CRITFC

TECHNICAL REPORT 21-01

Columbia River Inter-Tribal Fish Commission
700 NE Multnomah, Suite 1200
Portland, OR 97232
503.238.0667
www.critfc.org

Studies into Factors Limiting the Abundance of Okanagan and Wenatchee Sockeye Salmon in 2019

Jeffrey K. Fryer, Denise Kelsey, Howie Wright, Skyeler Folks, Richard Bussanich, Kim D. Hyatt, and Margot M. Stockwell

March 15, 2021

Studies into Factors Limiting the Abundance of Okanagan and Wenatchee Sockeye Salmon in 2019

Columbia River Inter-Tribal Fish Commission Technical Report for BPA Project 2008-503-00, Contract 75801

Report date range: 1/19–12/19

Jeffrey K. Fryer and Denise Kelsey
Columbia River Inter-Tribal Fish Commission

Howie Wright, Skyeler Folks, and Richard Bussanich
Okanagan Nation Alliance

Kim D. Hyatt and Margot M. Stockwell
Department of Fisheries and Oceans, Canada

March 15, 2021

EXECUTIVE SUMMARY

A total of 981 Sockeye Salmon (*Oncorhynchus nerka)* were sampled and 960 PIT tagged at the Bonneville Dam Adult Fish Facility (AFF) in 2019. Sockeye tagged by this project, along with previously PIT tagged Sockeye Salmon also sampled, were tracked upstream using data from detection arrays at mainstem Columbia River dam fish ladders as well as in-river arrays in the Wenatchee and Okanagan basins. Upstream detections of adult PIT tagged Sockeye Salmon tracked by this project resulted in an estimated survival in 2019 of 84.2% to McNary Dam and 81.6% Rock Island Dam.

Genetic stock identification (GSI) was combined with site of last PIT tag detection and used to classify the stock of 980 Sockeye Salmon sampled at Bonneville Dam in 2019. Concurrence between Sockeye Salmon classified both by genetics and final PIT tag detection site was 99.3% with the misclassifications being two Wenatchee-classified and one Okanagan-classified Sockeye Salmon last detected in the Snake River (although it is possible that these were offspring of a Yakima Sockeye reintroduction project that uses Okanagan- and Wenatchee stock Sockeye for broodstock). In addition, one Sockeye Salmon (3DD.003D36479E) classified as Yakima by Parental Based Tagging (PBT) was last detected in the Wenatchee River although GSI indicated that this fish was of Wenatchee parentage. Stock composition at Bonneville Dam in 2019 was estimated as 86.0% Okanagan, 12.5% Wenatchee, 1.1% Yakima, 0.4% Deschutes, and 0.0% Snake.

The predominant age group estimated from sampling at the AFF for mixed stock was 47.4% of the run for Age 1.1, followed by Age 1.3 at 27.9%, and Age 1.2 at 18.6%. The estimated age composition for Okanogan stock Sockeye Salmon (based on GSI) was 54.5% Age 1.1, 22.4% Age 1.3, and 17.1% Age 1.2, while for Wenatchee stock Sockeye Salmon it was 67.2% Age 1.3, 27.1% Age 1.2, 3.3% Age 2.2 and 0.4% Age 1.1.

In 2019, three other groups of Sockeye Salmon were available which provided useful comparisons with Sockeye tagged at Bonneville Dam. The first was Sockeye Salmon PIT tagged as juveniles at various locations and returning as adults, although the sample size was small (42 Sockeye returning from tag groups of Wenatchee and Okanagan stock salmon). The second was from 844 Sockeye captured, PIT tagged, and released in the Pound Net fishery at rkm 70 downstream of Bonneville Dam of which 764 were detected at Bonneville Dam. A third comparison group was provided by the Whooshh FishL™ Recognition System (WFRS) installed at the AFF to capture images of

passing salmon, from which species could be identified and length estimated. The total WFRS sample size was 977 Sockeye Salmon. The mean length of the WFRS sample was 43.6 cm (σ=8.5) compared to 44.6 cm (σ=7.5) for the AFF, which was significantly different, based on a Mann-Whiney test ($p<0.01$).

The estimated minimum fallback rates in 2019 at Columbia River mainstem dams tagged at the AFF ranged from 0.2% at Bonneville Dam, to 5.5% at John Day Dam, compared to a range from 0.1% at Bonneville Dam to 5.9% at John Day Dam for Sockeye tagged in the Pound Net fishery. Fallback rates for returning juveniles ranged from 0.0% at McNary, Rock Island, and Wells dams to 15.9% at John Day Dam.

Adult Sockeye Salmon travelled quickly upstream in 2019 with a median migration rates between mainstem dams ranging between 31.8 and 58.7 km/day for adults tagged at Bonneville; 31.8 to 56.9 km/day for adults tagged in the Pound Net fishery, and 30.0 to 59.8 km/d for tagged juveniles returning as adults. Migration rates from Bonneville to Wells Dam were remarkably consistent: 39.8 km/day for Bonneville-tagged and Pound Net-tagged Sockeye, and 39.6 km/day for returning Sockeye tagged as juveniles.

Upstream survival of Okanagan Sockeye Salmon to Rock Island Dam was higher than the Wenatchee stock (84.3% vs. 67.7%), however survival to the spawning grounds was lower (45.4% vs. 56.1%,) The estimated stock composition of Sockeye tagged in the Pound Net Fishery passing Bonneville Dam, based on GSI and site of last PIT tag detection, was 83.0% Okanagan, 16.8% Wenatchee, and 0.1% Yakima and 0.1% Deschutes. However, the Pound Net fishery ended before the tail of the run, thus no Pound Net Sockeye passed Bonneville Dam during the final three weeks of Sockeye Sampling at the AFF.

In the Okanagan Basin, PIT tag antennas installed and maintained by this project at Zosel Dam (ZSL), Okanagan Channel (OKC), Skaha Dam (SKA), and Okanagan Channel-Penticton (OKP) were operational for the entire year. Between January 1, 2019 and December 31, 2019, the number of Sockeye detections at these sites were 1002, 839, 212, and 152, respectively, in addition to smaller numbers of Chinook, Steelhead, and Coho. Low flows resulted in no Sockeye fish passage via the spillways at Zosel and Skaha dams, resulting in 100% detection rates of adult Sockeye that were also detected upstream of these sites. At OKC, an estimated 96.7% of adult Sockeye Salmon passing Zosel Dam were detected, with 7 of 8 undetected Sockeye likely passing during periods of power problems between July 2 and July 8, 2020.

Okanagan juvenile PIT tagging in 2019 resulted in 9,082 smolts tagged between April 25 and May 9, 2019 from Sockeye Salmon captured at two sites, SKAHAL (Skaha Lake) and OSOYOL (Osoyoos Lake North Basin) (Appendix C). For the first time there were sufficient detections at new Zosel Dam floating antennas to estimate the percent survival from release to Zosel Dam of 1.036 (SE=0.132) for the OSOYOL group and 0.651 (SE-0.08) for the SKAHAL group. Overall survival from release to Bonneville Dam was 0.341 (SE=0.071) for the OSOYOL group and 0.244 (SE=0.109) for the SKAHAL group.

This project is proposed to continue and evolve over the next several years as there are several priority areas to investigate. One area of continuing concern is adult survival between Wells Dam and Osoyoos Lake. We had thought we had a good understanding of mortality sites upstream of Wells Dam, thanks to PIT tag detection in Zosel fish ladders as well as acoustic tag results. However, in 2016, we dropped the acoustic tagging due to the large expense for the relatively small number of tags we could deploy, and instead focused on PIT tags. The PIT tag detection of returning adult Sockeye Salmon at Zosel Dam has varied from year to year depending on flow. At high flows, such as in 2018, a high percentage of Sockeye pass undetected through the spillway (58.5% in 2018). We would like to improve PIT tag detection at, or near, Zosel Dam to advance our understanding of adult survival to this point during high flows when Sockeye Salmon do not use the fish ladders.

Lake Wenatchee acoustic trawl surveys (ATS) and limnology data funded by this project indicate that the lake has unused zooplankton production capacity that may be able to support as many as double the number of Sockeye fry the lake currently supports. The surveys will continue along with limnological sampling to better estimate the annual production and future productive potential of Lake Wenatchee. The ATS data from Skaha, Osoyoos, and Wenatchee lakes are also used in Columbia Basin run forecasting for Sockeye.

ACKNOWLEDGMENTS

The following individuals assisted in this project: Steve Anglea and Brett Turley of Biomark, Victoria Boehlen, Maureen Kavanagh and Christine Peterson of Bonneville Power Administration, Joe Nowinski, Amber Cate, Crystal Chulik, David Graves, Doug Hatch, Jayson FiveCrows, and Jon Hess of the Columbia River Inter-Tribal Fish Commission; Sonya Schaller of the Confederated Tribes of the Colville Reservation; Ben Hausmann, Tammy Mackey, Jon Rerecich, and Casey Welch of the US Army Corps of Engineers; Howard Stiff (Fisheries & Oceans Canada); Tom Kahler of Douglas County PUD; Don McQueen; Ryan Benson, Jessica Hilton-McPherson, Sheena Hooley, Chelsea Mathieu, Edward Payne, Paul Snow, Amanda Stevens, Jamison Squakin, Dave Tom, Cash Tonasket, Lynnea Wiens, and Nicholas Yaniw of the Okanagan Nation Alliance, Jay O'Brien and Derek Mendoza of the Okanagan-Tonasket Irrigation District; Alan Brower and Nicole Tancreto of the Pacific States Marine Fisheries Commission; Al Josephy of Washington Department of Ecology; Travis Maitland, Ben Truscott, and Andrew Murdoch of Washington Department of Fish and Wildlife; Adrian Touhy of the Wild Fish Conservancy; and Keely Murdoch, Corey Kampaus, Kraig Mott, Casey Heemsah, Clifford Smith, and Terri Benson of the Yakama Nation.

This report summarizes research funded by the Bonneville Power Administration under the Columbia Basin Fish Accords and the Pacific Salmon Commission.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Sockeye Salmon, *Oncorhynchus nerka,* is one of the species of Pacific salmon native to the Columbia River Basin. Prior to European settlement of the region, it is estimated the Columbia Basin supported an annual Sockeye Salmon run averaging over three million fish (Northwest Power Planning Council 1986, Fryer 1995). Since the mid-1800's, however, the Sockeye Salmon run has severely declined, reaching a low of fewer than 9,200 fish in 1995 before rebounding in recent years to highs of over 500,000 Sockeye Salmon counted at Bonneville Dam in 2012, 2014, and 2015 (DART 2019, FPC 2019). The Bonneville Dam Sockeye count in the three years prior to the year of this report was 342,498 in 2016, 87,693 in 2017, and 193,816 in 2018. For 2019, the Sockeye count at Bonneville Dam was 63,406; the lowest since 2007.

The Columbia Basin Sockeye Salmon run was once composed of at least eight principal stocks (Fulton 1970, Fryer 1995). Today, only two major stocks remain (Figure 1); the first originating in the Wenatchee River-Lake Wenatchee System (Wenatchee stock) and the second in the Okanagan[1] River-Osoyoos and Skaha Lake System (Okanagan stock). A third remnant stock, comprising well under 0.1% of the run, returns to Snake River-Redfish Lake (Snake stock) and is listed under the Endangered Species Act. In recent years, there have also been efforts to restore Sockeye Salmon to the Deschutes and Yakima basins.

Okanagan Sockeye Salmon spawn in the Canadian portion of the Okanagan River and then rear in Osoyoos Lake, through which runs the border between the United States and Canada. In recent years, the range of Okanagan Sockeye Salmon has been extended to Skaha Lake and a hatchery program is operated by the Okanagan Nation Alliance (ONA) near Penticton, BC.

Okanagan Sockeye Salmon have persisted despite one of the longest, most difficult migrations of any salmon stock in the world. The stock migrates 986 km between the spawning grounds and the ocean through one dam and a series of irrigation control structures on the Okanagan River as well as nine mainstem Columbia River dams (Figure 1). The production of this run is believed to be limited by upstream and downstream migration survival as well as habitat factors in the spawning and rearing areas (Fryer 1995; Hyatt and Rankin 1999, Hyatt and

[1] The Canadian spelling for Okanagan will be used throughout this document as opposed to the American spelling (Okanogan).

Stockwell 2009).

The Wenatchee stock spawns in tributaries to Lake Wenatchee and rears in the lake. This stock migrates 842 km through two Wenatchee River dams and seven mainstem Columbia River dams. Since the spawning grounds and lake are relatively pristine, the production of this run is believed to be limited by upstream and downstream survival as well as the low productivity of the oligotrophic Lake Wenatchee (Fryer 1995).

This Columbia River Inter-Tribal Fish Commission (CRITFC) study, funded by the Columbia Basin Fish Accords, seeks to expand our knowledge of factors limiting production of Okanagan and Wenatchee Sockeye Salmon stocks. This study expands upon previous work, funded by the Pacific Salmon Commission from 2006-2008, to examine upstream survival and timing by inserting Passive Integrated Transponder (PIT) tags in Sockeye sampled at Bonneville Dam as part of the annual Pacific Salmon Commission (PSC)-funded Sockeye stock identification project. These PIT tagged fish can then be detected at upstream dam fish ladders with tag detection capability (The Dalles, John Day, McNary, Priest, Rock Island, Rocky Reach, and Wells dams on the Columbia River, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams on the Snake River, Tumwater Dam on the Wenatchee River, and Zosel and Skaha dams on the Okanagan River), as well as at in-stream tributary antennas.

The fact that there are only two significant Columbia Basin Sockeye Salmon stocks passing through multiple Columbia River dams with PIT tag detection makes the species ideal for PIT tag studies. Determination of migration timing and mortality for other salmon and steelhead species is difficult, since many tributaries are without detection facilities, or with detection facilities that only detect a fraction of fish passing, meaning that fish can escape undetected.

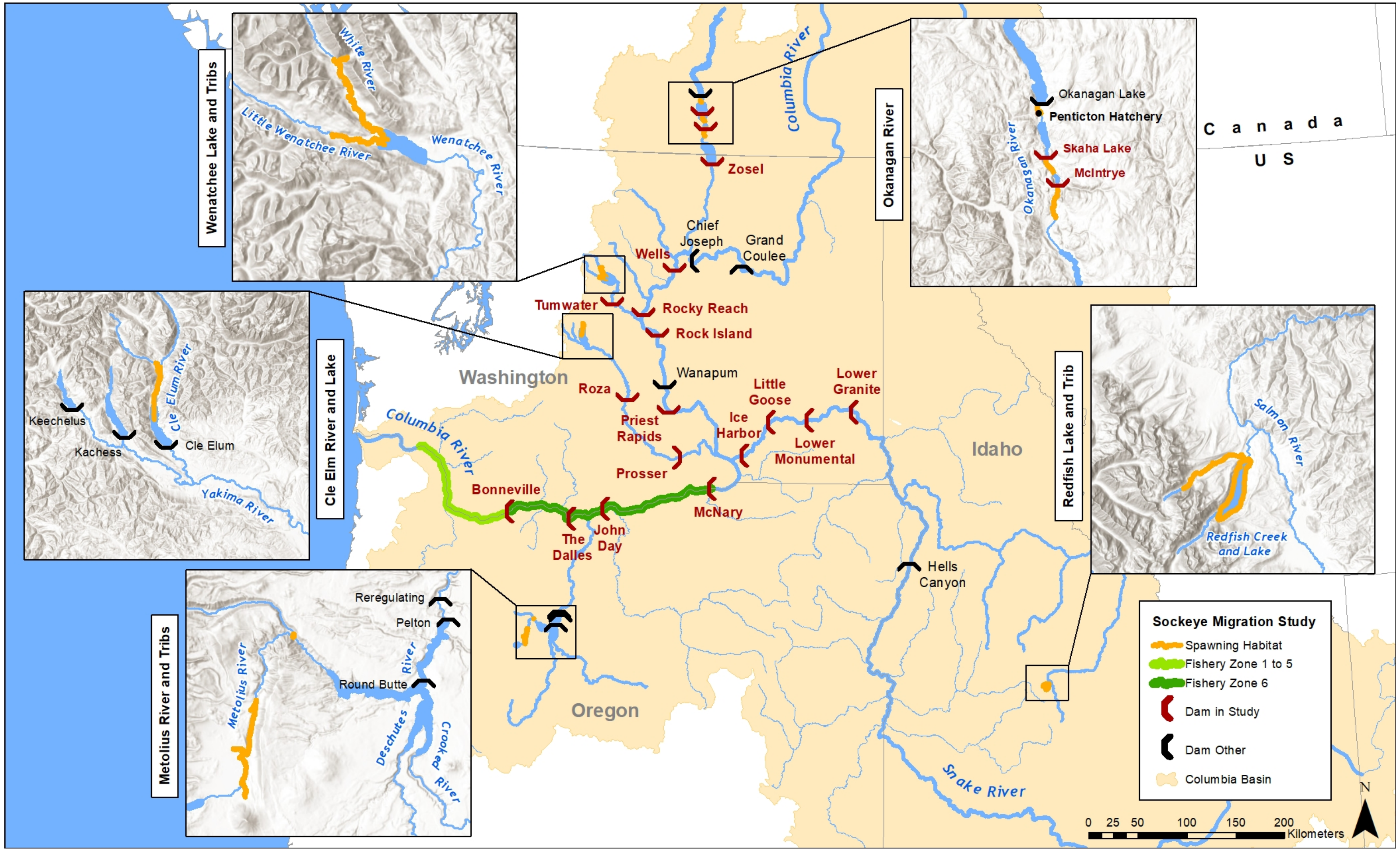


Figure 1. Map of the Columbia Basin showing fishery Zones 1-5 and 6, the major and minor Sockeye Salmon production areas and significant dams on their migration route.

The run timing of the adult Columbia Basin Sockeye Salmon migration is of particular interest because the migration timing has shifted earlier over the years in which Sockeye have been counted at Columbia River dams (Fryer 1995, Quinn et al. 1997). A 1997 radio-tagging study also found high mortality of the latter portion of the run (Naughton et al. 2005) as well as no difference in stock-specific migration timing. The radio tag study was conducted in an unusually high flow year that may not be typical of other years. Results of PIT tagging studies (Fryer 2007, 2009, Fryer et al. 2010, 2011a conducted by this project have generally concurred with the 1997 radio-tagging results (Naughton et al. 2005) regarding higher mortality during the latter portion of the run.

In 2009, PIT tag detection antennas were installed by Washington Department of Fish and Wildlife in natal streams in the Wenatchee Basin (Little Wenatchee and White rivers), making it possible to track Wenatchee Sockeye to the spawning grounds in near real time at www.ptagis.org. No similar detection system was available in the Okanagan Basin; therefore in 2009 this project funded installation of a PIT tag antenna on the Okanagan River upstream of Osoyoos Lake (known at www.ptagis.org as OKC) and in 2010 funded installation of antennas at both Zosel Dam fishways (ZSL) in 2010 (with several upgrades, including floating antennas in the spill bays, in subsequent years). This was followed by installations at Skaha Dam fishway (SKA) and McIntyre Dam spill way (OKM) in 2015, a second OKC antenna array in March 2017, and an antenna across the Okanagan River at Penticton Channel (OKP) in November 2017.

Since 2010, this project has funded a hydroacoustic survey of Lake Wenatchee to initiate standardized Sockeye Salmon smolt abundance estimation for the Wenatchee stock for comparison with similar estimates already available for Okanagan Sockeye in Osoyoos Lake. These data are used to estimate juvenile survival and compared to Wenatchee River smolt trap smolt estimates. Starting in 2012, this project has also funded limnological surveys of Lake Wenatchee with the goal of estimating potential smolt capacity of the lake, as well as the PIT tagging of Okanagan stock Sockeye Salmon to estimate downstream migration mortality.

METHODS

Adult PIT Tag Detection Infrastructure

Zosel and OKC PIT tag arrays

This project has installed five Okanagan River PIT tag detection sites to detect PIT tagged Sockeye Salmon as they ascend the Okanagan River. The first site (OKC at www.ptagis.org), installed in November 2009 (Fryer et al. 2010), is a channel-width array at river km 147, just downstream of Vertical Diversion Structure 3 near Oliver, BC. A second OKC channel-width array was added in 2017. The second site installed was at Zosel Dam (ZSL at www.ptagis.org) in September 2010 and consisted of two antennas in each of the two fish ladders at Zosel Dam in Oroville, WA (Fryer et al. 2011a). A floating antenna was added immediately upstream of one spillway at Zosel Dam in 2015 and a second spillway in 2016, and both antennas were upgraded for 2019. An experimental PIT tag antenna was added to one spillway at McIntyre Dam (OKM) as well two antennas in the Skaha Dam fish ladder (SKA at www.ptagis.org) in 2015. Finally, a channel-width PIT array was installed in the Penticton Channel downstream of Okanagan Lake (OKP) at rkm 196 on November 29, 2017. PIT tag detection results for these sites in 2019 are found in Appendix A.

Adult Sampling at Bonneville, Wells, and Priest Rapids dams

Bonneville Dam Sampling

Sockeye Salmon were sampled and tagged at the Adult Fish Facility located adjacent to the Second Powerhouse at Bonneville Dam (river km 235) in conjunction with the sampling of steelhead (*O. mykiss)* and Chinook Salmon (*O. tshawytscha)*. Sampling and tagging typically occurred between approximately 0800 and 1300 hours five days per week. A picket weir diverts fish ascending the Washington Shore fish ladder into the adult sampling facility collection pool. An attraction flow is used to draw fish through a false weir where they may be selected for sampling (Figure 2). Fish not selected and fish that have recovered from sampling then migrate back to the Washington Shore fish ladder above the picket weir.

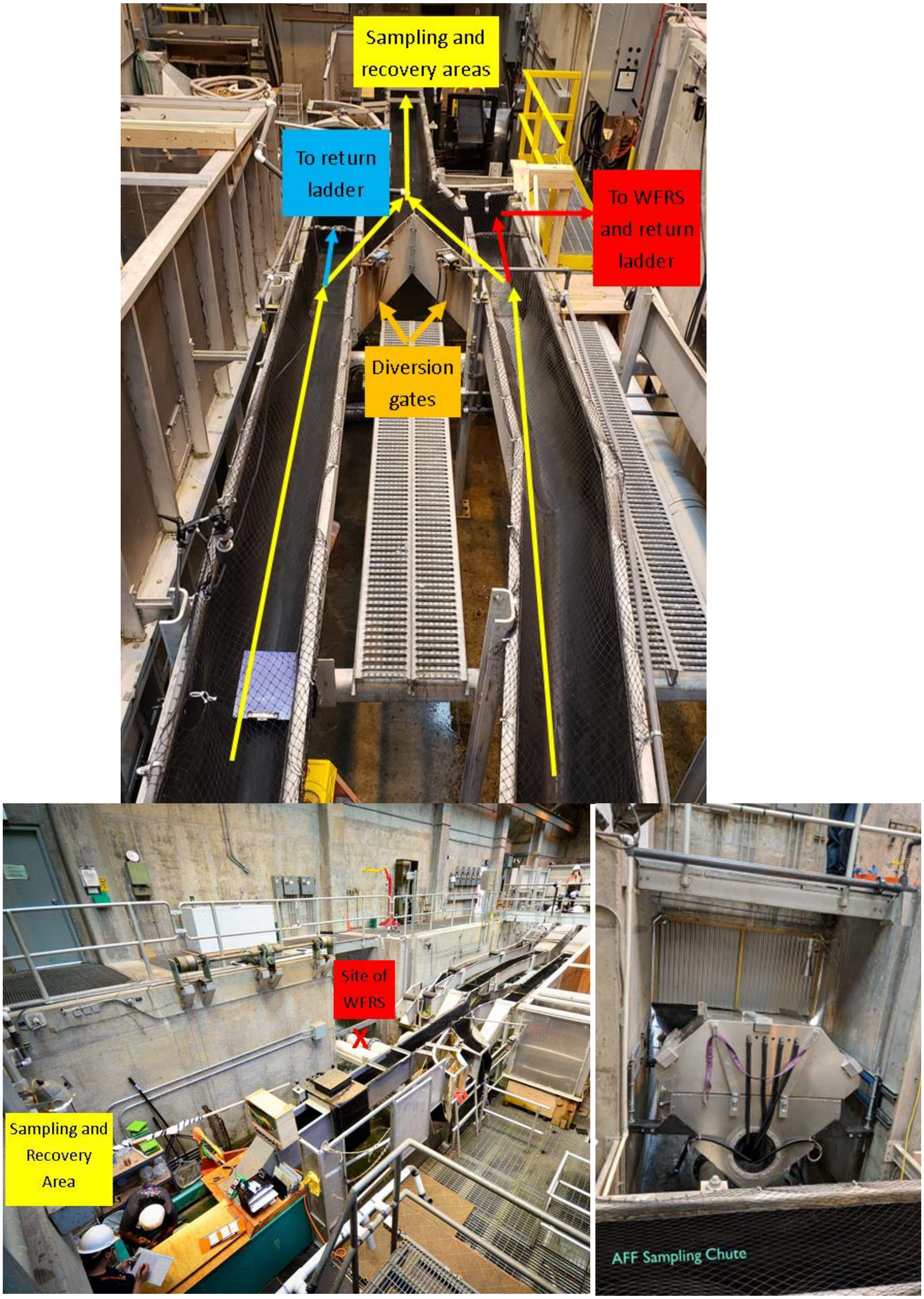


Figure 2. Bonneville Adult Fish Facility. The top picture shows the view from above with the routes fish can take. Lower left shows the site of the WFRS, lower right shows the WFRS unit being installed. A pipe connects it with the right side flume in the top picture.

Sockeye selected for tagging were examined for tags (including scanning for existing PIT tags using a Biomark HPR reader), fin clips, wounds, and condition. They were measured for length, and four scales were removed for later age analysis. If not already present, PIT tags were inserted into the body cavity of the Sockeye Salmon using standard techniques (CBFWA 1999) and the fish scanned again for PIT tags. If the PIT tag was not detected, no effort was made to implant another tag to eliminate the possibility of double tagging. Sockeye Salmon were allowed to recover prior to release. All PIT tag and sampling information was uploaded to the Columbia Basin PIT Tag Information System (PTAGIS) database (www.ptagis.org).

PIT tagged Sockeye Salmon were detected by existing detection arrays in adult fish ladders at Bonneville, The Dalles, John Day, McNary, Priest Rapids, Rock Island, Rocky Reach, and Wells dams on the Columbia River; Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams on the Snake River; Zosel and Skaha dams on the Okanagan River, and Tumwater Dam on the Wenatchee River (array configurations are available at www.ptagis.org) as well as several in-stream detection arrays. PIT tag detection data from these arrays are automatically uploaded several times daily to the PTAGIS database where they are immediately accessible to users of the site. If a tag was not detected after the fish was released, we removed it from further analysis.

We also calculated some migratory characteristics of Sockeye Salmon PIT tagged as juveniles for comparison with adult Sockeye PIT tagged by this project. These Sockeye were from PIT tagging programs in the Snake, Okanagan, and Wenatchee basins and mixed-stock juveniles tagged on their downstream migration at Rock Island Dam (Keller and Hopkins, 2020).

