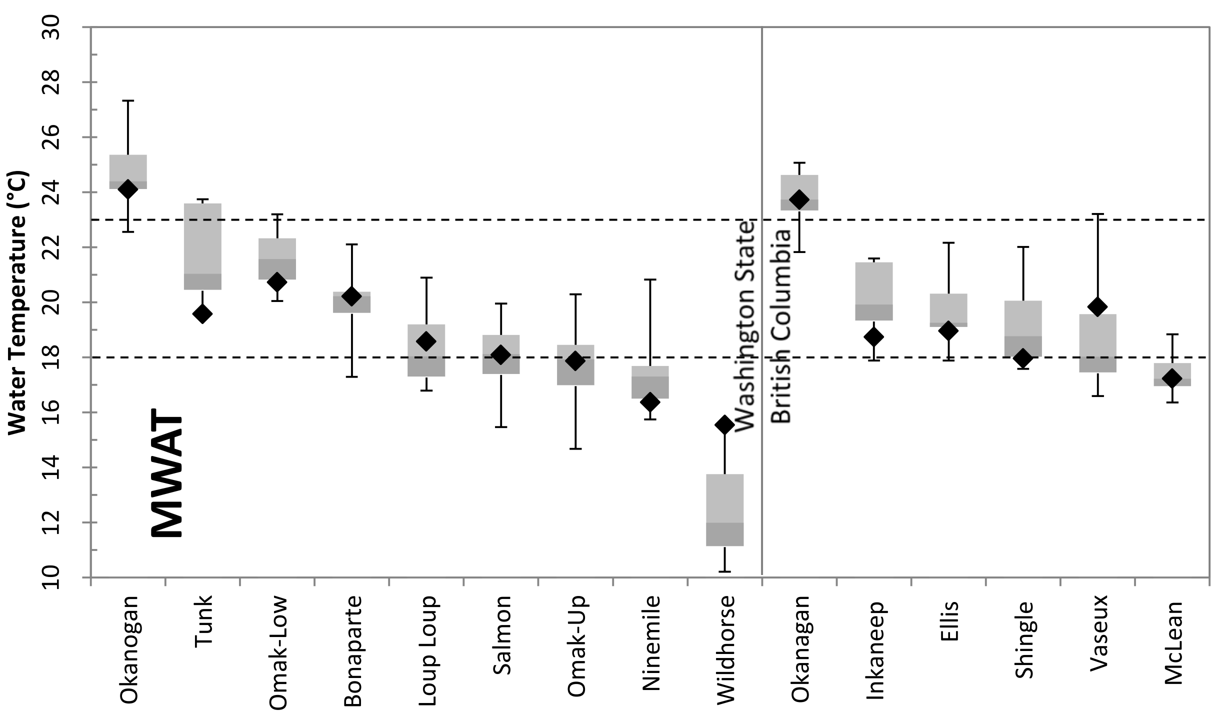


Figure 5. Maximum weekly average water temperatures (MWAT) in the Okanogan subbasin from 2005-2017. Black diamonds are 2017 MWAT values. Boxes represent 50-75th (Q3, light grey) and 25-50th (Q2, dark grey) quartiles of the MWAT distribution during 2005-2017 while whiskers display the maximum and minimum 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 88 years. Historic average monthly discharge at this location is displayed by averaging two decades per hydrograph (Figure 6). The year 2017 had higher than average peak discharge. High snowpack and early rains in the winter of 2016/2017 resulted in above average stream flows throughout the subbasin. The USGS has also cooperatively operated seven stream gages on tributaries to the Okanogan River from 2014 to 2017. For those tributaries, the year 2017 had the highest maximum discharges (Figure 7) and also the highest base flow periods (Figure 8). Additional trends in water quantity are presented in Appendix E.

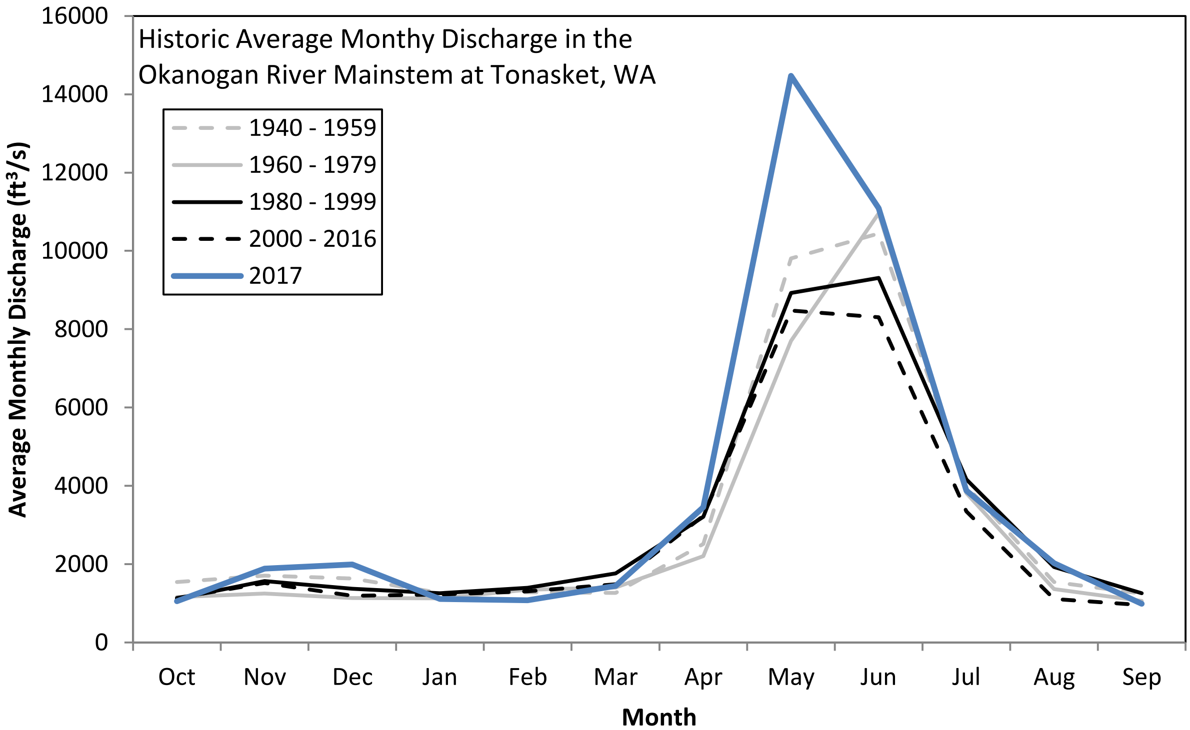


Figure 6. Average monthly discharge of the Okanogan River at Tonasket, WA (USGS Station 12445000, Okanogan River near Tonasket, WA).

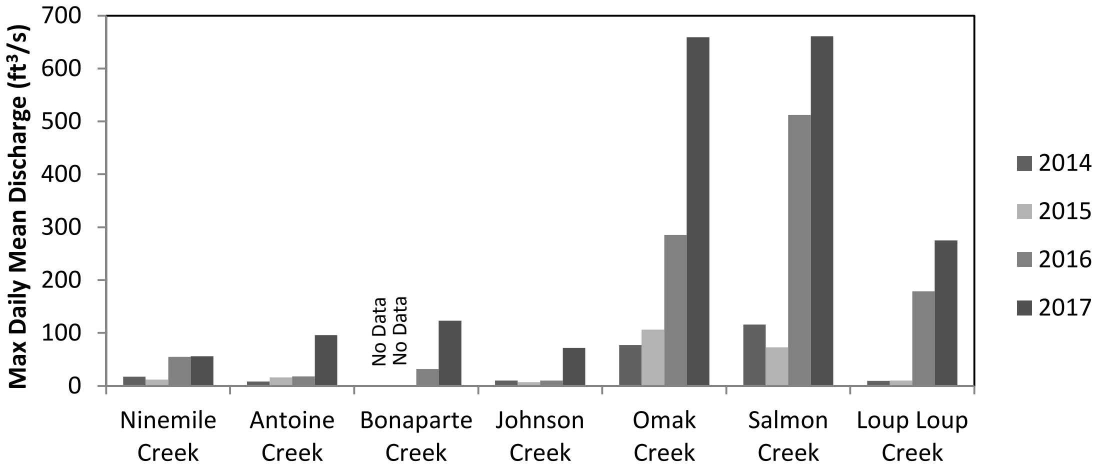


Figure 7. Maximum Daily Mean Discharge of seven tributaries to the Okanogan River, or the mean discharge for the highest peak flow day of the year.

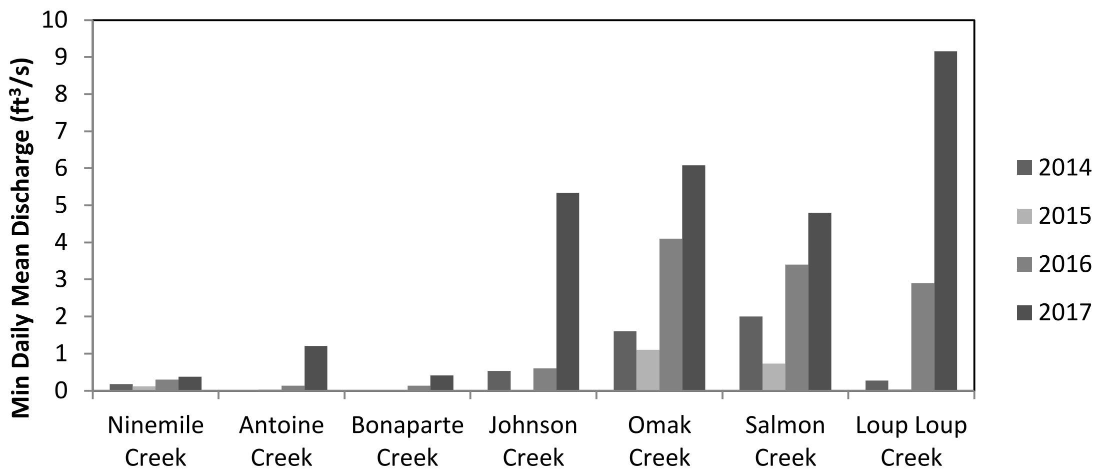


Figure 8. Minimum Daily Mean Discharge of seven tributaries to the Okanogan River, or the mean discharge for the lowest low flow day of the year.

4.0 Discussion/Conclusion

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

Adult Steelhead Monitoring

Monitoring has benefitted steelhead populations in the Okanagan 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 trend in abundance and spatial distribution of summer steelhead throughout the subbasin.

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

Juvenile Abundance and Outmigration Monitoring

The electrofishing-based juvenile abundance study implemented by OBMEP demonstrated that it was possible to determine an instream population estimate of juvenile salmonids in small creeks with a defined measure of precision. Over the past several years, it has been possible to detect change in status and trends in sub-populations of juvenile steelhead in relatively small, spatially distinct watersheds. Expanding these methods to the remaining ~three 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 has strived to maintain consistency in observer bias, using the same snorkeler(s) to collect tributary snorkel survey data for the past 9 years (2009-2017), variable observation rates were documented annually by site, and without a statistical evaluation it is not possible to definitively state if the trends are real. 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 further discussed in the habitat status and trend reports, 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.

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 2010-2013 modeling cycle and 2014 outmigrant estimates. It is notable that respective estimates from most productive tributary habitats agree on an order-of-magnitude basis and further that the theoretical abundance is either within or slightly outside of the confidence interval of the mark-recapture estimate. In a tributary with relatively few observed outmigrants (< 300, Bonaparte Creek), integrated abundance is estimated at zero in the 2010-2013 modeling cycle. This may be the result of a slight mischaracterization of habitat performance, an actual change in habitat conditions or some combination thereof. The next iteration of the status and trend report (due 2018) will fully align modeled and observed estimates (4 years, 2014-2017).

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 to agencies for use in more comprehensive, broad-scale analyses.

5.0 Adaptive Management & Lessons Learned

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

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

Some of the most requested monitoring data from managers have been fish abundance estimates for both adults and juveniles. Adult abundance metrics have been used by habitat practitioners to evaluate success of tributary instream flow projects, irrigation management, potential water purchases, habitat protection measures, passage success before and after impediment removal/redesign, and hatchery stocking, among others. Percent of adults spawning in individual subwatersheds have been analyzed by origin (hatchery and natural) to examine current status and success of habitat projects and to modify hatchery broodstock collection goals. Juvenile abundance data have been used to prioritize reach-based habitat plans, manage flow patterns, examine survival by life stage, and in the future may be used to estimate survival or growth. Detailed results from juvenile monitoring can be used to prioritize restoration or protective measures for habitat practitioners pertaining to priority stream reaches. Collection of detailed fish abundance data will also be used to validate or adjust EDT model parameters.

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

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

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

While high level, subbasin-wide indicators are some of the most commonly used information utilized in large-scale Columbia Basin-wide analyses, there is also substantial value in smaller, more site-specific datasets. Watershed, subwatershed, or reach-scale data are arguably more valuable for actively managing fish, hatcheries, and habitat restoration/protective actions, which lead to informed on-the-ground decisions that directly affect recovery of listed species. Adult abundance metrics and habitat status and trend information have been used by habitat practitioners to evaluate success of instream flow projects in specific subwatersheds. This information has been used for the management of irrigation systems, the evaluation of passage impediments, and the identification of measures to protect habitat. Juvenile abundance and small-scale habitat data have been used to prioritize reach-based habitat plans, manage flow patterns, and examine survival by life stage. Numeric escapement goals have been set based upon habitat capacity estimates and hatchery stocking of juvenile salmonids adjusted by specific subwatershed based on the adult returns and the proportion of natural origin spawners. In season fish passage and temperature data have been used to inform international harvest goals. Information collected may also help to inform or update recovery goals, providing objective data about adult returns and juvenile habitat capacity based on actual data rather than subjective or professional opinion.

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

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

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

Although results from monitoring can be reported in relatively succinct summaries, it is important to understand that a number of assumptions exist behind many of these studies, which can be difficult to explain in short segments (Salmon Monitoring Advisor 2010). Additionally, fisheries data are frequently complex, and "without manipulative experiments, it is not possible to definitively identify causes that lead to clear actions for mitigating the effects... on salmon ..." (Salmon Monitoring Advisor 2010). OBMEP was designed to monitor status and trends of abundance, productivity, diversity, and spatial structure of adult and juvenile Upper Columbia River summer steelhead and associated habitat in the Okanogan River and its tributaries. Readers and decision makers are encouraged to ask questions and learn more about relative assumptions and complexities of the data before investing in management decisions (Salmon Monitoring Advisor 2010). Additionally, monitoring staff can be contacted directly if more specific data or analyses are needed.

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7.0 Appendices

Appendix A. Adult Steelhead Abundance and Distribution

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

OBMEP. 2018. 2017 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/SteelheadSpawningSurveys

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

Introduction

In the Canadian portion of the Okanagan subbasin, previous studies have shown that, historically, steelhead were found throughout the Okanagan subbasin (Ernst and Vedan 2000). Prior to 2009, McIntyre Dam – at the outlet of nṗəxłpiẁ (Vaseux Lake) – was the upstream barrier for returning anadromous salmonids. During this time, akskʷəkʷant (Inkaneep Creek) and snʕax̌əlqaxʷiyaʔ (Vaseux Creek) were the only major tributaries accessible to anadromous steelhead for spawning and rearing. ONA Fisheries Department conducted redd surveys on both streams and operated a counting weir on akskʷəkʷant (Inkaneep Creek) through OBMEP from 2006 until 2011. While anadromous steelhead were documented during these monitoring actions (Audy et al. 2011), surveys were discontinued due to difficulties in data collection during spring freshet and low-confidence estimates. McIntyre Dam was refitted in 2009 to allow upstream migration of salmonids and, currently, migrating steelhead have access to habitat as far upstream as the kłusxnitkʷ (Okanagan Lake) outlet dam at snpintktn (Penticton). This allows steelhead access to at least four more major tributaries for spawning and rearing including Shuttleworth Creek, McLean Creek, snpiṅyaʔtkʷ (Ellis Creek) and akłxʷminaʔ (Shingle Creek). From 2012-2014, the only enumeration method used was a Passive Integrated Transponder (PIT) antenna array in the q̓awsitkʷ (Okanagan River) mainstem just upstream of suwiẁs (Osoyoos Lake) at Vertical Drop Structure (VDS) 3. In 2015, three more permanent PIT arrays were also installed in akskʷəkʷant (Inkaneep Creek), akłxʷminaʔ (Shingle Creek), and Shuttleworth Creek.

Results

For the Canadian portion of the Okanagan subbasin, PIT tag detections on the q̓awsitkʷ (Okanagan River) at VDS 3 (Okanagan Channel - OKC) upriver of suwiẁs (Osoyoos Lake) are listed in Table A-1 from 2010 to 2017. In all years listed, a higher proportion of wild steelhead detected at Zosel Dam continued up the q̓awsitkʷ (Okanagan River) upriver of suwiẁs (Osoyoos Lake) as compared to hatchery steelhead. However, these proportions were based on extremely 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. The Washington Department of Fish and Wildlife has conducted a PIT tagging effort at Priest Rapids Dam (PRD), on the Columbia River, since 2011 (Ben Truscott, pers. comm.) and abundance estimates listed below are taken from the tagging rates at PRD during sampling times only. Using a simple expansion factor based on the proportion of tagged to untagged fish at PRD and adjusting for the detection rate, escapement at the OKC PIT antenna array was estimated as follows:

Table A-1 . Abundance estimates of steelhead passage at OKC antenna array on the q̓awsitkʷ (Okanagan River) upstream of suwiw̓s (Osoyoos Lake).

Year	Origin	Number of tags detected at OKC (from PRD sample)	Adjusted number of tags based on detection rate	PRD tag rate* $Tag\ Rate = \frac{M}{N}$	Abundance estimate based on expansion factor $C = \frac{1}{Tag\ Rate} \times R$
2011	Hatchery	0	0	0.0834	0
2011	Wild	2	2.25	0.0834	27
2012	Hatchery	2	2.25	0.1309	17
2012	Wild	2	2.25	0.1311	17
2013	Hatchery	0	0	0.1343	0
2013	Wild	3	3.37	0.1339	25
2014	Hatchery	2	2.25	0.1446	16
2014	Wild	3	3.37	0.1448	23
2015	Hatchery	3	3.37	0.1742	19
2015	Wild	10	11.25	0.1744	65
2016	Hatchery	1	1.12	0.1940	6
2016	Wild	2	2.25	0.1942	12
2017	Hatchery	1	1.12	0.2126	5
2017	Wild	2	2.25	0.2205	10

* C = estimate of steelhead passage at OKC antenna array

* N = total number of steelhead sampled in Priest Rapids Dam study

* M = number of marked steelhead sampled in Priest Rapids Dam study

* R = number of marked steelhead detected at OKC antenna array

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.

In 2015, permanent PIT arrays were installed in akskʷəkʷant (Inkaneep Creek), akɬxʷminaʔ (Shingle Creek), and Shuttleworth Creek. While seasonal arrays have been used in other tributaries in previous years, none were conducted in 2017. There were no detections of tagged adult steelhead in akłxʷminaʔ (Shingle Creek) or Shuttleworth creeks in 2017; however, due to high freshet flows, the akłxʷminaʔ (Shingle Creek) array was damaged and unable to collect data after mid-May.

Table A-2. List of ONA-operated PIT arrays on tributaries to q̇awsitkʷ (Okanagan River) in the Canadian portion of the basin with associated number of adult steelhead detections since 2014.

Site	2014	2015	2016	2017
OKI – Inkaneep Creek	NA	2 (1 hatchery, 1 wild)	1 (hatchery)	1 (hatchery)
OKW – Shuttleworth Creek	0 (temporary array)	NA	0	0
OKS – Shingle Creek	NA	NA	0	0
Testalinden Creek (temporary)	NA	0	NA	NA
McLean Creek (temporary)	NA	0	NA	NA

Increased PIT detection efforts in the Canadian portion of the Okanagan basin has also benefited in information gathering for other listed species. In 2017, seven hatchery Spring Chinook were detected at the q̇awsitkʷ (Okanagan River) PIT array near Oliver, BC (OKC), and one spawning female (hatchery) was observed in Vaseux Creek. No Spring Chinook were detected in tributaries in 2017; however, in 2016 two Spring Chinook (one listed as “Unknown Run”) were detected in Shuttleworth Creek and one Spring Chinook was detected in akłxʷminaʔ (Shingle Creek).

Conclusions

The removal of barriers in the Canadian portion of the Okanagan subbasin potentially allows steelhead to access more tributary habitat for spawning and rearing. While current sample sizes are not sufficient to provide confident abundance estimates, baseline data are needed in order to detect if summer steelhead recolonize newly accessible habitat. Currently, the distribution of steelhead spawning past OKC antenna array is unknown. Expanding the PIT program further upriver and into tributaries will give resolution needed to determine more specific spawning areas and timing and could be coordinated with reintroduction programs. Adding more antenna arrays in the Canadian Okanagan River subbasin could also be used to test assumptions about detection efficiency of downstream arrays.