A second comparison group was used in 2019. These Sockeye Salmon were captured in a Pound net fish trap run by the Wild Fish Conservancy at rkm 70 downstream of Bonneville Dam near Cathlamet, Washington (https://wildfishconservancy.org/about/press-room/press-clips/pound-net-update-whats-old-is-new-again). In 2019 one element of this fishery was to PIT tag and release adult Sockeye Salmon which then continued their migration upstream. However, a desire to minimize sampling impacts meant that no scales were sampled from these fish for ageing, nor were accurate lengths obtained. This meant that while migratory characteristics between the Pound Net sample and the Bonneville sample could be compared, it was not possible to compare length and age

composition estimates. Also, the Pound-Net fishery ended on July 3, 2019, with only one fish passing Bonneville Dam on or after Week 28 (which began July 7, 2019), thus survival comparisons were limited to those passing prior to Week 28 while Sockeye Salmon continued to be tagged at Bonneville Dam through August 1 in Week 31. Genetics data from Pound-Net fish Sockeye was not obtained until the submission due date for this report so only limited analysis was conducted with the data.

Finally, there was a third group of Sockeye available for comparison in 2019 to the Sockeye sampled at Bonneville Dam. This was from images captured from the Whooshh FishL™ Recognition System (WFRS). This system was designed to capture images of passing fish that could be used for selection of fish to be transported via the WFRS passage system (www.whooshh.com). Whooshh Innovations installed the WFRS at one exit flume at the Adult Fish Facility (Figure 2) immediately downstream of the gate that diverted fish selected for sampling into the sample tank. Thus, the WFRS only collected images from those fish not selected for sampling from the right (south) flume.

The WFRS uses multiple images from three different camera angles, together with a proprietary algorithm, to calculate the fork length of an individual fish to 1/10 mm (provided there were no overlapping fish). Other data collected included adipose presence or absence, and species. The data from Sockeye that were not sampled was used to compare with data from sampled fish, as well as to assess the potential for improving precision of estimates provided by our study.

Since no scale or genetics samples could be collected from the WFRS Sockeye, and no PIT tags could be injected to determine destination or stock, the only characteristic that could be compared between WFRS and AFF samples was length. A Mann-Whitney U test was used to compare mean length between the two samples and a Kolmogorov-Smirnov test used to compare the length frequency distributions between the WFRS and AFF samples.

Wells Dam Sampling

Sockeye were trapped at the Wells east bank ladder fish trap where they were blocked from ascending the ladder by a picket weir with bars spaced 5.1 cm apart. Fish were diverted up a steep pass Denil fishway where they accumulated in an upwell enclosure. An attraction flow into the enclosure encouraged fish to voluntarily swim down a sorting chute, where an operator either diverted them into

a chute leading to a large holding tank or returned them to the ladder upstream of the barrier gate. The Sockeye were netted into a 380-liter stock tank and anesthetized in a 30ml solution of Aqui-S until they lost equilibrium and their opercular rate was slow but regular. Fish were examined for existing tags, fin clips, wounds, and condition. Fork length was also measured, and five scales were removed and placed on scale cards for later age analysis. All fish not previously PIT tagged were implanted with a PIT tag in the pelvic girdle, posterior to the pelvic fins. After sampling, fish were allowed to recover in a 380-liter stock tank with fresh water supplied with oxygen at a rate of 1.5 L/min until they were partially recovered, and then placed back into a fish ladder pool immediately upstream of the picket weir.

Stock Identification and Classification

A primary goal of CRITFC's Sockeye sampling programs since the project began in 1985 has been to estimate the stock composition of Columbia Basin Sockeye Salmon at Bonneville Dam with the data used in fisheries management and run forecasting. Scale pattern analysis was first used, where scale growth was measured from Okanagan and Wenatchee known stock samples as well as Bonneville Dam mixed-stock samples (Fryer and Schwartzberg, 1988) and a linear discriminant analysis used to classify those mixed-stock samples. With the widespread deployment of PIT tag infrastructure at Columbia, in 2006, we began PIT tagging Sockeye Salmon at Bonneville Dam and tracking them through PIT tag antennas located in upstream dam fish ladders and in-stream arrays. In 2012, we also began collecting genetics samples from Sockeye sampled to classify Sockeye Salmon using Genetics Stock Identification (GSI).

Genetic Stock Identification (GSI) and Parental Based Tagging (PBT)

Tissue samples in the form of a caudal fin punch were collected for genetic analyses from all adult Sockeye Salmon sampled at Bonneville Dam. Tissue samples were stored using a dry Whatman paper medium (LaHood et al. 2008). Genomic DNA was extracted from digested tissue samples using a standard Qiagen DNeasy protocol. Prior to amplification of single-nucleotide polymorphism (SNP) loci using primer-probe sets (fluorescent tags), an initial polymerase chain reaction (PCR) "pre-amp" step was implemented using whole genomic DNA to

jumpstart SNP amplification via increased copy number of target DNA regions. The cycling regime and PCR conditions for the pre-amp step were as follows: one initial cycle of 95C for 15 min, 14 cycles of 95C for 15 seconds, 60C for four minutes, and a final dissociation step. For each data collection run, each panel of 96 SNP loci were arrayed with 96 samples using a Fluidigm® microfluidic 96.96 chip (including one genotype indicator and one no-template control sample) to generate high throughput genotyping. Sample cocktails included: 3.4µl GTXpress Taqman (Applied Biosystems), 0.30µl GT load buffer (including taq polymerase), 0.30µl H2O and 2.0µl pre-amp DNA template. Single SNP assays were prepared in a 5.0µl reaction mix (per sample), containing the following reagents: 2.5µl DA load buffer, 0.25µl Rox 19 dye, 1µl H2O, and 1.25µl primer/probe. Microfluidic chips were loaded with assay cocktail dispensed at 4.5µl per well, and sample cocktail dispensed at 5.0µl per well. Chip loading was completed following standard manufacturers protocol on a Fluidigm IFC controller. Amplification conditions using a fast-cycling protocol were; 70C for 30 minutes, 25C for 10 minutes, and 95C for 1 minute, followed by 50 cycles of 95C for 5 seconds, and 50C for 25 seconds, and a final cool down step of 25C for 10 minutes. Chips were imaged and scored on a Fluidigm EP1 imager using Fluidigm SNP Genotyping Analysis Software version 3.1.1. Successful genotyping for a given sample was defined proportionally as less than 10% missing data (i.e. fewer than ten missing SNP genotypes per individual for *O. nerka*). Sockeye Salmon GSI analyses utilized the baseline described in Hess et al. (2013) and has previously been shown to accurately discriminate among the three major stocks in the Columbia River: Wenatchee, Okanagan, and Snake River Sockeye Salmon. The program ONCOR was used to estimate the most likely population-of-origin for the Sockeye Salmon samples. Individuals were assigned using a "best estimate" approach - Assigning individual samples using Individual Assignment (IA) genetic methods v1.0 (ID: 1334) (Published). We also used GSIsim for "Mixture modeling to estimate stock proportions v1.0" (ID: 1333).

In 2019, Sockeye Salmon samples were classified using GSI to the four stocks Wenatchee, Okanagan, Snake, and Deschutes (Figure 1). Parental-based tagging was used to identify some Yakima Sockeye Salmon for which genetic samples had been collected from parents**.**

PIT Tag Stock Identification

Since PIT tag antennas were installed at the Tumwater Dam fishways in 2008 (complementing existing antennas at Rocky Reach, Wells and Snake River

dams), Sockeye Salmon stock determinations (Wenatchee, Okanagan, Snake, or Unknown) have been made by the last detection point. Those individuals last observed at or upstream of Rocky Reach Dam have been classified as being Okanagan stock. Individuals that were last observed at, or upstream of, Tumwater Dam, were classified as Wenatchee stock. Sockeye last observed at or upstream of Ice Harbor Dam were classified as being Snake River stock. Sockeye Salmon last detected at sites downstream of Ice Harbor or Rocky Reach/Tumwater dams were classified as "Unknown".

In 2012, GSI was in concurrence over 99% of the time with PIT stock classifications for those Sockeye that could be classified by terminal area PIT tag detections (Fryer et al. 2013). Given this concurrence, in both 2013 and 2014 we did GSI only on Sockeye classified as unknown by PIT tags or those with unusual PIT tag detection histories. However, since 2015, GSI has been conducted on virtually all Sockeye sampled at Bonneville Dam which was the case in 2019. In addition, GSI was conducted on Sockeye PIT tagged at Wells Dam that were not detected in the Okanagan River as past results have found 100% of Sockeye detected in the Okanagan were classified by Genetics as Okanagan River with the exception of a handful of likely sample mix ups.

Final Stock Classification Rules

In 2019 a combination of GSI, PBT, and PIT tag detections was used to classify Sockeye Salmon:

1.) If GSI classified a Sockeye to the Okanagan, Wenatchee, Snake or Deschutes stock, that classification was used. The exception was Yakima Sockeye as there is no GSI baseline for this stock as they are offspring of Wenatchee and Okanagan stock Sockeye reintroduced into the Yakima Basin (see 3 below) and thus would classify to those stocks.
2.) If no GSI results are available, classify any Sockeye last detected in the Snake, Wenatchee, or Okanagan Basin as being of that stock. If last detected elsewhere, classify as unknown origin.
3.) For Yakima Sockeye, we do not have a GSI baseline but do have a limited baseline using parental-based tagging (PBT). If PBT indicated Yakima Sockeye, this classification was used. Also, if Sockeye were last detected in the Yakima Basin, they were classified as Yakima stock. In past years, Sockeye have been detected at the Priest Rapids Dam adult fish trap followed by Roza Dam, in which case the fish was likely transported from

Priest Rapids Dam to Cle Elum Dam as part of a reintroduction program and fell back downstream to be detected at Roza Dam. For these fish, the GSI classification was used. In 2019 the low count of Sockeye at Bonneville Dam was insufficient to allow this program to occur based on collection protocols, thus there were no Sockeye detected at Roza Dam which missed detection at Prosser Dam.

Age Analysis

Visual assessment of scale patterns was used to determine age composition through techniques developed for the Bonneville Stock Sampling project (Whiteaker and Fryer 2008, Kelsey et al. 2011). We used the European method for fish age description (Koo 1955) where the number of winters a fish spent in freshwater (not including the winter of egg incubation) is described by an Arabic numeral followed by a period. The number following the period indicates the number of winters a fish spent in saltwater. Total age, therefore, is equal to one plus the sum of both numerals. If poor scale quality, particularly in the freshwater phase, prevents age determination in any of the scales collected from a particular fish, no age is assigned.

Site Detection Efficiencies

Any fish detected at an upstream dam should have been detected at lower dams (with the exception of Bonneville, McNary, Ice Harbor, and Lower Granite dams where it is possible that a fish could use the navigation locks to pass the dam). The percentage of PIT tagged fish missed at each dam with PIT tag detection arrays was calculated by looking at the fish detected upstream of the site in question and estimating the percentage not detected at that site. For example, the percentage missed at Rocky Reach Dam was calculated as:

$$P = \frac{R_m}{R_d}$$

where R_m was the number of fish missed at Rocky Reach Dam but detected upstream of Rocky Reach Dam and R_d was the number of fish detected upstream of Rocky Reach Dam.

Escapement

Escapement to upstream sites and dams was estimated as:

$$N = \sum_i \frac{B_i R_i}{T_i}$$

where *N* was the estimated escapement at a particular upstream site, B_i is the weekly (Sunday to Saturday) total visual count passing Bonneville Dam in week *i* (DART 2019, FPC 2019), T_i is the number of fish PIT tagged and detected at Bonneville Dam sites BO1 in week *i*, and R_i is the number of PIT tag detections at the dam where escapement is being estimated of those fish tagged in week *i*.

Upstream Survival/Conversion Rates

Survival/conversion rates were calculated for Sockeye to upstream dams with PIT tag detection as:

$$S = \sum_i \frac{W_i D_i}{N_i}$$

where W_i is the proportion of the Sockeye run passing Bonneville Dam in week *i,* D_i is the number of Sockeye detected at or above the dam in question, and N_i is the number of tagged Sockeye Salmon detected subsequent to release at Bonneville Dam. Given that the percentage of PIT tagged fish passing undetected upstream through dams is typically very small, this provides a good approximation of survival to upstream dams. However, at terminal in-stream antennas (such as OKC in the Okanagan and LWN and WTL in the Wenatchee) where the percentage of PIT tagged fish undetected is much higher and there is no, or insufficient, detection of PIT tagged fish upstream to estimate this percentage, estimation using these techniques cannot be considered a survival rate. The nomenclature in the Columbia Basin is to call this a conversion rate and this term will be used in this report when referring to the percentage of tagged fish being detected at an in-stream antenna.

Migration Timing and Passage Time

Run timing was estimated using the date and time of detection at the different dams. Migration rates were calculated between dam pairs as the time between the last detection at the lower dam and the first detection at the upper dam. The amount of time required to pass each dam was estimated as the difference between the first detection time at a dam and the last detection time at the same dam.

Bonneville Stock Composition Estimates Using PIT Tag Recoveries

The overall stock composition, P_i, for stock *i* (where *i* denotes the Wenatchee or Okanagan stock) at Bonneville Dam was estimated as:

$$P_i = \sum_j W_j * S_{ij}$$

where W_j is the proportion of the run passing Bonneville Dam in week *j*, and S_{ij} is the percentage of the run estimated in week *j* to belong to stock *i* based on upstream recoveries.

The stock composition estimated by PIT tag recoveries was compared with that estimated from two visual counts, the first estimating the Wenatchee stock abundance as the difference between the Rock Island and Rocky Reach Dam counts and the second using Tumwater Dam visual counts to estimate the Wenatchee stock abundance.

Okanagan and Wenatchee Age and Length-at-age Composition

The age composition for the Okanagan and Wenatchee stocks was estimated as:

$$T_{i,j} = \sum_k A_{i,j,k} * W_k$$

where $T_{i,j}$ was the estimate for stock *i and age gro*up *j,* $A_{i,j,k}$ was the percentage of Sockeye for stock *i* and age group *j* in week *k* and W_k was the percentage of the run that passed Bonneville Dam in week *k.*

Night Passage

Fish passing viewing windows at Columbia Basin dams are not always counted using the same time period. Fish passing Bonneville and McNary Dam fish viewing windows are counted by observers only from 0400 to 2000 hours Pacific Standard Time for 50 minutes of each hour and the counts expanded by a factor of 1.2. Video records of fish migration at Priest Rapids, Rock Island, Rocky Reach, and Wells dams are recorded 24 hours per day and subsequently reviewed to yield total counts of daily fish passage. In this study, night passage rates (where night is defined as 2000 to 0400 hours) were calculated by stock, for all dams passed, based on the last detection time for a given fish ladder. The last time at the uppermost antenna was used as an approximation for passage time as this antenna was closer to the fish counting window than the lowermost antenna (where the first detection would be made). This was the case at all sites except at BO4 near the fish counting facility on the Washington shore at Bonneville Dam where the distance between the uppermost and lowermost antennas is only about 15 meters, so the uppermost antenna was still used for consistency.

Fallback

Three methods were used to estimate fallback, which is defined as a fish that ascends a fish ladder into the reservoir above the dam, then "falls back" to the downstream side of the dam either over the spillway, or through the navigation locks, juvenile bypass systems, or turbines. The first method was if a PIT tagged adult Sockeye Salmon was detected in the juvenile bypass system. However, on the Columbia River, only Bonneville, John Day, McNary, Rocky Reach dams have juvenile bypass system while all four Snake River dams (Ice Harbor, Lower Monumental, Little Goose, and Lower Granite) have such systems, all with PIT tag detection. Furthermore, there is no detection at any dam for fish falling back over the spillway[2] or through the navigation locks or turbines. Therefore, a second method of estimating fallback was to look at each dam for fish detected at the uppermost antenna followed by detection more than two hours later at an antenna located downstream in the same ladder (or at another ladder for multiple ladder dams). Finally, a third method of defining fallback was ascertained by fish that passed an upstream PIT tag detector at a given dam, then were next observed at

[2] This changed in 2020 with the installation of the GRS site at a single Lower Granite Dam spillway.

a site downstream of the dam in question. Thus, if a fish was detected at the upper antenna at Wells Dam and then subsequently detected at Tumwater Dam, it would be considered a fallback at both Wells and Rocky Reach dams. Similarly, if a fish was last detected at the Wells Dam upper antenna and then detected at the Rocky Reach juvenile bypass, it would be considered a fallback at Wells and Rocky Reach dams.

A list of possible fallbacks was compiled using each of these methods and duplicates eliminated. Each fallback PIT tag detection record was examined to determine whether it met the criteria above. If a fish fell back over a dam multiple times, each time was considered a separate fallback. A fish passing downstream through the fish ladders was not considered a fallback. Fallbacks were compiled by dam and a fallback rate calculated by dividing the number of fallbacks by the total number of PIT tagged fish passing the dam in question. The resulting estimated fallback is almost certainly biased low as it will not include fish that fall back over a dam and are not subsequently detected.

Acoustic Trawl Surveys for Juvenile Sockeye Abundance

The goals of the Lake Wenatchee Sockeye Salmon research program are to quantify life history parameters for the population, investigate the physical, chemical, and biological factors that may be regulating population growth in freshwater, and to estimate lake carrying capacity for this species. The in-lake program began in 2010 with a single acoustic and trawl survey. This was expanded to two acoustic and trawl surveys in 2011 and in 2012, the program was expanded to include a full limnological assessment including estimates of lake-turnover, oxygen-temperature profiles, water chemistry, phytoplankton, zooplankton, and Sockeye fry abundance. Between 2012 and 2019, survey intensity has increased.

Night-time juvenile Sockeye Salmon densities in Wenatchee, Osoyoos, and Skaha lakes[3] were estimated by executing specialized acoustics and trawl-based survey (ATS) methods by ONA crews. Several whole-lake transects covering depth strata from the lake surface to bottom were traversed with hydro-acoustics gear (Biosonics sounders operating at 200 kHz) deployed from a boat at night (Hyatt et al. 1984). Acoustic signal returns from juvenile Sockeye were digitally

[3] Only Lake Wenatchee surveys were funded by this project. The other surveys were conducted by the ONA using other funding, but survey results are included in this report.

recorded for subsequent population estimates of the total number of targets comprising pelagic fish located between the lake's bottom and surface. Echo counting is frequently confounded by fish schooling behavior during short nights in May–July; therefore, the best estimates are normally obtained during ice-free periods in the fall to early spring. Fish density estimates, in combination with species composition and biological traits (length, weight, age) data from trawl catches, are used to determine numbers and biomass of juvenile Sockeye Salmon found in the lake. Data from multiple surveys may be used to estimate salmon mortality between consecutive seasonal intervals (fall-spring, spring-summer, summer-fall).

Fish bio-samples were collected using a small, mid-water trawl net (5 x 7m mouth opening, 7.5-m length). Haul depths were based on echo-sounding results that indicate depths at which juvenile Sockeye Salmon were most likely to be caught.

Immediately upon capture, pelagic fish destined for laboratory analysis (biological traits, stomach contents, etc.) were placed into a 90% solution of ethanol and then subsequently frozen. Random samples of up to 150 juvenile Sockeye and/or kokanee were normally retained from each survey date. Trawl segment duration was adjusted to shorter or longer times depending on catch success. Larger catches triggered short trawl sets (10-15 minutes) such that most fish remained in good condition upon trawl retrieval. Following random withdrawal of a sub-sample of fish from a large catch, all other trawl caught fish were released unharmed.

Juvenile PIT Tagging

Skaha and Osoyoos lakes were seined using a 183 m long seine of 1.27 cm (1/2") knotted mesh pulled behind an 8.5 m long purse seine boat to capture smolts for PIT tagging. Depths up to 12 m could be fished with this boat and gear. Purse seining concentrated in the central and northern basins of Osoyoos Lake where the majority of Sockeye smolts were congregating. Seining in Skaha Lake was concentrated in the southern area where smolts were congregating.
.

The procedures outlined by PTAGIS (2014) and Biomark (2020) were used for marking smolts. We deployed Biomark HPT 12 PIT tags (134.2 kHz) measuring 12.5 mm in length. Tags were implanted with the MK25 Rapid Implant Gun along

with HPT9 pre-loaded sterile needles manufactured by Biomark. Fish were removed from holding pens and placed in a 19-L (5-gal) pail containing a 40 mg/l solution of tricaine methanesulfonate (MS 222). Fish were kept in the solution until they lost equilibrium (approximately 2-3 minutes). Each smolt was measured for fork length (mm) and general body condition/descaling percentage was recorded. The tagging needle was inserted on the right side between the pectoral fin and lateral line, and then the trigger was depressed until the tag was inserted into the incision hole. The tagged smolt was scanned and logged using an HPR Plus reader (Biomark®).

The system was connected to a Trimble® Yuma® 2 computer or Panasonic tablet which logged and saved each tag number into a P4 software tagging session file. This configuration allowed taggers to enter data and tagging comments directly into the tagging file without the need for post-season data entry.

Following processing, each tagged fish was placed in a bucket of aerated water until fully recovered. All tagged smolts were returned to the holding pens and released back into the lake the same day, typically between 21:00 and 23:00 to reduce predation. Fish were released from the North side of Haynes Point just offshore (OSOYHA), or in the North Basin at 20m depth (OSOYOL) in Osoyoos Lake. In Skaha Lake, smolts were released just offshore from the tagging site upstream of Skaha Dam. All post-tagged smolt mortalities were removed and sampled. PIT tag numbers from fish mortalities were removed from the database.

On-line tools (http://www.cbr.washington.edu/dart/query/pit_sum_tagfiles) developed by the University of Washington School of Aquatic and Fishery Sciences Columbia Basin Research were used to estimate Cormack-Jolly-Seber survival estimates as well as travel times. In addition, a request was made to the Fish Passage Center to analyze the data and the resulting memo is located in Appendix D.

RESULTS

Upstream Migration Analysis

Bonneville Sample Size and Upstream Detection

In 2019, a total of 981 Sockeye Salmon were sampled for this project at the Bonneville Dam Adult Fish Facility between June 3 and August 1 (Table 1). Of these, 963 were tagged, along with 16 recaptures of Sockeye which had been previously PIT tagged in the Pound Net fishery, plus one recapture of a CRITFC AFF-tagged Sockeye. While the Pound Net fishery-tagged Sockeye were added to our sample, the CRITFC recapture (3DD.003D364679 which was tagged on July 9 and recaptured July 12) was not. Six Sockeye were not detected after release and there was one mortality, resulting in a total of 972 Sockeye tracked upstream (which will hereafter be referred to as Bonneville-tagged Sockeye although this includes recaptures). In 2019, sampling restrictions resulting in raised picket leads on 27 sampling days during weeks Sockeye Salmon were sampled; 23 of which were due to high shad abundance and 4 days due to high water temperatures (21.1 - 22.2C, Table 1)[4]. An additional two days of sampling were lost due to a 4-day weekly sampling limit when temperatures were between 21.1 and 22.2C in weeks 30 and 31. Temperatures exceeded 22.2C from August 2 through 11, 2019, resulting in no sampling during a period when 0.1% of the Sockeye run passed Bonneville Dam (as estimated using visual fish counts).

Sockeye not detected after tagging may have shed their tags, had defective tags, or died. It is also possible that these fish passed downstream without being detected, as Sockeye Salmon often swim over the top of weirs in the fish ladder rather than through the underwater slots where PIT tag antennas are located (e.g. at PTAGIS site BO3; Figures 3 and 4)[5]. It is unlikely that Sockeye Salmon pass upstream through Bonneville Dam fish ladders undetected as that would require swimming through a series of antennas at the upper end of both the Oregon and Washington shore fish ladders that detect virtually all passing PIT tagged fish (antennas 1-4 at both BO1 and BO4, Figure 5). If a Sockeye does pass through

---

[4] Raising picket leads is required by trap regulations and decreases the number of fish going through the trap and can introduce trap biases (Fryer et al. 2011b).

[5] Of the 844 Sockeye Salmon captured, PIT tagged, and released in the Pound Net Fishery, 520 were detected at BO4 at the upstream end of the Washington shore ladder. Of these Sockeye, only 235 (45.2%) were detected at the BO2 or BO3 antennas located in the ladder downstream of BO4 which indicates the extent to which upstream migrating Sockeye avoid the monitored underwater slots.

the ladder downstream to the tailrace after tagging, it is possible to pass upstream through the navigation locks without being detected at PIT tag antennas at Bonneville Dam (Figure 5). This is also possible at The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams. All other dams with PIT tag detection arrays have antennas in fish ladders that Sockeye Salmon must navigate, though data from 2006-2019 indicate that, even at those dams without navigation locks, PIT tagged Sockeye can and do avoid detection as they migrate upstream (Table 2).

Table 1. Number of Sockeye Salmon sampled, and PIT tagged at Bonneville Dam and tracked upstream by date and statistical week in 2019.

Sampling Dates	Statistical Week[6]	% of Run	Sampled (N)	Tagged	Previously Tagged		Mortalities	Not Detected After Tagging	Detected After Tagging	Days Sampling Restrictions in Effect		
					By CRITFC at AFF	Other Agencies				Reduced Sampling Temperature	Shad or Salmon Abundance	No Sampling Temperature
6/3-6/7	23	0.9	15	15	0	0	0	1	14	0	4	0
610-6/14	24	6.6	66	65	0	1	0	0	66	0	5	0
6/17-6/21	25	23.7	139	139	0	0	0	0	139	0	5	0
6/24-6/28	26	35.1	289	276	0	12	1	3	284	0	5	0
7/1-7/4	27	20.6	209	208	0	1	0	0	209	0	4	0
7/8-7/12	28	8.2	148	145	1[7]	2	0	1	146	0	0	0
7/15-7/19	29	3.1	67	67	0	0	0	0	67	0	0	0
7/22-7/25	30	1.2	28	28	0	0	0	0	28	0	0	1
7/29-8/1	31	0.6	20	20	0	0	0	1	19	4	0	1
Total			**981**	**963**	**1**	**16**	**1**	**6**	**972**	**4**	**23**	**2**

[6] Statistical weeks are sequentially numbered calendar-year weeks. Excepting the first and last week of most years, statistical weeks are seven days long beginning on Sunday and ending on Saturday. In 2019, for instance, Statistical Week 23 began on June 2 and ended on June 8.
[7] This Sockeye (3DD.003D364679) was tagged on July 9, dropped downstream in the Washington Shore ladder, and was recaptured on July 12. This second sampling event was omitted from further analysis.