Additional Datasets

Table A-3. Estimated adult steelhead spawner abundance for hatchery-origin returns (HOR) and natural-origin returns (NOR) in the Washington State portion of the Okanogan subbasin for 2017 and the 2005-2017 mean.

Category	**Description/location**	2017 HOR	*2005-2017 mean HOR*	2017 NOR	*2005-2017 mean NOR*
WA Mainstem	Okanogan River 1	7	*13*	1	*1*
WA Mainstem	Okanogan River 2	28	*46*	2	*5*
WA Mainstem	Okanogan River 3	5	*10*	1	*1*
WA Mainstem	Okanogan River 4	23	*38*	2	*4*
WA Mainstem	Okanogan River 5	38	*62*	3	*6*
WA Mainstem	Okanogan River 6	10	*16*	1	*2*
WA Mainstem	Okanogan River 7	241	*395*	21	*45*
WA Mainstem	Similkameen River 1	82	*133*	7	*15*
WA Mainstem	Similkameen River 2	62	*101*	5	*11*
WA Tributary	Loup Loup Creek	21	*34*	3	*10*
WA Tributary	Salmon Creek	191	*129*	32	*34*
WA Tributary	Omak Creek	36	*156*	8	*72*
WA Tributary	Wanacut Creek	4	*3*	1	*1*
WA Tributary	Johnson Creek	42	*27*	0	*7*
WA Tributary	Tunk Creek	20	*31*	3	*10*
WA Tributary	Aeneas Creek	9	*2*	0	*0*
WA Tributary	Bonaparte Creek	38	*65*	5	*31*
WA Tributary	Antoine Creek	28	*10*	5	*3*
WA Tributary	Wild Horse Spring Creek	5	*42*	5	*10*
WA Tributary	Tonasket Creek	24	*23*	0	*7*
WA Tributary	Ninemile Creek	5	*18*	0	*7*
Area	**Washington State Mainstem**	**496**	***814***	**43**	***90***
Area	**Washington State Tributaries**	**423**	***540***	**62**	***192***

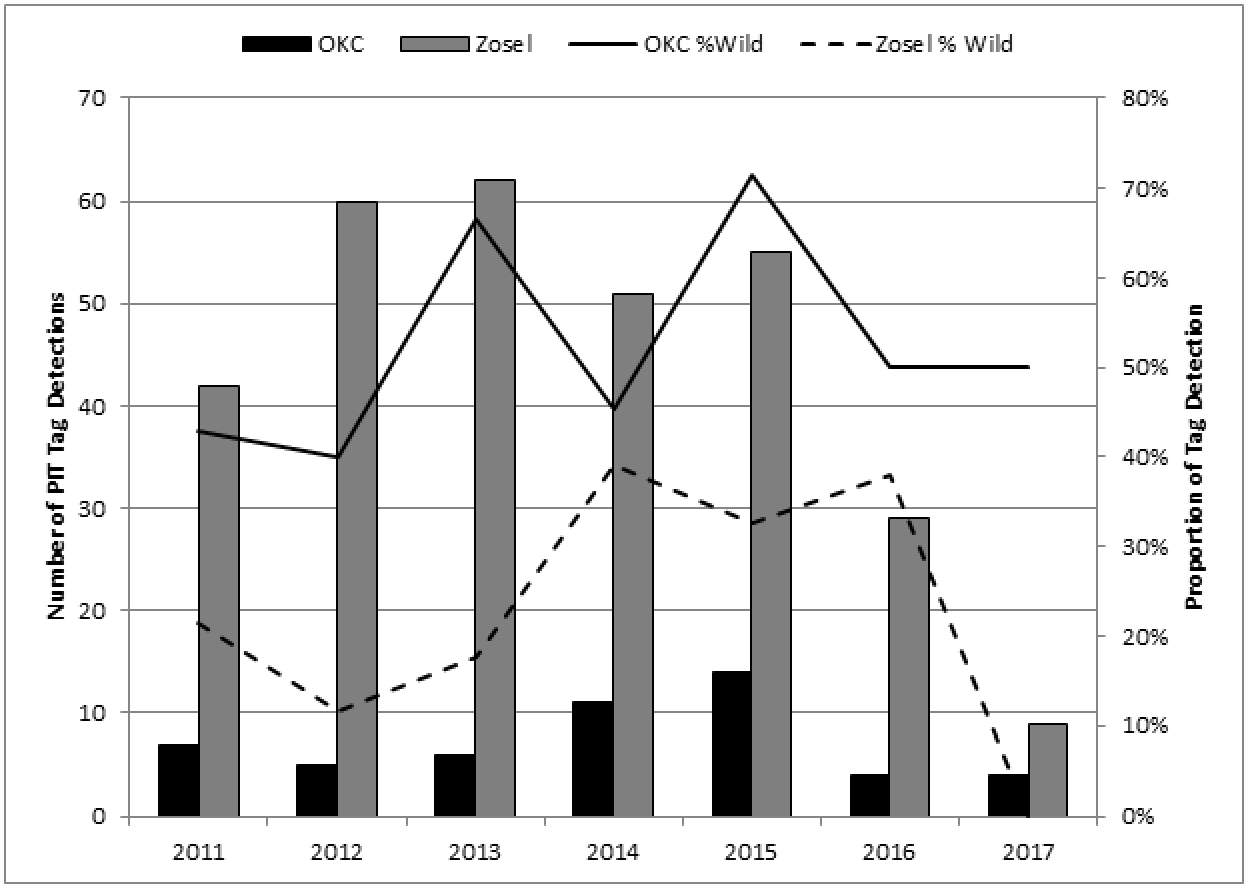


Figure A-1. Steelhead PIT tag detections on the q̓awsitkʷ (Okanagan River) at VDS 3 (OKC) as compared to detections at Zosel Dam.

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

Spawning Year	PRD Steelhead Escapement*	PRD Tag Rate* Hatchery	Wild
2011	26,806	0.0834	0.0834
2012	20,806	0.1309	0.1311
2013	17,192	0.1343	0.1339
2014	15,072	0.1446	0.1448
2015	19,659	0.1742	0.1744
2016	14,303	0.1940	0.1942
2017	2,868	0.2126	0.2205

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

Appendix B. Juvenile Steelhead Abundance and Distribution

Introduction

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

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

The Washington Department of Fish and Wildlife (WDFW) and the Colville Confederated Tribes (Colville Tribes) installed a series of permanent and temporary PIT tag arrays from 2012-2014 near the mouth of tributaries with known or potential steelhead spawning habitat (BPA Project #2010-034-00). In 2013-2015, 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 outmigrate from the system.

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 estimate 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). PIT tag interrogation site LLC consists of three pass-over PVC antennas in series is located near the mouth of the creek in the town of Malott, WA.

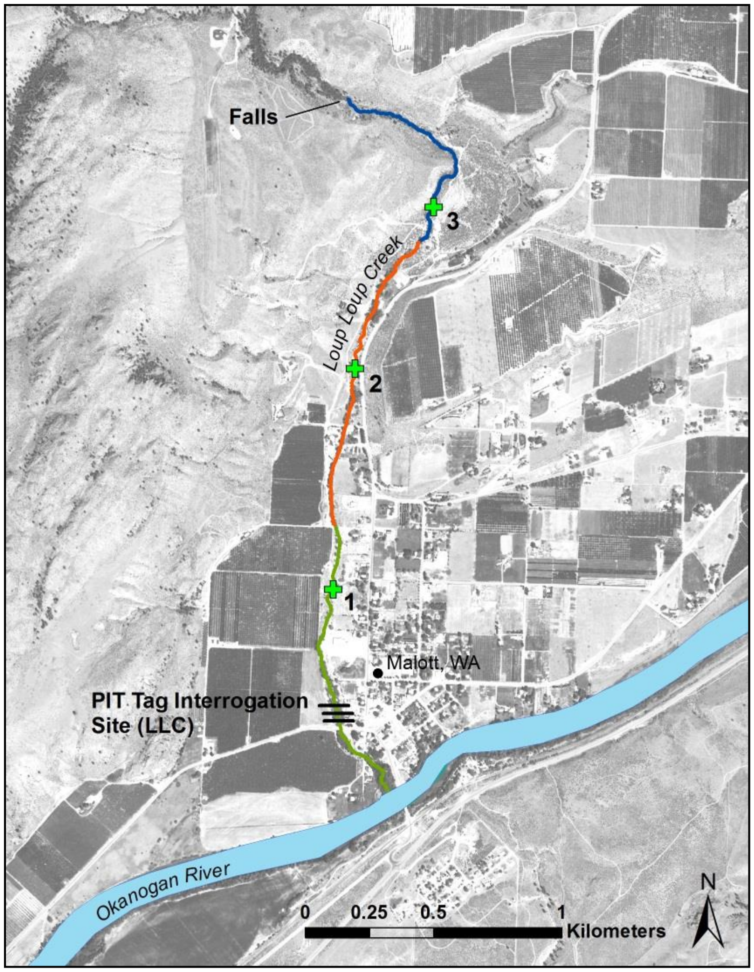


Figure B-1. Loup Loup Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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.

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 (site SA1) is located upstream from mouth of Salmon Creek, 2.9 km upstream from the confluence with the Okanogan River. The system arrangement consists of three pass-over PVC antennas grouped in three series. A second PIT tag interrogation site (SA0) is located immediately downstream of the OID diversion dam and consists of two rows of pass-over PVC antennas.

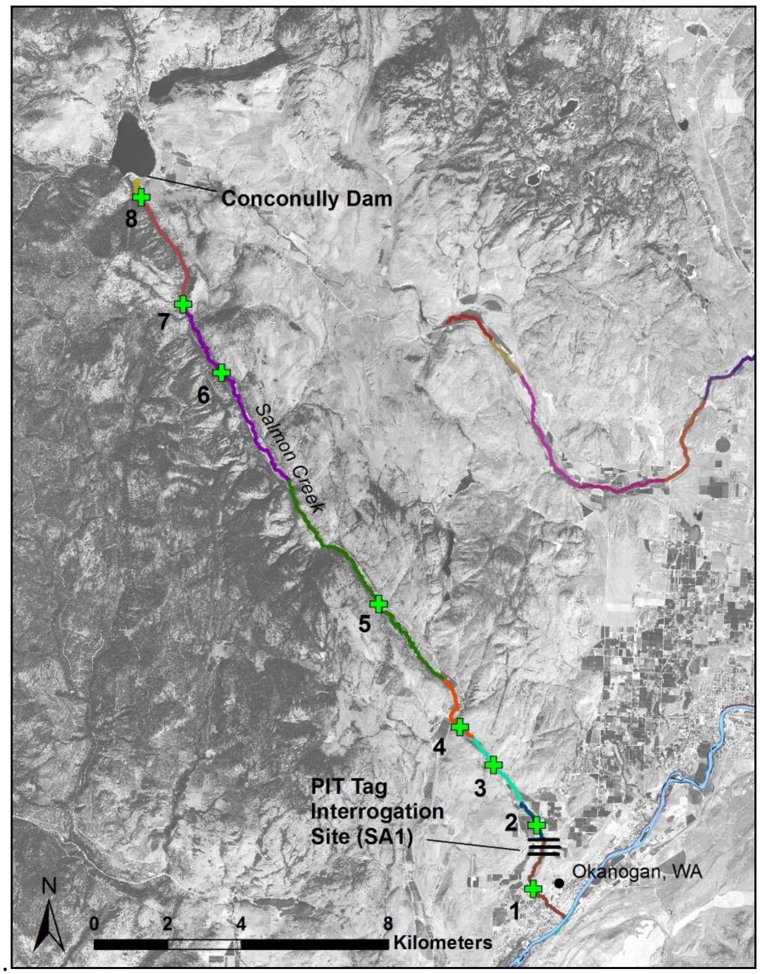


Figure B-2. Salmon Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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.

A parallel PIT tag array (site OMK) is located near the mouth of Omak Creek, 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 antennas. 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.

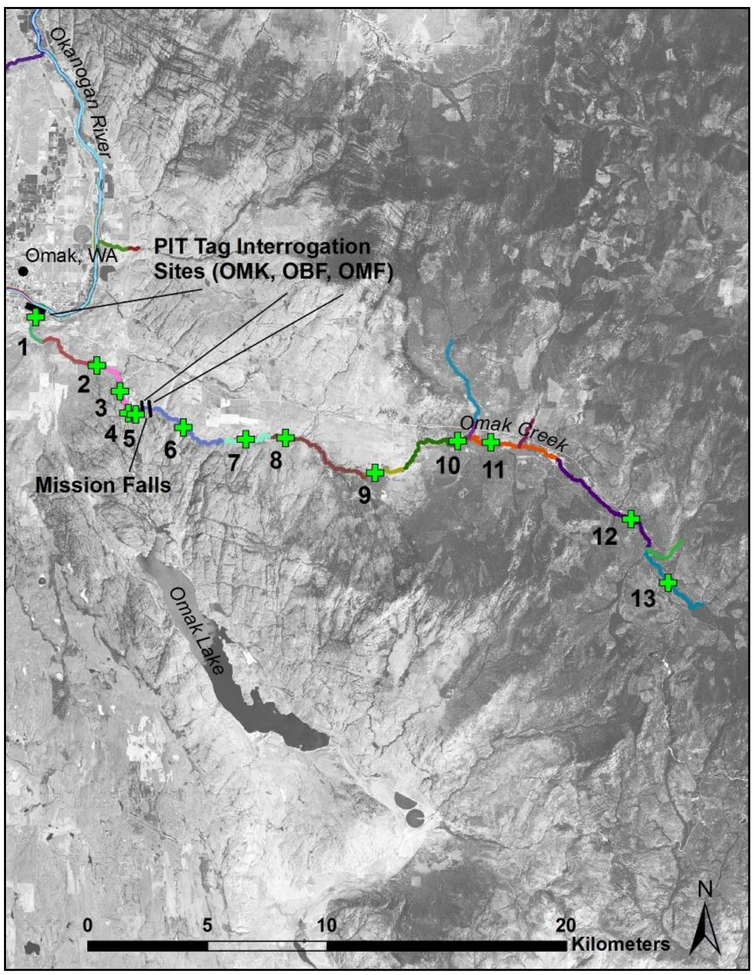


Figure B-3. Omak Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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 temporary PIT tag antenna (site 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.

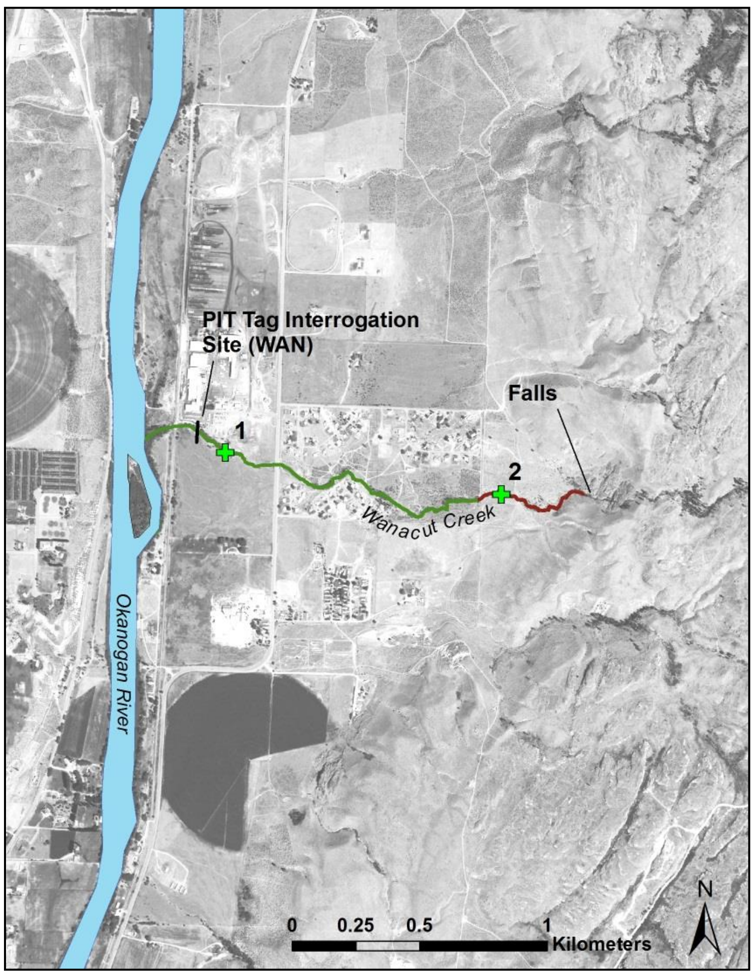


Figure B-4. Wanacut Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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 temporary single PIT tag antenna (site TNK) is installed seasonally near the mouth of the creek. Tunk Creek was surveyed as one reach below the falls.

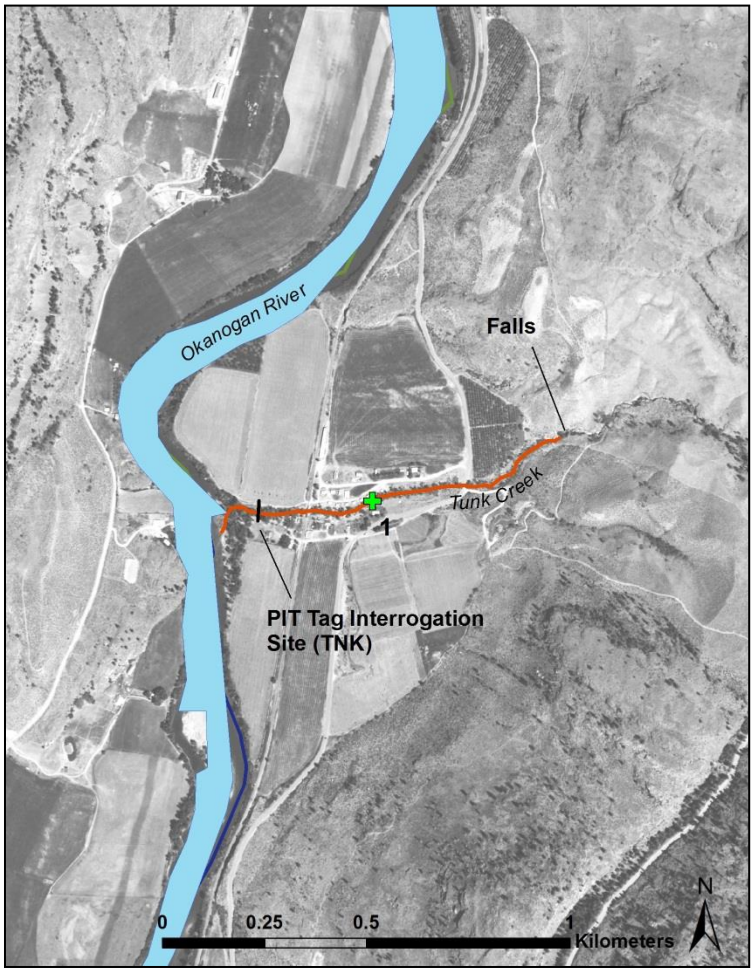


Figure B-5. Tunk Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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 temporary PIT tag antenna was placed 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.

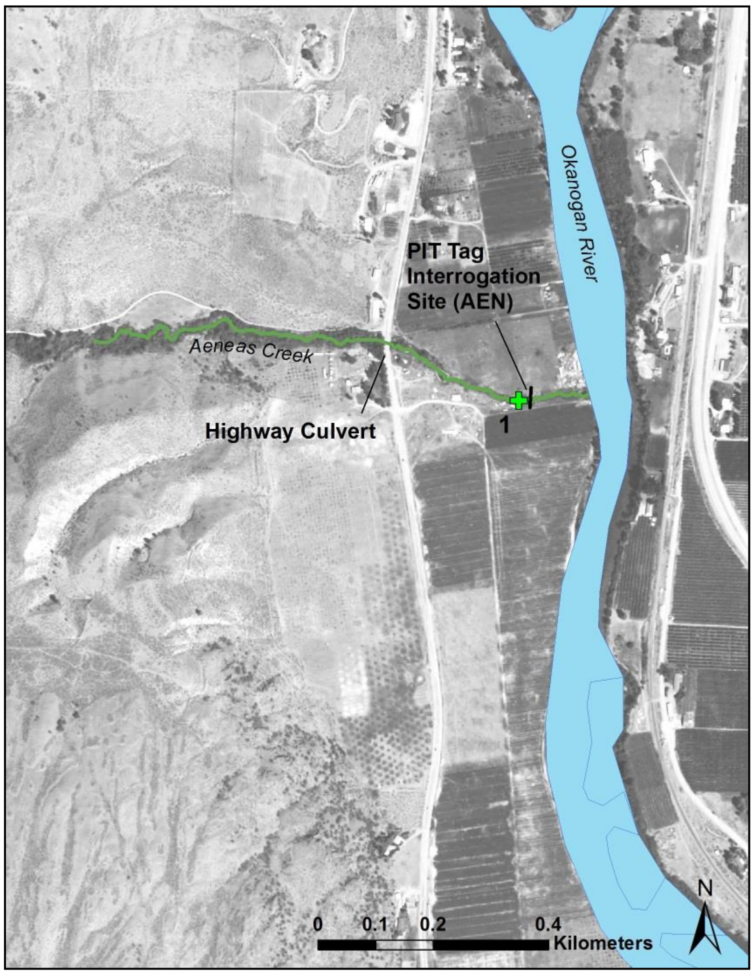


Figure B-6. Aeneas Creek juvenile *O. mykiss* mark-recapture study site (green numbered markers) and strata (colored stream lines).