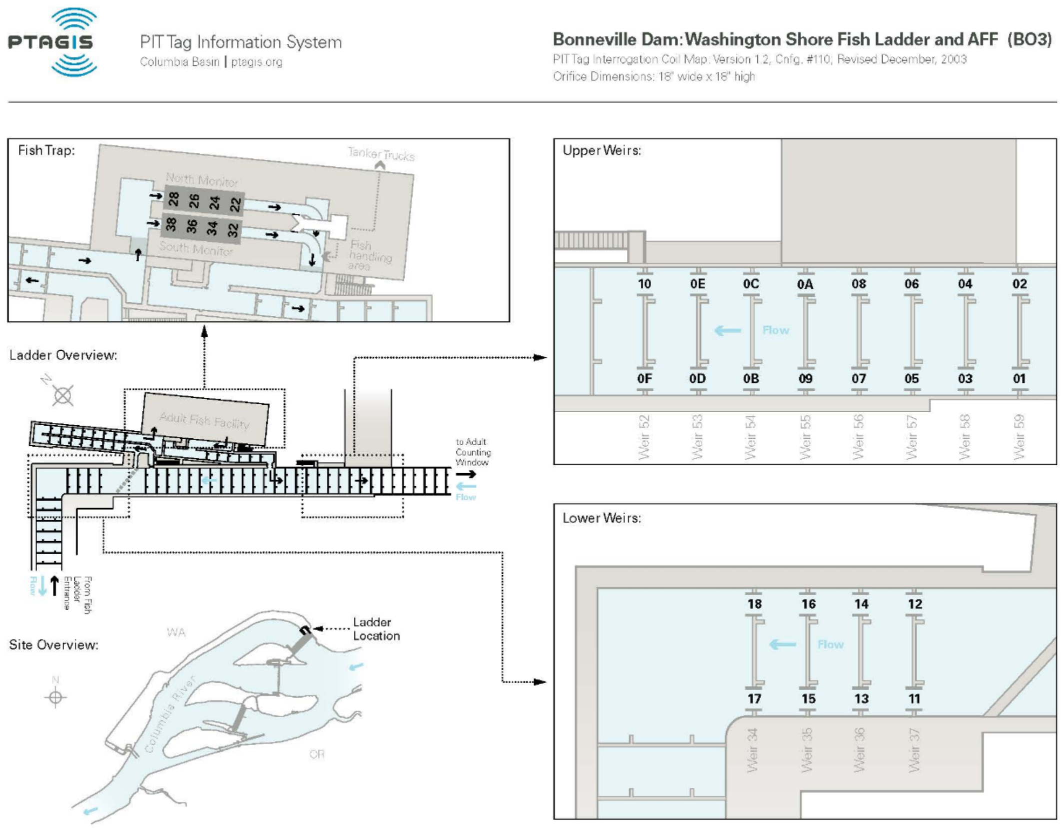


Figure 3. PTAGIS site BO3 Configuration. Antennas 01 to 10 are upstream of the Adult Fish Facility while antennas 11 to 18 are downstream. Antennas 22-28 and 32-28 are in the Adult Fish Facility flumes.

Bonneville Dam Vertical Slot Antenna

Bonneville Dam underwater antenna with unmonitored overflow weir

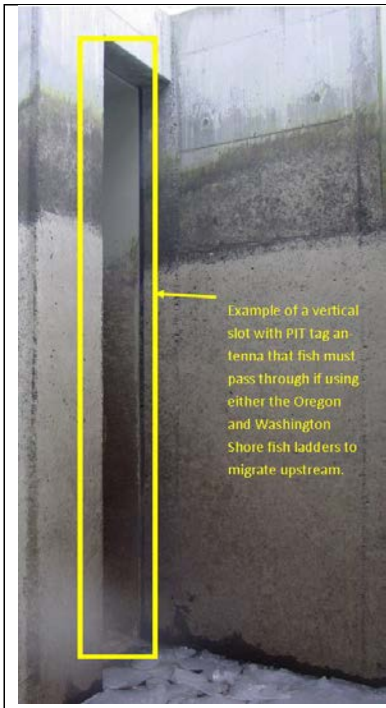


Figure 4. Pictures of the two types of PIT tag antennas at Bonneville Dam. The vertical slot antennas are at the upper end of both ladders, while the underwater antennas are in the lower parts of the ladders (photos courtesy of PTAGIS).

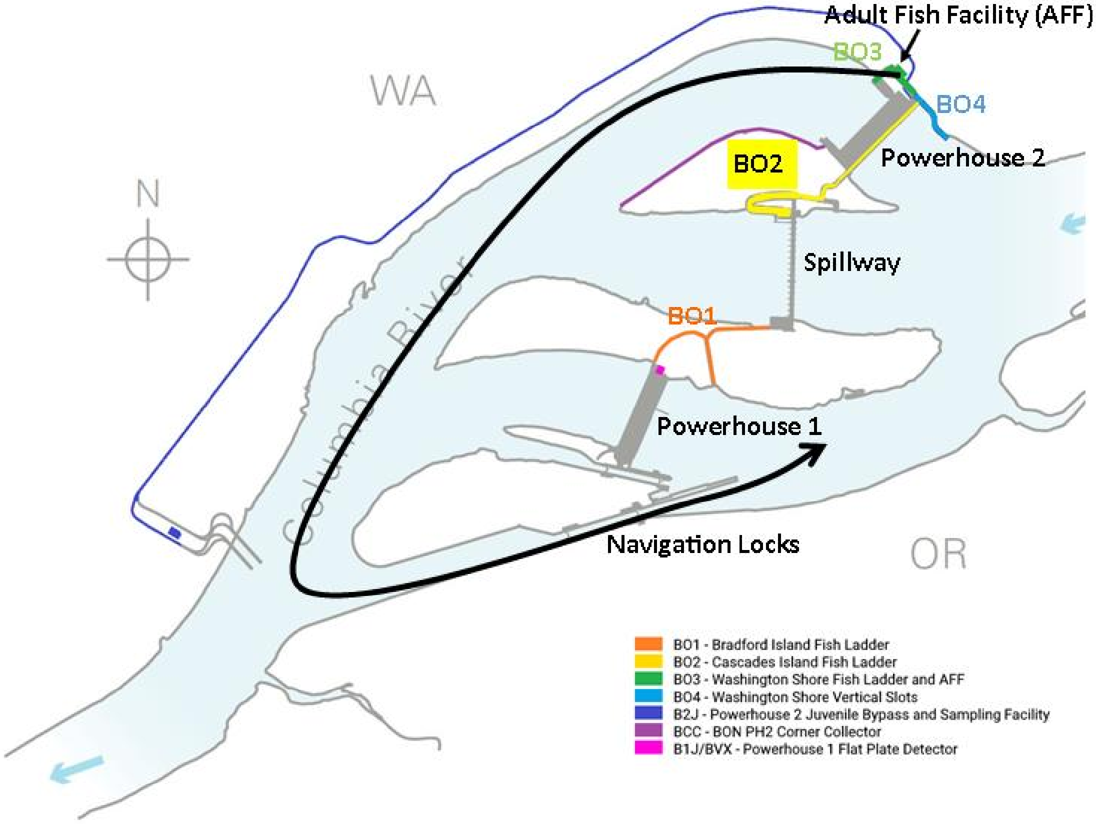


Figure 5. Site of Bonneville Dam PIT tag antennas and the most likely route (shown as a black line) for Sockeye Salmon tagged at the Adult Fish Facility to pass upstream undetected (Figure modified from www.ptagis.org).

Table 2. Percentage of Bonneville Dam PIT tagged Sockeye Salmon not detected at upstream dams and in-stream PIT tag arrays on their migration route for 2006-2019. Data from Pound Net-tagged Sockeye Salmon are included for 2019[8].

	Percentage Not Detected by Dam and Year															
Dam/Array	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2019 Pound Net [9]**	**2006-2019 Mean (BON-tag Only)**
Bonneville (BO1 & BO4)	0.2	2.1	0.4	0.6	0.7	0.5	1.8	0.4	0.7	1.6	2.8	0.2	1.1	1.5	4.0	1.0
The Dalles	--	--	--	--	--	--	--	1.6	0.3	0.6	0.4	2.1	0.9	0.5	1.0	0.9
John Day	--	--	--	--	--	--	--	--	--	--	--	--	2.8	3.3	4.4	3.1
McNary	3.1	6.5	10.1	5.0	3.8	1.6	12.1	2.1	3.8	1.1	2.4	5.2	2.9	2.9	3.4	4.5
Priest Rapids	0.0	0.8	0.3	0.3	0.6	0.2	0.4	0.0	0.2	0.4	0.3	0.0	0.1	0.0	0.0	0.3
Rock Island	1.3	6.8	6.9	2.6	6.2	4.4	5.4	4.4	41.5	10.2	2.9	5.9	28.3	4.1	10.5	9.4
Rocky Reach	12.3	0.7	0.2	0	0.5	0.7	1.4	0.0	0.3	0.0	0.0	0.7	0.2	0.0	0.0	1.2
Wells	--	--	--	--	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ice Harbor	--	--	0.0	20.0	0.0	--	0.0	--	12.5	0.0	0.0	0.0	0.0	0.0	0.0	3.3
Lower Monumental	--	--	--	--	--	--	--	--	--	0.0	0.0	0.0	0.0	0.0	--	0.0
Little Goose	--	--	--	--	--	--	--	--	--	0.0	0.0	0.0	0.0	0.0	--	0.0
Lower Granite	--	--	--	--	--	--	--	--	0.0	--	0.0	0.0	0.0	0.0	--	0.0
Tumwater	--	--	--	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zosel	--	--	--	--	--	98.6	83.0	87.3	0.9	0.0	1.6	74.5	57.5	0.0	0.3	44.8
LWE	--	--	--	--	--	--	--	--	48.0	17.9	54.7	49.6	68.4	33.3	31.8	45.3
UWE	--	--	--	--	--	--	--	--	52.7	24.6	9.7	9.3	9.9	3.2	8.1	18.2
OKL	--	--	--	--	--	--	--	--	68.9	13.8	59.4	47.4	50.1	66.7	62.4	51.1
OKC	--	--	--	--	--	--	--	--	--	--	16.9	--	7.7	5.3	2.3	10.0
Skaha	--	--	--	--	--	--	--	--	--	--	--	--	--	0.0	0.0	0.0

[8] No data indicates either that no antennas were installed at the site in question or that there were no detections upstream of the site.
[9] One Sockeye, recaptured by this project at Wells Dam, was found to be double tagged in the Pound Net fishery with tag codes 3DD.003D6E1FB7 and 3DD.003D6E1F5B. This fish was not detected at any PIT tag antennas until Zosel Dam and was omitted from this table.

Based on Sockeye PIT tagged at Bonneville Dam by this study, the dam with the highest percentage passing upstream undetected in 2019 was Rock Island Dam (4.1%, Table 2), although this was less than the 2006-2019 mean of 9.4% for this site. Rock Island Dam fishways have long had problems with electrical noise adversely affecting the ability of PIT tag antennas to detected PIT tags (Fryer et al. 2017).

The rate of Pound Net-tagged Sockeye missing detection was greater than that for AFF-tagged Sockeye at all six dams (Bonneville, The Dalles, John Day, McNary, Rock Island, Zosel) where the percentage missed was greater than zero for either group. The largest percentage point difference was at Rock Island, while second largest was at Bonneville Dam. Bonneville Dam is not surprising as the most likely way a Bonneville-tagged Sockeye would miss detection at Bonneville Dam is to go downstream after tagging, then enter and pass through the navigation locks, while a Pound Net-tagged Sockeye would only have to do the latter (Figure 5). The difference is likely due to different tag types. Pound Net Sockeye were tagged with HPT12 PIT tags, while tagging at the AFF was conducted with APT12 PIT tags which have a stronger signal that gives a 10% increase in read range in noisy environments typical of fish ladders at dams (email from Steve Anglea, Biomark, October 23, 2020). The difference in performance is not as significant at low noise environments such as in-stream arrays (email from Steve Anglea, Biomark, October 23, 2020) where Pound Net-tagged Sockeye had a lower rate of missing detection at 3 out of 4 sites (LWE, OKL, and OKC) and a greater rate at the remaining site (UWE), when compared to AFF-tagged Sockeye (Table 2).

Age Composition

The predominant age group in 2019, at 47.4% of the run, was estimated to be Age 1.1, followed by Age 1.3 at 27.9% of the run, and Age 1.2 at 18.6% (Table 3). Among these age groups, the percentage of Age 1.1 Sockeye increased as the run progressed while Age 1.3 and 1.2 decreased; however for none of these age groups did a linear regression find the increase significant (p=0.09, 0.08, and 0.19 respectively, Figure 6).

Table 3. Weekly and total age composition of Sockeye Salmon at Bonneville Dam as estimated from scale patterns in 2019. (Composite estimates are weighted by the percentage of the run passing Bonneville Dam in each week.)

Statistical Week	% of Run	N Ageable	Age Class 1.1	1.2	2.1	1.3	3.1	2.2	2.3
23	0.9%	15	20.0%	33.3%	0.0%	46.7%	0.0%	0.0%	0.0%
24	6.6%	65	40.0%	21.5%	1.5%	24.6%	0.0%	12.3%	0.0%
25	23.7%	138	39.1%	20.3%	2.2%	32.6%	0.0%	5.8%	0.0%
26	35.1%	284	42.3%	19.7%	0.4%	31.7%	0.0%	5.3%	0.7%
27	20.6%	204	62.3%	13.7%	0.5%	22.5%	0.0%	1.0%	0.0%
28	8.2%	146	61.6%	17.8%	2.1%	15.1%	0.7%	2.1%	0.7%
29	3.1%	65	58.5%	16.9%	0.0%	16.9%	0.0%	7.7%	0.0%
30	1.2%	28	46.4%	21.4%	0.0%	32.1%	0.0%	0.0%	0.0%
31	0.6%	18	44.4%	16.7%	5.6%	27.8%	0.0%	5.6%	0.0%
Composite	**100.0**	**963**	**47.4%**	**18.6%**	**1.0%**	**27.9%**	**0.1%**	**4.7%**	**0.3%**

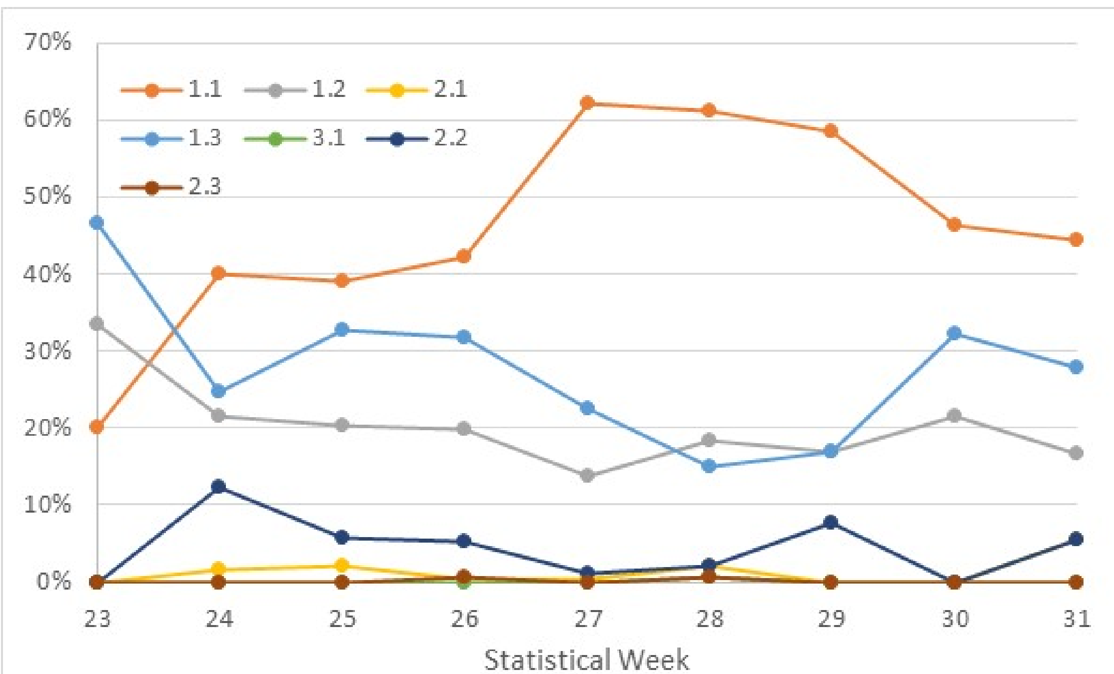


Figure 6. Weekly age composition estimates by Statistical Week for Sockeye Salmon sampled at Bonneville Dam in 2019.

Upstream Recoveries, Mortality, and Escapement

The percentage of Sockeye Salmon passing Bonneville Dam that were estimated to pass upstream dams (Figure 7) was higher in 2019 than the 2006-2019 mean to all dams except Tumwater Dam (Table 4)[10]. Estimates from Pound-

[10] Tumwater Dam is only passed by Wenatchee stock Sockeye Salmon so rate differences to Tumwater Dam (as well as Rocky Reach and Wells dams) also reflect annual variations in stock composition.

Net tagged Sockeye were only compared with AFF estimates through Week 28 as only one Pound Net-tagged Sockeye passed Bonneville Dam after Week 28. Over those weeks, survival of Pound Net Sockeye was between 0.9 and 0.4 percentage points higher to the Dalles and John Day Dam respectively than AFF-tagged Sockeye, but 0.9 percentage points lower to Priest Rapids and Rock Island dams (Table 4). McNary Dam for unknown reasons, had a much greater difference, while rates to dams upstream of Rock Island are skewed by differing stock composition as will be presented later in the Stock Composition Estimates section of this report.

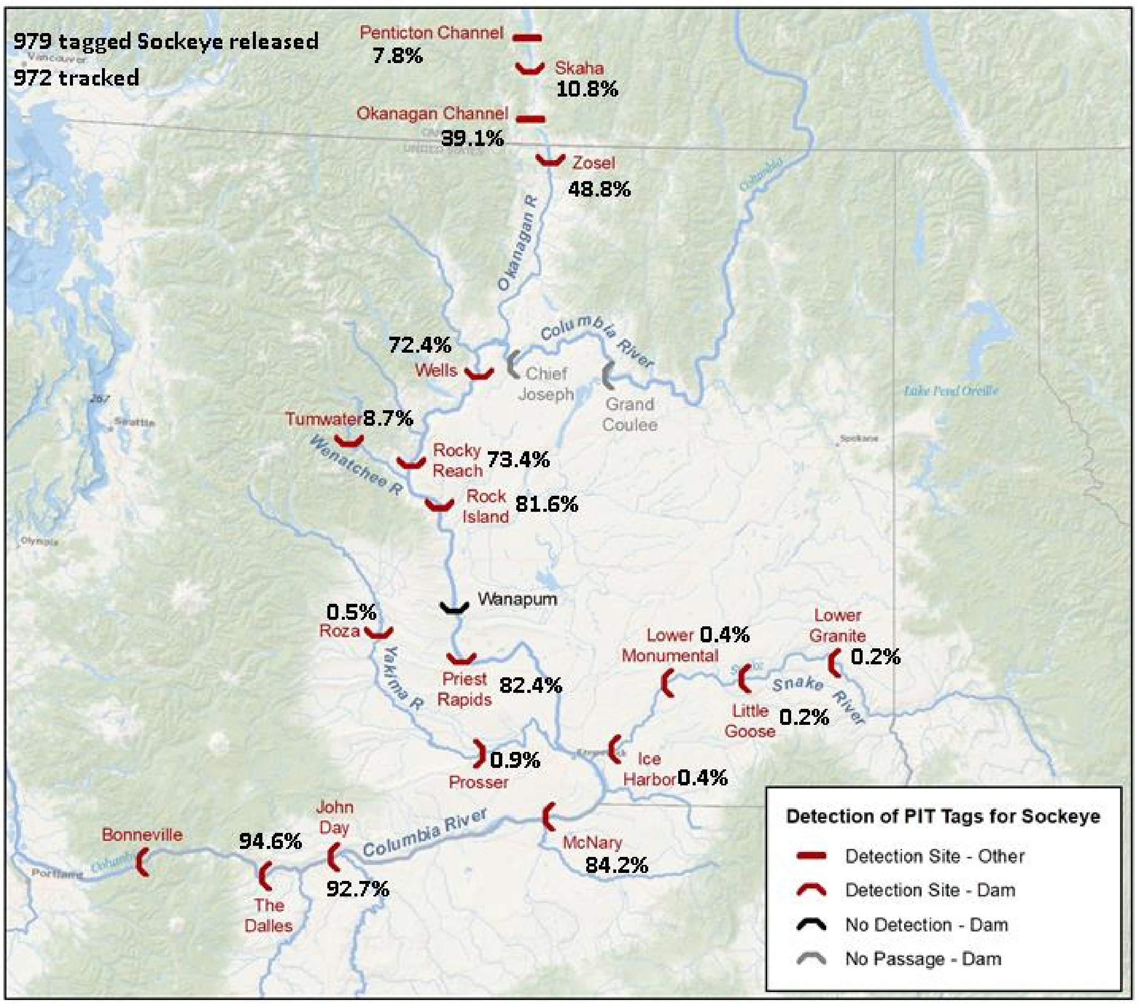


Figure 7. Map of the Columbia River Basin showing the number of fish PIT tagged at Bonneville Dam, and the percentage of the run estimated to pass upstream dams in 2019.

Table 4. Estimated survival of Sockeye Salmon PIT tagged at Bonneville Dam passing upstream dams 2006-2019. Estimated survivals from 2019 Pound Net-tagged Sockeye are also included for comparison.

	Percentage by Year and Mean of All Years																
															Weeks 23-28 Only[11]		
Dam	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2019	2019 Pound Net	Mean (AFF tags only)
The Dalles	--	--	--	--	--	--	--	89.5	93.1	82.8	94.0	89.3	93.3	94.6	94.9	95.8	90.9
John Day	--	--	--	--	--	--	--	--	--	--	--	--	90.9	92.7	93.3	93.7	91.8
McNary	88.4	84.0	89.4	85.7	81.5	76.1	82.4	83.6	88.3	54.0	89.2	81.7	88.9	84.2	85.6	90.2	82.7
Priest Rapids	84.8	77.4	86.3	82.1	78.4	71.9	77.3	78.6	84.5	44.9	85.3	74.6	85.4	82.4	83.7	82.6	78.1
Rock Island	81.1	73.4	85.8	80.2	76.3	68.9	75.0	74.2	79.5	40.6	81.6	70.8	80.7	81.6	83.0	82.1	75.0
Rocky Reach	58.8	62.2	73.7	67.1	63.7	55.3	62.1	52.4	65.3	31.6	60.5	43.7	73.9	73.4	74.5	68.0	60.3
Wells	53.8	60.9	71.1	65.2	62.6	53.9	60.8	50.5	64.2	29.4	59.3	42.5	72.7	72.4	73.6	67.0	58.5
Tumwater	NA	NA	9.4	12.2	13.3	14.2	12.9	20.9	13.6	8.3	20.8	25.8	6.0	8.7	8.1	11.6	13.8

[11] Only one Pound Net-tagged Sockeye was detected at Bonneville Dam after Week 28 as tagging was focused on early and middle portions of the run due to research impact limitations. Therefore, data on AFF-tagged Sockeye through Week 28 is presented for comparison purposes.

Survival rates were also calculated using similar methods for returning adults from a group of juvenile Sockeye (project goal is 3000) captured and PIT tagged annually at the Rock Island Dam juvenile bypass since 2008[12] (Table 5). Both Wenatchee and Okanagan juvenile Sockeye Salmon pass this site, making it a mixed stock most similar to Sockeye tagged as adults at Bonneville Dam[13]. However, sample sizes of returning adults from the Rock Island tagging program tend to be small, with only 20 returns to Bonneville Dam in 2019 (Table 5). Those Sockeye tagged by this program which passed Bonneville Dam in 2019 had high survival rates; 100% to John Day Dam and a combined 80.0% to Wells and Tumwater dams. Annual survival rates for these fish from Bonneville Dam to Priest Rapids Dam are compared with adults tagged by this study at Bonneville Dam in Figure 8[14]. This survival rate was greater for returning Rock Island-tagged juvenile salmon compared to Bonneville-tagged adults in 8 out of 13 years, however only in 2018 was this difference significant at $\alpha=0.05$ ($p=0.002$).

Table 5. Survival of Sockeye PIT tagged as smolts at Rock Island Dam, on their adult upstream migration from Bonneville Dam to upstream dams 2008-2019[15].

	Percentage by Year and Mean of All Years												
Dam	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Mean**
# at Bonneville	38	33	130	125	121	66	155	128	35	16	32	20	74.9
# Tagged at Rock Is.	1910	2059	3528	2977	3231	2674	3131	1689	4109	2210	3332	2859	2809
The Dalles	No PIT tag detection at this site					87.9	92.9	85.9	82.9	87.5	100.0	100.0	91.0
John Day	No PIT tag detection at this Site										100.0	100.0	100.0
McNary	89.5	100	82.3	74.4	74.4	80.3	87.1	60.2	74.3	81.3	100.0	90.0	82.8
Priest Rapids	89.5	93.9	81.5	73.6	71.9	74.2	83.9	54.7	74.3	68.8	100.0	85.0	79.3
Rock Island	81.6	90.9	79.2	68.8	69.4	68.2	77.4	46.9	68.6	68.8	93.9	85.0	74.9
Rocky Reach	55.3	87.9	70.0	55.2	48.8	56.1	60.0	36.7	45.7	68.8	65.6	55.0	58.8
Wells	55.3	87.9	68.5	52.8	43.8	56.1	58.7	32.8	42.9	62.5	62.5	55.0	56.6
Tumwater	26.3	3.0	10.0	14.4	23.1	10.6	16.1	13.3	22.9	6.3	25.0	25.0	16.3

[12] Tagging of juvenile Sockeye Salmon at Rock Island Dam has occurred since 1992; however, returns from these fish were lower and there were fewer detection sites prior to 2008.
[13] Juvenile Sockeye are also tagged in the Okanagan and Wenatchee basins. However, these programs have a shorter data set in terms of years tagged with collection methods and tag numbers that have varied by year.
[14] Priest Rapids was chosen as it is the last dam with a high PIT tag detection rate passed by both Okanagan and Wenatchee Sockeye Salmon.
[15] Years prior to 2008 were not included due to low sample sizes for returning Sockeye tagged as juveniles at Rock Island Dam. From 2002-2007, the number of Sockeye PIT tagged at Rock Island Dam as juveniles detected returning to Bonneville ranged between one and eight fish annually. Year 2013 the first year for detection at The Dalles Dam, and 2018 the first year for John Day Dam.