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 (BON) is located just upstream from the confluence with the Okanogan River (Figure B-7).

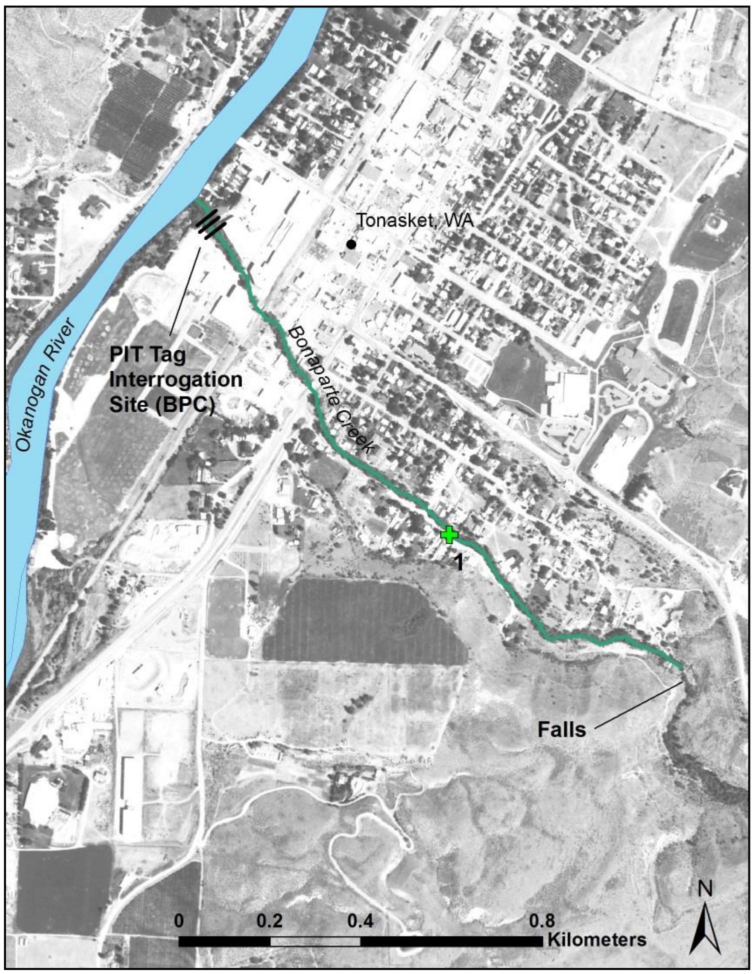


Figure B-7. Bonaparte Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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-8). A single seasonal PIT tag antenna is operated near the confluence of the creek with the Okanogan River.

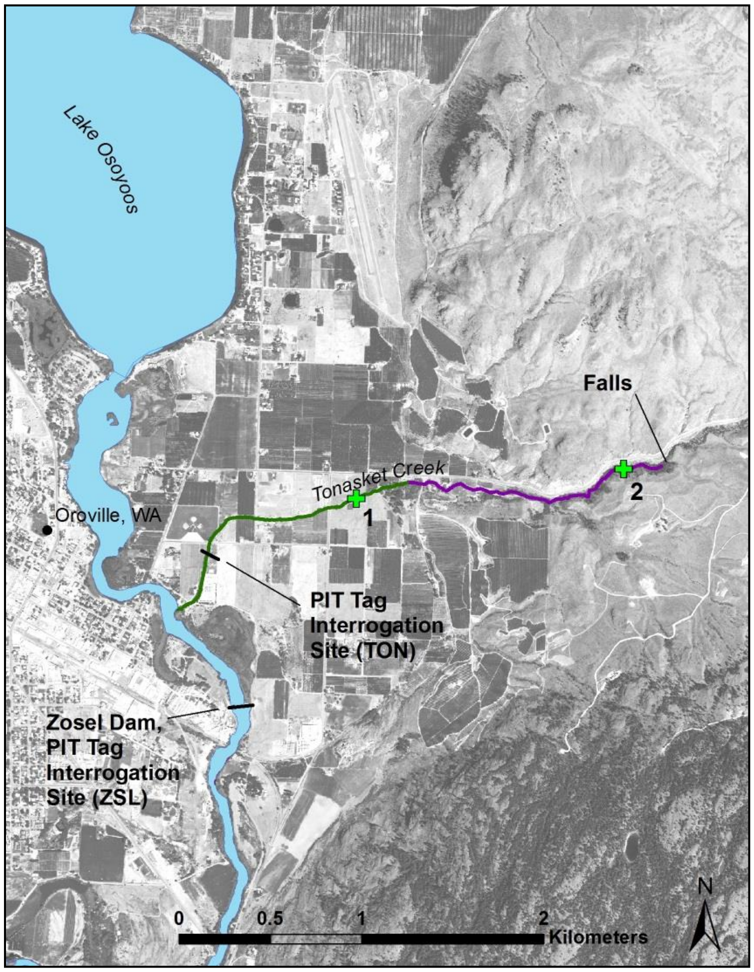


Figure B-8. Tonasket Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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-9). A permanent four-antenna PIT tag array is located near the mouth of the creek, which enters into the east side of Lake Osoyoos.

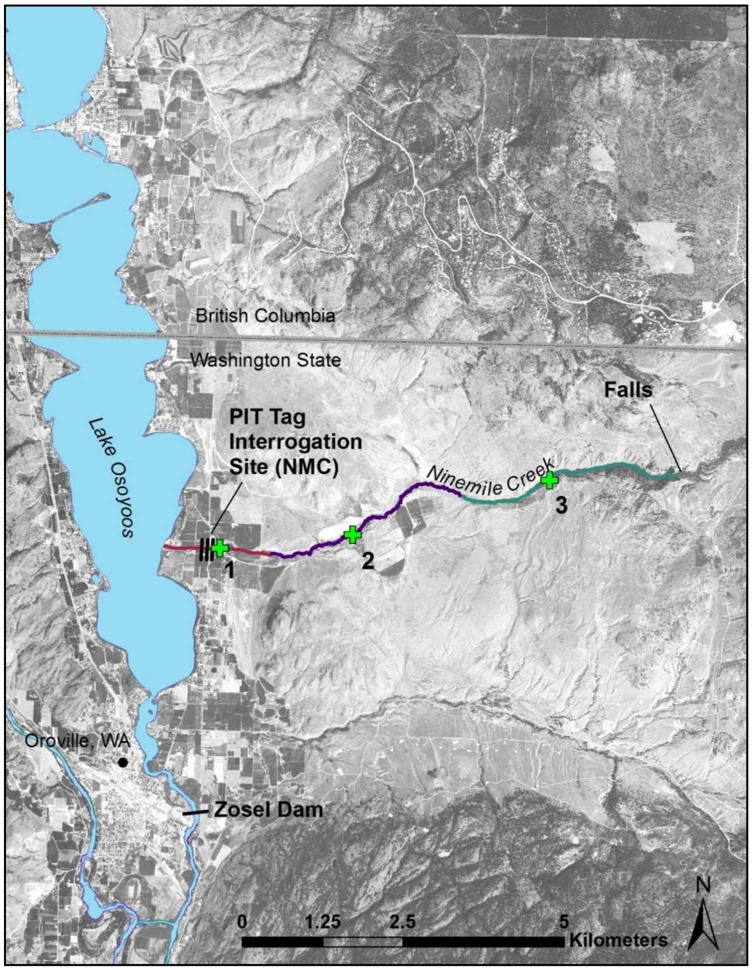


Figure B-9. Ninemile Creek juvenile *O. mykiss* mark-recapture study sites (green numbered markers) and strata (colored stream lines).

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 years studies include Chilliwist, Johnson, Antoine, 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 suwiw̓s (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). A permanent 3 antenna PIT tag array is located 1 km from the mouth.

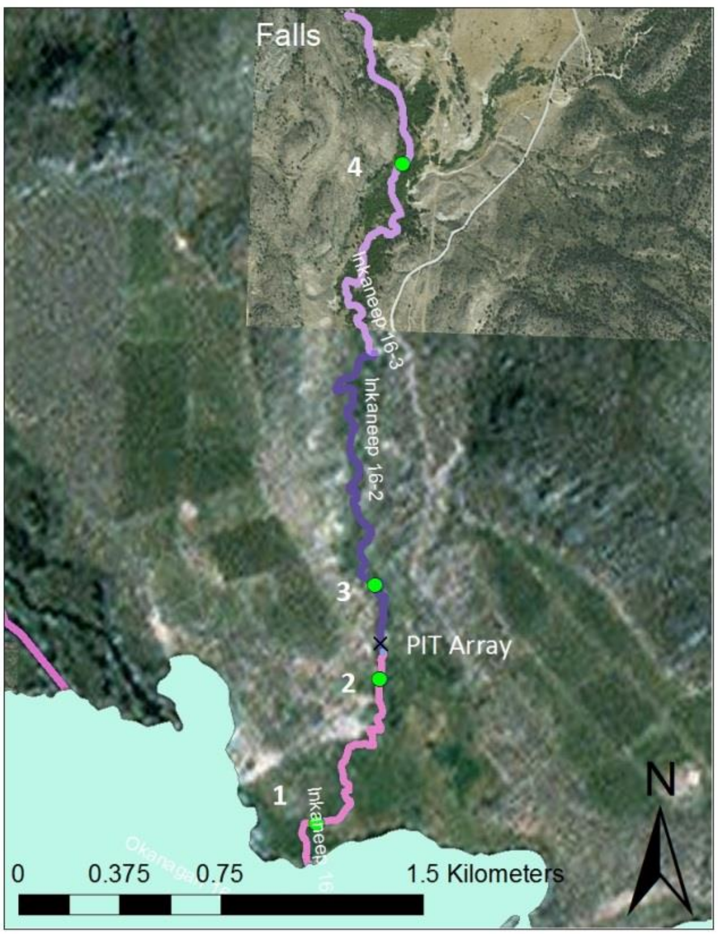


Figure B- 10. Inkaneep Creek juvenile *O. mykiss* mark-recapture study sites (green numbered dots) and strata (colored stream lines).

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 q̓awsitkʷ (Okanagan River) at RKM 175 just downstream of the q̓awstik̓ʷt (Skaha Lake) outlet dam at OK 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-11). A permanent 2 antenna PIT tag array is located 0.5 km from the mouth.

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

akłxʷminaʔ (Shingle Creek)

The akłxʷminaʔ (Shingle Creek) drainage area is approximately 308 km^2. It is a 6th order stream at the mouth where it drains into the q̓awsitkʷ (Okanagan River) at RKM 195 downstream of the kłusxnitkʷ (Okanagan Lake) outlet dam at snpintktn (Penticton), BC. The main tributary to akłxʷminaʔ (Shingle Creek) is Shatford Creek (Figure B-12). 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 akłxʷminaʔ (Shingle Creek) and Shatford Creek were divided into 18 survey reaches (Figure B-12). A permanent 4 antenna PIT tag array is located 1 km from the mouth.

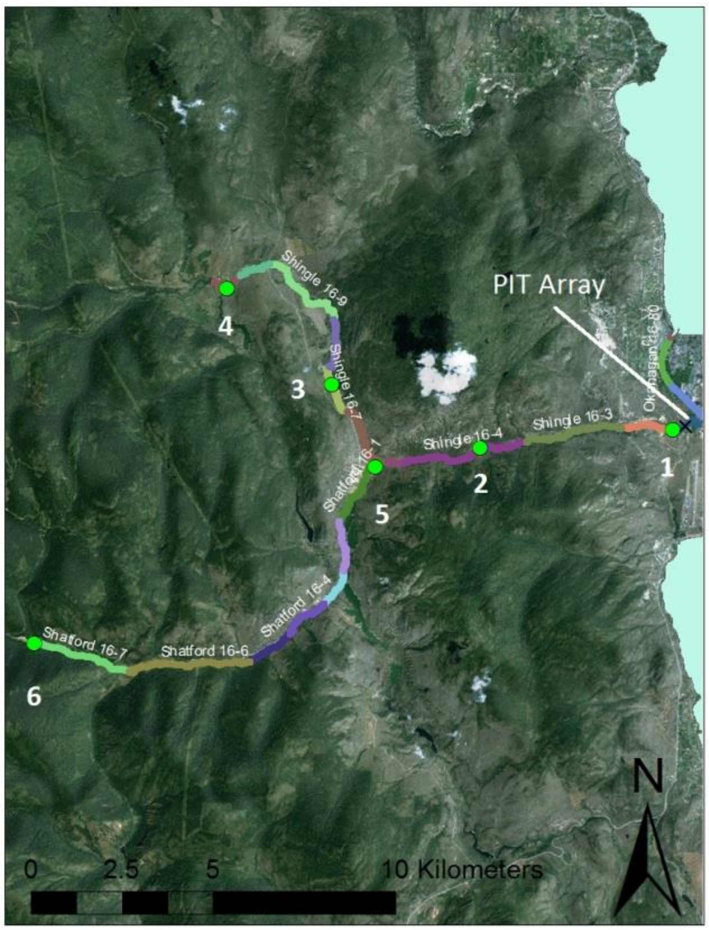


Figure B- 12. Shingle and Shatford Creek juvenile *O. mykiss* mark-recapture study sites (green numbered dots) and strata (colored stream lines).

Site Based Abundance Estimate

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

In order to complete the site in one day and maintain a closed population with the use of block nets (which are frequently weighed down with heavy leaf fall during the fall season), a three hour wait period occurred before the second pass was conducted (Temple and Pearsons 2006). During the second pass, all fish were examined for a mark. If the fish was unmarked, the length was recorded and the fish was released at the location where captured. Unmarked *O. mykiss* greater than 95 mm also received a PIT tag to increase the number of PIT tagged fish available for later interrogation (i.e. when emigrating from the creek).

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

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

(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:

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

Expanding Site Abundance to Reach and Tributary Population Estimates

The site-based abundance N was expanded to estimate the population of juvenile *O. mykiss* in each of the strata (ex. Omak Creek, $\widehat{N}_i$ 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),

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

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

$$\widehat{N}_i = N_i R_i\ . \qquad \text{(eq. 4)}$$

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

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

with a variance of

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

and a 95% confidence interval (CI) of

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

The coefficient of variation (CV) was calculated as:

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

Outmigration Estimates Based on PIT Tagged Fish

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

Method 1:

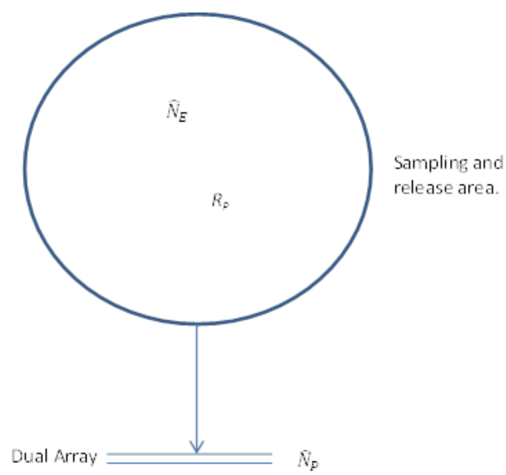


Figure B- 13. Diagram of the study.

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.

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

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)

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

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.

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

with a variance of

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

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

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

with a variance of

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

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

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

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

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

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 oftentimes more blurred in reality, which can vary among location and between years. In the absence of sufficient scale data for linking length to age within the subbasin, it may be feasible to coarsely estimate age breaks visually from obvious bi-modal distributions. Length frequency distributions are much more distinct at the site-level, before rolling data up to the sub-watershed-level. In this document and in the early years of this study, we may refer to fry (age-0) and parr/juvenile+ (age-1+) age classes, but it is important to note that those divisions came from professional judgement based on length frequency distributions rather than scale aging. In future years, if time and funding allow, scale data or statistical analysis of length frequency distributions may be used to more precisely define length by age-class.

Results

Instream Abundance

Between 2014 and 2017, nine tributaries were representatively sampled in Washington State to determine abundance of juvenile *O. mykiss* in stream reaches accessible to anadromous fish. 2016 was the first year of this work in the British Columbia portion of the subbasin. Estimated abundance with 95% confidence intervals are presented in Table B-1. The largest number of fry and juvenile *O. mykiss* in the Okanogan subbasin were found in Salmon Creek, followed by lower and upper Omak, and Loup Loup Creeks. A number of small creeks in the Okanogan subbasin contain flowing water in the upper reaches, but water flows sub-surface before entering the mainstem Okanogan River in late-summer, including Salmon, Wanacut, Tunk, and Tonasket Creeks.

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 natural-origin *O. mykiss* (±95%CI) in tributaries to the Okanogan River in Washington State and British Columbia.

Age-0 *O. mykiss*				
Tributary	2014	2015	2016	2017
Salmon Cr	46,434 ± 8,602	56,501 ± 5,945	61,234 ± 7,383	27,717 ± 3,065
Lower Omak Cr	29,136 ± 2,145	27,671 ± 3,921	29,243 ± 4,321	4,064 ± 1,755
Upper Omak Cr	-	-	13,104 ± 1,811	10,510 ± 4,311
Loup Loup Cr	19,787 ± 1,643	6,597 ± 593	13,191 ± 1,713	728 ± 181
Ninemile Cr	6,177 ± 1,289	3,030 ± 965	6,705 ± 1,613	5,304 ± 1,763
Bonaparte Cr	3,149 ± 396	989 ± 362	2,532 ± 582	208 ± 125
Tonasket Cr	2,192 ± 716	0	7,911 ± 745	5,684 ± 497
Tunk Cr	0	0	1,412 ± 358	212 ± 131
Aeneas Cr	111 ± 18	15 ± 2	1,204 ± 131	697 ± 102
Wanacut Cr	0	0	501 ± 95	3,407 ± 793
Johnson Cr	-	-	-	-
Antoine Cr	-	-	-	-
Wildhorse Sp Cr	-	-	-	-
Lower Shingle Cr	-	-	15,293 ± 7,485	7,112 ± 4,639
Upper Shingle Cr	-	-	13,989 ± 9,632	6,593 ± 1,703
Shatford Cr	-	-	53,022 ± 16,235	104,611 ± 30,251
Inkaneep Cr	-	-	21,304 ± 7,284	2,327 ± 1,480
Shuttleworth Cr	-	-	9,207 ± 2,190	16,078 ± 7,211

Age-1+ *O. mykiss*				
Tributary	2014	2015	2016	2017
Salmon Cr	31,498 ± 2,379	31,630 ± 2,461	50,621 ± 3,931	38,556 ± 2,136
Lower Omak Cr	7,581 ± 836	4,488 ± 387	7,252 ± 779	7,264 ± 812
Upper Omak Cr	-	-	25,697 ± 1,633	16,820 ± 1,642
Loup Loup Cr	2,177 ± 267	1,282 ± 111	2,422 ± 683	2,722 ± 295
Ninemile Cr	2,136 ± 333	3,017 ± 367	2,141 ± 683	6,971 ± 673
Bonaparte Cr	137 ± 22	273 ± 46	913 ± 88	437 ± 104
Tonasket Cr	526 ± 51	9 ± 0	69 ± 0	1,423 ± 71
Tunk Cr	164 ± 26	0	142 ± 53	138 ± 19
Aeneas Cr	138 ± 26	56 ± 29	74 ± 37	112 ± 23
Wanacut Cr	0	0	21 ± 0	2,113 ± 177
Johnson Cr	-	-	-	-
Antoine Cr	-	-	-	-
Wildhorse Sp Cr	-	-	-	-
Lower Shingle Cr	-	-	6,532 ± 3,322	13,515 ± 6,622
Upper Shingle Cr	-	-	2,797 ± 1,105	2,286 ± 366

Shatford Cr	-	-	4,756 ± 148,309	9,465 ± 3,863
Inkaneep Cr	-	-	2,200 ± 1,457	4,556 ± 2,368
Shuttleworth Cr	-	-	3,314 ± 1,165	2,658 ± 798

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-2 column 2017 represent outmigration of juvenile steelhead from that year, derived from fish PIT tagged and released in the fall of 2016 and detected from September 2016 through August 2017. Based on combined detections of PIT tagged fish from within and out of the Okanogan subbasin, a total of 28,991 (95%CL=19,919 to 38,063) juvenile steelhead outmigrated from the defined strata. 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-14). A similar trend was documented in Salmon Creek (Figure B-15), where a larger proportion of fish outmigrated from the lower reaches, compared with higher in the watershed.

Table B-2. Juvenile steelhead outmigration estimates by year from subwatersheds within the Okanogan subbasin.