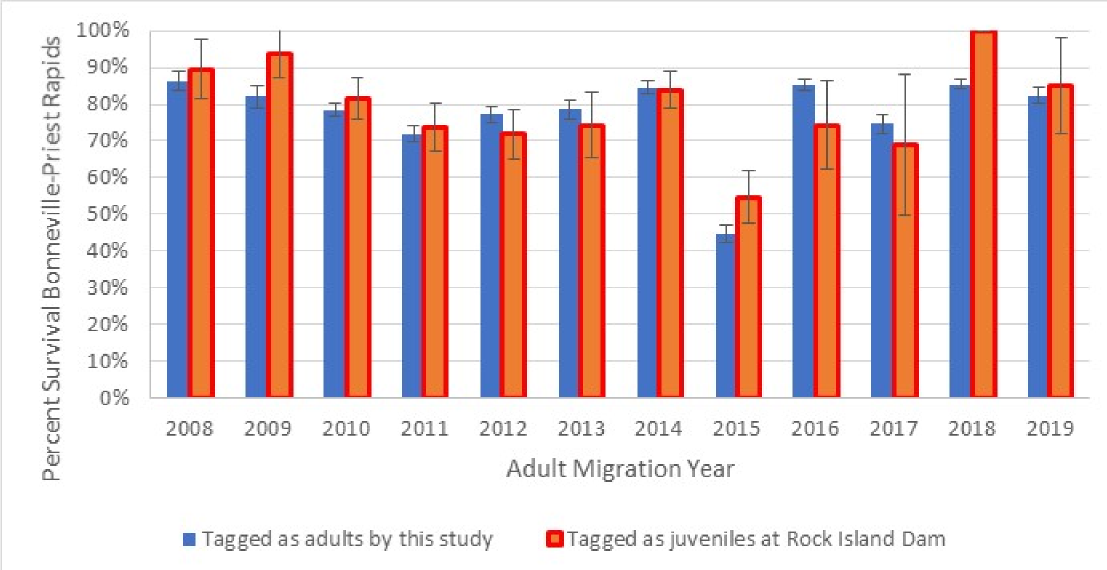


Figure 8. Annual survival rate with 90% CI from Bonneville Dam to Priest Rapids Dam for adult Sockeye Salmon tagged by this study at Bonneville Dam and for returning Sockeye Salmon tagged as juveniles at Rock Island Dam 2008-2019.

Upstream survival from Bonneville Dam to Rock Island Dam in 2019 was similar for Sockeye tagged at Bonneville Dam, the Pound Net Fishery, and for returning adults from juveniles tagged at Rock Island Dam (Figures 9 and 10). Upstream of Rock Island Dam, some differences are apparent for Rock Island-tagged Sockeye which had a higher percentage detected in the Wenatchee River (but with only n=5) and lower percentage in the Okanagan River than with Sockeye tagged as adults at Bonneville or in the Pound Net Fishery (Figure 9).

The estimated escapement based on upstream PIT tag detections of the Bonneville-tagged Sockeye was greater than the number of Sockeye counted at The Dalles, John Day, McNary, and Priest Rapids dams, but less at Rock Island, Rocky Reach, Wells, and Tumwater dams (Table 6, Figure 11). The PIT tag estimates show a consistent decrease in Sockeye escapement estimates as the run progresses upstream which is to be expected as Sockeye drop out on the upstream migration due to fisheries and natural mortality. However, the visual dam counts show an irregular pattern of increases and decreases as the Sockeye run progresses upstream. There were almost as many Sockeye counted at Rock Island Dam (58,562) as at Bonneville Dam (63,046), while the number of Sockeye counted at Priest Rapids Dam (45,231) immediately downstream of Rock Island Dam was less than at any other dam on the Columbia River. PIT tag estimates for Snake River and Yakima River dams were based on too few detections (one to seven) to provide meaningful comparisons with visual estimates.

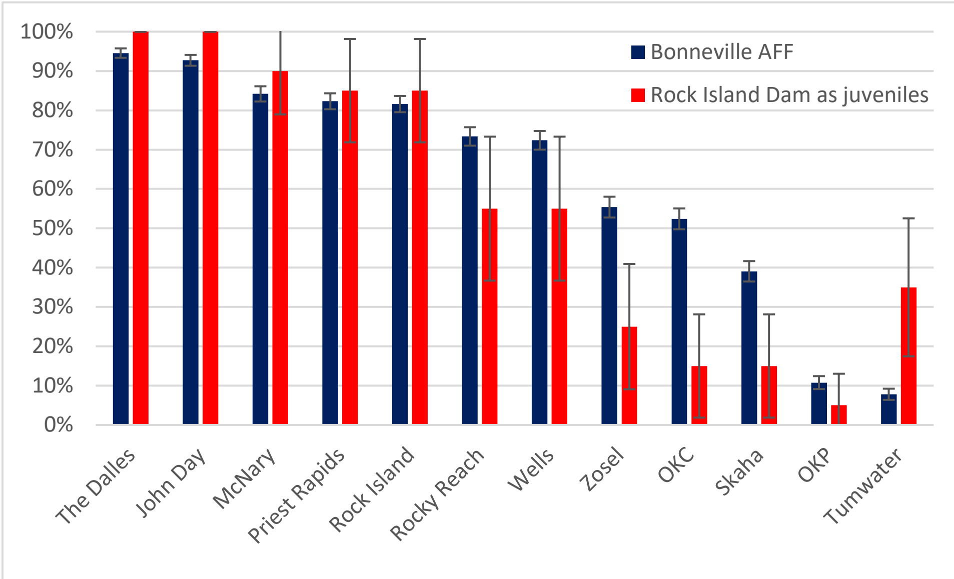


Figure 9. Estimated survival from Bonneville Dam to upstream sites (with 90% CI) in 2019 for adults tagged at Bonneville Dam and for returning Sockeye tagged as juveniles at Rock Island Dam in 2019.

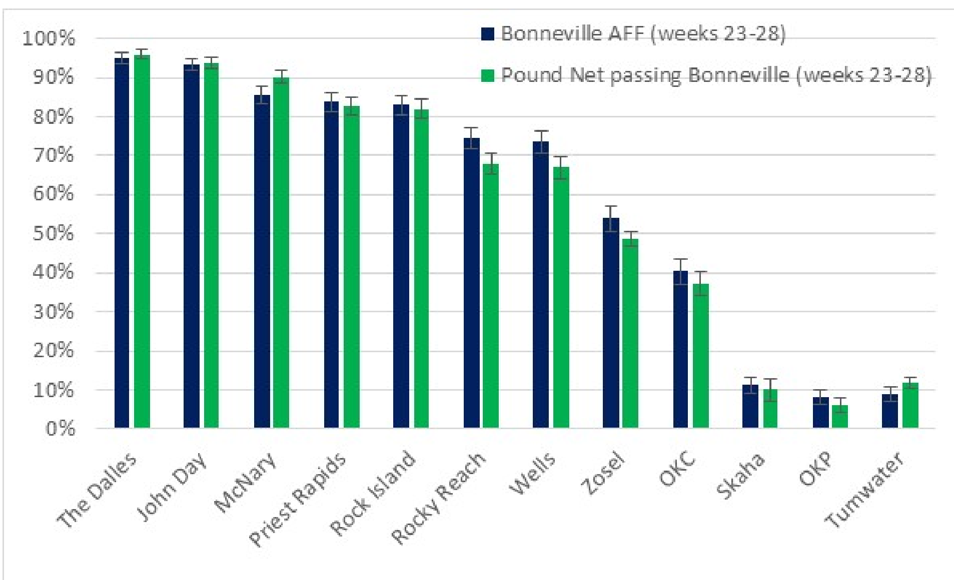


Figure 10. Estimated from Bonneville Dam survival through Week 28 to upstream sites (with 90% CI) in 2019 for adults tagged at Bonneville Dam and in the Pound Net fishery in 2019. Data after Week 28 was excluded because only one Sockeye from the Pound Net Fishery passed Bonneville after that week.

Table 6. Estimated Sockeye escapement from both PIT tags and visual means, and the difference between the PIT tag and visual escapement estimate at Columbia Basin dams in 2019.

Dam	Escapement Estimate Using Bonneville PIT Tagged Sockeye	Visual Dam Count	Difference Between Bonneville PIT Tag and Visual Estimates
Bonneville	--	63,046	--
The Dalles	59,618	50,687	17.6%
John Day	58,462	52,526	11.3%
McNary	53,106	51,561	2.9%
Priest Rapids	51,926	45,231	14.7%
Rock Island	51,472	58,562	-12.2%
Rocky Reach	46,271	50,464	-8.3%
Wells	45,651	49,862	-8.5%
Tumwater	5,485	8,875	-38.2%
Ice Harbor	240	320	-24.9%
L. Monumental	240	195	23.2%
Little Goose	114	84	35.9%
Lower Granite	114	81	40.9%
Prosser	587	110	433.4%
Roza	304	201	51.2%

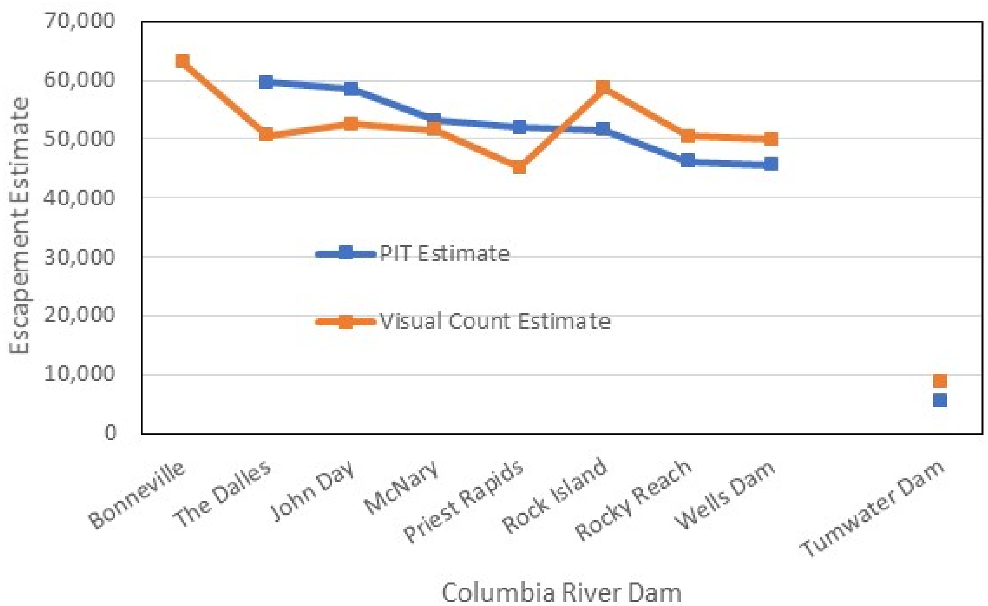


Figure 11. Estimated PIT tag and visual count estimates of escapement at Columbia River and Tumwater dams in 2019.

Sockeye Salmon tagged at Bonneville Dam show a significant decrease in survival to upstream dams over the period of the run in 2019 (Table 7, Figure 12).

There was not a significant linear relationship to Priest Rapids Dam for Sockeye tagged in the Pound Net fishery (p=0.096), as juveniles in the Okanagan Basin (p=0.266), or as juveniles at Rock Island Dam (p=0.113)

Table 7. Sockeye Salmon survival through selected reaches by statistical week as estimated by PIT tag detections in 2019 and the p-value for a linear regression between weekly reach survival and statistical week. No p-values were estimated for returning Sockeye tagged as juveniles due to the low number of returning adults.

Statistical Week at Bonneville Dam	Survival from Bonneville for Sockeye Tagged as Adults at Bonneville Dam					Sockeye Tagged as Juveniles Survival from Bonneville-Priest Rapids		
	The Dalles	John Day	McNary	Priest Rapids	Rock Island	Wenatchee (n=1)	Okanagan (n=21)	Rock Island (n=20)
23	92.9%	92.9%	85.7%	85.7%	78.6%	--	--	100.0%
24	96.9%	93.8%	89.1%	85.9%	89.1%		100.0%	100.0%
25	97.1%	94.2%	86.9%	85.4%	84.7%		100.0%	71.4%
26	94.4%	93.3%	87.3%	85.2%	84.5%	100.0%	83.3%	100.0%
27	93.2%	93.2%	83.5%	82.0%	80.1%	--	100.0%	50.0%
28	93.7%	90.8%	77.5%	74.6%	74.6%	--	100.0%	--
29	91.0%	88.1%	71.6%	70.1%	70.1%	--	--	--
30	85.7%	67.9%	32.1%	32.1%	28.6%	--	--	--
31	77.8%	72.2%	27.8%	27.8%	27.8%	--	--	
Composite[16]	**94.6%**	**92.7%**	**84.2%**	**82.4%**	**81.6%**	**100.0%**	**95.2%**	**85.0%**
p-value	**0.010**	**0.010**	**0.004**	**0.003**	**0.007**	**--**	**0.266**	**0.113**

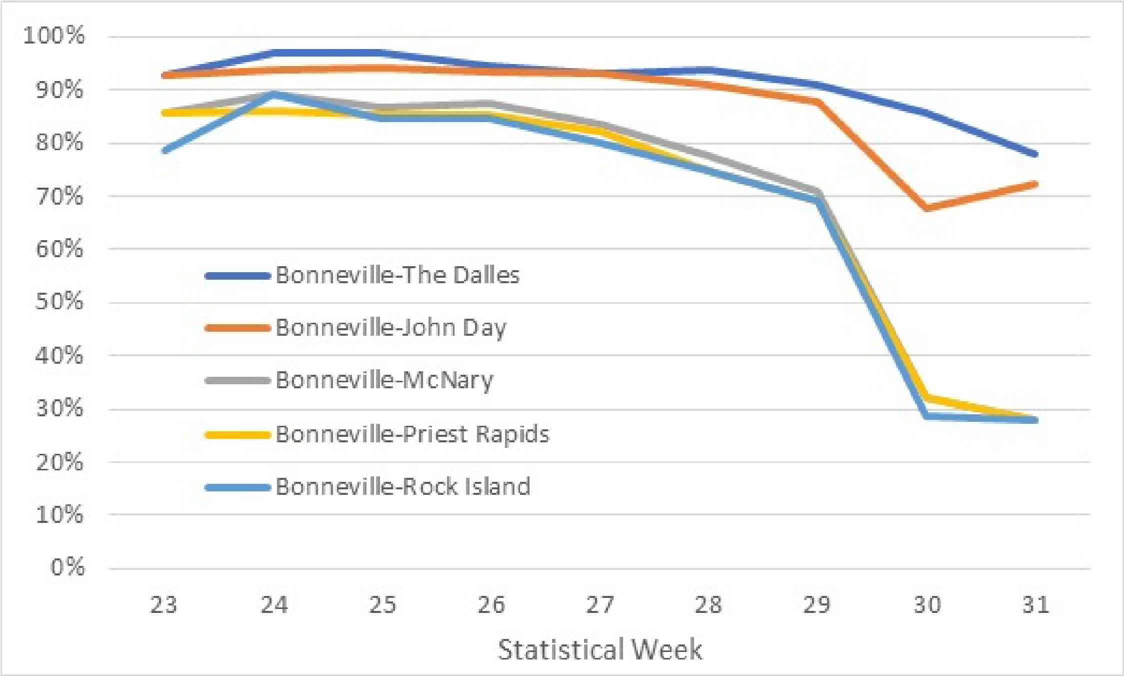


Figure 12. Survival of Sockeye Salmon PIT tagged at Bonneville Dam to The Dalles, McNary, Priest Rapids, and Rock Island dams by statistical week in 2019.

[16] Composite estimates for Bonneville Dam- and Pound Net-tagged Sockeye Salmon are weighted by Statistical Week, juvenile estimates are unweighted.

Comparisons between survival estimates for Sockeye PIT tagged by this study at Bonneville Dam and returning adult Sockeye tagged as juveniles are of limited use due to the low returns in 2019 of adults tagged as juveniles (Table 8), particularly for the Wenatchee (n=1) and Snake (n=2).

The returning Rock Island juvenile-tagged Sockeye had high upstream survival, with 17 of the 20 (85%) passing Bonneville Dam also detected at Priest Rapids Dam. Returning Okanagan juvenile-tagged Sockeye had higher survival to all upstream dams than did Bonneville adult-tagged Sockeye from this study. Among the 2 returning Snake juvenile-tagged Sockeye, both were detected at Ice Harbor and 1 was last detected at the Redfish Lake Weir (RFL) immediately downstream of the spawning grounds. The single returning Wenatchee Sockeye Salmon detected at Bonneville was last detected on the spawning grounds for a conversion rate to the spawning grounds of 100%. Excluding that calculation, spawning ground conversion rates were highest for Bonneville adult-tagged Sockeye (46.9%), followed by returning Sockeye tagged as juveniles in the Okanagan Basin (38.1%). Sockeye tagged as juveniles at Rock Island Dam displayed the lowest conversion rates (30.0%, Table 8).

Table 8. Survival of Sockeye groups PIT tagged as juveniles from Bonneville Dam to upstream dams with adults tagged by this study at Bonneville Dam included for comparison in 2019. Yellow shaded cells represent sites that are not on the migration route for the group tagged.

			Percent Survival to Upstream Dam									
Tagging Location	Life Stage at Tagging	# at BON	The Dalles	John Day	McNary	Priest Rapids	Rock Island	Rocky Reach	Wells	Tumwater	Ice Harbor	Conversion Rate BON to PIT Arrays on Spawning Ground (%)[17]
Okanagan	Juvenile	21	100.0	100.0	95.2	95.2	90.5	90.5	90.5	0.0	0.0	38.1
Wenatchee	Juvenile	1	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0	0.0	100.0
Rock Island	Juvenile	20	100.0	100.0	90.0	85.0	85.0	55.0	55.0	25.0	0.0	30.0
Snake	Juvenile	2	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	100.0	50.0
Bonneville	Adult	1848	94.6	92.7	84.2	82.4	81.6	73.4	72.4	8.7	0.4	46.9

Migration Rates and Passage Time

Adult Sockeye Salmon travelled quickly upstream in 2019 with median migration rates between mainstem dams ranging between 31.8 and 58.7 km/day

[17] Spawning grounds means detection at or above OKC in the Okanagan, LWE or WTL in Wenatchee, or RFL in the Snake Basin.

for adults tagged at Bonneville; 31.8 to 56.9 km/day for adults tagged in the Pound Net fishery, and 30.0 to 59.8 km/day for tagged juveniles returning as adults (Table 9). Maximum migration rates occurred between John Day and McNary. Migration rates from Bonneville to Wells Dam were remarkably consistent: 39.8 km/day for Bonneville-tagged and Pound Net-tagged Sockeye, and 39.6 km/day for adult returning Sockeye tagged as juveniles.

Unlike previous years, Sockeye Salmon tagged at Bonneville Dam later in the migration did not travel significantly faster than those tagged earlier in the migration, with the exception of Bonneville-Wells and Bonneville-Rock Island ($\alpha=0.05$, Table 10). Median travel times between the Okanagan and Wenatchee stocks differed by 0.5 days or less for all dam pairs listed that are in the migration corridor for both stocks. Three Wenatchee Sockeye which were detected at Wells Dam had longer migration times to Rocky Reach and Wells Dam than did Okanagan Sockeye on their usual migration route.

Table 9. Median Sockeye Salmon migration rates and travel time between dams as estimated by PIT tag detections in 2019.

		Tagged at Bonneville Dam		Tagged in Pound Net Fishery		Adults Tagged as Juveniles	
Dam Pair	Distance (km)	Median Travel Time (days)	Median Migration Rate (km/day)	Median Travel Time (days)	Median Migration Rate (km/day)	Median Travel Time (days)	Median Migration Rate (km/day)
Bonneville-The Dalles	74	1.64	43.5	1.35	52.9	1.31	54.6
The Dalles-John Day	39	0.88	49.2	0.87	49.8	0.98	44.2
John Day-McNary	63	2	58.7	2.06	56.9	1.96	59.8
McNary-Priest Rapids	167	4.14	40.7	4.17	40.4	4.35	38.7
Priest Rapids-Rock Island	89	2.77	32.5	2.82	31.9	2.47	36.4
Rock Island-Rocky Reach	33	1.01	31.8	1.01	31.8	1.08	30.0
Rocky Reach-Wells	65	1.79	38.1	1.81	37.7	3.08	32.6
Rock Island-Tumwater	73	9.23	7.5	10.03	6.9	9.56	7.2
Bonneville-John Day	113	2.65	43.3	2.30	50	2.5	46.0
Bonneville-McNary	231	4.70	49.3	4.56	50.9	4.54	51.1
Bonneville-Priest Rapids	329	8.91	44.9	8.88	45.1	8.91	44.9
Bonneville-Rock Island	487	11.88	41.3	11.82	41.5	11.85	41.4
Bonneville-Tumwater	560	22.46	24.9	22.7	24.6	21.36	26.2
Bonneville-Wells	585	14.83	39.8	14.84	39.8	14.92	39.6

The median passage time at a dam (defined as the difference between the first and last detection at a dam and weighted by the number of detections at each dam) for Sockeye tagged at Bonneville Dam in 2019 was 4.6 minutes compared to 5.8 minutes for Pound Net-tagged adults, and 6.7 minutes for Sockeye tagged as juveniles (Table 11). The weighted mean percentage of Sockeye taking more than 12 hours to pass a dam was also greater for Sockeye tagged as juveniles (4.0%) and in the Pound Net fishery (4.2%) compared to those tagged as adults at the Bonneville (2.3%, Table 11).

Table 10. Adult Sockeye Salmon median travel time in days between dam pairs by statistical week tagged at Bonneville Dam, the p-value for a linear regression between travel time and statistical week, and mean travel time by stock as estimated using PIT tags in 2019.

Statistical Week at Bonneville Dam	BON to TDA	BON to JDA	BON to MCN	BON to PRA	BON to RIA	BON to TUF	BON to RRF	BON to WEA	BON to ZSL	WEL to ZSL	RIA to TUF
23	1.9	3.1	4.9	9.6	16.3	--	15.8	20.0	23.4	6.4	15.0
24	1.8	2.9	4.8	9.4	13.9	27.1	15.0	17.9	22.5	5.7	10.0
25	1.7	2.7	4.7	9.6	13.0	22.7	13.9	17.0	30.6	12.0	9.8
26	1.7	2.7	4.7	8.9	12.7	22.8	12.9	15.9	25.5	10.2	9.2
27	1.5	2.6	4.6	8.3	12.0	21.3	12.0	14.9	20.4	7.2	9.4
28	1.6	2.5	4.6	8.8	11.0	19.2	12.5	13.8	51.6	35.8	7.5
29	1.6	2.5	4.8	9.0	11.2	29.0	12.9	14.6	43.7	28.0	12.4
30	1.9	2.8	4.8	9.1	12.0	26.6	13.3	14.3	26.9	11.5	14.6
31	1.7	3.0	5.6	10.1	12.1	--	14.8	15.3	31.6	18.6	15.0
p-value	**0.49**	**0.47**	**0.24**	**0.97**	**0.01**	**0.81**	**0.27**	**0.01**	**0.25**	**0.13**	**0.47**
Stock											
Okanagan	1.6	2.6	4.7	8.9	11.8	N/A	12.9	14.8	25.3	10.1	N/A
Wenatchee	1.6	2.7	4.7	9.1	12.3	22.5	14.2	23.5	N/A	N/A	9.2

Table 11. Sockeye Salmon median passage time (from time of first detection at a dam to last detection at a dam) and the percentage of Sockeye Salmon taking greater than 12 hours between first detection and last detection in 2019.

	Adults Tagged at Bonneville Dam			Tagged in Pound Net Fishery			Previously Tagged as Juveniles		
Dam	N	Median Passage (Minutes)	%>12 Hours	N	Median Passage (Minutes)	%>12 Hours	N	Median Passage (Minutes)	%>12 Hours
Bonneville	1772	9.2	0.1	520	13.0	0.4	75	7.6	0.0
The Dalles	1689	0.1	1.9	725	0.1	1.8	98	0.1	3.1
John Day	1607	0.1	3.4	681	0.2	9.1	91	0.1	4.4
McNary	1544	0.2	1.9	667	0.2	2.4	91	0.4	12.1
Priest Rapids	1512	5.0	1.6	636	8.1	4.6	85	6.4	2.4
Rock Island	1030	2.0	0.6	565	3.9	0.9	58	1.5	1.7
Rocky Reach	1316	6.0	1.7	532	6.0	1.1	65	6.5	1.5
Wells	1296	5.7	5.6	517	13.3	14.9	64	5.4	6.2
Zosel	370	37.2	10.2	379	0.7	4	11	0.2	0.0
Tumwater	98	7.4	0.0	88	48.6	9.1	13	27.7	0.0
Ice Harbor	4	0.2	0.0	1	29.2	0	5	2.0	0.0
Lower Monumental	1	0.1	0.0	1	0.2	0	5	3.9	20.0
Little Goose	1	224.6	0.0	0	NA	NA	5	0.1	0.0
Lower Granite	1	5.7	5.6	0	NA	NA	5	419.2	0.0
Weighted Mean (by detection number)	**12241**	**4.6**	**2.3**	**5312**	**5.8**	**4.2**	**671**	**6.7**	**4.0**

Night Passage

Okanagan Sockeye Salmon tagged at Bonneville Dam passed PIT tag antennas at night (2000-0400 hours) at a higher rate than Wenatchee Sockeye Salmon at 7 out of 8 dams where Sockeye from both stocks were detected (Table

12), with the sole exception being at The Dalles Dam. Adults tagged at Bonneville passed dams at night at a higher rate than Sockeye tagged both in the Pound Net fishery and as juveniles at 5 out of 10 dams.

Table 12. Estimated Sockeye Salmon night passage (2000-0400) by stock at Columbia River, Zosel, and Tumwater dams in 2019.

Dam	Adults Tagged at Bonneville Dam			Sockeye Tagged as Juveniles	Adult Sockeye Tagged in Pound Net Fishery
	All Adults	Okanagan	Wenatchee		
Bonneville	1.7%	1.8%	1.0%	7.1%	1.9%
The Dalles	8.2%	7.3%	14.3%	6.8%	6.8%
John Day	5.7%	6.0%	3.2%	4.7%	4.0%
McNary	9.2%	10.1%	3.4%	2.4%	6.0%
Priest Rapids	4.8%	5.1%	1.2%	2.6%	2.8%
Rock Island	6.3%	6.6%	3.9%	8.3%	6.0%
Rocky Reach	5.4%	5.5%	0.0%	0.0%	5.5%
Wells	13.8%	13.9%	0.0%	10.0%	16.1%
Tumwater	7.0%	NA	7.0%	0.0%	2.3%
Zosel	53.2%	53.2%	NA	78.9%	55.4%

Fallback

Fallback rates at Columbia River dams for adults tagged at Bonneville Dam in 2019 ranged from 0.2% at Bonneville Dam to 5.5% at John Day Dam (Table 13). Pound Net-tagged Sockeye Salmon at those same dams had fallback rates ranging from 0.1% at Bonneville Dam to 5.9% at John Day Dam. Numbers of returning adults tagged as juveniles in 2019 were low with only 44 detected passing Bonneville Dam. Combined-stock fallback rates for returning juveniles ranged from 0% at McNary Dam to 50.0% at Lower Granite (n=2) and 15.9% at John Day Dam.

Table 13. Estimated minimum fallback rates for Sockeye Salmon at mainstem dams in 2019[18]. NA indicates Sockeye were not detected at a dam outside the range of the particular stock. The sample size (n) is the number of tagged Sockeye detected moving upstream past Bonneville Dam.