Tributary	2014	2015	2016	2017
Salmon Cr	9,077 ± 1,130	7,918 ± 1,159	8,831 ± 1,902	20,730 ± 6,700
Lower Omak Cr	3,063 ± 415	3,156 ± 466	1,688 ± 272	4,590 ± 1,359
Upper Omak Cr	-	-	-	25,697 ± 23,584
Loup Loup Cr	-	1,193 ± 255	600 ± 112	1,984 ± 433
Ninemile Cr	-	0	655 ± 250	836 ± 387
Bonaparte Cr	201 ± 71	112 ± 0	195 ± 62	767 ± 151
Tonasket Cr	-	24 ± 0	2 ± 2	30 ± 26
Tunk Cr	-	131 ± 119	0	0
Aeneas Cr	-	198 ± 103	32 ± 32	54 ± 16
Wanacut Cr	-	0	0	0
Sum	12,341 ± 1,616	12,732 ± 2,102	12,003 ± 2,632	28,991 ± 9,072[a]

[a]Does not include estimates from Upper Omak Creek for consistency and due to wide confidence bounds.

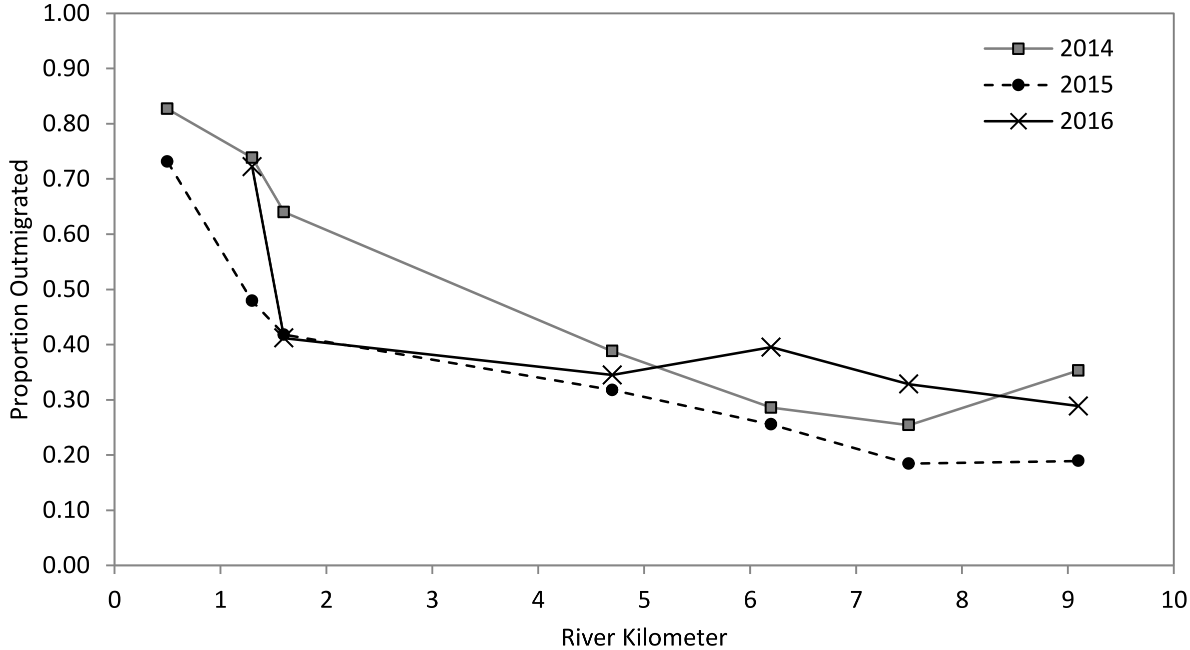


Figure B- 14. Proportion of PIT tagged natural origin juvenile steelhead that outmigrated in Omak Creek by river kilometer (distance upstream from the confluence with the Okanogan River).

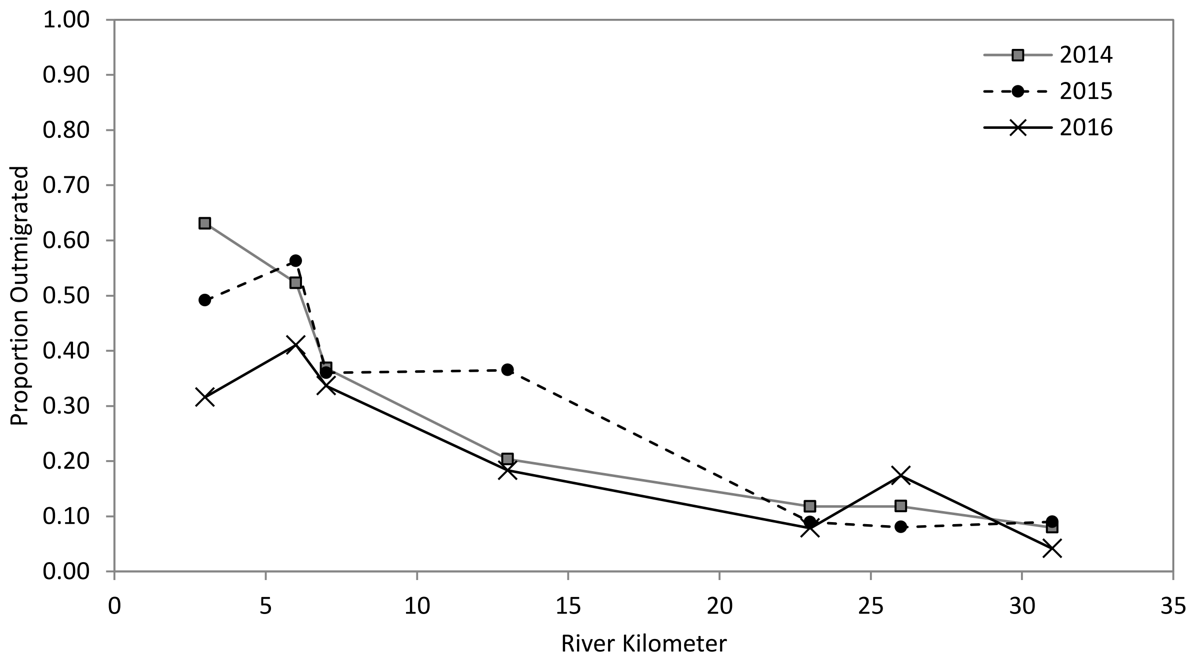


Figure B- 15. Proportion of PIT tagged natural origin juvenile steelhead that outmigrated in Salmon Creek by river kilometer (distance upstream from the confluence with the Okanogan River).

In the Canadian portion of the Okanagan basin, outmigration estimates can only be attributed to each individual tributary (Table B-3) due to the proximity of lakes within 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 suwiw̓s (Osoyoos Lake) in following years will indicate the migratory life histories of tagged *O. mykiss*.

In the spring of 2017, *O.mykiss* tagged in akskʷəkʷant (Inkaneep) and Shuttleworth creeks were detected in juvenile bypass facilities in the Columbia River (John Day Dam and Rocky Reach Dam).

Table B-3. Juvenile *O. mykiss* outmigration estimates by year from tributaries within the Canadian portion of the Okanagan Basin.

Tributary	2016	2017
akskʷəkʷant (Inkaneep Cr)	-	131 ± 136
Shuttleworth Cr	-	406 ± 254
Lower akɬxʷminaʔ (Shingle Cr)	-	667 ± 885
Upper akɬxʷminaʔ (Shingle Cr)	-	0
Shatford Cr	-	0

Conclusions

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

Many of the stated assumptions used in this study appeared to be adequate, but remained untested. Block nets were meticulously placed in small trenches and back filled with substrate in attempts to 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 marks were lost prior to outmigration. In this study, no fish were recaptured that had a tag puncture wound and were found without a tag. Additionally, 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 hypotheses in the future, due to the fact that these abundance data were collected at existing long-term habitat monitoring sites. Determining abundance of fish in respect to specific habitat characteristics may help to further describe variables favored in this system and assist in focusing habitat restoration efforts.

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

Appendix C. Snorkel Surveys

Total numbers and densities of juvenile *O. mykiss* for all streams and rivers in 2017 are shown in Table C-1 for Washington and Table C-2 for British Columbia. Due to the rotating panel design, not all tributaries are sampled each year and are labeled as “not sampled” in the summary table below. Specific long term results are shown in further detail in the figures following, organized by individual site.

Table C-1. Total observed numbers and densities of juvenile *O. mykiss* in the United States portion of the Okanogan subbasin, 2017.

Stream Name	Total Observed *O. mykiss* (N)	Density (fish/m^2)
Aeneas Creek	not sampled	n/a
Antoine Creek	68 [a]	0.28 [b]
Bonaparte Creek	28	0.09
Chiliwist Creek	not sampled	n/a
Johnson Creek	not sampled	n/a
Loup Loup Creek	136	0.14
Ninemile Creek	114	0.38
Okanogan River	0 [a]	0 [b]
Omak Creek	119 [a]	0.04 [b]
Salmon Creek	156 [a]	0.05 [b]
Similkameen River	14 [a]	>0.00 [b]
Siwash Creek	not sampled	n/a
Stapaloop Creek	not sampled	n/a
Tonasket Creek	not sampled	n/a
Trail Creek	not sampled	n/a
Tunk Creek	not sampled	n/a
Wanacut Creek	not sampled	n/a
Wildhorse Spring Cr.	not sampled	n/a

[a] sum of all juvenile *O. mykiss* from multiple sites per creek.
[b] average density of all juvenile *O. mykiss* from multiple sites per creek.

Table C-2. Total observed numbers and densities of juvenile *O. mykiss* in the Canadian portion of the Okanagan subbasin, 2017.

Stream Name	Total Observed *O. mykiss*	Density (fish/m^2)
snpin’yaʔtkʷ (Ellis Creek)	not sampled	n/a
akskʷəkʷant (Inkaneep Creek)	11	0.02
McLean Creek	91	0.28
q̓awsitkʷ (Okanagan River)	12[a]	>0.00[b]
akłxʷminaʔ (Shingle Creek)	not sampled	n/a
Shuttleworth Creek	Dry	Dry
snʕax̌əlqaxʷiyaʔ (Vaseux Creek)	262[a]	0.05[b]

[a] sum of all juvenile *O. mykiss* from multiple sites per creek.
[b] average density of all juvenile *O. mykiss* from multiple sites per creek.

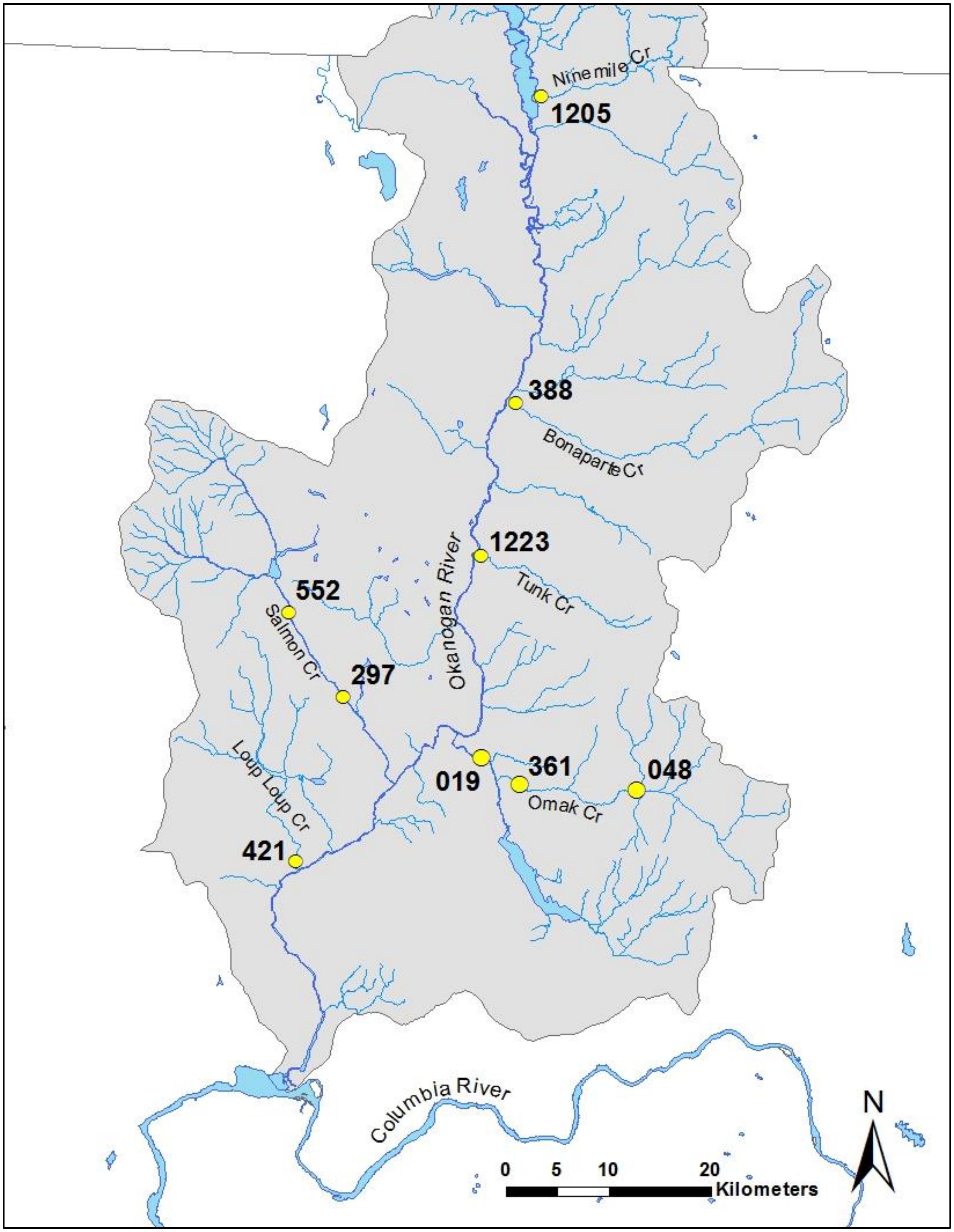
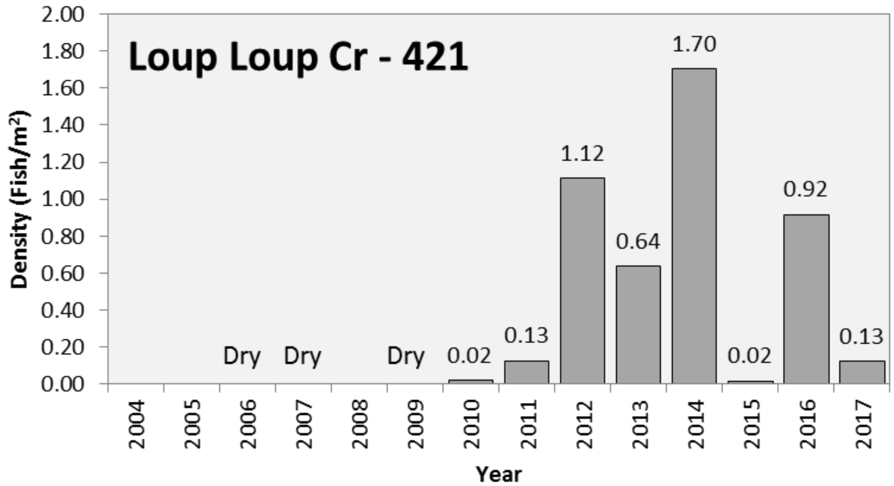
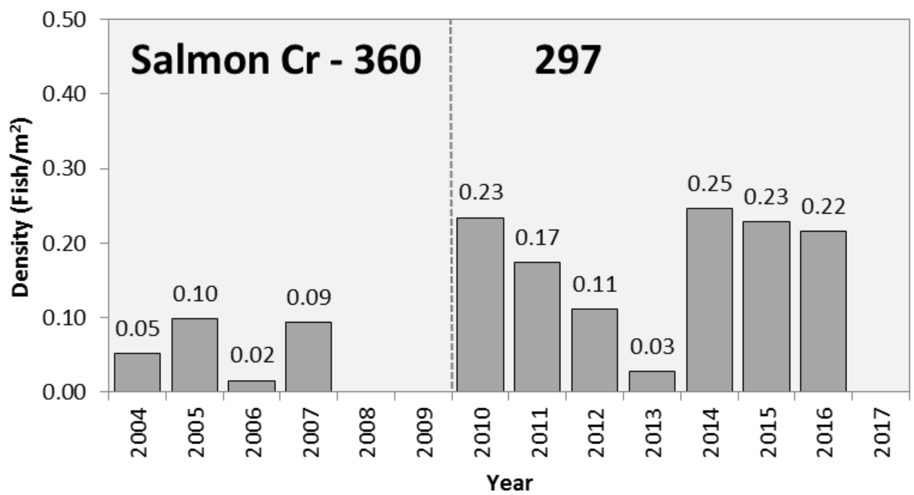


Figure C-1. Location of annual snorkel survey sites on tributaries to the Okanogan River. Rotating panel sites are not shown due to fewer years of data for each site.



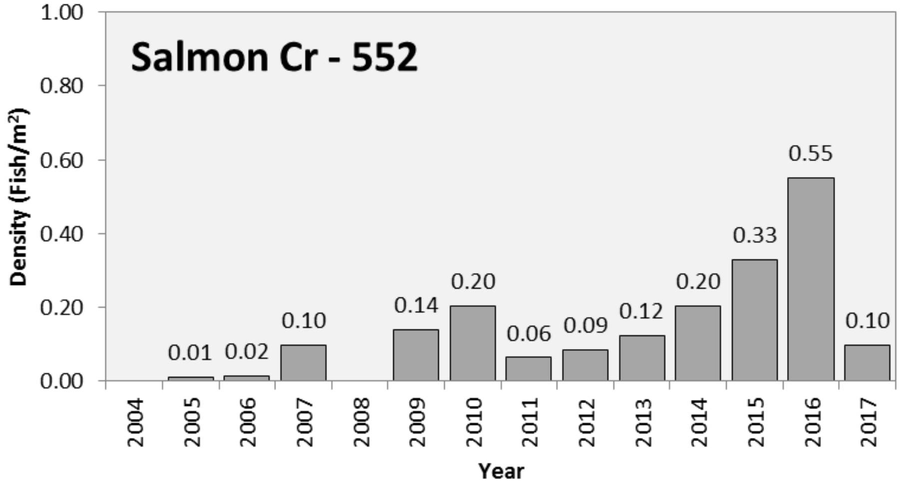
Year	# Obs.
2004	NS
2005	0
2006	Dry
2007	Dry
2008	NA
2009	Dry
2010	6
2011	48
2012	484
2013	269
2014	587
2015	6
2016	387
2017	52

Figure C-2. Observed density and count of juvenile (< 300mm) *O. mykiss* in Loup Loup Creek, in the town of Malott, WA.



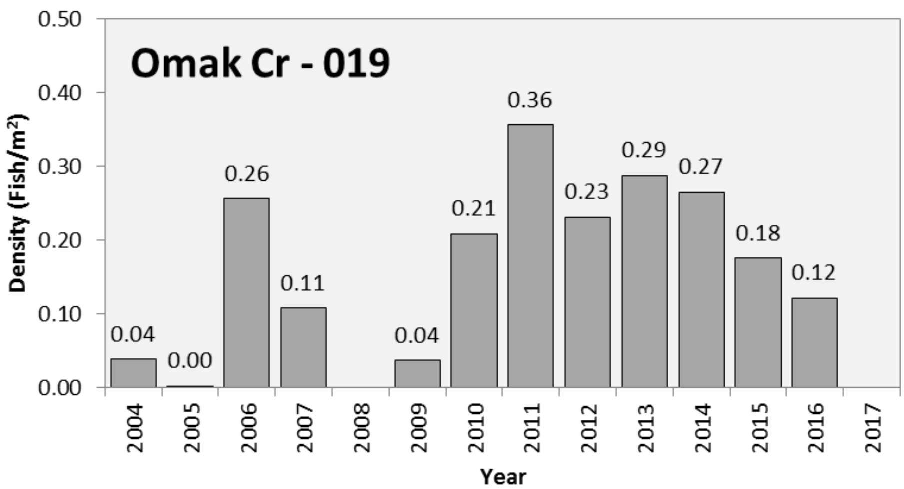
Year	# Obs.
2004	100
2005	157
2006	19
2007	104
2008	NA
2009	NS
2010	193
2011	158
2012	93
2013	20
2014	174
2015	167
2016	176
2017	NS

Figure C-3. Observed densities of juvenile (< 300mm) *O. mykiss* in Salmon Creek. In 2009, site 297 replaced nearby site 360 that was moved due to access related issues. In 2013, the site was electrofished prior to snorkeling, which likely affected observed counts.



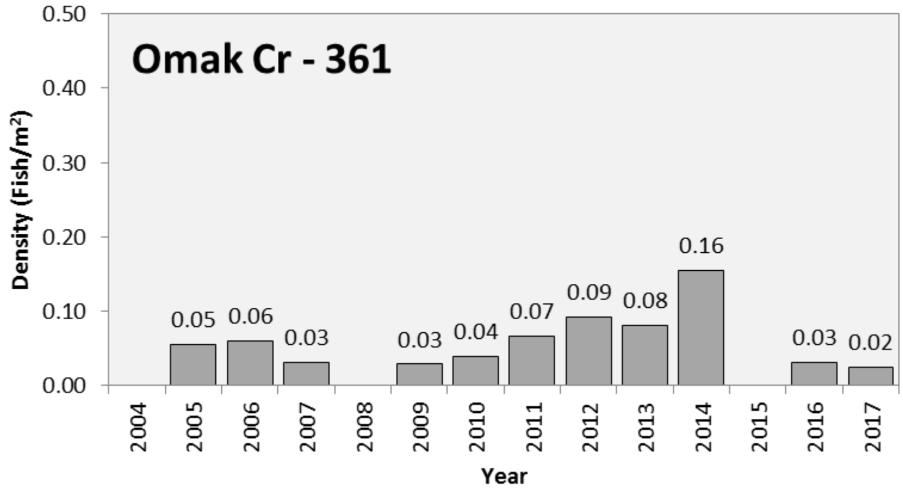
Year	# Obs.
2004	NS
2005	10
2006	18
2007	107
2008	NA
2009	103
2010	214
2011	75
2012	85
2013	126
2014	173
2015	267
2016	500
2017	95

Figure C-4. Observed densities of juvenile (< 300mm) *O. mykiss* in Salmon Creek, the upper most annual site on the creek, near the historical townsite of Ruby.