	Sockeye Tagged as Adults		Sockeye Tagged as Juveniles by Tagging Location				
Dam	Bonneville AFF (n=941)	Pound Net (n=764)	Okanagan Basin (n=21)	Rock Island Dam (n=20)	Snake Basin (n=2)	Wenatchee Basin (n=1)	Total (n=44)
Bonneville	0.2%	0.1%	4.8%	0.0%	0.0%	0.0%	2.3%
The Dalles	3.1%	2.0%	4.8%	5.0%	0.0%	0.0%	4.8%
John Day	5.5%	5.9%	14.3%	10.0%	100.0%	0.0%	15.9%
McNary	0.4%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%
Priest Rapids	3.5%	4.1%	0.0%	11.8%	NA	0.0%	5.3%
Rock Island	0.7%	0.3%	0.0%	0.0%	NA	0.0%	0.0%
Rocky Reach	3.1%	3.2%	0.0%	9.1%	NA	NA	3.3%
Wells	3.1%	2.7%	5.3%	9.1%	NA	NA	0.0%
Tumwater	1.4%	0.0%	NA	0.0%	NA	0.0%	0.0%
Zosel	3.6%	3.2%	16.7%	0.0%	NA	NA	10.5%
Skaha	2.2%	1.2%	0.0%	0.0%	NA	NA	0.0%
Ice Harbor	0.0%	0.0%	NA	NA	0.0%	NA	0.0%
Lower Monumental	0.0%	0.0%	NA	NA	0.0%	NA	0.0%
Little Goose	0.0%	NA	NA	NA	0.0%	NA	0.0%
Lower Granite	100.0%	NA	NA	NA	50.0%	NA	50.0%

Of the 152 Sockeye tagged as adults by this project in 2019 which fell back over at least one dam, 16 fell back over two dams while 4 fell back over three dams (Table 14). Among the 133 Sockeye tagged in the Pound Net fishery that fell back over at least one dam, 20 fell back over two dams, and 2 fell back over three dams. Among Sockeye tagged as juveniles, the mean number of fallback events per Sockeye Salmon ranged from 0 for Sockeye tagged in the Wenatchee Basin (n=1) to 1.50 for the Snake Basin (n=2) compared to 0.21 for adult-tagged Sockeye in our Bonneville study (Table 14).

[18] Does not include Sockeye Salmon that fell back over a dam and were not subsequently detected.

Table 14. Number of fallback events by tag group for returning Sockeye tagged as juveniles and Sockeye included in our Bonneville adult tagging study in 2019.

	Sockeye Tagged as Adults		Sockeye Tagged as Juveniles by Tagging Location			
Fallback Events	Bonneville Dam AFF	Pound Net Fishery	Okanagan Basin	Rock Island Dam	Snake Basin	Wenatchee Basin
1	132	111	5	5	1	0
2	16	20	0	1	1	0
3	4	2	1	0	0	0
≥4	0	0	0	0	0	0
Number of Sockeye falling back at least once	**152**	**133**	**6**	**6**	**2**	**0**
% of Sockeye with at least one fallback event	**16.2%**	**17.4%**	**28.6%**	**30.0%**	**100.0%**	**0.0%**
Total fallback events	**176**	**157**	**8**	**7**	**3**	**0**
Number of Sockeye detected at or upstream of Bonneville Dam	**941**	**764**	**21**	**20**	**2**	**1**
Fallbacks events per Sockeye	**0.19**	**0.21**	**0.38**	**0.40**	**1.50**	**0.00**

Comparisons with WFRS Sockeye Salmon

A total of 1266 Sockeye Salmon were detected passing through the WFRS during 2019 compared to 977 tagged at the AFF (Table 15, Figure 13). The weekly distribution of the WFRS sample was similar to that of the run at Bonneville Dam as estimated by visual fish counts. The AFF sample under-sampled the middle of the run relative to visual fish counts and the WFRS. This was due to a limit on how many Sockeye it is possible to sample given restrictions in trap operations while also sampling Chinook and Steelhead. AFF sample peaked at 288 Sockeye sampled in week 26.

Table 15. Mean length with standard deviation of Sockeye Salmon by Statistical Week for Sockeye sampled at the AFF and by the WFRS in 2019.

	AFF			WFRS				% of Visual Count
Statistical Week	Mean	Standard Deviation	N	Mean	Standard Deviation	N with Length	Total N	
22				35.8	1.9	2	2	0.1%
23	48.5	7.2	15	44.1	9.1	6	6	0.9%
24	45.5	7.6	66	44.8	9.6	66	66	6.6%
25	46.4	7.2	137	44.1	8.4	255	258	23.7%
26	45.8	7.6	288	44.7	8.6	486	491	35.1%
27	43.2	7.3	209	42.3	8.1	242	247	20.6%
28	42.3	6.7	147	40.9	7.2	134	135	8.2%
29	43.4	7.2	67	41.6	8.0	41	41	3.1%
30	45.2	6.9	28	39.9	5.3	10	10	1.2%
31	44.3	8.3	20	51.0	7.9	2	2	0.4%
32	AFF Closed due to temperatures at or above 22.2C, no sampling							0.2%
33[19]	NA	NA	0	NA	NA	0	0	0.1%
34	NA	NA	0	48.5	6.3	7	7	0.0%
35	NA	NA	0	49.8	NA	1	1	0.0%
Total	**44.6**	**7.5**	**977**	**43.6**	**8.5**	**1252**	**1266**	

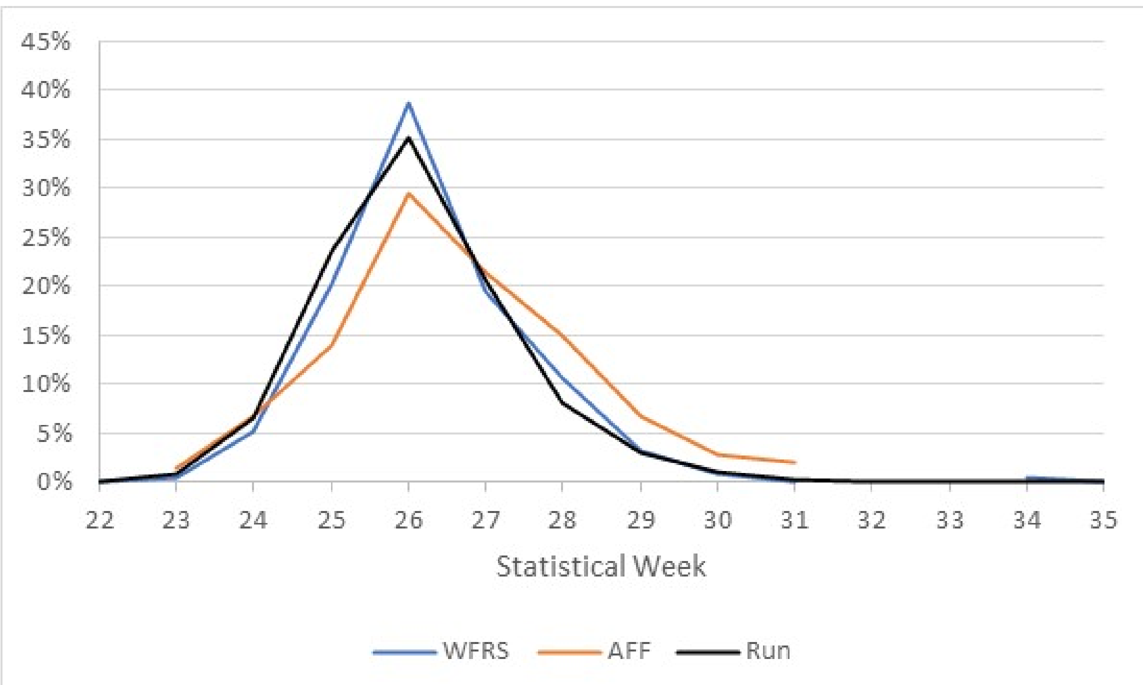


Figure 13. Comparison of the weekly percentage of the visual fish count at Bonneville Dam and the percentage of Sockeye sampled in the Adult Fish Facility and by the WFRS in 2019.

The weekly mean fork length for WFRS- and Bonneville-tagged Sockeye Salmon differed by 1.8 cm or less between weeks 24 and 29 and diverged in earlier

---

19 AFF only operated two days due to temperatures at or above 22.2C in Week 33. No Sockeye were sampled at the AFF or by WFRS in Week 33, however, Sockeye were sampled in weeks 34-35 by the WFRS.

and later weeks when sample sizes were smaller (Figure 14, Table 15). The distribution of fish size was bimodal due to the age structure of returns, which exhibited a high proportion of age 1.1 jacks averaging 34-38 cm in length in 2019, compared to 50-55 cm for 4- and 5-year old Sockeye (Figure 15). The overall mean length for Bonneville-tagged Sockeye was 44.6 cm compared to 43.6 cm for WFRS. A Mann Whitney test found a significant difference ($Z=4.8$, $p<0.01$) between lengths of AFF and WFRS-sampled Sockeye. A Kolmogorov-Smirnov test also found a significant difference between cumulative length distribution of AFF and Whooshh-sampled Sockeye ($\chi^2=65.2$, $p<0.01$, Figure 16).

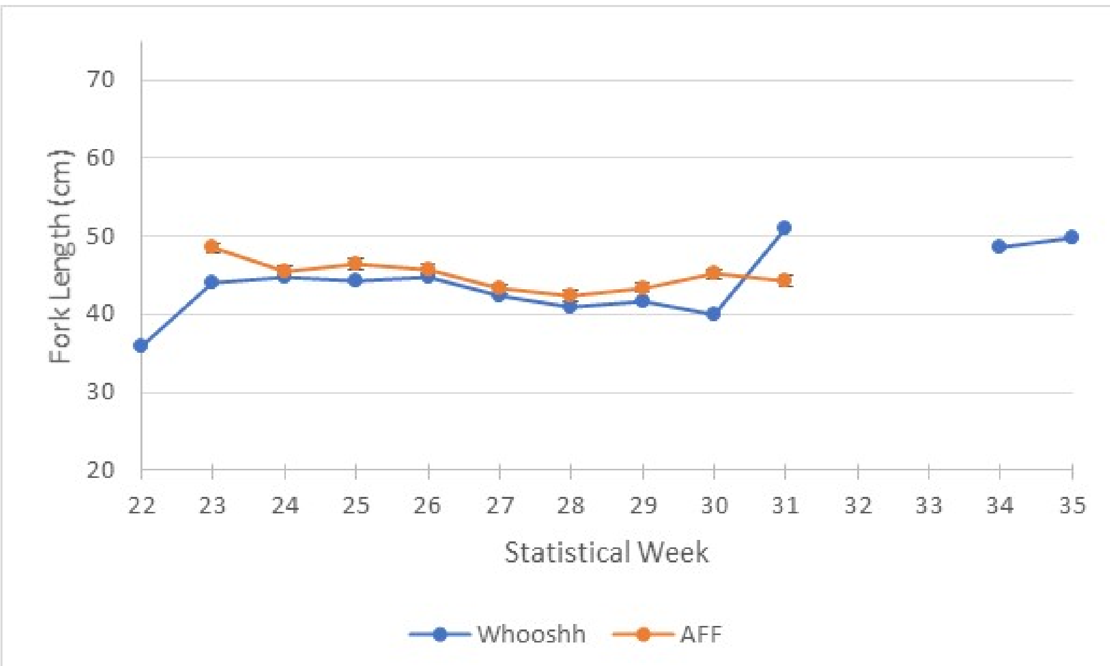


Figure 14. Weekly mean length for Sockeye Salmon sampled at the AFF and by WFRS at Bonneville Dam in 2019.

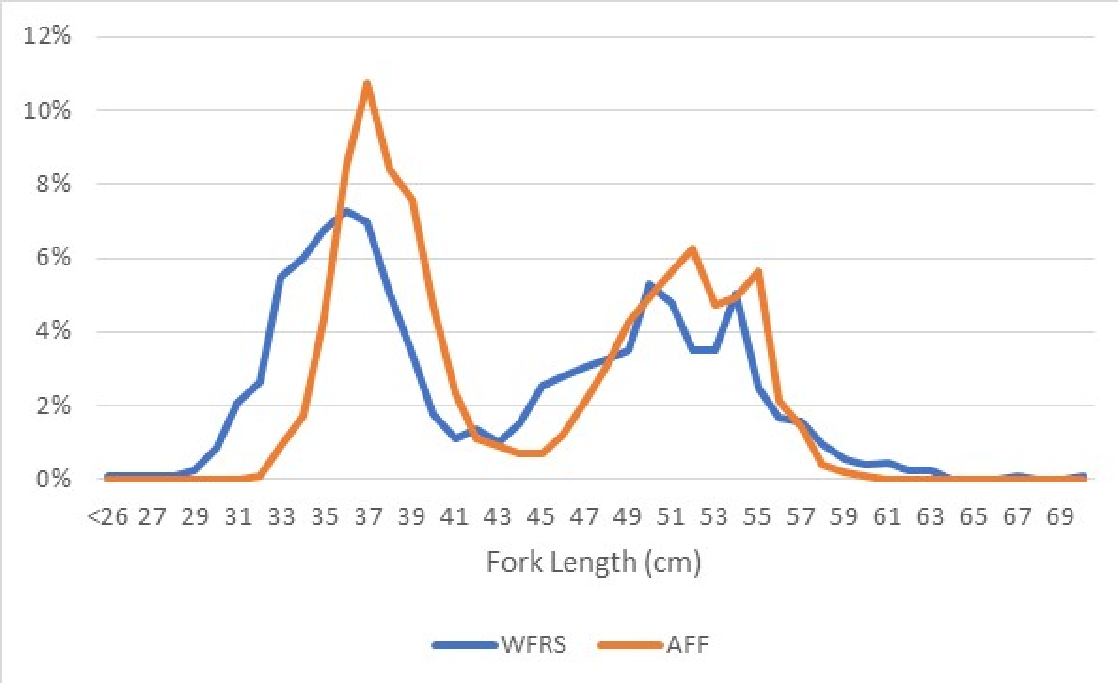


Figure 15. Length frequency distribution for Sockeye Salmon measured at Bonneville Dam at the AFF and by the WFRS in 2019.

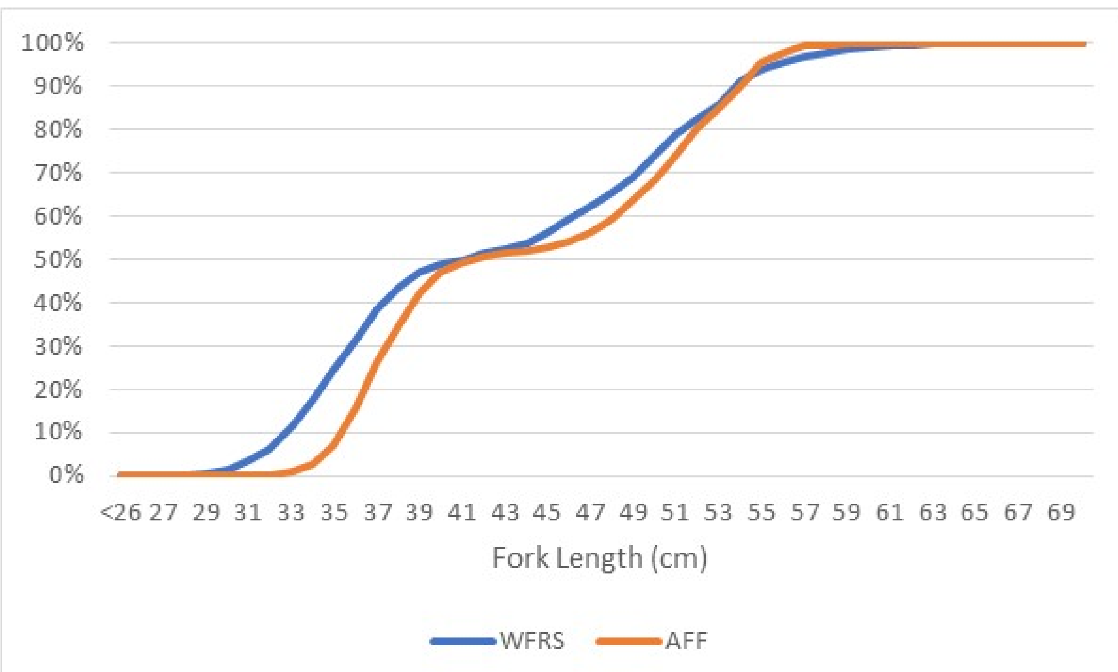


Figure 16. Cumulative length frequency distribution at Bonneville Dam for Sockeye Salmon measured at AFF and by WFRS in 2019.

Stock Composition Estimates

AFF Sample

In 2019, Genetic Stock Identification (GSI) and Parental Based Tagging (PBT) was used to classify samples from 980 Sockeye Salmon collected at Bonneville Dam and compared to stock composition based on the site of final PIT tag detection (Table 16).[20] Of the 579[21] Sockeye that could be classified to stock by both GSI and PIT tags, there were only four disagreements (0.5%): three of which were Sockeye last detected in the Snake River. Two Sockeye (3DD.0077BFDA70 and 3DD.003D36459D) classified by GSI as being of Wenatchee origin were last detected in the Clearwater Basin, one at SW1 on the Selway River and the other at LRU on the Lochsa River (Table 16). The third Sockeye, (3DD.003D36459D), was classified as being of Okanagan origin and was last detected at Lower Monumental Dam (LMA). The fourth misclassified Sockeye Salmon (3DD.003D36479E) was identified by PBT as being Yakima stock, however GSI classified it as Wenatchee stock as it was an offspring of Wenatchee stock Sockeye translocated to the Cle Elum Lake.

Table 16. Comparison of stock composition estimates for individual Sockeye Salmon sampled at Bonneville Dam in 2019. Green shading indicates agreement between the two methods, orange indicates the stock estimates differed. Yakima Sockeye are primarily from Okanagan and Wenatchee broodstock thus a no determination on agreement could be made for Sockeye returning to the Yakima River that were classified by GSI as being of Okanagan or Wenatchee origin.

Stock Estimated Using PIT Tags	Stock Estimated by Genetics (PBT or GSI)						
	Okanagan	Wenatchee	Snake	Deschutes	Yakima	Unknown[22]	Total
Okanagan	502	0	0	0	0	3	505
Wenatchee	0	72	0	0	1	0	73
Snake	1	2	0	0	0	0	3
Deschutes	0	0	0	1	0	0	1
Yakima	3	4	0	0	0	0	7
Unknown[23]	338	38	0	9	1	5	391
Total	**844**	**116**	**0**	**10**	**2**	**8**	**980**

[20] In analysis of genetics results, there was one highly likely sample mix-up identified and corrected. A Sockeye classified as Okanagan stock was last detected at WTL (3DD.003D3647CC) followed by a Wenatchee stock Sockeye last detected at Zosel Dam (3DD.003D3647CB). These were the only cases of a Wenatchee stock Sockeye detected by this project in the Okanagan Basin (with the exception of a few similar mix-ups) and the only Okanagan stock Sockeye detected in the Wenatchee Basin in 2019.

[21] This excludes the seven Sockeye last detected in the Yakima that were classified by GSI as Wenatchee or Okanagan stock as the Yakima stock are offspring of Wenatchee and Okanagan stock Sockeye Salmon and would be expected to so classify genetically.

[22] Either no genetics sample available or the sample did not classify to a particular stock.

[23] No PIT tag or not detected in terminal area (at or upstream of OKL, LWN, PRO, or ICH or upstream of DRM).

Only a small fraction of Sockeye Salmon spawning in the Yakima Basin are sampled for PBT, thus few returning Yakima Sockeye can be classified by stock. Only two Bonneville-tagged Sockeye in 2019 were classified using PBT as Yakima origin. One, 3DD.003D3646E6, was last detected at McNary Dam (MC1), while the other was untagged (Table 17). A total of seven Sockeye were last detected in the Yakima River, three were last detected at Prosser Dam and four at Roza Dam (all of which were also detected at Prosser Dam), none of which were classified as Yakima using PBT (Table 17). Of the seven Yakima returns, three were classified by GSI as Wenatchee stock, and four were classified as Okanagan stock (Tables 16 and 17) which is to be expected as the run is being restored from a mixture of Wenatchee and Okanagan Sockeye transported from Priest Rapids Dam to Cle Elum Lake in the Yakima Basin. In past years, this has resulted in Bonneville-tagged Sockeye being detected at the Priest Rapids Dam adult trap followed by Roza Dam, missing detection at Prosser Dam as these fish, after release in Cle Elum Lake, migrated downstream to Roza. The low Sockeye return in 2019 resulted in no Priest Rapids trapping under the protocols for this translocation program. With no transport of Sockeye Salmon to Cle Elum Lake in 2019, there were no Sockeye detected at Roza Dam that were not detected at Prosser Dam in 2019.

Among the 10 Sockeye classified as Deschutes origin based on PIT tag detections, 9 were last located at sites en route from Bonneville Dam to the spawning grounds in the upper Deschutes River (Table 17). Of these 9, 1 was last detected at Sherar's Falls (DSF), 3 at the Deschutes River mouth (DRM), 2 at The Dalles (1 each at TD1 and TD2), and 4 at the Bonneville Dam Washington shore fish ladder (BO4). One Deschutes-origin Sockeye Salmon overshot the Deschutes River and was last detected exiting the McNary Dam Oregon shore fish ladder (MC1).

The single Sockeye last detected in the Entiat River at ENL (rkm 2) and the two Sockeye last detected in the Methow (LMR at rkm 8 and MRC at rkm 45) were all classified by GSI as being of Okanagan stock (Table 17). There were also two Okanagan stock Sockeye Salmon last detected at the Deschutes River mouth (DRM at rkm 1). No other Okanagan stock Sockeye Salmon were detected outside the migration corridor (Columbia River) on their way to the Okanagan Basin, although there was one detection at the mouth of Omak Creek (OMK, located at Omak Creek rkm 0 in the Okanagan Basin.)

Table 17. Final stock classification of Sockeye Salmon by last detection area/site for Sockeye PIT tagged at Bonneville Dam in 2019.

Area (Site) of Last Detection	Final Stock Classification Using GSI, PBT, and Last PIT Tag Detection as Described in This Report						
Non-Terminal Areas	**Okanagan**	**Wenatchee**	**Snake**	**Deschutes**	**Yakima**	**Unknown[24]**	**Total**
Bonneville (BCC, BO1, BO2, BO3, BO4)	54	13	0	4	0	1	72
Deschutes River Mouth (DRM at rkm 1)	2	0	0	2	0	0	4
Entiat River (ENL)	1	0	0	0	0	0	1
John Day Dam (JO1, JO2, JDJ)	32	5	0	0	0	2	39
McNary Dam (MC1, MC2, MCJ)	44	7	0	1	1	0	53
Methow River (LMR, MRC)	2		0	0	0	0	2
Priest Rapids Dam (PRA)	10	1	0	0	0	0	11
Rock Island Dam (RIA)	5	5	0	0	0	0	10
Rocky Reach Dam (RRF, RRJ)	11	0	0	0	0	0	11
The Dalles (TD1, TD2)	12	3	0	2	0	0	17
Wells Dam/Hatchery (WEA, WEJ, WEH)	160	2	0	0	0	0	162
Terminal Areas							
Deschutes River-Sherar's Falls (DSF)	0	0	0	1	0	0	1
Wenatchee River (ICL, LWE, LWN, TUF, UWE, WTL)	0	73	0	0	0	0	73
Okanagan River (OKC, OKL, OKM, OKP, OKS, OMK, SKA, ZSL)	503	0	0	0	0	0	503
Snake River (LMA, LRU, SW1)	1	2	0	0	0	0	3
Yakima River (ROZ)	4	3	0	0	0	0	7
No Tag or Tag Not Subsequently Detected	6	1	0	0	1	3	10
Total	**843**	**112**	**0**	**10**	**9**	**6**	**980**

Among the 73 Sockeye Salmon of Wenatchee origin that passed Rock Island Dam, 6 (8.2%) bypassed the Wenatchee River and were detected at Rocky Reach Dam with 3 (4.1%) also detected at Wells Dam. All 6 of these Sockeye were subsequently detected in the Wenatchee River at Tumwater Dam with 5 last detected at the White River PIT array (WTL) immediately downstream of the spawning grounds. No Wenatchee Sockeye Salmon (as determined by GSI) were last detected in the Columbia Basin upstream of the Wenatchee River confluence.

When combining PIT and GSI stock determinations as described in the methods, this study estimated that the stock composition at Bonneville Dam in 2019 was 86.0% Okanagan, 12.5% Wenatchee, 1.1% Yakima, 0.4% Deschutes and 0% Snake (Table 18 and Figure 17). Using only PIT tag detections of Sockeye last detected in terminal areas resulted in a stock composition of 84.9% Okanagan,

[24] Either no genetics sample available or the sample did not classify to a particular stock.

13.2% Wenatchee, 1.3% Yakima, 0.1% Deschutes, and 0.4% Snake. The higher PIT tag estimate for the Snake River stock relative to the GSI estimate is attributable to all three Sockeye last detected in a "terminal area" classifying genetically to other stocks. Using visual fish counts at dams to estimate Okanagan stock abundance relative to the Wenatchee yielded a similar percentage (86.1% and 85.0%), respectively, Table 18) as did PIT and GSI estimates.

There was a significant linear relationship between statistical week and the percentage of Okanagan Sockeye (p=0.04) at Bonneville Dam (estimated using PIT and GSI), but not for the percentage of the Wenatchee stock (p=0.42) (Table 18 and Figure 17).

Table 18. Weekly and composite Sockeye Salmon stock composition at Bonneville Dam as estimated by PIT tags and GSI in 2019 with a comparison to stock composition estimates estimated using visual dam counts as well as using only PIT tags and GSI.

Statistical Week at Bonneville Dam	% of Sockeye Run	% Okanagan	% Wenatchee	% Yakima	% Deschutes	% Snake
23	0.9	93.3	6.7	0.0	0.0	0.0
24	6.6	90.9	6.1	3.0	0.0	0.0
25	23.7	82.7	15.1	2.2	0.0	0.0
26	35.1	84.6	15.1	0.3	0.0	0.0
27	20.6	88.9	10.1	1.0	0.0	0.0
28	8.2	91.1	7.5	0.0	1.4	0.0
29	3.1	92.4	4.5	1.5	1.5	0.0
30	1.2	67.9	17.9	0.0	14.3	0.0
31	0.6	70.0	15.0	0.0	15.0	0.0
Combined PIT and GSI Estimate		**86.0**	**12.5**	**1.1**	**0.4**	**0.0**
PIT Tag Only Estimate		**84.9**	**13.2**	**1.3**	**0.1**	**0.4**
GSI Only Estimate		**86.4**	**13.0**	**0.2**	**0.4**	**0.0**
Visual Fish Counts at dams[25]		**86.1**	**13.9**			
Visual Fish Counts at dams[26]		**85.0**	**15.0**			

[25] Using difference between Rock Island and Rocky Reach counts to estimate proportion Wenatchee escapement; Rocky Reach to estimate Okanagan escapement.
[26] Using Tumwater count to estimate proportion Wenatchee escapement; Rocky Reach to estimate Okanagan.