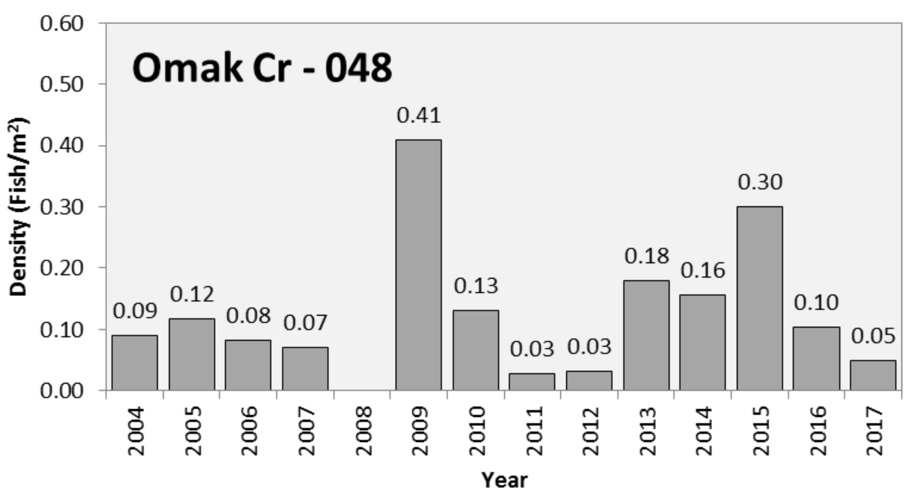
Year	# Obs.
2004	31
2005	2
2006	181
2007	67
2008	NA
2009	21
2010	142
2011	288
2012	176
2013	199
2014	174
2015	121
2016	87
2017	NS

Figure C-5. Observed densities of juvenile (< 300mm) *O. mykiss* in Omak Creek, the lower most site on the creek, and the only annual site below Mission Falls.



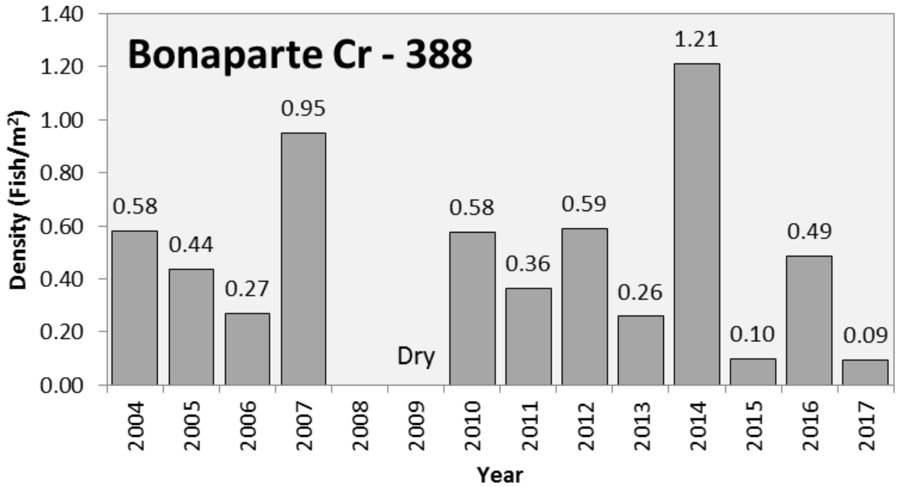
Year	# Obs.
2004	NS
2005	79
2006	106
2007	45
2008	NA
2009	26
2010	37
2011	108
2012	128
2013	126
2014	177
2015	NS
2016	38
2017	34

Figure C-6 Observed densities of juvenile (< 300mm) *O. mykiss* in Omak Creek, located in the middle portion of the watershed, but above Mission Falls.



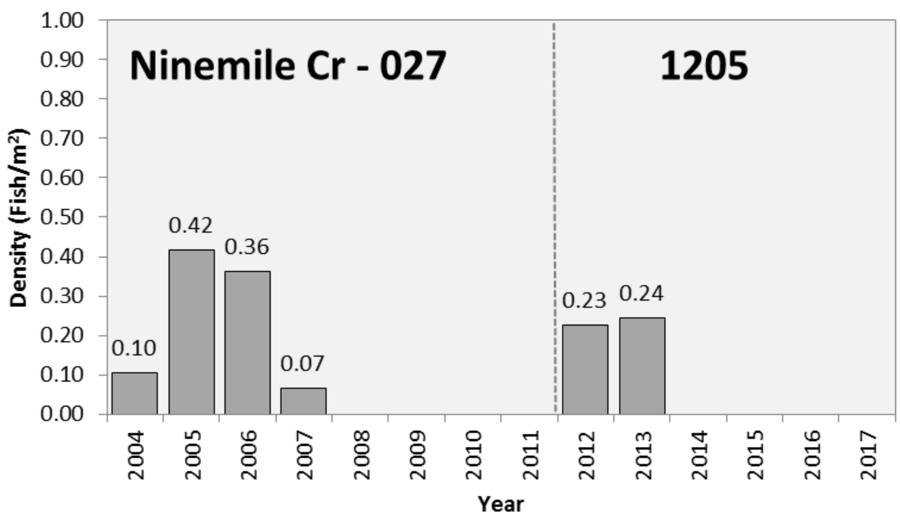
Year	# Obs.
2004	96
2005	108
2006	78
2007	74
2008	NA
2009	288
2010	141
2011	26
2012	33
2013	162
2014	142
2015	289
2016	92
2017	46

Figure C-7. Observed densities of juvenile (< 300mm) *O. mykiss* in Omak Creek, the upper most site in the Omak Creek watershed.



Year	# Obs.
2004	210
2005	149
2006	100
2007	220
2008	NA
2009	Dry
2010	179
2011	94
2012	144
2013	57
2014	237
2015	19
2016	152
2017	28

Figure C-8. Observed densities of juvenile (< 300mm) *O. mykiss* in Bonaparte Creek in the city of Tonasket, WA.



Year	# Obs.
2004	29
2005	108
2006	99
2007	15
2008	NA
2009	NS
2010	NS
2011	NS
2012	72
2013	67
2014	NS
2015	NS
2016	NS
2017	NS

Figure C-9. Observed densities of juvenile (<300mm) *O. mykiss* on Ninemile Creek. Site 1205 was shifted a few transects downstream of previous annual site 027; both sites occasionally could not be sampled due to complete poison ivy coverage or very low water depths.

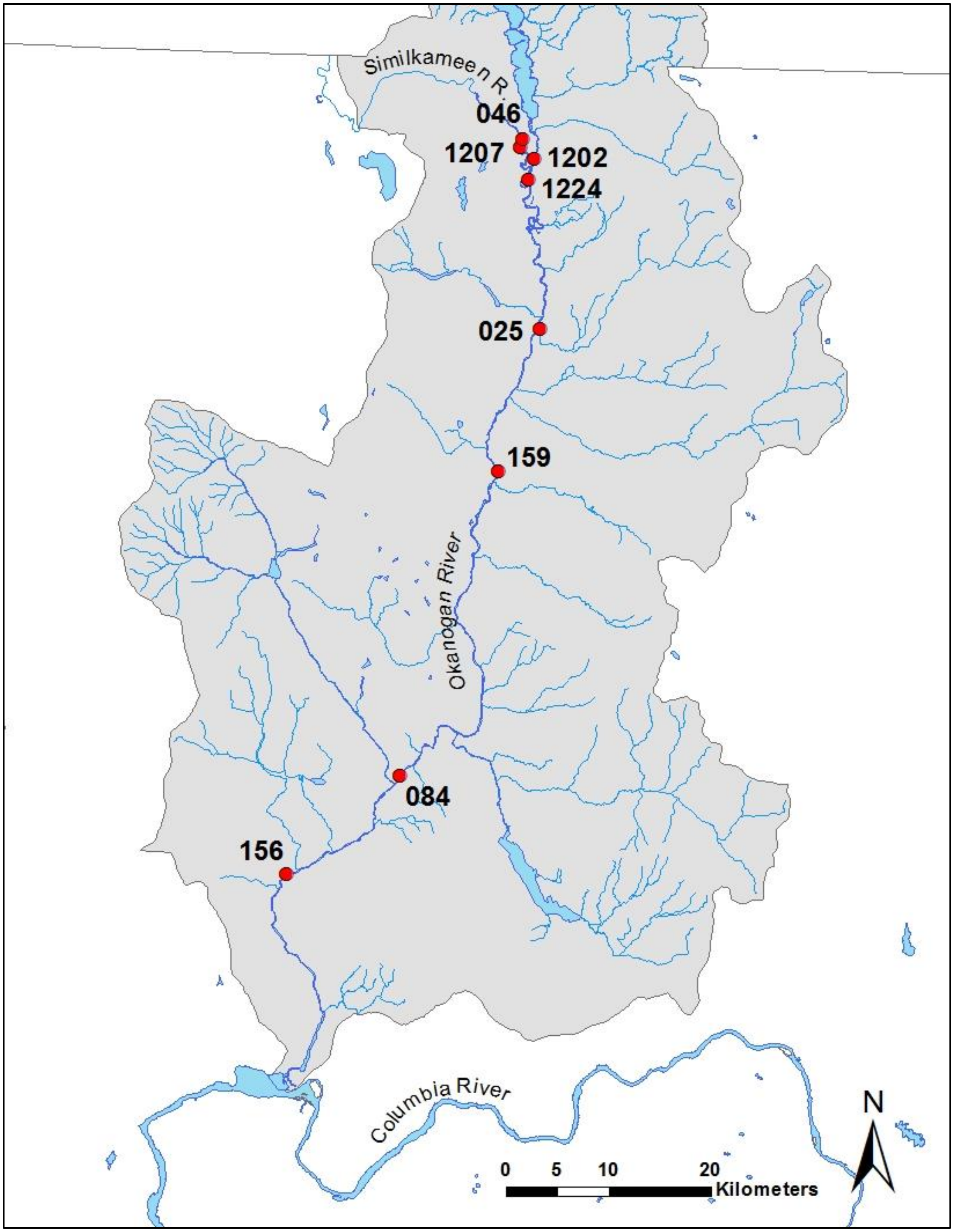


Figure C-10. Location of annual snorkel survey sites on the mainstem Okanogan and Similkameen Rivers. Rotating panel sites are not shown due to fewer years of data.

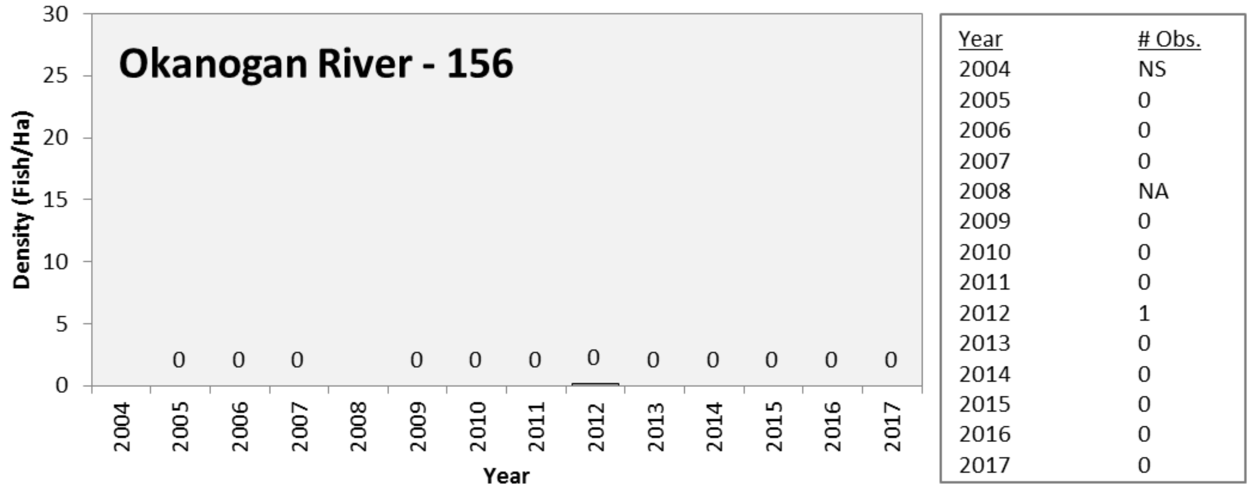


Figure C-11. Observed densities of juvenile (< 300mm) *O. mykiss* in the Okanogan River, downstream of the confluence with Loup Loup Creek.

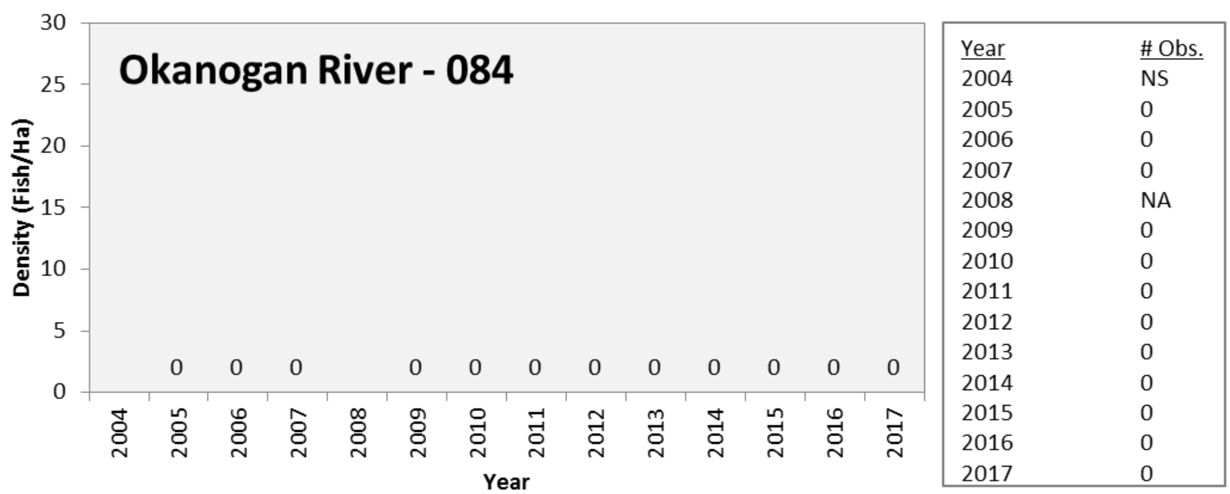
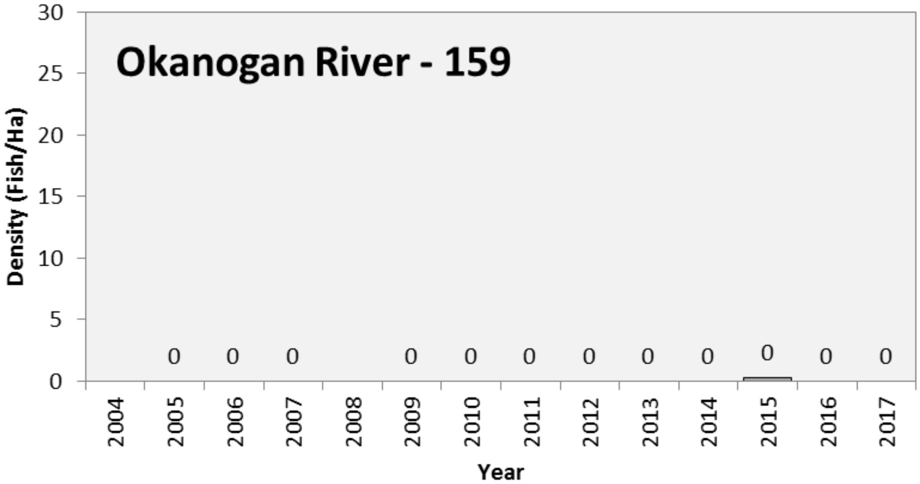
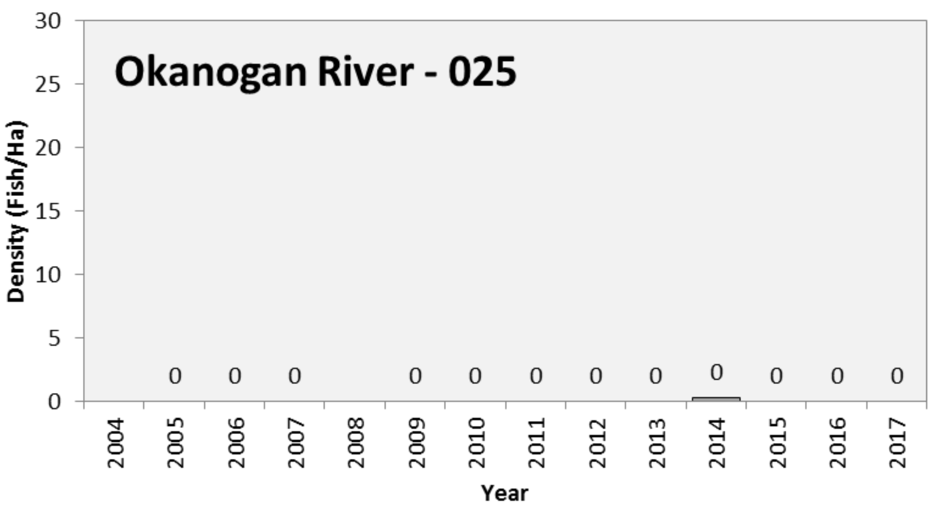


Figure C-12. Observed densities of juvenile (< 300mm) *O. mykiss* in the Okanogan River, upstream of the confluence with Salmon Creek.



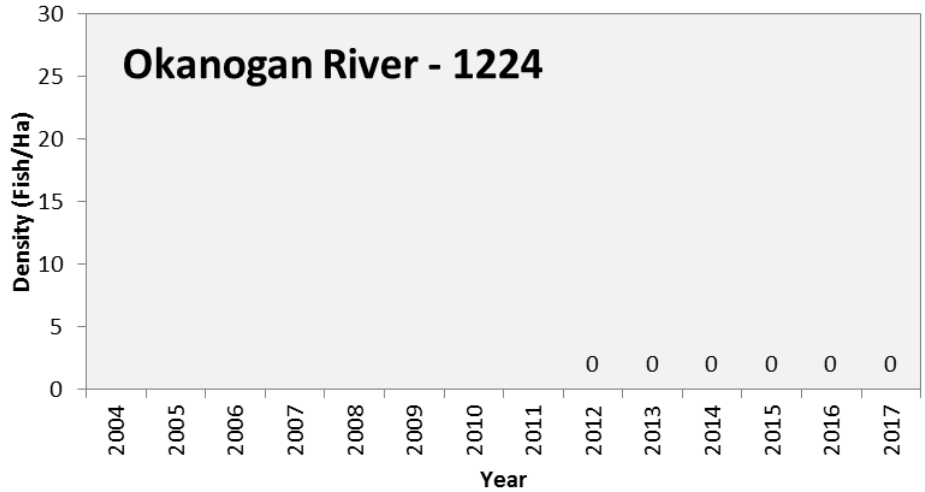
Year	# Obs.
2004	NS
2005	0
2006	0
2007	0
2008	NA
2009	0
2010	0
2011	0
2012	0
2013	0
2014	0
2015	1
2016	0
2017	0

Figure C-13. Observed densities of juvenile (< 300mm) *O. mykiss* in the Okanogan River, south of Tonasket, WA, below Janis Bridge.



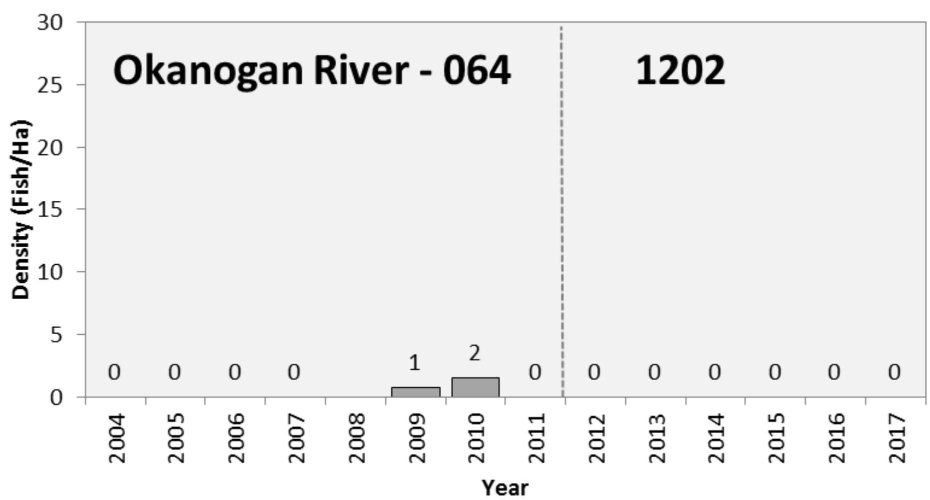
Year	# Obs.
2004	NS
2005	0
2006	0
2007	0
2008	NA
2009	0
2010	0
2011	0
2012	0
2013	0
2014	1
2015	0
2016	0
2017	0

Figure C-14. Observed densities of juvenile (< 300mm) *O. mykiss* in the Okanogan River, upstream of the confluence with Antoine Creek.



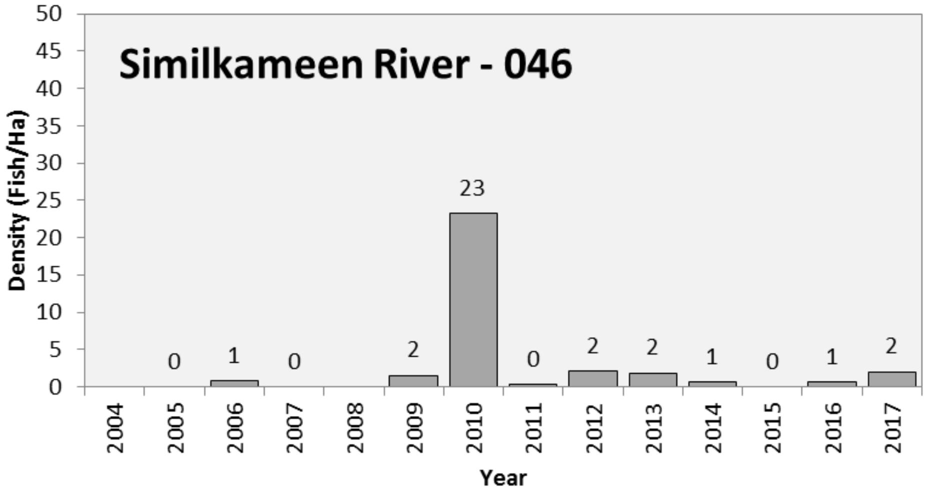
Year	# Obs.
2004	NA
2005	NA
2006	NA
2007	NA
2008	NA
2009	NA
2010	NA
2011	NA
2012	0
2013	0
2014	0
2015	0
2016	0
2017	0

Figure C-15. Observed densities of juvenile (<300mm) *O. mykiss* in the Okanogan River. This new site was added in 2012 and is in the narrow part of the Okanogan River just before the confluence with the Similkameen.



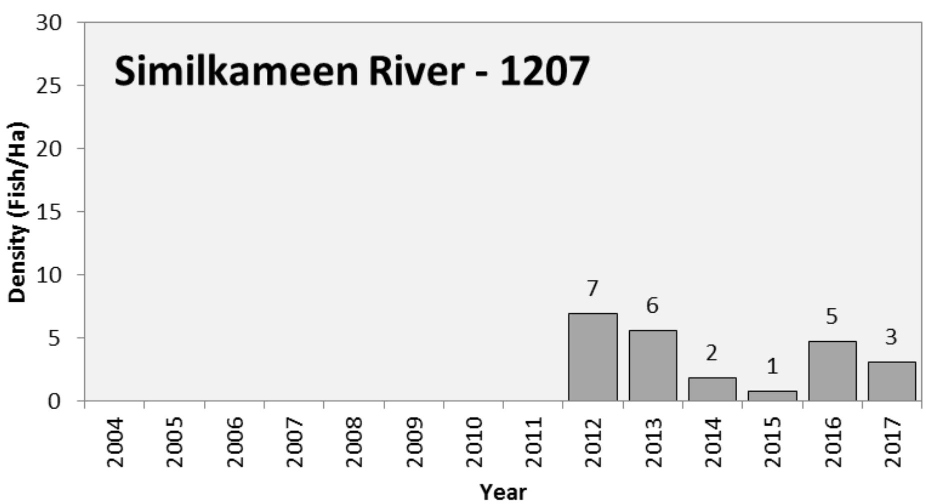
Year	# Obs.
2004	0
2005	0
2006	0
2007	0
2008	NA
2009	1
2010	2
2011	0
2012	0
2013	0
2014	0
2015	0
2016	0
2017	0

Figure C-16. Observed densities of juvenile (<300mm) *O. mykiss* in the Okanogan River. Site 1202 was moved two transects downstream of previous annual site 064 which overlapped the upper cross-channel with the Similkameen.



Year	# Obs.
2004	NS
2005	0
2006	2
2007	0
2008	NA
2009	4
2010	75
2011	1
2012	6
2013	6
2014	2
2015	0
2016	1
2017	6

Figure C-17. Observed densities of juvenile (< 300mm) *O. mykiss* in the Similkameen River, near the city of Oroville, WA.



Year	# Obs.
2004	NA
2005	NA
2006	NA
2007	NA
2008	NA
2009	NA
2010	NA
2011	NA
2012	18
2013	16
2014	5
2015	2
2016	13
2017	8

Figure C-18. Observed densities of juvenile (<300mm) *O. mykiss* in the Similkameen River. This new site was added in 2012.

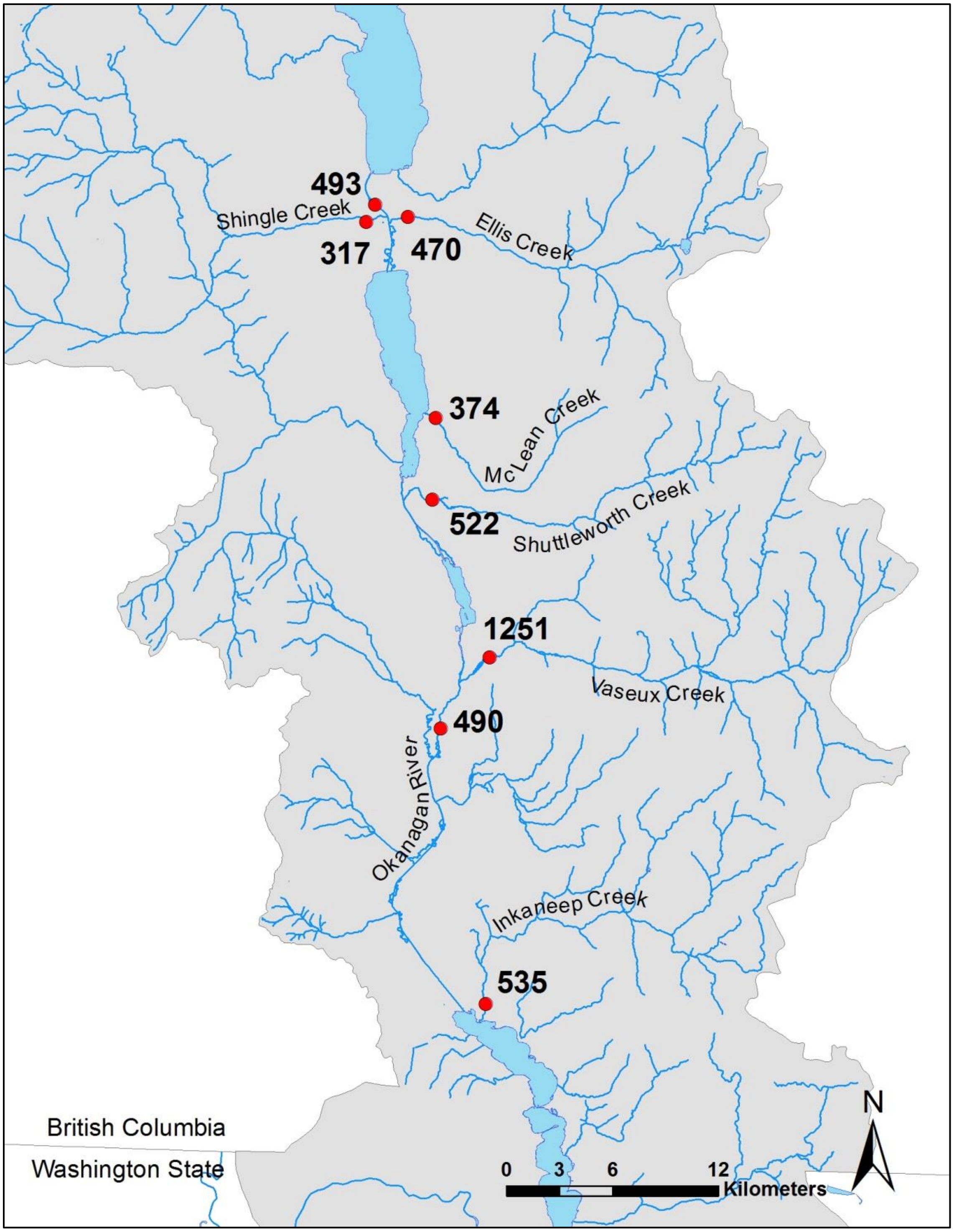
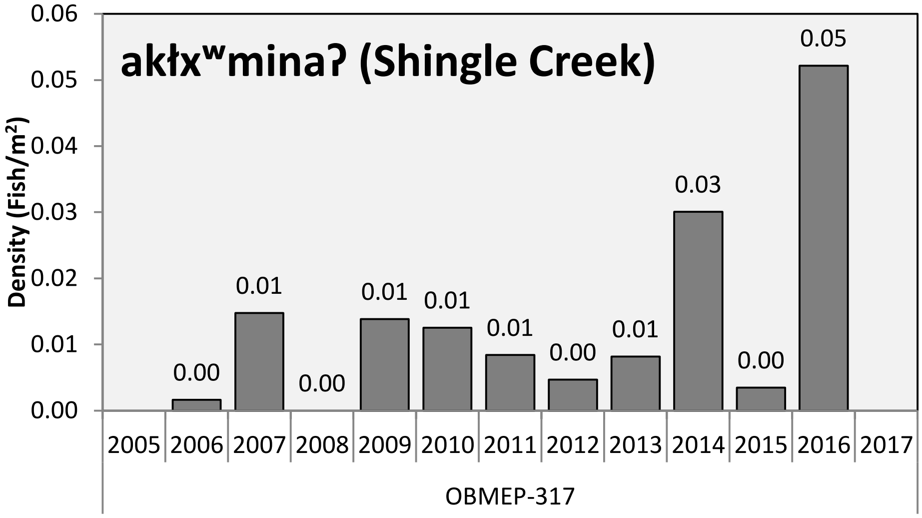
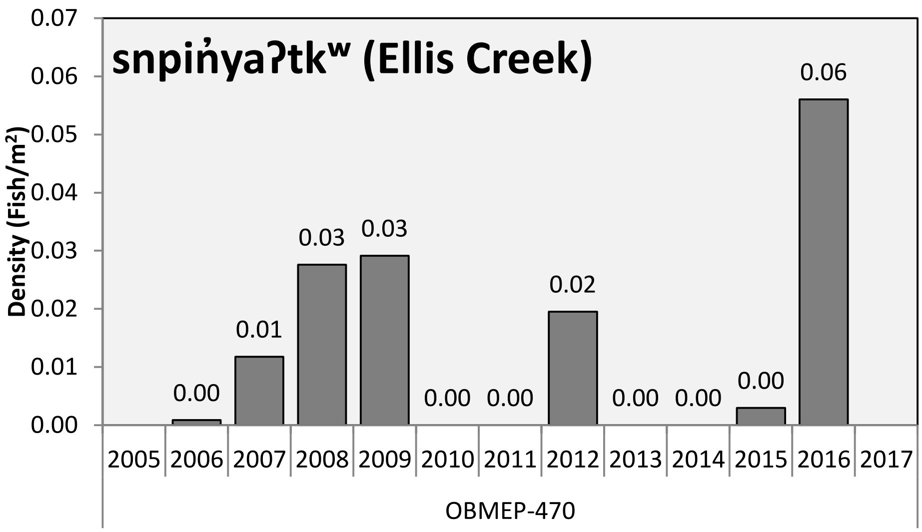


Figure C-19. Location of annual snorkel survey sites on the British Columbia portion of the Okanagan subbasin. Rotating panel sites are not shown due to fewer years of data.



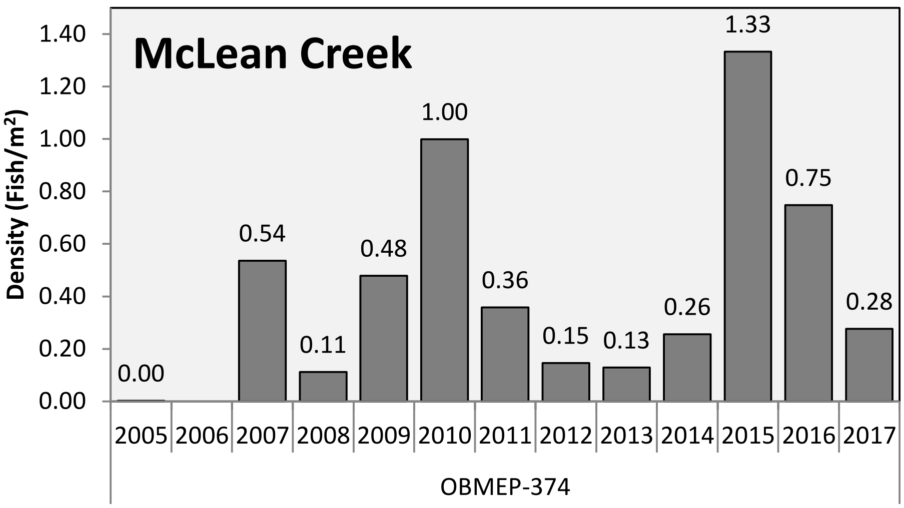
Year	# Obs.
2004	NA
2005	NA
2006	1
2007	10
2008	0
2009	8
2010	7
2011	5
2012	3
2013	5
2014	19
2015	2
2016	48
2017	NA

Figure C-20. Observed densities of juvenile (< 300mm) *O. mykiss* in lower akłx̌ʷminaʔ (Shingle Creek) at site 317.



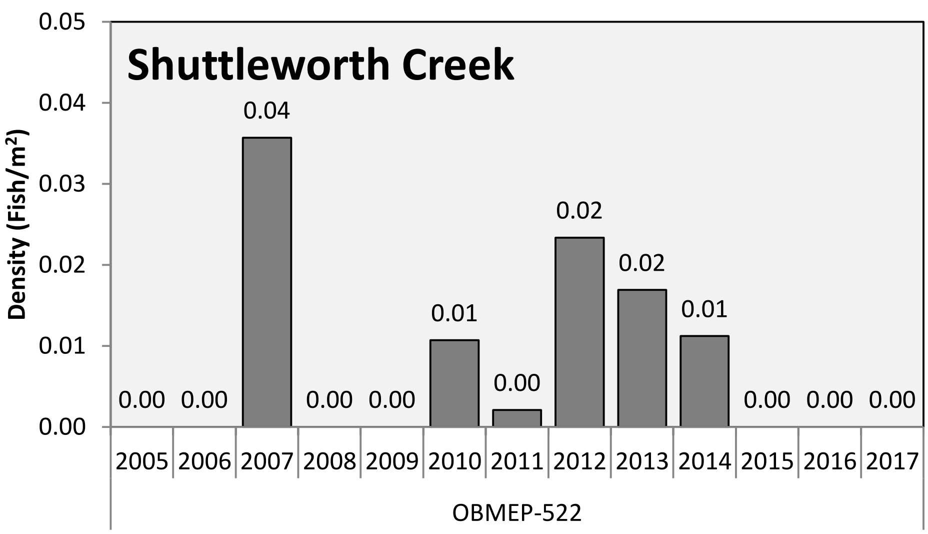
Year	# Obs.
2004	NA
2005	0
2006	1
2007	12
2008	28
2009	27
2010	0
2011	0
2012	23
2013	0
2014	0
2015	3
2016	65
2017	NA

Figure C-21. Observed densities of juvenile (< 300mm) *O. mykiss* in lower snpin'yaʔtkʷ (Ellis Creek) at site 470.



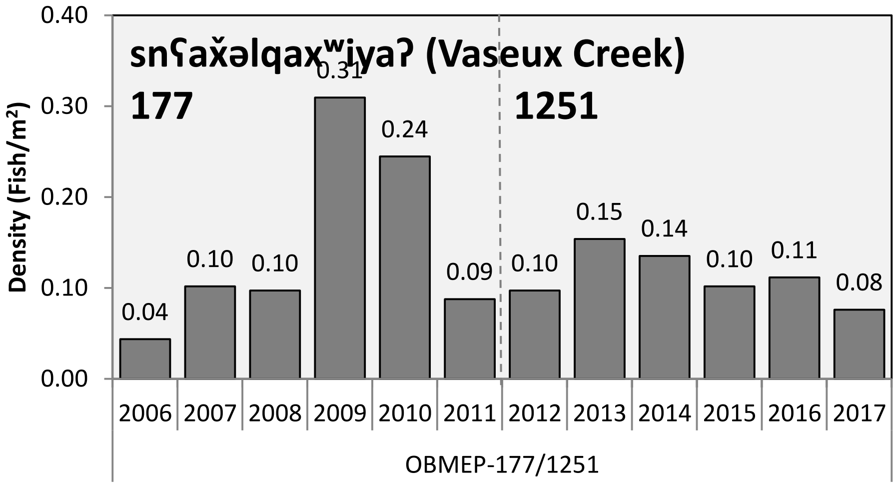
Year	# Obs.
2004	NA
2005	1
2006	NS
2007	178
2008	45
2009	93
2010	323
2011	139
2012	48
2013	47
2014	89
2015	446
2016	318
2017	91

Figure C-22. Observed densities of juvenile (< 300mm) *O. mykiss* in McLean Creek at site 374.



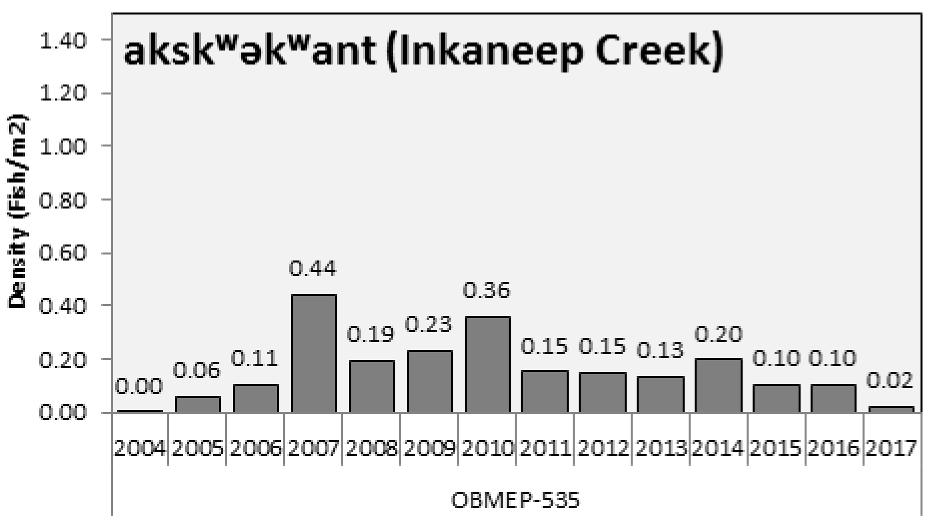
Year	# Obs.
2004	NA
2005	0
2006	0
2007	25
2008	0
2009	0
2010	5
2011	1
2012	15
2013	13
2014	9
2015	0
2016	0
2017	Dry

Figure C-23. Observed densities of juvenile (< 300mm) *O. mykiss* Shuttleworth Creek at site 522.



Year	# Obs.
2006	70
2007	167
2008	265
2009	576
2010	563
2011	227
2012	256
2013	565
2014	487
2015	344
2016	324
2017	223

Figure C-24. Observed densities of juvenile (< 300mm) *O. mykiss* snʕax̌əlqaxʷiyaʔ (Vaseux Creek). In 2012, site 177 was shifted a few transects down and renamed site 1251.



Year	# Obs.
2004	2
2005	38
2006	81
2007	295
2008	127
2009	132
2010	226
2011	84
2012	113
2013	94
2014	133
2015	63
2016	90
2017	11

Figure C-25. Observed densities of juvenile (< 300mm) *O. mykiss* akskʷəkʷant (Inkaneep Creek) at site 535.