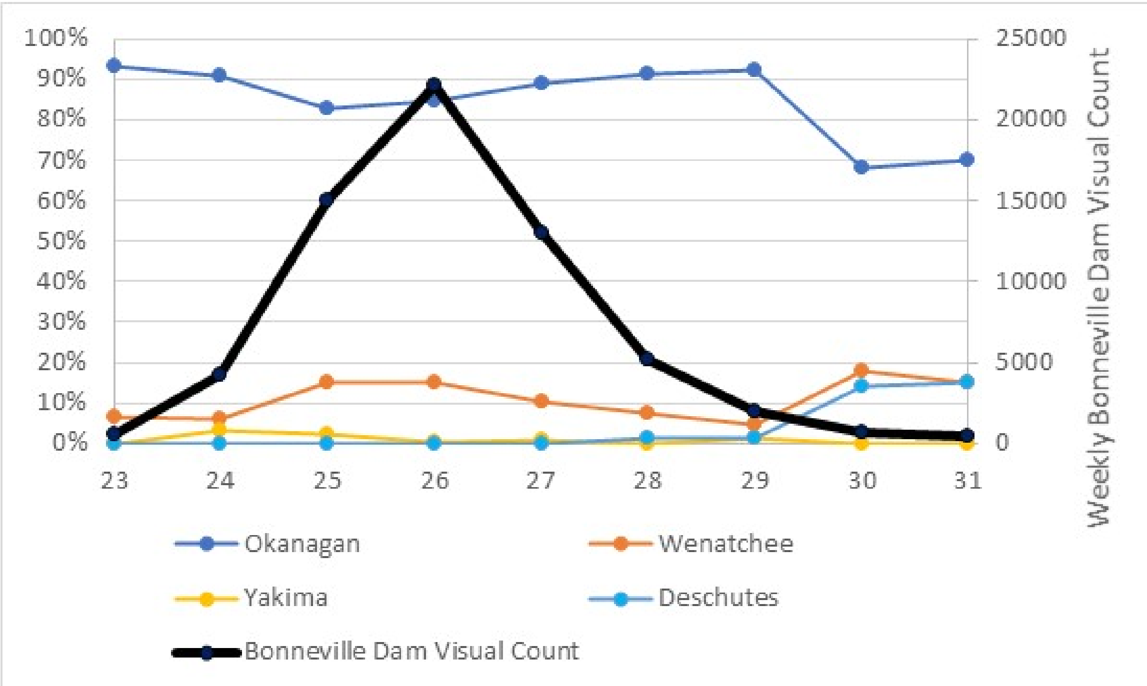


Figure 17. Percentage of the Sockeye run at Bonneville Dam estimated to be of Okanagan, Wenatchee, Snake, Yakima, and Deschutes origin by week in 2019.

A total of 15 Sockeye sampled by this project at Bonneville Dam were maxillary clipped or ventral clipped (Table 19). Juvenile Sockeye are maxillary clipped in the Deschutes River, but it is unknown what project is responsible for ventral or maxillary clipping of Okanagan Sockeye Salmon. Two Okanagan stock Sockeye Salmon with maxillary clips were last detected at Wells Dam and one each at Zosel Dam, Priest Rapids Dam, and OKP while the ventral clipped Okanagan Sockeye was last detected at Zosel Dam.

Table 19. Type and number of fin clips and marks by stock for Sockeye Salmon sampled at Bonneville Dam in 2019.

	Fin Clip			
Stock	Left Maxillary	Right Maxillary	Right Ventral	Total
Okanagan	2	2	1	5
Deschutes	0	10	0	10
Total	**2**	**12**	**1**	**15**

Pound Net Sample

A total of 844 Sockeye Salmon were sampled and PIT tagged in the Pound Net fishery in 2019 (Table 20), 828 were classified by stock using GSI with an additional 7 classified by last PIT tag site using the methods described on page 12. Sockeye sampling was halted on July 3, 2019 during Week 27; by comparison, Sockeye sampling at the AFF continued through August 1 during Week 31. The resulting stock composition estimate was 82.7% Okanagan, 17.0% Wenatchee, 0.1% Yakima, and 0.1% Deschutes (Table 20). All Wenatchee and Okanagan Sockeye Salmon which could be classified both by GSI and site of last PIT tag detection were similarly classified (Table 21) with one exception. The sole exception was a Yakima Sockeye that was classified by GSI as being of Okanagan origin that was last detected at Prosser Dam and so detected as Yakima stock. However, as was previously explained, there is no GSI baseline for Yakima stock as this stock is mostly offspring of translocated Okanagan and Wenatchee Sockeye.

Table 20. Weekly and total stock composition of Sockeye captured in the Pound Net fishery as estimated using GSI and PIT Tags

Statistical Week Captured	N (Sample Size)	N (Classified by GSI or PIT Tag)	Stock Classification			
			Okanagan	Wenatchee	Yakima	Deschutes
22	1	1	100.0%	0.0%	0.0%	0.0%
23	16	15	80.0%	20.0%	0.0%	0.0%
24	92	89	90.9%	9.1%	0.0%	0.0%
25	309	308	86.2%	13.8%	0.0%	0.0%
26	339	336	79.3%	20.4%	0.3%	0.0%
27	87	86	75.6%	23.3%	0.0%	1.2%
Unweighted Total	**844**	**835**	**82.7%**	**17.0%**	**0.1%**	**0.1%**

Table 21. Comparison of stock composition estimates for individual Sockeye Salmon sampled in the Pound Net fishery in 2019. Green shading indicates agreement between the two methods, orange indicates the stock estimates differed. Yakima Sockeye are primarily from translocated Okanagan and Wenatchee broodstock thus the single Yakima Sockeye classified by GSI as being of Okanagan origin likely was an offspring of translocated Okanagan Sockeye.

Stock Estimated Using PIT Tags	Stock Estimated by Genetics (PBT or GSI)						
	Okanagan	Wenatchee	Snake	Deschutes	Yakima	Unknown[27]	Total
Okanagan	384	0	0	0	0	7	391
Wenatchee	0	98	0	0	0	0	98
Deschutes	0	0	0	0	0	0	0
Yakima	1	0	0	0	0	0	1
Unknown[28]	301	43	0	1	0	9	354
Total	**686**	**141**	**0**	**1**	**0**	**16**	**844**

A comparison of stock composition estimates at Bonneville Dam from the Pound Net Fishery and the AFF sample is adversely affected by the end of the Pound Net Sockeye fishery on July 3 resulting in no Pound Net Sockeye passing Bonneville Dam after Week 28 (July 8-14). Through Week 28, the estimated stock composition for the Pound Net sample was 83.0% Okanagan, 16.8 % Wenatchee, and 0.1% for both Yakima and Deschutes compared to 84.7% Okanagan, 13.4% Wenatchee, 0.5% Snake 1.4% Yakima, and 0.0% Deschutes for Sockeye sampled at the AFF(Table 22). When compared to the AFF sample, Pound-Net Sockeye Salmon passing the Oregon Shore had a higher percentage of Wenatchee Stock Sockeye (19.0% versus 16.6%) and lower percentage of Okanagan Stock Sockeye (80.7% versus 83.0%). The sole Deschutes stock Sockeye Salmon tagged in the Pound Net Fishery (Table 20) was not detected at Bonneville Dam and therefore does not appear in Table 22.

[27] Either no genetics sample available or the sample did not classify to a particular stock.
[28] No PIT tag or not detected in terminal area (at or upstream of OKL, LWN, PRO, or ICH or upstream of DRM).

Table 22. Comparison of weekly and weighted stock composition at Bonneville Dam of Sockeye tagged at the AFF and for Pound Net Fishery Sockeye detected at Bonneville Dam in 2019[29].

Week at Bonneville	% of Run	Adult Fish Facility					Pound Net			
		% Okanagan	% Wenatchee	% Snake	% Yakima	% Deschutes	% Okanagan	% Wenatchee	% Yakima	% Deschutes
23	0.9	87.5	12.5	0.0	0.0	0.0	100.0	0.0	0.0	0.0
24	6.6	89.1	6.5	0.0	4.3	0.0	83.3	16.7	0.0	0.0
25	23.7	79.8	17.0	0.0	3.2	0.0	83.9	16.1	0.0	0.0
26	35.1	84.2	15.3	0.5	0.0	0.0	80.1	19.9	0.0	0.0
27	20.6	87.0	10.9	0.7	1.4	0.0	81.0	17.8	0.6	0.6
28	8.2	91.3	7.2	1.4	0.0	0.0	90.9	9.1	0.0	0.0
29	3.1	90.0	6.7	0.0	0.0	3.3	NA	NA	NA	NA
30	1.2	80.0	20.0	0.0	0.0	0.0	NA	NA	NA	NA
31	0.6	100.0	0.0	0.0	0.0	0.0	NA	NA	NA	NA
Weeks 23-31		**84.9**	**13.2**	**0.4**	**1.3**	**0.1**	**NA**	**NA**	**NA**	**NA**
Weeks 23-28 only										
WA and OR Shore		**84.7**	**13.4**	**0.5**	**1.4**	**0.0**	**83.0**	**16.8**	**0.1**	**0.1**
Oregon Shore							**80.7**	**19.0**	**0.3**	**0.0**
WA Shore							**83.2**	**16.6**	**0.0**	**0.2**

Stock Specific Upstream Survival

Upstream survival of Okanagan Sockeye Salmon to Rock Island Dam was higher than the Wenatchee stock (84.3% vs. 67.7%), however survival to the spawning grounds was lower (45.4% vs. 56.6%, Table 23). For weeks 23-28, the combined survival of the AFF Sockeye to the spawning grounds was greater than that of the Pound Net Sockeye (48.5% versus 45.0%, Table 23).

[29] No Pound Net Sockeye were tagged after Week 27 therefore there were no detections at Bonneville Dam after Week 28. Also, no Pound-Net Sockeye were classified as Snake or Deschutes stock.

Table 23. Stock specific survival (%) from Bonneville Dam weighted by estimated stock-specific weekly Bonneville Dam run size, as estimated by GSI and PIT tags for Sockeye Tagged at Bonneville Dam and in the Pound Net Fishery in 2019.

	Estimated Survival from Bonneville Dam by Stock (%)							
	Okanagan (n=825)			Wenatchee (n=115)			Combined (n=940)	Pound Net (n=764)
Statistical Week	Rock Island Dam	Zosel Dam	Spawning (OKC)	Rock Island Dam	Tumwater Dam	Spawning (LWE or WTL)	Okanagan/ Wenatchee Spawning (LWE, WTL, OKC)	
23	76.9	53.8	53.8	100.0	100.0	0.0	50.0	0.0
24	91.5	66.1	50.8	60.0	60.0	60.0	51.6	58.3
25	87.7	64.0	44.7	71.4	71.4	66.7	48.1	54.0
26	86.6	65.3	49.4	72.1	67.4	60.5	51.1	44.3
27	82.4	62.6	50.0	68.2	63.6	63.6	51.5	47.6
28	78.7	40.9	27.6	45.5	45.5	27.3	27.5	36.4
29	71.7	40.0	25.0	75.0	75.0	0.0	23.4	NA
30	36.8	15.8	10.5	20.0	20.0	20.0	12.5	NA
31	33.3	8.3	8.3	33.3	0.0	0.0	6.7	NA
23-31	**84.3**	**60.7**	**45.4**	**67.7**	**64.9**	**56.6**	**47.0**	**NA**
23-28	**85.5**	**62.1**	**46.6**	**69.6**	**66.8**	**60.8**	**48.5**	**45.0**

Wells Dam Sampling

A total of 315 Sockeye Salmon were sampled at the Wells Dam east bank fish ladder in 2019 (Table 24), 13 of which were previously PIT tagged (11 by this project at Bonneville Dam, 1 in the Pound Net fishery, and 1 tagged on 7/10 at Wells and resampled at Wells on 7/17). The number of PIT tagged Sockeye Salmon detected and tracked was 311.

Table 24. Number of Sockeye Salmon sampled, and PIT tagged at Wells Dam by date and statistical week in 2019.

Sampling Dates	Statistical Week	Sampled (n)	PIT Tagged	Previously Tagged	PIT Tagged Sockeye Released	Tracked
6/24,27	26	12	12	0	12	12
7/1,2	27	54	52	2	54	54
7/8,10	28	137	130	7	137	135
7/15,17	29	63	60	3	63	61
7/22,23	30	27	27	0	27	27
7/29,30	31	22	21	1	22	22
Total		**315**	**302**	**13**	**315**	**311**

Sex was visually estimated as part of the Wells Dam sampling protocol. Based on these visual estimations, 76.8% of females were age 1.3 compared to 38.8% of the males (Table 25). Age 1.2 was most abundant age class for males (25.2%; females: 9.2%). Of the 6 Sockeye recovered on the spawning grounds for which sex was determined, all 3 males were correctly identified while 2 of 3 females were correctly identified.

Table 25. Age composition by week and sex for Sockeye Salmon sampled at Wells Dam in 2019. Sex was visually estimated when the fish were sampled.

					Percentage at Age					
Stat Week	**Sampling Dates**	**Percentage of Run**	**N**	**N Ageable**	**1.1**	**1.2**	**2.1**	**1.3**	**2.2**	**2.3**
26	6/24,27	4.3	52	51	8.3	16.7	0.0	75.0	0.0	0.0
27	7/1,2	21.8	102	101	13.0	7.4	0.0	75.9	1.9	1.9
28	7/8,10	35.7	276	273	16.3	16.3	0.7	60.7	5.9	0.0
29	7/15,17	24.0	242	236	17.7	22.6	3.2	56.5	0.0	0.0
30	7/22,23	9.0	108	108	22.2	11.1	0.0	40.7	25.9	0.0
31	7/29,30	5.2	25	24	20.0	20.0	0.0	55.0	5.0	0.0
Composite			**315**	**305**	**16.3**	**15.6**	**1.0**	**61.5**	**5.1**	**0.4**
Males (visual ID)			186	183	24.4	25.2	1.6	38.8	9.0	1.0
Females (visual ID)			129	125	10.7	9.2	0.7	76.8	2.6	0.0

Okanagan and Wenatchee Age, and Length-at-Age Composition

Age composition estimates for Sockeye sampled at Bonneville, Tumwater, and Wells dams are presented with Bonneville Dam GSI-based stock-age composition in Table 26. The GSI estimates found that Wenatchee stock were comprised primarily of Age 1.3 Sockeye (similar to Tumwater Dam Sockeye sampling provided by Washington Department of Fish and Wildlife (WDFW)), while Age 1.1 was the largest age class for Okanagan Sockeye Salmon.

The age distribution of Sockeye Salmon sampled at Wells Dam differed from that estimated for the Okanagan Stock at Bonneville Dam using GSI (Table 26). While the Bonneville Dam estimate for Okanagan age composition was 54.5% Age 1.1 and 22.4% Age 1.3, the Wells Dam estimate was 16.3% Age 1.1 and 61.5% at 1.3. This is likely attributed to the 5.1 cm spacing of the bars on the weir diverting fish into the Wells Dam fish trap being sufficiently wide for small fish to slip the weir and thus avoid being diverted into the trap.

Table 26. Age composition (%) of Columbia Basin Sockeye Salmon stocks as estimated by PIT tag detections as well as by sampling at Wells and Tumwater dams[30] in 2019.

Sampling Site	Stock	Ageable Sample Size	Brood Year and Age Class						
			2016	2015		2014			2013
			1.1	1.2	2.1	1.3	2.2	3.1	2.3
Bonneville Dam	Mixed	963	47.4%	18.6%	1.0%	27.9%	4.7%	0.1%	0.3%
Bonneville Dam	Wenatchee: Stock determined as described on page 11 of this report	109	0.4%	27.1%	0.0%	67.2%	3.3%	0.0%	2.0%
Tumwater Dam	Wenatchee	737	0.1%	20.8%	0.0%	62.6%	12.1%	0.0%	4.4%
Bonneville Dam	Okanagan Stock determined as described on page 11 of this report	831	54.5%	17.1%	1.2%	22.4%	4.6%	0.1%	0.1%
Wells Dam	Okanagan	305	16.3%	15.6%	1.0%	61.5%	5.1%	0.0%	0.4%

Both Okanagan Sockeye sampled at Wells Dam and Wenatchee Sockeye sampled at Tumwater Dam had greater mean fork lengths than was estimated for those stocks from GSI of Bonneville-tagged Sockeye for all age groups where the sample size was greater than 4 for each group (Table 27). The aforementioned trap bias at Wells Dam may explain this difference at Wells Dam, but the reason for this difference at Tumwater is unknown although sampling more mature fish is one possibility due to male Sockeye developing a kype.

[30] Tumwater Dam age data was provided by WDFW (Alainah Hedrickx email dated October 28, 2020) which samples Sockeye Salmon at that site.

Table 27. Length-at-age (fork length) composition of Wenatchee and Okanagan Sockeye Salmon stocks estimated by detection of Sockeye Salmon previously PIT tagged at Bonneville and sampled at Wells and Tumwater dams in 2019.

		Brood Year and Age Class							
		2016	2015		2014			2013	All
Stock	Statistic	1.1	1.2	2.1	1.3	2.2	3.1	2.3	Ages[31]
Bonneville Dam-Mixed Stock	Mean Length	37.7	49.0	41.5	53.7	51.3	42.0	52.7	44.6
	St. Dev.	2.2	2.7	1.6	2.5	2.2	--	1.9	7.5
	N	478	177	10	250	42	1	3	977
Okanagan-based on GSI of Sockeye tagged at Bonneville Dam	Mean Length	37.7	48.9	41.5	53.4	51.3	42.0	50.5	43.5
	St. Dev.	1.9	2.7	1.6	2.2	2.1	--	--	7.2
	N	471	138	10	172	34	1	1	827
Okanagan-Wells Sampling	Mean Length	38.5	50.7	39.3	55.5	53.1		58.0	51.6
	St. Dev.	1.9	3.1	1.2	2.3	2.3		--	6.8
	N	51	49	3	189	17		1	315
Wenatchee based on GSI of Bonneville Dam-tagged Sockeye	Mean Length	42.0	49.5		54.4	51.0		53.5	52.8
	St. Dev.	--	2.0		2.0	3.3		-	3.1
	N	1	28		73	6		1	109
Wenatchee adult sampling at Tumwater Dam[32]	Mean Length	37.0	52.6		56.6	52.4		56.0	55.2
	St. Dev.	--	3.0		2.2	2.2		2.0	3.1
	N	1	152		463	86		35	766

Stock Composition at Wells Dam

In 2019 the project had insufficient funds to conduct GSI on all Sockeye sampled at Wells Dam. Therefore, GSI was only conducted on Sockeye not detected in the Okanagan Basin as, in previous years (as well as for Bonneville-tagged Sockeye in 2019), no Sockeye detected in the Okanagan River have been classified as anything other than Okanagan stock using GSI. This was the case in 2019 for the eight Sockeye which were analyzed using GSI that were detected in the Okanagan subsequent to selection of GSI samples to be analyzed.

Among the Sockeye PIT tagged at Wells Dam that moved downstream, all 10 detected in the Wenatchee Basin were classified as Wenatchee stock (Table 28), 3 Sockeye Salmon last detected at Rocky Reach Dam were classified as Okanagan stock, and 1 Sockeye last detected in the Entiat River was classified as Okanagan stock. Of the three Sockeye last detected upstream of Wells Dam in

[31] Includes lengths of Sockeye Salmon with unageable scales.
[32] Tumwater Dam length-at-age data was provided by WDFW which samples Sockeye Salmon at that site (Alainah Hedrickx email dated October 28, 2020).

the Methow River, two were classified as Okanagan stock and one as Wenatchee stock.

Table 28. Stock Classification for Sockeye Salmon sampled at Wells Dam that were classified using GSI in 2019[33].

	Classification		
Last Detection	**Okanagan**	**Wenatchee**	**Total**
Wenatchee Basin (TUF, ICL, WTL)	0	10	10
Rocky Reach Dam (RRF, RRJ)	3	0	3
Entiat Basin (ENL)	1	0	1
Wells Dam/Hatchery/Bypass (WEA, WEH, WEJ)	92	3	95
Methow Basin (LMR, MRC, CRU)	2	1	3
Okanagan Basin (OKC, OKL, OKS)[34]	8	0	8
Not Detected	2	1	3
Total	**108**	**15**	**123**

The overall stock composition estimated from Sockeye sampled and tagged at Wells Dam was 95.3% Okanagan and 4.7% Wenatchee compared to 99.5% Okanagan and 0.5% Wenatchee for Sockeye tagged at Bonneville Dam that were detected at Wells Dam (Table 29). Of the 15 Wenatchee stock Sockeye identified in the Wells Dam sample, 11 (73.3%) were Age 1.3 with 2 each that were Age 1.2 and 2.2. Given that the Wells Dam trap tends to exclude smaller Sockeye due to the spacing of the bars in the weir diverting Sockeye into the trap, and Wenatchee Sockeye are larger than Okanagan Sockeye, it is likely that the Wells sample is biased towards a higher proportion of Wenatchee Sockeye which are typically comprised of a greater percentage of larger Age 1.3 and 2.2 Sockeye, while all the smaller Age 1.1 Sockeye are typically of Okanagan origin. This is especially likely in a year such as 2019 with a high percentage of smaller jacks in the Okanagan run.

[33] Sockeye Salmon last detected in the Okanagan Basin were assumed to be Okanagan stock and not selected for genetic analysis. Exceptions were eight Sockeye that were detected in the Okanagan Basin after sample selection for GSI occurred; all were classified as Okanagan stock.
[34] Of the eight Sockeye Salmon analyzed using GSI last detected in the Okanagan Basin, six were detected at OKC and one at OKS in addition to one at OKL even though our criteria for analysis was only Sockeye last detected downstream of Zosel. This was due to late upstream movement after Sockeye for analysis were chosen.

Table 29. Stock composition of Sockeye Salmon tagged at Wells Dam and Sockeye Salmon passing Wells Dam as estimated using GSI and PIT tags in 2019. (Both Wells and Bonneville-tagged groups are weighted by the weekly Wells Dam run size). No sampling occurred at Wells Dam in weeks 32-35, however Bonneville-tagged Sockeye passed Wells Dam during these weeks.

Week at Wells Dam	Tagged at Bonneville Dam			Tagged at Wells dam		
	N	Okanagan	Wenatchee	N	Okanagan	Wenatchee
26	33	100.0%	0.0%	12	100.0%	0.0%
27	90	100.0%	0.0%	49	99.0%	1.0%
28	213	99.1%	0.9%	133	95.9%	4.1%
29	172	100.0%	0.0%	60	96.6%	3.4%
30	96	100.0%	0.0%	25	94.4%	5.6%
31	44	100.0%	0.0%	18	100.0%	0.0%
32	17	88.2%	11.8%	--	--	--
33-35	8	100.0%	0.0%	--	--	--
Total	**673**	**99.5%**	**0.5%**	**297**	**95.3%**	**4.7%**

Migration into Natal Areas - Okanagan River

Low flows in 2019 resulted in high rates of PIT tag detection at most sites in the Okanagan Basin (See Appendix A for tables and figures referenced in this paragraph). Both Zosel and Skaha Dam spill gates were sufficiently closed during the Sockeye migration that there was no passage through the spillways. This meant that all Sockeye passed through the fish ladders resulting in 100% detection (Appendix A). The detection rate at OKC was 96.7% (Table A7) with seven of the eight Sockeye missing detection likely due to power problems at OKC. The one exception to the higher rates of detection in 2019 was OKL (Figure A1). Despite lower Okanagan River flows that would be expected to keep Sockeye migrating lower in the water column closer to the array, 66.7% of the Bonneville-tagged Sockeye passing the lower Okanagan River array (OKL) missed detection (Table 2), and 61.8% of all PIT tagged Sockeye passing OKL missed detection (Table A7).

The percentage of Sockeye Salmon passing or tagged at Wells Dam that were detected on the spawning grounds was 55.4% for Bonneville-tagged Sockeye Salmon, 47.1% for Wells-tagged Sockeye, and 52.9% for Pound Net-tagged Sockeye with the percentage decreasing as the run progressed over Wells Dam (Figure 18, Table 30).

Sockeye tagged at Wells Dam in Week 26 had the highest conversion rate to the spawning grounds (OKC, SKA, OKP/OKS) at 66.7%, declining to a low of

22.2% for Sockeye tagged in Week 30 (Figure 18, Table 30)[35]. A similar trend was observed for Bonneville-tagged Sockeye Salmon with the rate dropping from 75.8% in Week 26 to <40% in weeks 30 and 31 (Figure 18, Table 30).

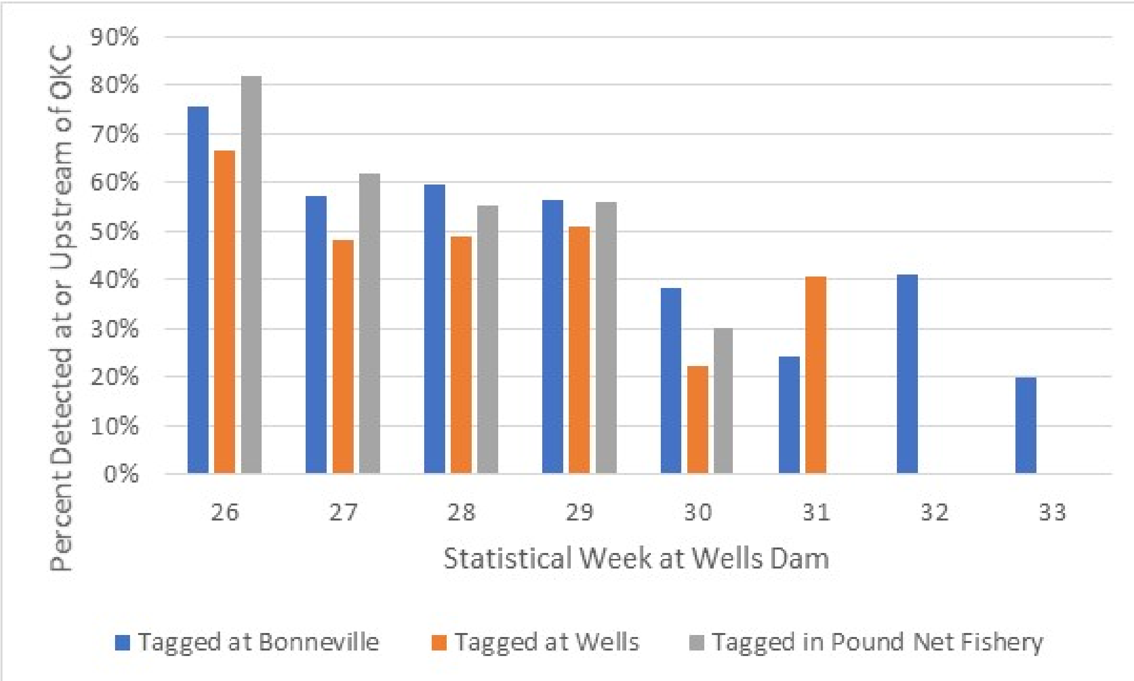


Figure 18. Percentage of Sockeye Salmon tagged at Bonneville and Wells dams and the Pound Net fishery last detected on Okanagan River spawning grounds (at or upstream of OKC) by week passing Wells Dam in 2019.