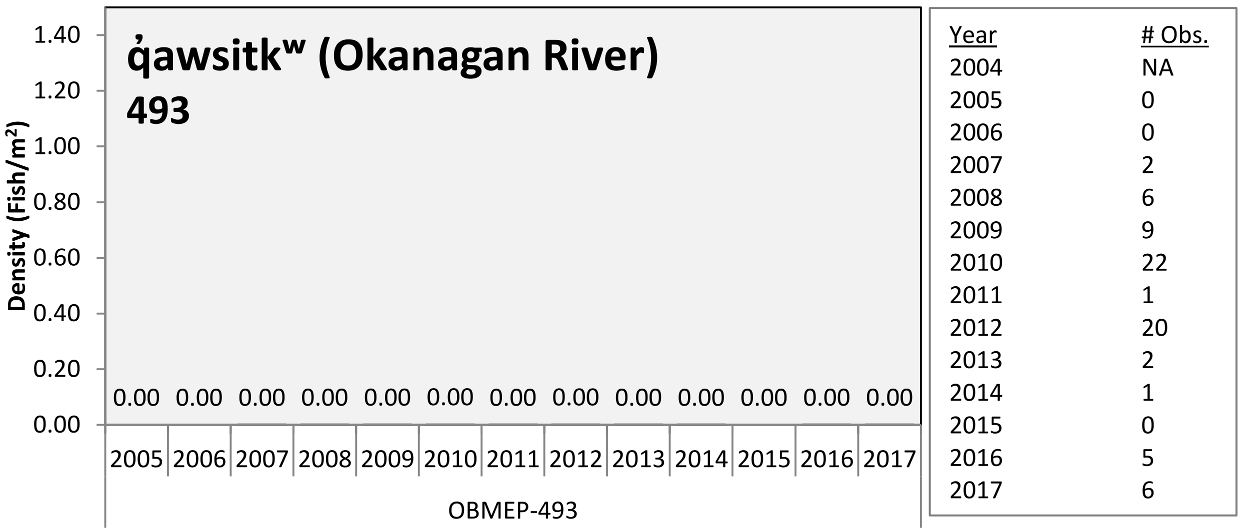


Figure C-26. Observed densities of juvenile (< 300mm) *O. mykiss* q̓awsitkʷ (Okanagan River) at site 493 (Penticton channel).

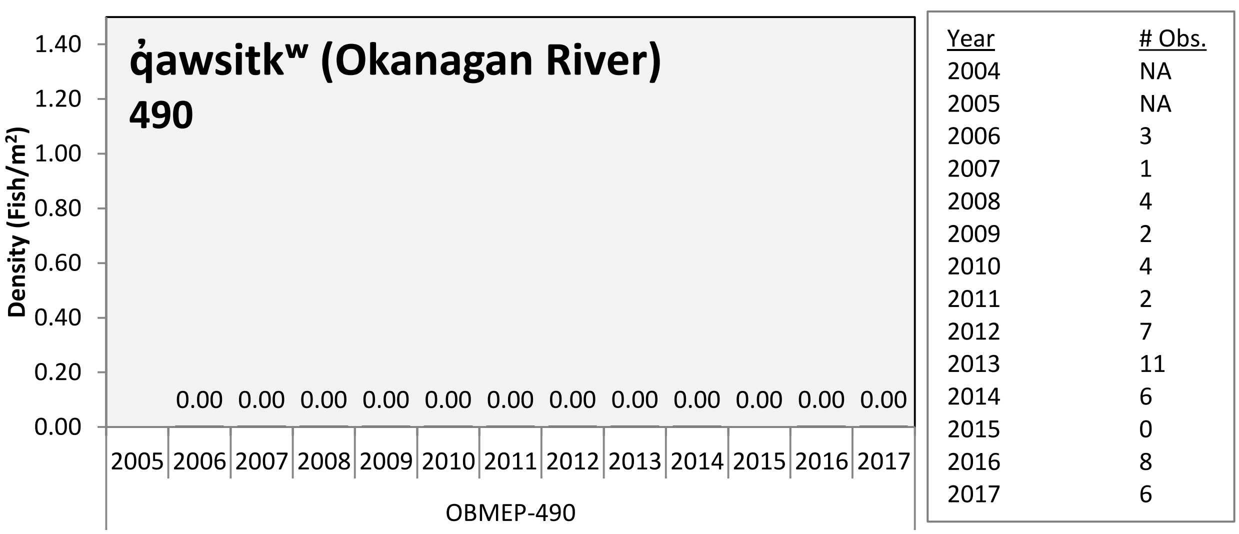


Figure C-27. Observed densities of juvenile (< 300mm) *O. mykiss* q̓awsitkʷ (Okanagan River) at site 490 (near Oliver).

Appendix D. Water Temperature

Introduction

Water temperature plays a fundamental role in dictating the distribution and abundance of salmonids in the Columbia River Basin especially 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
OBMEP - Habitat Monitoring (ID:9)
https://www.monitoringresources.org/Document/Protocol/Details/9

OBMEP collected hourly water temperature data in the Okanogan subbasin from 2005 through 2016, in both the mainstem and tributary reaches. Water temperature was collected at all annual and rotating panel 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 q̓awsitkʷ (Okanagan River) mainstem was also conducted through Water Survey of Canada (Environment Canada 2017). 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 are compiled on the OBMEP server located at the CCT Fish and Wildlife office in Omak, WA.

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

In 2015, additional investigations began to characterize variation between surface and hyporheic water temperatures at select major spawning areas in the Okanogan subbasin. During the initial study year, four sites were selected, two on the Okanogan mainstem below Zosel dam, one on the Similkameen mainstem, and one on Omak Creek. Two piezometers were installed at each site, one to monitor surface water temperature and one to monitor hyporheic temperature at egg-pocket depth ~20cm below the river surface. Temperature data were recorded hourly. The variation between surface and hyporheic temperatures was simply the difference in daily average. Projections of hatch and emergence timing were made using daily average 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 - 2017) 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 2017 MWAT values trended near or slightly below median and tended to be relatively colder in the northern portion of the Okanogan subbasin, with the exception of Vasuex Creek.

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 2017, the MWMT in the mainstem, most of the tributaries in the US, and all of the tributaries in Canada exceeded the 18°C threshold (Figure D-2). Weekly maximum stream temperature trended similarly to MWAT, as the majority of high temperatures in Summer 2017 were at or below median.

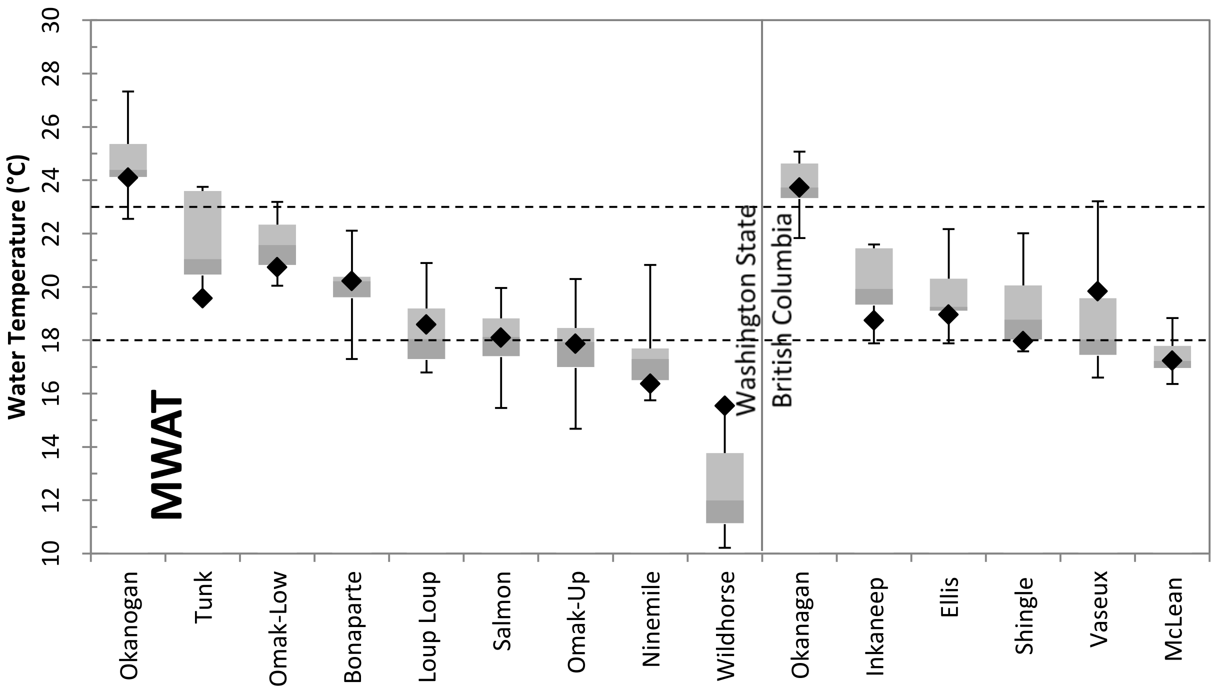


Figure D-1. Maximum weekly average water temperatures (MWAT)in the Okanogan subbasin from 2005-2017. Black diamonds are 2017 MWAT values. Boxes represent upper (Q3, light grey) and lower (Q1, dark grey) quartiles of MWAT during 2005-2017 while whiskers display the range of values. Dashed lines delineate 18°C (preferred rearing) and 23°C (lethal) thresholds (EPA 2003).

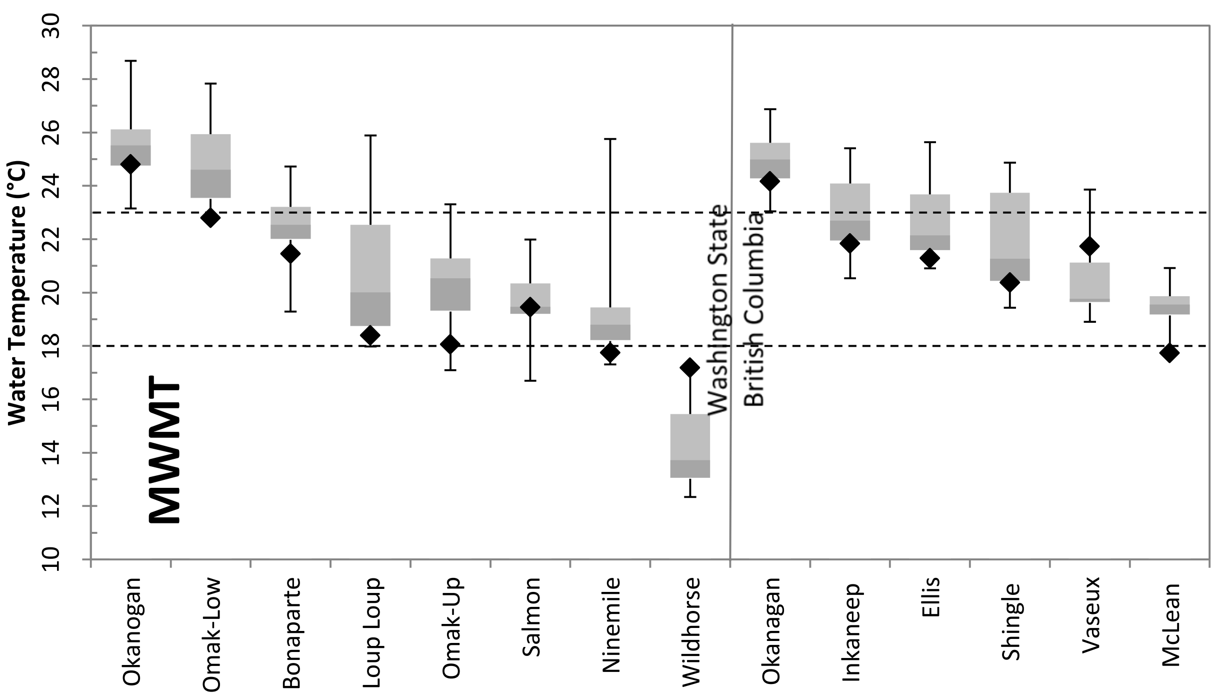


Figure D-2. Maximum weekly maximum water temperatures (MWMT) in the Okanogan subbasin from 2005-2017. Black markers are 2017 data; dashed line represents 18 and 23°C exceedance (EPA 2003).

Habitat Unit Scale Hypohorheic/Surface Water Variation

Several notable patterns emerged from investigating surface and hyporheic temperatures in the mainstem Okanogan River, Similkameen River, and Omak Creek during 2015, especially during steelhead spawning and egg incubation time frames. At two closely spaced sites in the Okanogan River below Zosel Dam, the daily average hyphorheic water temperature was typically within 1°C (0.1°C and 0.6°C) of the surface water temperature (Figure D-3) between March 1st and May 15th, at which point one of the monitoring locations diverged to an average difference of approximately 1°C . At those locations, the subsurface temperatures exhibited diel fluctuations similar in magnitude to surface water, suggesting that there is little to no groundwater influence. Conversely, at the Similkameen River and Omak Creek sites there was approximately a 1-6°C difference between subsurface and surface water temperatures. This differential increased through time as surface water warmed. Hyporheic water temperature did not exhibit strong diel fluctuations at either location with observed weekly variation in relative water temperature being driven by trends in surface water temperature on the Similkameen River or Omak Creek.

Mean surface water temperature in lower Omak Creek is typically 5°C in early April and can exceed 20°C by late-July and early-August (Figure D-4). Average exceedance of 15°C occurs in mid-June on average, but ranges from late-May through late-June. Observed surface water temperature was variable as temperatures alternately were recorded as the minimum and maximum values for the period of record throughout spawning and egg incubation.

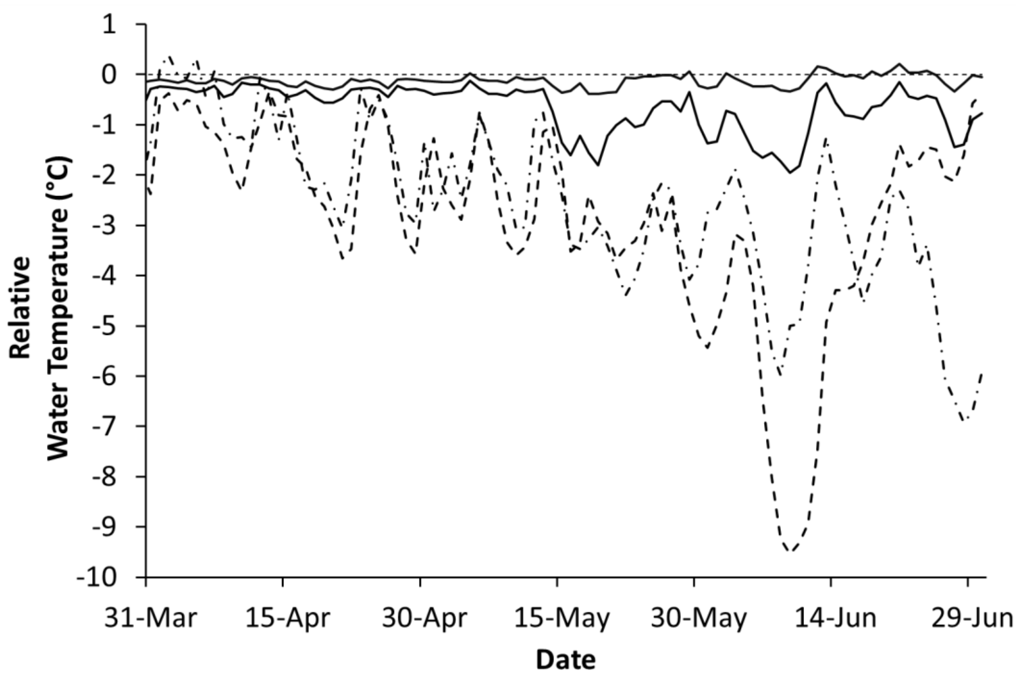


Figure D-3. Relative difference between average daily hyporheic and surface water temperatures in the Okanogan River below Zosel Dam (solid lines), Similkameen River (dashed line) and Omak Creek (dashed/dotted line).

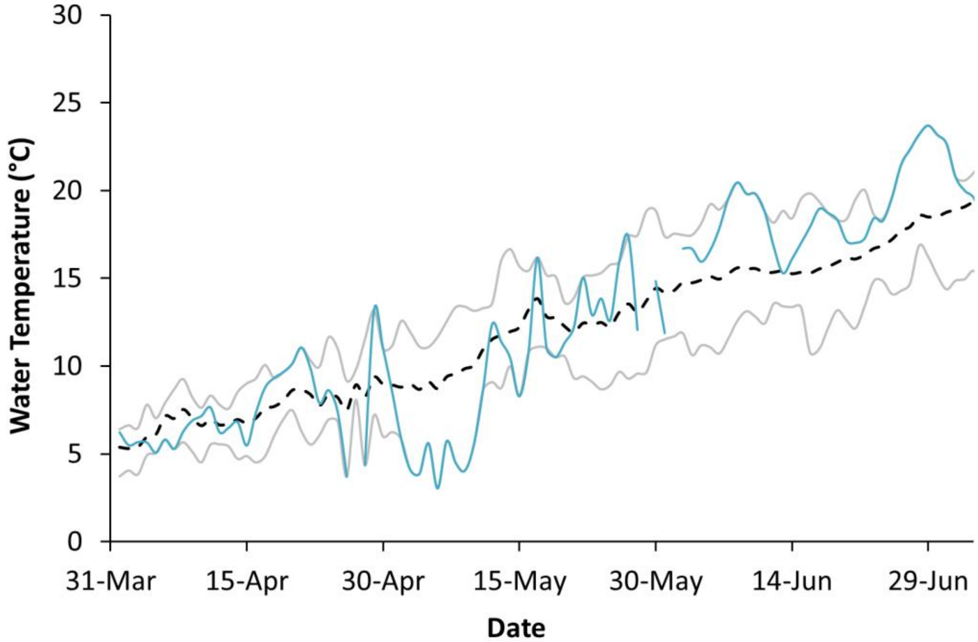


Figure D-4. Mean daily surface water temperature for lower Omak Creek (OBMEP site 019) during spring of 2015 (blue line) and approximating the timing of spawning and egg incubation. The dashed line is the average surface water temperature at this location for the period of record. Upper and lower gray lines are the minimum and maximum mean daily temperatures during the period of record.

The 10-year average temperature in the Okanogan River near Zosel Dam exceeds 15°C in mid-May with approximately two weeks of annual variation (Figure D-5), the earliest being early-May in 2005 and the latest the first week of June in 2011. Mean daily surface water temperature was above average for the duration of spawning and egg incubation in the study area during the pilot in 2015 and again in 2016.

Predicted timing of hatch and emergence (Table D-2) ranges from hatch timing in early-May for early April spawning in the Okanogan River to early-June for late-April spawning in the Similkameen River. Exceedance of approximate thermal thresholds for survival of eggs and alevin in hyporheic zone generally occurred after predicted emergence of late-April spawn timing at the Similkameen River and Omak Creek site. Hyporheic temperatures exceeding 16°C occurred coincident to predicted emergence of mid-April spawning at the Okanogan River site.

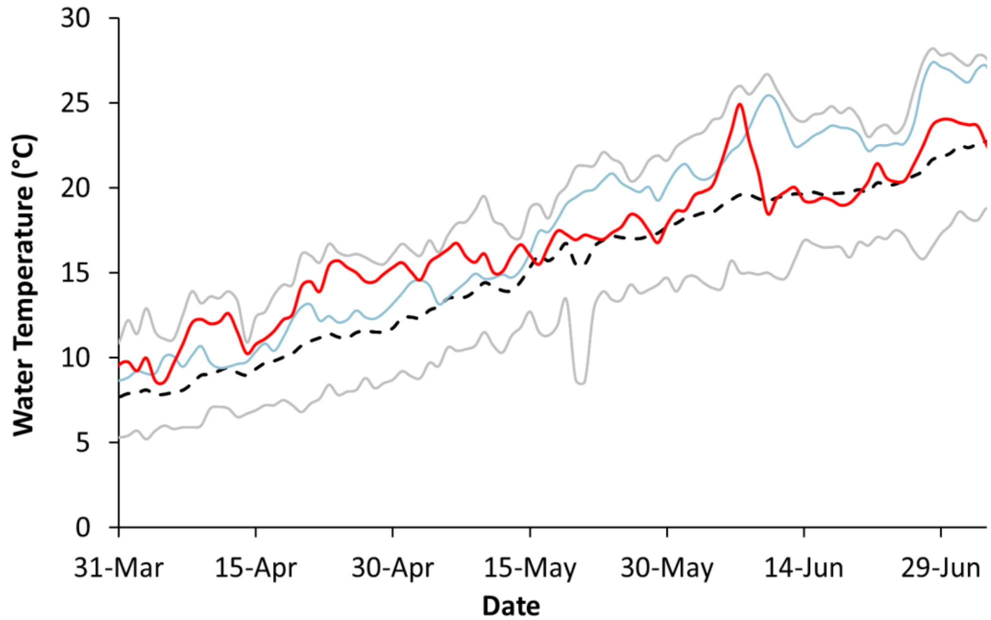


Figure D-5. Mean daily surface water temperature for Okanogan River below Zosel Dam (USGS Station 12439500, Okanogan River at Oroville, WA) during spring of 2015 (blue line) and 2016 (red line) and approximating the timing of spawning and egg incubation. The dashed line is the average surface water temperature at this location for the period of record. Upper and lower gray lines are the minimum and maximum mean daily temperatures during the period of record.

Table D-2. Predicted timing of hatch and emergence for three hyporheic monitoring locations and three spawning dates in 2015 including dates at which the average daily surface and hyporheic water temperatures exceed 16°C. Assumes 300 ATU to hatch and 450 ATU for emergence.