[35] Sampling at Wells Dam had ceased for the year after Week 31 due to few Sockeye passing in the following weeks.

Table 30. Number of Sockeye tagged at Wells Dam and subsequent last detection site by week in 2019 as well as detection rate on Okanagan River spawning grounds. Rates for adults tagged at Bonneville Dam and tagged in the Pound Net fishery and detected at Wells Dam are shown for comparison. NA indicates no Sockeye detections at Wells Dam for the tag group.

			Site of Last Detection (Downstream to Upstream)												Wells Tagged	BON Tagged[36]	Pound Net[37]
Week Tagged or Passing at Wells Dam	**% of Total Wells Count by Week (Weight)**	**N**	**Wenatchee Basin**	**Rocky Reach Dam**	**Entiat River**	**Wells Hatchery**	**Wells Dam (WEA, WEJ)**	**Methow River**	**OKL Array**	**Zosel Dam (ZSL)**	**OKC Array**	**McIntyre Dam (OKM, OKV)**	**Skaha Dam (SKA)**	**OKP/OKS**	**Last Detected on Spawning Grounds (OKC, SKA, OKP, or OKS)**		
26	4.3	49	0.0%	0.0%	0.0%	0.0%	33.3%	0.0%	0.0%	0.0%	41.7%	0.0%	0.0%	25.0%	66.7%	75.8%	81.8%
27	21.8	96	3.7%	0.0%	0.0%	0.0%	38.9%	0.0%	0.0%	9.3%	35.2%	0.0%	1.9%	11.1%	48.1%	57.1%	62.1%
28	35.7	274	2.2%	0.7%	0.7%	0.0%	28.1%	0.7%	3.0%	15.6%	39.3%	2.2%	0.0%	7.4%	48.9%	59.6%	55.1%
29	24.0	240	3.3%	1.6%	0.0%	0.0%	27.9%	0.0%	6.6%	9.8%	41.0%	1.6%	0.0%	8.2%	50.8%	56.4%	56.0%
30	9.0	106	3.7%	3.7%	0.0%	0.0%	37.0%	3.7%	22.2%	7.4%	22.2%	0.0%	0.0%	0.0%	22.2%	38.5%	30.0%
31	3.2	23	9.1%	0.0%	0.0%	4.5%	27.3%	4.5%	0.0%	13.6%	31.8%	0.0%	0.0%	9.1%	40.9%	24.4%	0.0%
32	1.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	41.2%	0.0%
33	0.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	20.0%	NA
34	0.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.0%	0.0%
35	0.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.0%	NA
Weighted Total		**311**	**3.2%**	**1.0%**	**0.3%**	**0.2%**	**31.4%**	**0.8%**	**4.6%**	**11.3%**	**37.0%**	**1.2%**	**0.4%**	**8.6%**	**47.1%**		
Bonneville Tagged Sockeye Detected at Wells		**671**	**0.3%**	**0.3%**	**23.6%**	**0.3%**	**4.4%**	**0.1%**	**17.3%**	**39.0%**	**0.6%**	**2.3%**	**11.7%**	**0.3%**		**55.4%**	
Pound Net-tagged Sockeye detected at Wells		**516**	**0.3%**	**0.0%**	**0.0%**	**27.2%**	**3.2%[38]**	**0.5%**	**2.8%**	**16.3%**	**37.5%**	**0.3%**	**5.8%**	**9.3%**			**52.9%**

[36] One Bonneville-tagged Sockeye was detected at Wells Dam in Week 34 and two in Week 35, none were detected at, or upstream of OKC.
[37] One Pound Net-tagged Sockeye was detected at Wells Dam in weeks 31, 32, and 34, none were detected at, or upstream of OKC.
[38] Based on a single detection in this week.

In 2019, Sockeye Salmon entered the Okanagan River either prior to river temperatures exceeding approximately 22C or on subsequent drops in temperature (Figures 19 and 20, Table 31). The first group of Sockeye Salmon detected at OKL passed between 6/24 and 7/21, a period during which the mean daily river temperature increased from 19C to 22.8C but then declined to below 22C on 7/20 which was the day with the greatest number of detections at OKC in 2019. This group of Sockeye had the highest conversion rate to both Zosel Dam (94.8%) and OKC (75.3%). Groups of Sockeye attempting to migrate on brief drops in temperature between late July and mid-August had the lowest conversion rates to Zosel Dam and OKC. Survival improved for those Sockeye Salmon passing OKL in late August and September. Overall survival from Wells Dam to Zosel Dam was 73.4% for Sockeye detected at Wells on or before July 19, 2019 compared to 47.5% for Sockeye passing Wells Dam after July 19, 2019 (Figure 21).

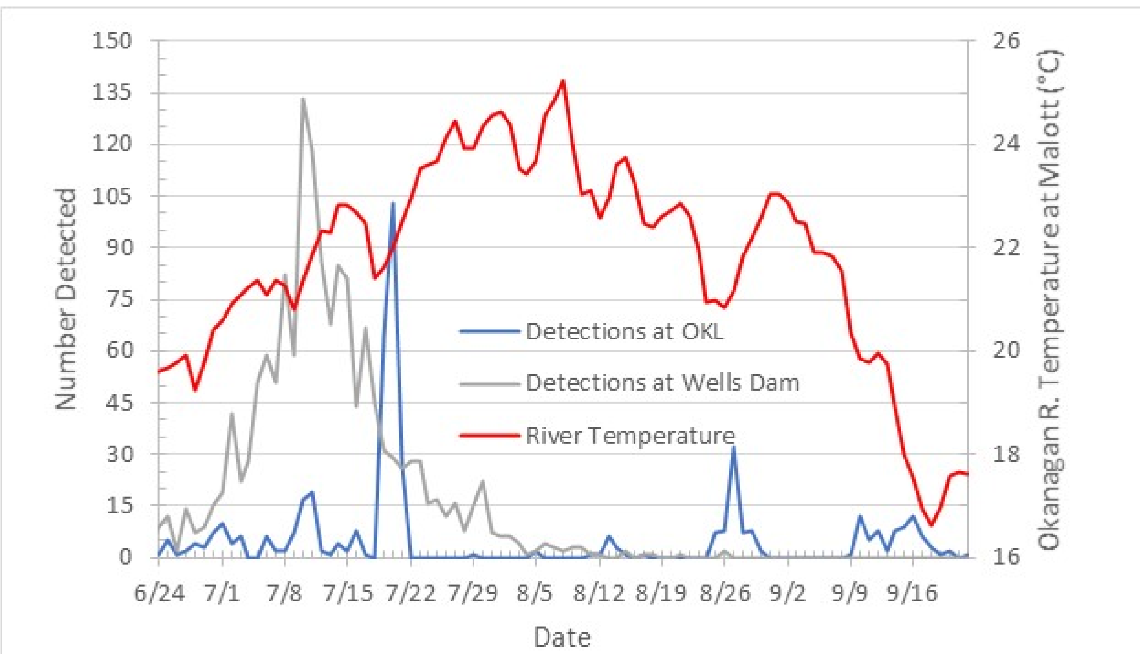


Figure 19. Number of PIT tagged adult Sockeye Salmon detected at Wells Dam, the OKL PIT array at Okanagan rkm 25, and mean Okanagan River water temperature at Malott (rkm 27) by date in 2019.

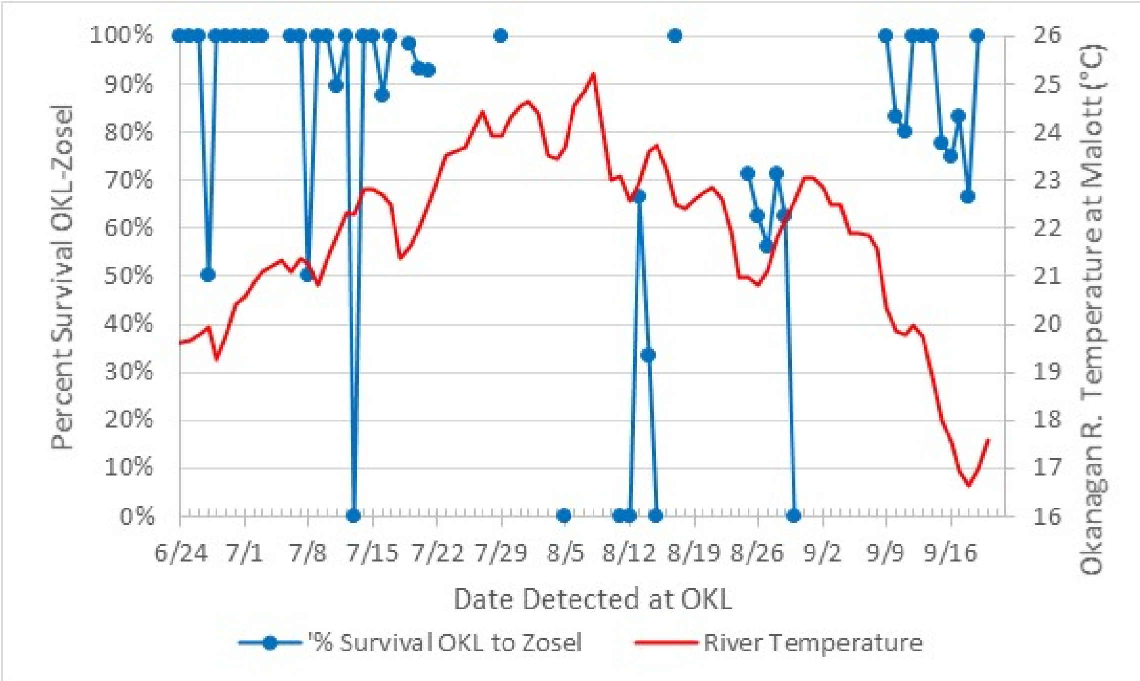


Figure 20. Survival rate by date from the lower Okanagan River PIT tag array (OKL) to Zosel Dam for Sockeye Salmon detected at Wells Dam in 2019.

Table 31. Groups of PIT tagged Sockeye passing OKL and percent detected upstream at OKC by date at passing OKL in 2019.

Dates	N at OKL	% Detected at ZSL	% Detected at OKC
6/24-7/21	308	94.8	75.3
7/29-8/5	3	33.3	33.3
8/11-8/21	14	42.9	21.4
8/25-8/30	64	59.4	34.4
9/9-9/22	70	81.4	67.1
9/29-11/6	2	50.0	50.0
Total	**461**	**85.7**	**66.4**

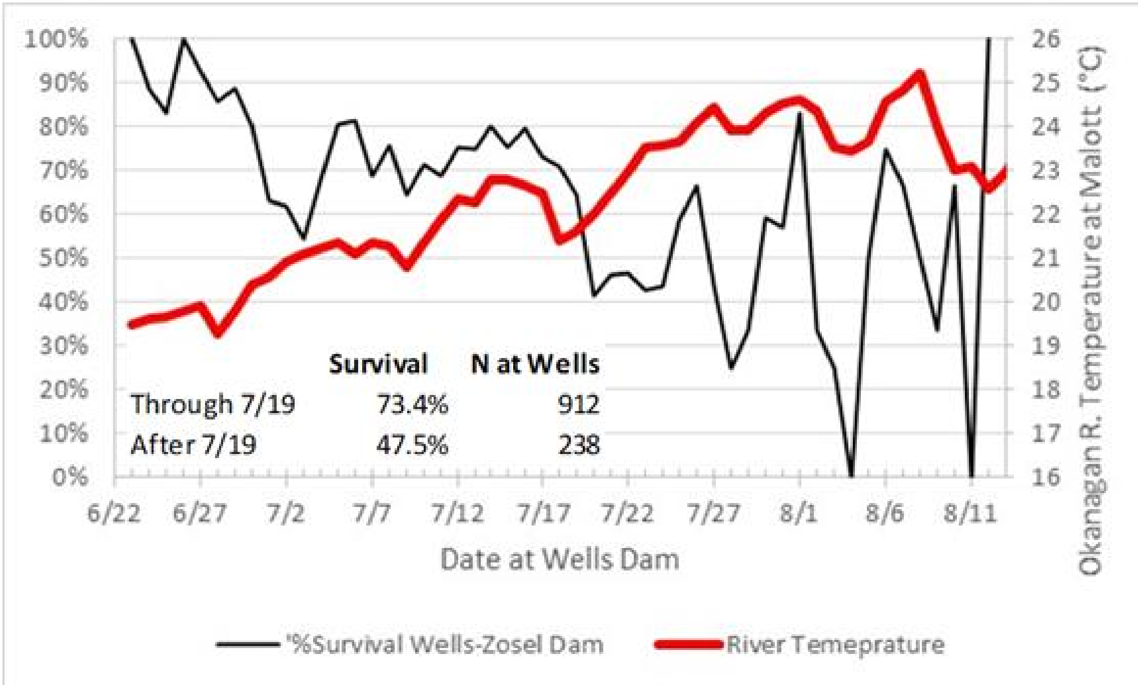


Figure 21. Survival rate by date from Wells Dam to Zosel Dam for Sockeye Salmon detected at Wells Dam in 2019.

Migration into Natal Areas-Wenatchee River

In 2019, of the 49 adult Bonneville-tagged Sockeye Salmon detected at LWE (Figure 22), 48 were detected at Tumwater Dam (Table 32) resulting in an estimated survival of 98.0% compared to 99.2% in 2018, 97.5% in 2016, and 71.3% in the high temperature year of 2015 (Fryer et al. 2017, 2018, 2020). A single Sockeye Salmon (3DD.003D3644B0) was detected at the PIT tag array at Icicle Creek (ICL at rkm 0.4), downstream of Tumwater Dam. This Sockeye passed LWE in the lower Wenatchee River on August 4, 2019, then passed Tumwater Dam on August 8, falling back over the dam, and was last detected at ICL on August 9 and 10.

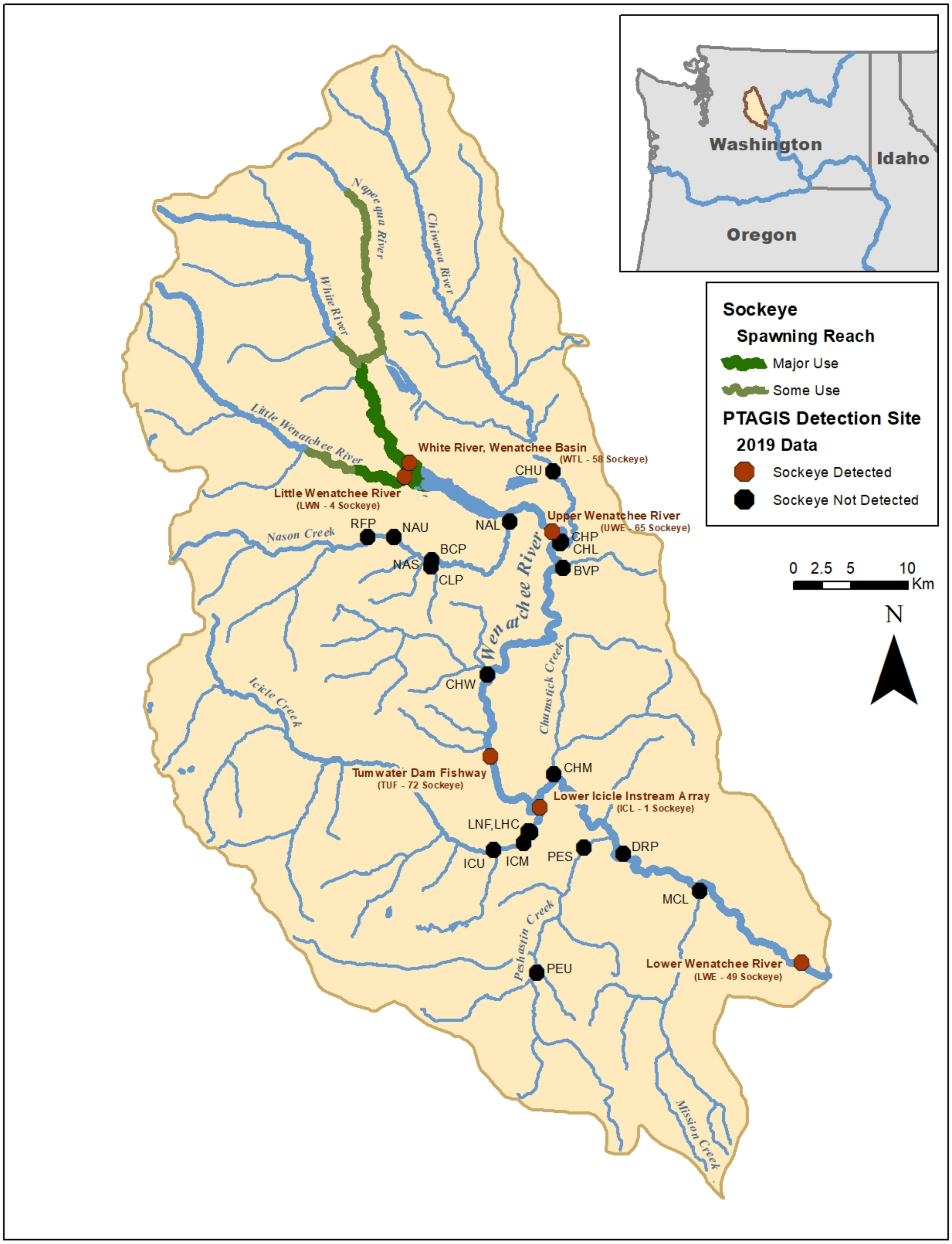


Figure 22. The Wenatchee Basin showing PIT tag interrogation sites and highlights the sites where Sockeye were detected in 2019. Also displayed is the spawning area of Sockeye. Appendix B, Table B1 has site information.

Table 32. Survival of Bonneville PIT-tagged Sockeye Salmon from the Lower Wenatchee River (LWE) to Tumwater Dam and the spawning grounds as well as the percentage last detected in tributaries downstream of Tumwater Dam in 2019.

Statistical Week Detected at LWE	Number Detected at LWE	Mean Temperature at Monitor	% Survival from Detection at LWE to Tumwater Dam	Median Travel Time LWE to Tumwater Dam (days)	Mean Daily flow at Monitor (CMS)
26	3	14.7	100.0	10.8	69.4
27	7	17.4	100.0	8.8	54.8
28	20	18.0	100.0	8.5	44.9
29	15	18.4	93.3	7.1	35.3
31	1	21.2	100.0	6.8	20.2
32	1	22.5	100.0	4.5	17.3
34	1	20.3	100.0	8.3	13.9
Unweighted Total	**48**[39]		**97.9**	**8.1**	

Of the Bonneville-tagged Sockeye detected at Tumwater Dam, 86.3% were detected by spawning ground arrays at LWN and WTL (Table 33, Figure 21). Of these fish, 92.1% were last detected in the White River and 7.9% were least detected in the Little Wenatchee River. Spawning ground detection rates and distribution were similar for other groups in Table 33, including the large group tagged by WDFW at Tumwater Dam.

Table 33. Spawning ground distribution of adult PIT tagged Sockeye Salmon detected or tagged at Tumwater Dam in 2019.

Tagging Location	Life Stage at Tagging	Number Detected or Tagged at Tumwater Dam	Percentage Detected on Spawning Grounds	Percent Spawning Ground Distribution (Last Detection)	
				Little Wenatchee (LWN)	White River (WTL)
Bonneville AFF	Adult	73	86.3	7.9	92.1
Columbia Estuary (Pound Net)	Adult	88	84.1	10.8	89.2
Tumwater Dam Adult Ladder	Adult	750	81.2	6.6	93.4
Rock Island Juvenile Bypass	Juvenile	5	100.0	20.0	80.0
Wenatchee River	Juvenile	1	100.0	0.0	100.0

[39] An additional 25 Sockeye Salmon were not detected at LWE but detected upstream in 2019.

2019 Okanagan Basin Juvenile PIT Tagging

In 2019, a total of 9,082 Sockeye smolts were captured, PIT tagged, and released between April 25 and May 9, 2019, at the Osoyoos Lake North Basin (OSOYOL) and Skaha Lake (SKAHAL) (Table 34).

Table 34. Summary of Okanagan Sockeye smolt PIT tagging effort, 2019.

	Number of PIT Tagged Sockeye Released by Site		
Release Date	**OSOYOL**	**SKAHAL**	**Total**
April 25	282	--	1236
April 26	4295	--	285
April 27	391	--	1358
April 28	--	3169	2429
May 9	--	945	472
Total	**4968**	**4114**	**9082**

Downstream survival estimates were calculated for all release groups. In 2019, survival from release to Rocky Reach Dam did not differ significantly between those Sockeye released at the two Osoyoos Lake sites (p=0.15). There was also not a significant difference between those Sockeye released in Osoyoos Lake and those released in Skaha Lake (p=0.12) (Table 35). Low precision of survival estimates, a consequence of low numbers of detections at downstream sites, meant no other comparisons in survival yielded significant results.

Table 35. Mean survival estimates for juvenile Sockeye released in the Okanagan and Wenatchee basins and Rock Island Dam in 2019[40].

Release Site (individual or pooled)	Released (n)	Release-Zosel		Zosel-Rocky Reach		Rocky Reach-McNary		McNary-John Day		John Day-Bonneville		Release-Bonneville	
		Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
OSOYOL	4968	1.036	0.132	0.646	0.089	0.819	0.141	0.669	0.152	0.928	0.246	0.341	0.071
SKAHAL	4114	0.651	0.080	0.517	0.074	0.843	0.211	0.688	0.225	1.25	0.622	0.244	0.109
Skaha plus Osoyoos	9082	0.888	0.078	0.584	0.058	0.827	0.117	0.678	0.127	0.983	0.226	0.286	0.054

Survival to downstream points was also estimated for other groups of PIT tagged Columbia Basin Sockeye Salmon that out-migrated in 2019. These included a group of 1,062 juvenile Wenatchee Sockeye Salmon tagged at a rotary screw trap in the Wenatchee River, 2,859 out-migrating juveniles trapped at Rock Island Dam that consisted of mixed Okanagan and Wenatchee origin, and over

[40] Estimates were compiled June 26, 2020 using www.cbr.washington.edu/dart/query/pit_sum_tagfiles.

62,462 juvenile Snake River Sockeye tagged at traps and hatcheries in the Snake Basin. Survival of the Rock Island releases to McNary Dam was significantly higher than that of the combined Okanagan releases (p=0.03), (Table 36, Figure 23). There were no other significant differences in survival between the combined Okanagan Snake River and the Wenatchee, Rock Island, or Snake River releases for those releases in Table 36.

Table 36. Mean survival estimates for juvenile Sockeye released in the Okanagan and Wenatchee basins, the Snake Basin, and Rock Island Dam in 2019[41].

Capture Group	Release- McNary		McNary-John Day		John Day-Bonneville		Release-Bonneville	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Osoyoos Lake	0.548	0.090	0.669	0.152	0.928	0.242	0.341	0.071
Skaha Lake	0.284	0.068	0.688	0.225	1.250	0.622	0.244	0.109
Combined Okanagan	0.429	0.058	0.678	0.127	0.983	0.226	0.286	0.054
Wenatchee	0.648	0.136	0.642	0.195	0.633	0.332	0.263	0.126
Rock Island	0.946	0.126	0.535	0.095	1.474	0.418	0.746	0.193
Snake	0.381	0.021	0.714	0.055	0.786	0.067	0.214	0.014

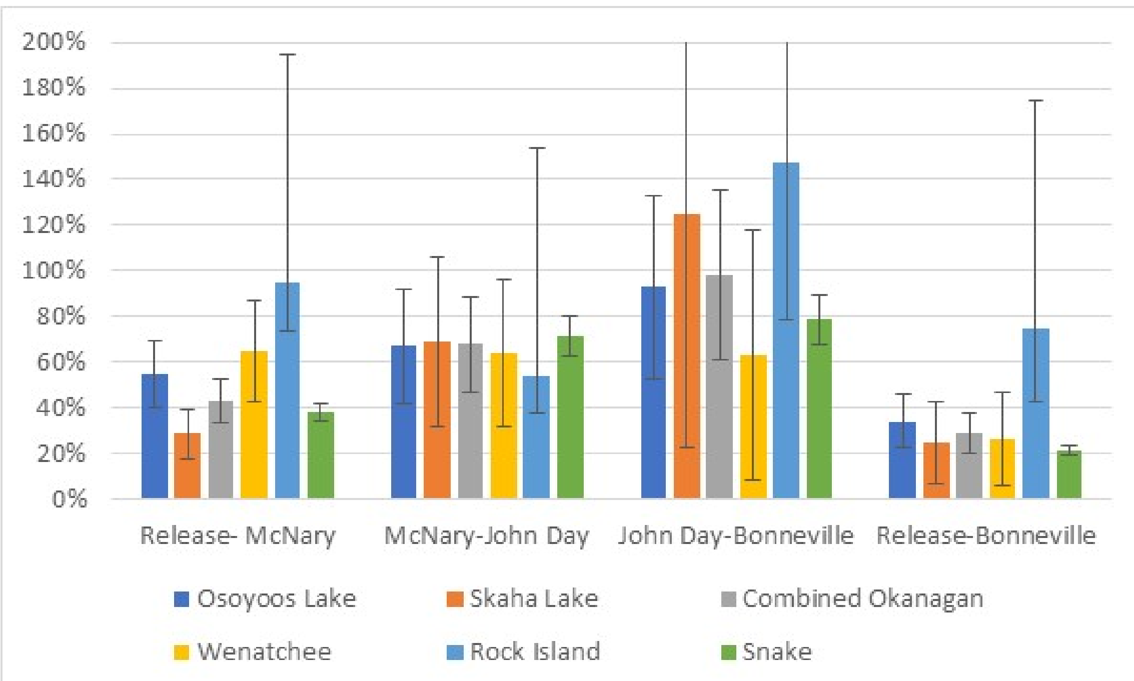


Figure 23. Survival of juvenile Sockeye PIT tagged in the Okanagan, Wenatchee, and Snake basins as well as at Rock Island Dam to McNary, John Day, and Bonneville dams with 90% confidence intervals in 2019.

[41] Estimates were compiled June 26, 2020 using www.cbr.washington.edu/dart/query/pit_sum_tagfiles.

Travel times for smolts to downstream detection locations were also compiled (Table 37). Sockeye tagged at Osoyoos Lake had longer migration times to all sites when compared to releases upstream at Skaha Lake. The combined Okanagan group took the longest time to McNary Dam, on average 17.5 days more than Rock Island-tagged Sockeye Salmon, 11.1 days more than Wenatchee-tagged Sockeye Salmon, and 9.5 days greater than Snake River-tagged Sockeye (Table 37).

Table 37. Harmonic mean travel time[42] from release to downstream sites for Sockeye tagged in the Okanagan, Wenatchee, and Snake basins as well as at Rock Island Dam in 2019. (estimated using http://www.cbr.washington.edu/dart/query/pit_sum_tagfiles on June 28, 2020.