Site	**Life Stage**	**Spawn Date**			**Ambient Temperature**	
		4/1	4/15	4/30	Surface	Hyporheic
Okanogan River						
	Hatch	4/28	5/8	5/20	5/15	5/16
	Emerge	5/9	5/18	5/27		
Similkameen River						
	Hatch	5/11	5/21	6/2	6/6	6/19
	Emerge	5/28	6/6	6/16		
Omak Creek						
	Hatch	5/10	5/17	5/27	6/5	6/27
	Emerge	5/23	5/29	6/7		

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.

Water temperatures in Omak Creek and the Similkameen River do not appear to considerably limit early life-stage survival during many years; however some effects may be occurring to later spawning individuals in warmer than average years. Relatively cooler hyporheic water may buffer negative effects rapidly heating surface water in these locations. However, little cold water refugia may exist in the hyporheic zone in the mainstem river reach below Zosel dam. At this location water temperatures exceeded published thresholds prior to predicted emergence of fry originating during or after peak spawning in approximately mid-April. As shown in Figure D-2, the 10-year average temperature in this reach exceeded 16°C in mid-May. This is of note as approximately 49% of the Okanogan steelhead population spawns annually in this reach (OBMEP 2015). The earliest that the temperature was exceeded was early-May in 2005 and the latest exceedance date was the beginning of June in 2011.Although specific research has not been conducted on egg-to-fry survival for the Okanogan subbasin for steelhead, the temperature range presented by Myrick and Cech (2001) suggest that elevated temperature may be negatively affecting steelhead at the incubation and emergence life stages in this reach.

Although high summer water temperatures occur in the tributaries, acclimation and diel temperature fluctuations 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 10-year snorkel survey datasets (Appendix G), juvenile salmonids are consistently observed in greater numbers in small tributaries than in the mainstem Okanogan River, where they are infrequently observed. Thermal tolerances for juvenile salmonids suggest there should be few or no juvenile salmonids in the mainstem during high summer temperatures. However, concern exists over this apparent absence because approximately 50% of steelhead spawning occurs in the mainstem on a given year (OBMEP 2015). It is unknown if high summer water temperatures cause direct mortality to juveniles or alter their behavior by avoiding high temperatures, or if both are occurring, and to what degree. Juveniles may seek refuge in interstitial spaces between the gravels and snorkeling may not be as efficient for observing juveniles in the mainstem. Although summer water temperatures may limit use of certain habitats for a few months these same habitats can be utilized for many months when water temperatures are not limiting but this seasonal use is still not well studied. Monitoring temperature in the mainstem Okanogan River and its tributaries will continue to play an important role in understanding life histories and seasonal habitat use of steelhead in the Okanogan subbasin.

Appendix E. Water Quantity/Discharge

Introduction

The Okanogan subbasin consists of two large mainstem rivers, the Okanogan and Similkameen, which combined have a substantial catchment area, roughly 21,000 km^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 runoff period, followed by very low base flow periods throughout the rest of the year. Many small tributaries flow subsurface in the lower reaches in mid-summer, which may result in disconnection of streams from the mainstem river. Primary causes may be attributed to the semi-arid climate and geology of the Okanogan subbasin, minimal catchment area for some small watersheds, and water diversion/withdrawals for irrigation usage.

Methods

OBMEP - Water Quality Sampling (ID:5)
https://www.monitoringresources.org/Document/Protocol/Details/5
OBMEP - Habitat Monitoring (ID:9)
https://www.monitoringresources.org/Document/Protocol/Details/9

Discharge data were collected on the mainstem by the USGS and Canadian governmental organizations. 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 work (measuring the velocity and volume of water passing a point at a given time), automated data loggers (electronics located at the stream gage site that upload to the internet), and data analysis (creating stream discharge rating curves 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 on the river. Discharge in the U.S. Okanogan mainstem are 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 discharge trends in the US Okanogan mainstem (Figure E-1) compared to the Canadian Okanagan mainstem (Figure E-2). The USGS has continuously operated the Okanogan mainstem stream gauge at Tonasket for the last 88 years. Similarly the Water Survey of Canada (WSC) has operated the gauge near Oliver, British Columbia for 73 years.

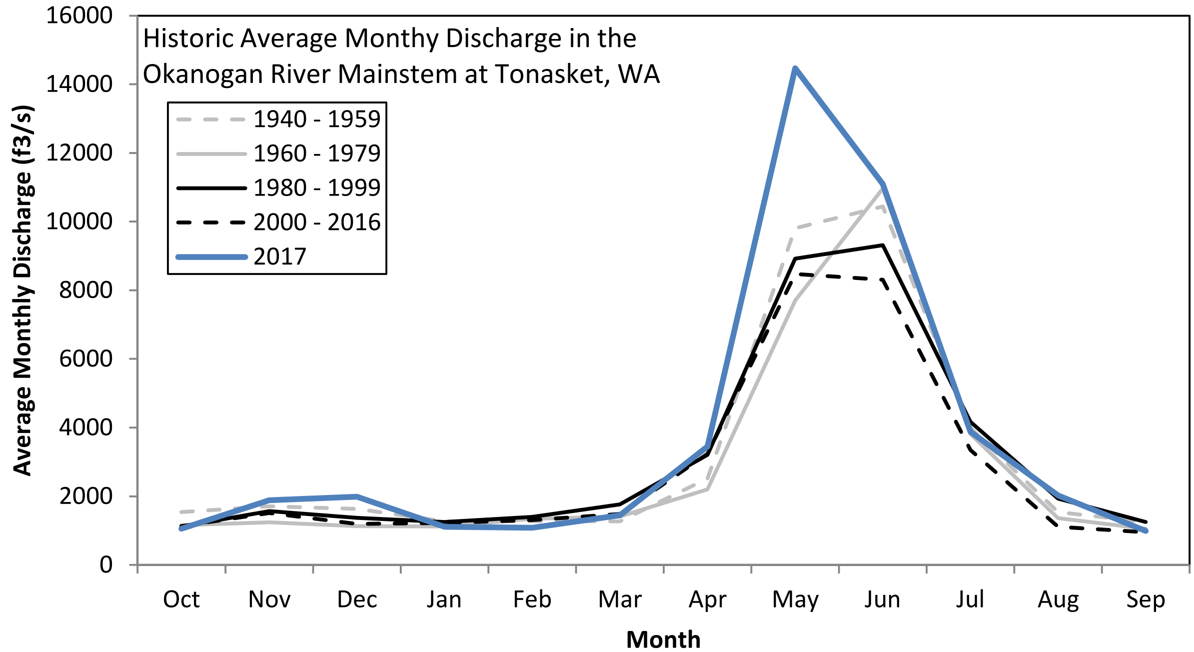


Figure E-1. Average monthly discharge of the Okanogan River at Tonasket, WA (USGS Station 12445000, Okanogan River near Tonasket, WA).

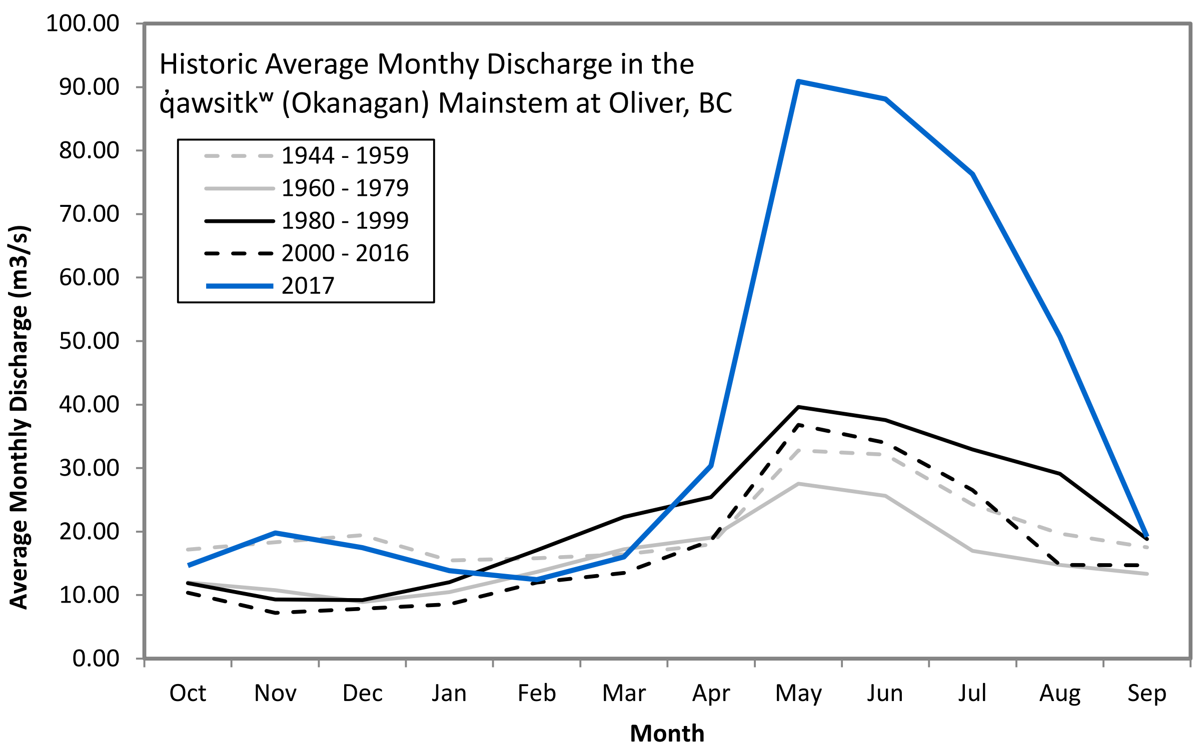


Figure E-2. Historic mean monthly discharge recorded at Water Survey of Canada station 08NM085 near Oliver from 1944 to 2016 (Environment Canada 2017).

Historic average monthly discharges for both locations are displayed in Figure E-1 and Figure E-2. The historic time periods are represented in 20-year divisions for the entire span of operation. For the 2017 water year, the annual inflow into kłusxnitkʷ (Okanagan Lake) was 172% of normal representing the sixth highest overall inflow on record since 1921. This was primarily the result of above-average late snowpack emanating into the highest recorded inflow into kłusxnitkʷ (Okanagan Lake) for the month of May (Shaun Reimer, MoFLNRO, 2017, pers com).

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

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

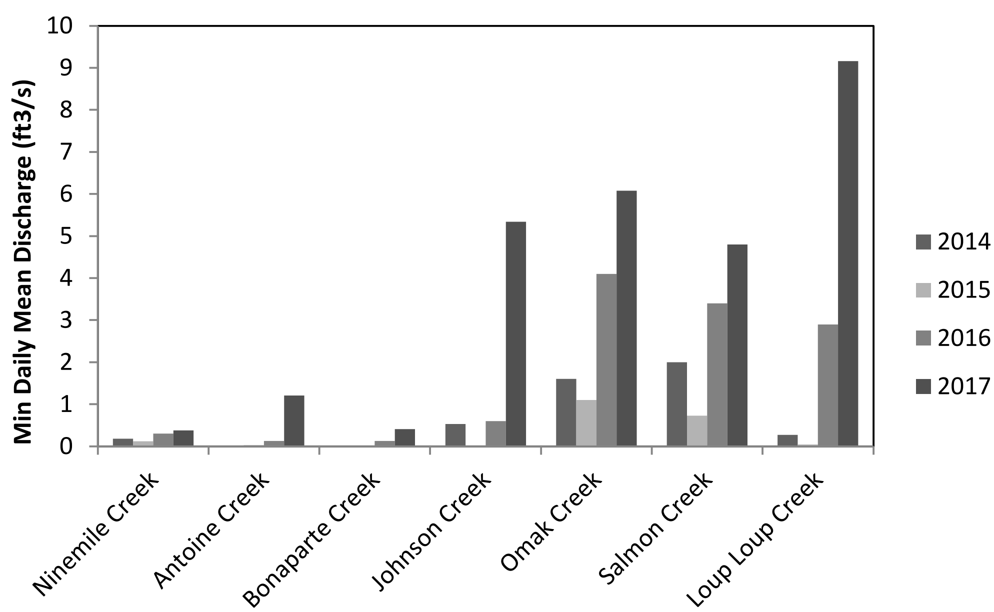


Figure E-3. Minimum Daily Mean Discharge of seven tributaries to the Okanogan River, or the mean discharge for the lowest low flow day of the year.

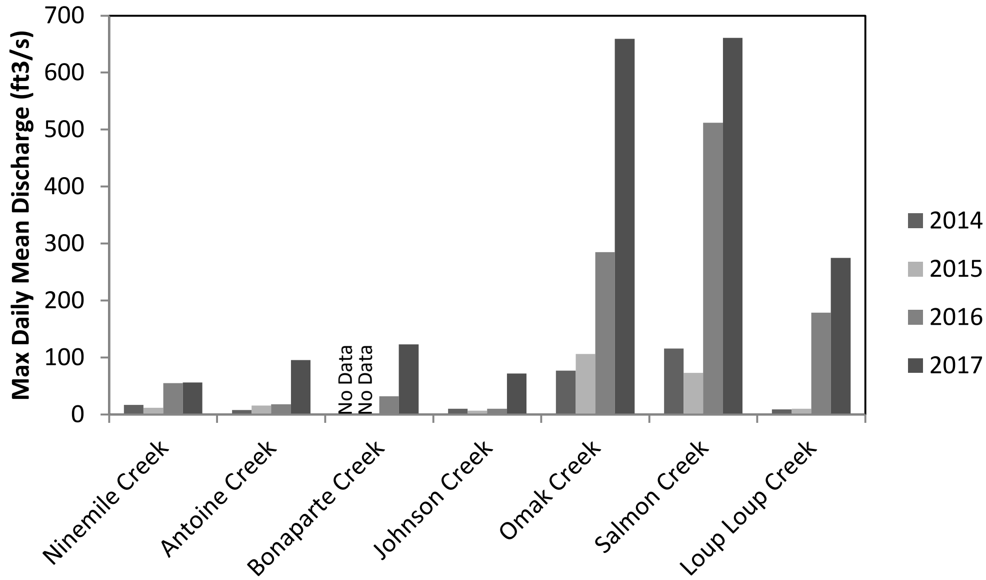


Figure E-4. Maximum Daily Mean Discharge of seven tributaries to the Okanogan River, or the mean discharge for the highest peak flow day of the year.

Conclusions

Although much progress has been made over the past 10 years, habitat projects focusing on quantity of water in streams will continue to be an important focus, particularly during the summer base flow period and maintaining connectivity of tributaries with the mainstem Okanogan River. Projects should focus on tributaries that have a sufficient biological capacity to support juvenile rearing, including Loup Loup, Salmon, Omak, and Antoine Creeks in Washington State. 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 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, discharge rates at the base flow period in tributaries have an inverse correlation with juvenile parr densities. For example, Bonaparte Creek has one of the highest densities of steelhead parr on an annual basis (refer to snorkel surveys, Appendix C), regularly 2-6 times the densities observed in lower Omak Creek. Due more because of limited base flow and very narrow wetted widths, rather than exceptional productivity of the system. Often, winter low flows constrain juvenile production and survival such is the case in Salmon Creek. Results of stream flow are further discussed in the habitat status and trend reports, where specific instances that water quantity may be limiting by life stage are clearly defined.

Appendix F. Fine Sediment Analyses

Introduction

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

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

Studies show that small changes in the percentages of silt and very fine sediments contained within medium and 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

Bulk Streambed Sediment Sampling (ID:6698)
https://www.monitoringresources.org/Document/Method/Edit/6698

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 2017, 32 samples were collected in 10 tributaries to the Okanogan River. Two previous years of bulk sediment sampling were also included in the analysis, as the basic protocol remained unchanged in 2017, excepting for increasing the volume of the sample taken relative to the apparent grain size distribution. Although plans exist to expand sediment data collection to include the mainstem Okanogan and Similkameen Rivers, no samples have been collected due to permitting issues.

Bulk samples were collected according to the 1% sample error target in Church et al. (1987). After collection, samples were wet sieved through 64, 32, and 16 mm sieves in the field. The portion of the sample finer than 16mm was homogenized and subsampled in the field. Subsamples were processed in the lab by drying for 24 hours at 105°C and passed through a single-phi interval sieve stack on a Rotap sieve shaking table for 10 minutes. A 0.850 mm screen sieve was included in the sieve set to provide consistency with existing sediment research. Each fraction was then weighed to the nearest 0.01g.

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

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

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

Results

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

Tributary average estimated egg-to-fry survival ranged from zero to 71%. Locations with an estimate of zero percent survival were strongly skewed towards relatively large fractions of fine sand and silt (Aeneas and Antoine Creek) or had relatively high fractions of medium and coarse sand (Bonaparte Creek). With the exception of the samples from Aeneas and Antoine creek, the proportion of sediment less than 0.125 mm (fine sand) was generally less than 1% of the total sample mass. Of 56 total samples, 12 had a geometric mean of less than approximately 8.5 mm (Figure F-1) resulting in an estimated 100% egg mortality. Predicted egg-to-fry survival was consistently around 50% among several other subwatersheds including Omak, Loup Loup, Salmon, Ninemile and Wanacut Creeks (Table F-1). Of note, is that the sample size was relatively low in most tributaries other than Omak Creek.

Table F-1. Okanogan River tributary, sample size *n*, and average percent substrate finer than specified size class. 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).

Tributary	*n*	Percent finer than *x* mm				*S*
		2.00	1.00	0.850	0.125	
Omak	27	19.4	13.5	12.2	**0.8**	50
Loup Loup	8	**20.8**	12.4	10.7	**0.8**	49
Tunk	6	**28.3**	**20.7**	**18.6**	**0.9**	27
Salmon	3	19.3	13.7	12.2	0.4	45
Trail	3	**25.3**	**18.8**	17.2	**0.7**	18
Bonaparte	2	**52.9**	**39.6**	**28.5**	**0.5**	0
Swimpkin	2	**20.2**	13.1	11.6	**0.8**	37
Aeneas	1	**61.2**	**53.0**	**51.2**	**14.5**	0
Antoine	1	**50.3**	**45.4**	**44.6**	**17.0**	0
Ninemile	1	19.8	13.4	12.1	**0.8**	45
Tonasket	1	15.1	8.4	7.0	0.2	71
Wanacut	1	17.5	13.1	12.1	**0.8**	54

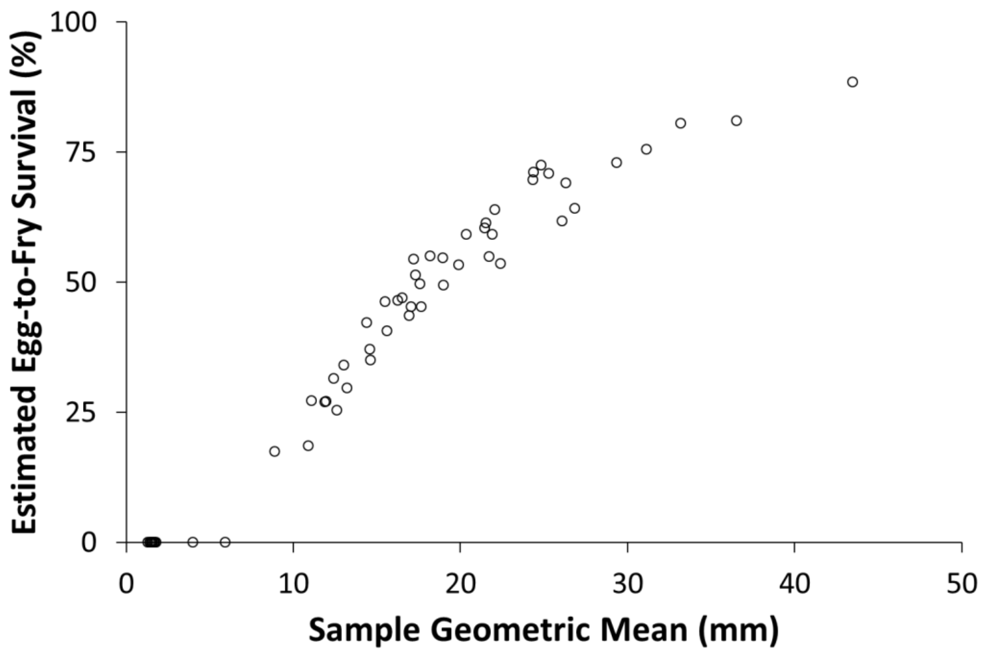


Figure F-1. Estimated egg-to-fry survival and sample geometric mean. Note that 12 of 56 samples (21%) have an estimated survival of 0%.

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 estimated using values from existing literature.

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

As previously noted, substrate conditions in 12 of the 56 samples resulted in an estimated survival rate of zero percent. The sample geometric mean in these locations was below approximately 10.0 mm and had a D_{84} of 32–60mm, 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 central or superlative 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 bulk sediment analyses be expanded to include the Okanogan mainstem below Zosel dam and the Similkameen River, which respectively account for approximately 26% and 15% of the total steelhead redds on an annual basis. Increasing the number of samples taken in tributaries to the Okanogan River will also further refine analyses. Continued years of data collection will allow annual variation and trend analyses of sediment conditions throughout the subbasin.