		Harmonic Mean Travel Time from Release to:					
Release Site	**Statistic**	**Zosel**	**Rocky Reach**	**McNary**	**John Day**	**Bonneville**	**Estuary Trawl**
Osoyoos Lake (OSOYOL)	Mean	22.7	21.4	26.0	28.6	30.1	33.7
	SE	0.5	0.2	0.4	0.5	0.2	0.8
Skaha Lake (SKAHAL)	Mean	18.9	19.6	24.2	27.6	27.9	32.6
	SE	0.5	0.3	0.6	0.7	0.5	1.1
Combined Okanagan	Mean	20.4	20.8	25.4	28.3	29.5	33.4
	SE	0.4	0.1	0.3	0.4	0.2	0.6
Wenatchee	Mean	-	-	14.3	21.0	22.4	22.6
	SE	-	-	0.5	0.9	0.7	1.8
Rock Island	Mean	-	-	7.9	11.0	11.2	14.3
	SE	-	-	0.3	0.4	0.2	0.6
Snake	Mean	-	-	15.9	16.1	16.8	18.5
	SE	-	-	0.09	0.1	0.03	0.15

A report detailing Okanagan Sockeye juvenile PIT tagging can be found in Appendix C and Fish Passage Center memos reviewing survival and migration times in 2019 can be found in Appendix D.

Lake Wenatchee Acoustic Trawl and Limnology Surveys

Detailed results can be found in a report in Appendix E. To summarize, the 2012-19 results suggest that Lake Wenatchee provides excellent habitat for Sockeye fry. Although the lake is oligotrophic and Sockeye fry growth is expected to be limited, a unique mix of physical and biological conditions permits unusually high rates of Sockeye growth and production. These factors include (i) a well oxygenated, cold water hypolimnion, (ii) a ratio of edible to total phytoplankton

[42] Harmonic mean travel times were used rather than mean travel times due to the number of 2019 releases of Okanagan Basin juvenile Sockeye Salmon that did not migrate downstream until 2020, thus inflating the mean travel time.

which is exceptionally high suggesting that most of the algal species found in Lake Wenatchee have sizes, shapes and digestibility that make them excellent food sources for freshwater zooplankton, and (iii) a zooplankton community that includes two large bodied species (*Daphnia schodleri* and *Hesperodiaptomus kenai*) which provide excellent food sources for Sockeye fry.

Through the period 2010-19, the fall population density for Lake Wenatchee Sockeye fry averaged 2121 ha^{-1}. Age-0 Sockeye fry growth rates were about equal in all years and were higher than expected when compared to similar data from Osoyoos Lake. Year 2017-19 bioenergetics-based production and consumption analysis showed that the percentage of prey production that was consumed per day by Sockeye fry was always much lower than the carrying capacity (i.e. 2017 = average 6.0% of prey production consumed per day, 2018 = 8.3% and 2019 = 14.7%). In no case was there any indication that consumption by age-0 and age-1 fry was capable of limiting prey availability. We conclude that for the summer-early fall period Lake Wenatchee has zooplankton production that is unused and could be consumed by Sockeye fry. This could be tested by increasing population of fry to a density of 4000 ha^{-1} which is almost twice the current mean fall density of 2121 ha^{-1}. For further details, including cautions and caveats, see Appendix E.

DISCUSSION

This report covers 2019 which was the 11th year of this Accords study and the 14h year of PIT tagging Sockeye Salmon at Bonneville Dam.

After the abnormally high temperature year of 2015, which resulted in high mortality (Fryer et al. 2017) of Sockeye, temperatures and survival through the Columbia River have returned to more typical levels (Table 4). The mean survival to McNary Dam estimated by this study over the past 4 years of 86.0% has been the highest since the first four years of PIT tagging (2006-2009) when the mean survival was 86.9%. River temperatures were generally at or slightly above the ten-year (2009-2018) average at Bonneville Dam (Figure 24).

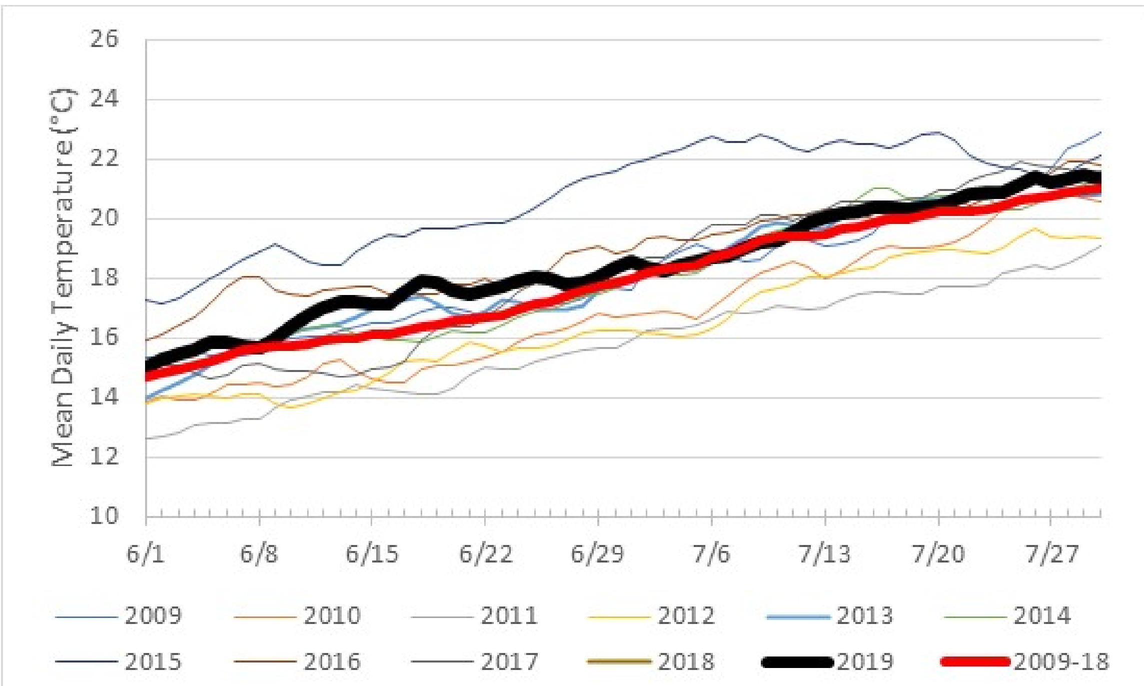


Figure 24. Mean daily water temperature at Bonneville Dam by year during the months of June for 2019 with the 2009-2018 mean.

Columbia River flows encountered by Sockeye migrating in 2019 were among the lowest in the past 11 years (Figure 25). The median travel time of 4.7 days from Bonneville to McNary Dam was the third shortest in the 14 years of PIT tagging Sockeye Salmon at Bonneville Dam. Over that period, there has been a significant positive linear relationship between mean travel time and mean flow at Bonneville Dam ($p<0.01$, Figure 26). Similarly, the median time from McNary to Priest Rapids of 4.14 days was sixth shortest and the time from Priest Rapids to

Rock Island of 2.76 days was the second shortest since we started this study in 2006. There is a significant relationship between mean flow at Priest Rapids Dam and mean travel time from McNary to Priest Rapids and from Priest Rapids to Rock Island ($p<0.01$, Figures 26 and 27).

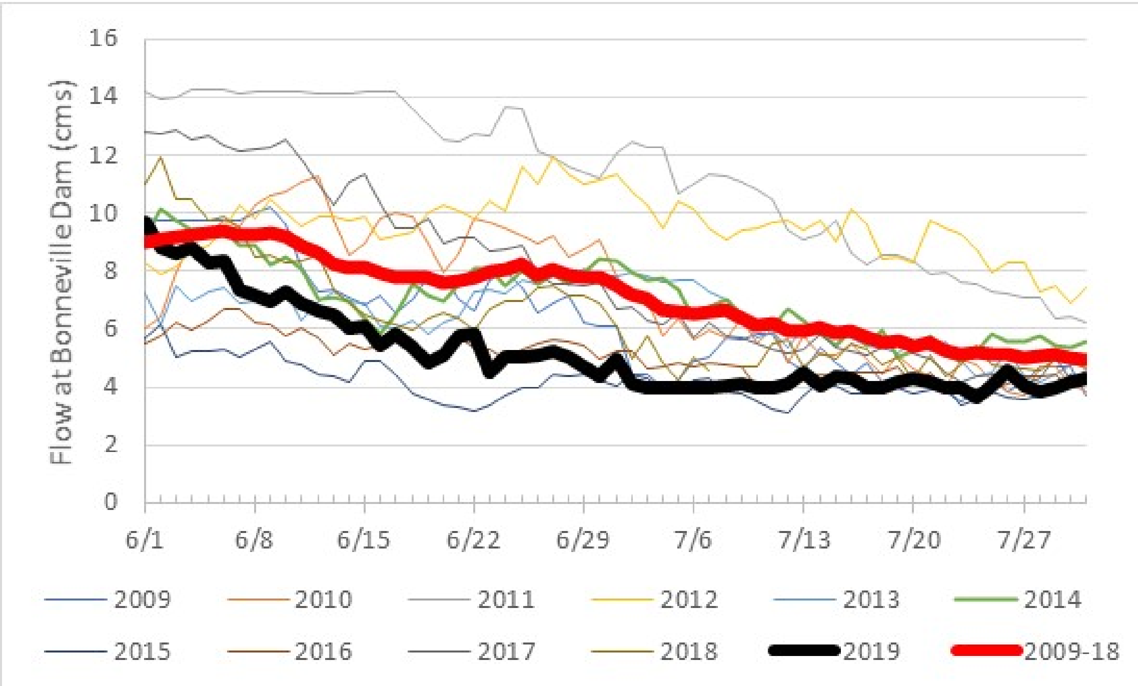


Figure 25. Mean daily flow at Bonneville Dam by year during the months of June and July in the years 2009-2019 with the mean 2009-208 flow for comparison.

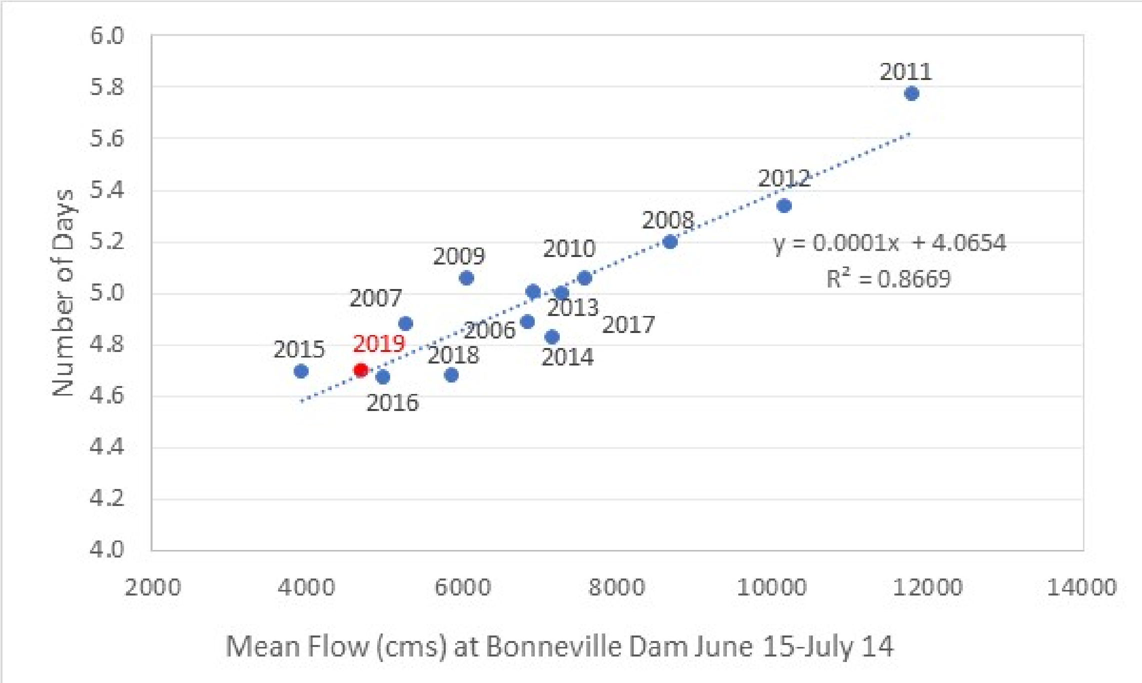


Figure 27. Relationship between mean annual Sockeye Salmon travel time for Sockeye PIT tagged at Bonneville Dam from Bonneville to McNary Dam and mean annual June 15-July 14 flow at Bonneville Dam for migration years 2006-2019.

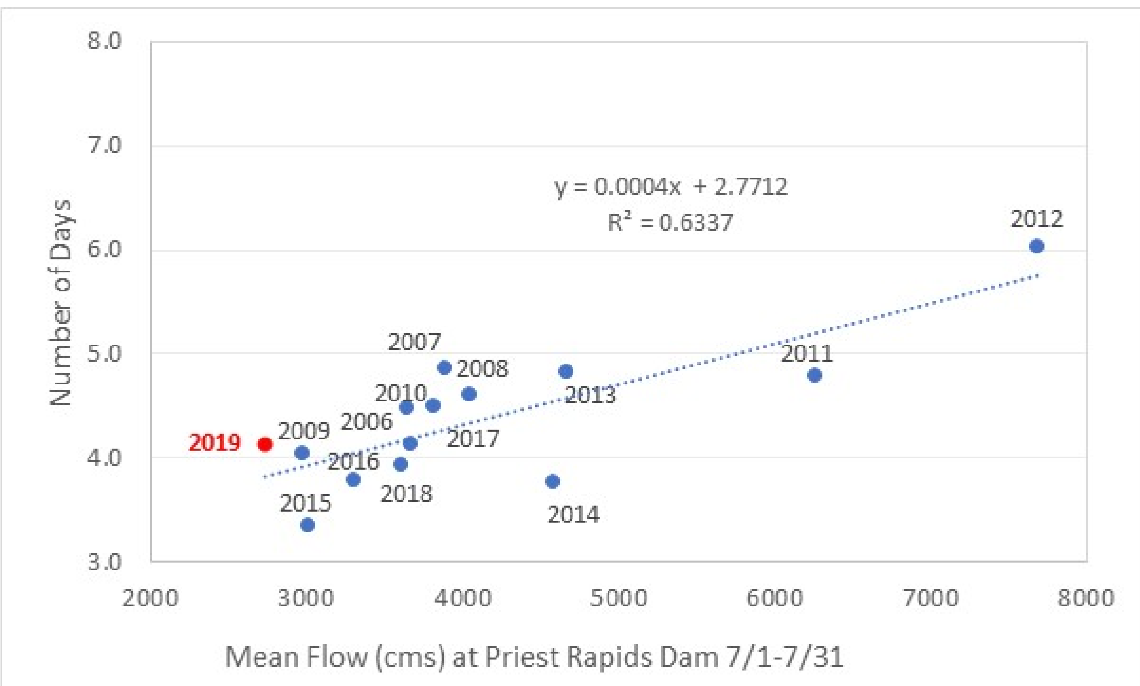


Figure 26. Relationship between mean annual Sockeye Salmon travel time for Sockeye PIT tagged at Bonneville Dam from McNary to Priest Rapids Dam and mean annual July flow at Priest Rapids Dam for migration years 2006-2019.

For the first time, we had an opportunity to compare Sockeye sampled at the Bonneville AFF with those collected by the WFRS installed at the AFF as well as from Sockeye PIT tagged in the Pound Net fishery in the Columbia River estuary. Unfortunately, both sets of comparison data had limitations. The Pound Net fishery did not collect accurate lengths and genetics data are not yet available, but it was possible to compare migratory characteristics as well as stock composition. The overall stock composition estimate for the two principal stocks was 79.1% Okanagan and 20.7% Wenatchee, and 0.2% Yakima compared to 84.9% Okanagan,13.2% Wenatchee, and 1.1% Yakima for the AFF sample. However, looking at Pound Net Sockeye subject to trapping on the Washington Shore ladder (BO3) resulted in a stock composition estimate for the primary stocks of 91.2% Okanagan and 8.8% Wenatchee Sockeye. This suggests the AFF sample may be biased towards Okanagan stock Sockeye Salmon, although it is also possible that biases also exist in the Pound Net sample as well as how Sockeye Salmon use the overflow weirs in BO3.

The data from the Pound Net sample provides some insights into fish movement through Bonneville Dam as well as possible biases in the AFF sample. Salmon at Bonneville Dam can pass through ladders on both the Washington and Oregon side of the river. Those passing on the Oregon side pass through the PIT tag antennas at PTAGIS site BO1, while those passing on the Washington side pass through antennas BO2, BO3, and BO4 (Figure 5). BO4 is located near the upstream exit and all fish passing must go through the four antennas at this site (Figure 4). Site BO2 is located at the fish ladder that runs from the spill bay to BO4, connecting to the Washington Shore ladder upstream of BO3 which is where the AFF is located. At both BO2 and BO3, only underwater orifices are monitored with overflow weirs unmonitored.

Washington and Oregon shore stock composition estimates based on detections of Pound Net-tagged Sockeye Salmonat the full slot antennas at BO1 and BO4 (Figure 5) show little difference in estimated run composition with the Okanagan stock comprising 80.2% of the Oregon Shore (BO1)[43] run and 81.6% of the Washington shore (BO4) run (Table 38). Stock composition estimates by PIT antenna site show the highest percentage of Okanagan Sockeye detected at

[43] For fish counts by ladder, see http://www.cbr.washington.edu/dart/wrapper?type=php&fname=adultladder_1607638396_867.php/ Based on visual ladder counts in 2019, 72.0% of the Sockeye run passed Bonneville Dam along the Washington shore, and 28.0% passed along the Oregon shore.

BO3 (Table 38), which is where AFF trapping occurs, suggesting trapping at this site may overestimate the percentage of Okanagan Sockeye Salmon in our stock composition estimates. However, it should be noted that only 253 PIT tagged Sockeye were detected at BO2 or BO3, compared to 520 PIT tagged Sockeye detected upstream at BO4 (Table 38). Among Sockeye that were not detected at BO2 or BO3, 72.4% were estimated as Okanagan stock compared to 27.4% for the Wenatchee. This suggests that Wenatchee Sockeye Salmon are more likely to use the overflow weirs at BO2 and BO3 than Okanagan Sockeye Salmon. If most of the Wenatchee fish migrating via the overflow weirs migrated through the Washington Shore ladder, then the perceived bias towards Okanagan Sockeye Salmon using BO3 would be reduced, or even eliminated. The monitoring of overflow weirs at Bonneville Dam BO2 and BO3 weirs will make it easier to determine if such biases exist and, if so, to allow an estimate of the magnitude of the bias.

Table 38. Number and percentage of Pound Net-tagged Sockeye detected at Bonneville Dam PIT tag antenna sites BO1, BO2, BO3, and BO4 by stock in 2019. Also included are Pound Net Sockeye not detected at BO2 and BO3 that were detected upstream at BO4. Percentages are unweighted.

	Bonneville Dam PIT Tag Site				
Stock	**BO1**	**BO2**	**BO3**	**BO4**	**Detected at BO4 but not BO2 or BO3**
Okanagan	174	17	211	417	189
Wenatchee	42	4	19	94	71
Yakima	1	0	0	0	0
Deschutes	0	0	0	1	1
Unknown	2	0	2	8	6
Total	**219**	**21**	**232**	**520**	**267**
% Okanagan	80.2%	81.0%	91.7%	81.4%	72.4%
% Wenatchee	19.4%	19.0%	8.3%	18.4%	27.2%
% Yakima	0.5%	0.0%	0.0%	0.0%	0.0%
% Deschutes	0.0%	0.0%	0.0%	0.2%	0.4%

Although the difference between the mean length of the WFRS and AFF sample was only 1.0 cm, this was significant, as was the difference in the cumulative length frequency distribution with the WFRS sampling smaller Sockeye. Unfortunately, we were unable to do any validation of the WFRS system by putting known-length fish through the system (e.g. by first measuring the fish in the AFF and then putting them through the WFRS). It appears likely that small Sockeye Salmon are not being selected for diversion into the trap. The high

percentage of small Sockeye in the 2019 run made this effect more pronounced than in other years. It will be reiterated to staff that these smaller Sockeye Salmon are to be sampled.

Both the Pound Net fishery and the WFRS offered intriguing comparisons with AFF data and it was hoped that these projects might continue with better collaboration. The WFRS approval and installation happened immediately prior to the start of the 2019 sampling making pre-season testing and coordination difficult. Unfortunately, Whooshh staff were required to remove the WFRS in January 2020 meaning we will not have a second year of Whooshh data in 2020.

We were unaware of the Pound Net fishery occurring downstream of Bonneville Dam and the AFF until Sockeye PIT tagged by this fishery started appearing in our samples. We have worked with the Wild Fish Conservancy on analysis of the data and expect to work more closely with the group if there are similar projects in the future.

In 2019, there were 73 Wenatchee stock Sockeye (as identified by GSI) tagged or recaptured by this project at Bonneville Dam detected in the Wenatchee Basin. Of the Sockeye last detected in the Wenatchee River, six (8.2%) initially bypassed the Wenatchee River and were detected at Rocky Reach Dam, with three (4.1%) also detected at Wells Dam prior to returning to the Wenatchee and being detected at Tumwater Dam. An additional two Wenatchee stock Sockeye Salmon were last detected at Wells Dam. No Okanagan stock Sockeye Salmon were detected in the Wenatchee basin (although three Okanagan Sockeye detected at Wells Dam were last detected at Rocky Reach Dam), nor were any Wenatchee stock detected in the Okanagan River. Of the 669 Bonneville Sockeye Salmon detected at Wells Dam for which the genetic stock was available, 664 (99.3%) were of Okanagan origin. In contrast, out of the 312 Sockeye this project sampled and tagged at Wells Dam and classified either using GSI or by being last detected in the Okanagan River, 15 (or 4.8%) were Wenatchee stock Sockeye Salmon. The increased Wenatchee proportion in the Wells-tagged sample as compared to Bonneville-tagged Sockeye detected at Wells Dam has been noted in some other years (Fryer et al. 2020) and is likely due to the trap at Wells Dam selecting for larger Sockeye which are more likely to be Wenatchee-origin fish. This was illustrated in Table 27 where the mean length of Bonneville-tagged Sockeye Salmon that classify as Okanagan stock was 43.5 cm compared to a mean of 51.6 cm for Sockeye sampled at Wells Dam.

This project has been funding, in collaboration with Grant and Chelan Public Utility Districts and the Department of Fisheries and Oceans, Canada, the PIT tagging of juvenile Sockeye Salmon in the Okanagan Basin since 2013. Initially, these fish were collected using a fyke net or by a rotary screw trap as they out-migrated down the Okanagan River through the Narrows under the Highway 3 bridge in Osoyoos immediately downstream of Osoyoos Lake or just downstream of Skaha Lake. However, since 2016 an increasing percentage of juvenile Sockeye have been captured using a seine in Osoyoos and Skaha lakes, reaching 100% collection by this method in 2018 and 2019 (Table 39). Fish captured by fyke net or rotary screw trap are presumably actively migrating; such may not be the case for Sockeye seined out of Osoyoos and Skaha lakes. It seems reasonable that seining in the lakes might include Sockeye that are going to migrate after additional years in the lake or are, in fact, kokanee that will eschew downstream migration entirely and instead migrate upstream to spawn. The PIT tag data suggests that this is occurring, although at low levels. The percentage of juveniles detected migrating downstream the year after tagging has not exceeded 1.1% of subsequent detections of tagged Sockeye, while the percentage not migrating downstream and being detected upstream has not exceeded 0.6% since this project began in 2013 (Table 40).

Table 39. Number and percentage of Sockeye Salmon captured in the Okanagan Basin by gear type 2013-2019.

Tagging Year	Osoyoos Bridge Fyke Net	Skaha Dam Tailrace Rotary Screw Trap	Osoyoos Lake Seine	Skaha Lake Seine	Percent Fyke Net	Percent Rotary Screw Trap	Percent Lake Seining
2013	2,783	703	57	--	78.5	19.8	1.6
2014	3,706	978	--	--	79.1	20.9	0.0
2015	1,741	5,435	--	--	24.3	75.8	0.0
2016	1,754	3,101	3,044	2,338	17.1	30.3	52.6
2017	2,794	--	8,794	--	24.1	0.0	75.9
2018	--	--	5,083	5,860	0.0	0.0	100.0
2019	--	--	4,968	4,114	--	--	100.0
Total	**12,778**	**10,217**	**21,946**	**12,312**	**22.3**	**17.8**	**59.8**

Table 40. Comparison of the number of Sockeye Salmon PIT tagged as juveniles subsequently detected downstream in the year of tagging, those detected moving downstream in subsequent years, and those only detect upstream (kokanee) for release years 2013-2019.

Release Year	Same Year Downstream Detections	Following year Downstream Detections		Only Upstream Detections (probable kokanee)		Total Detected
		N	%	N	%	
2013	898	10	1.1	2	0.2	910
2014	1,271	--	0.0	--	0.0	1,271
2015	1,747	16	0.9	6	0.3	1,769
2016	3,442	3	0.1	13	0.4	3,458
2017	3,298	18	0.5	4	0.1	3,320
2018	2,916	7	0.2	0	0.0	2,924
2019	2,400	21	0.9	14	0.6	2,435
Total	**15,972**	**76**	**0.5**	**39**	**0.2**	**13,652**

In addition to PIT tagging Sockeye Salmon, this project has also funded the installation of PIT tag antennas beginning with OKC in 2009 and Zosel Dam in 2010. In 2015, we added a floating antenna on the west-most spillway in at Zosel Dam which detected 31 outmigrating smolts (Fryer et al. 2017). A second floating antenna was added in 2016 but high flows in 2016 resulted in poor detection (Fryer et al. 2018) and side-to-side oscillation almost caused the metal cable attaching the antennas to the spillway walls to cut through the fiberglass sleds the antennas sat on. High flows precluded reinstalling antennas in 2017, but in 2018, one antenna was installed with a new mounting system (Fryer et al. 2020). After good results, despite very high flows, we planned to upgrade the mounting system for the second antenna and deploy it in early 2019. This was delayed by a cold winter resulting in the dam being encrusted in ice until early March 2019. This included the east side antenna which was left deployed over the winter (Figure 28). The forebay finally melted out sufficiently so that the second antenna could be deployed on March 12, 2019. With both antennas operational, a total of 289 outmigrating juvenile Sockeye Salmon were detected at the floating antennas in addition to 53 juveniles detected migrating through the fish ladders between May 8, 2019 and June 2, 2019 with one additional detection on June 24, 2019 (Figure 29). This resulted in the lowest standard error for survival from release to Zosel Dam that has yet been generated for this stock and resulted in the decision to make further upgrades to the Zosel Dam infrastructure (including larger floating antennas) in early 2020, that will be discussed in the 2020 report.

Figure 29. Ice encased floating PIT tag antenna at Zosel Dam February 11, 2019.

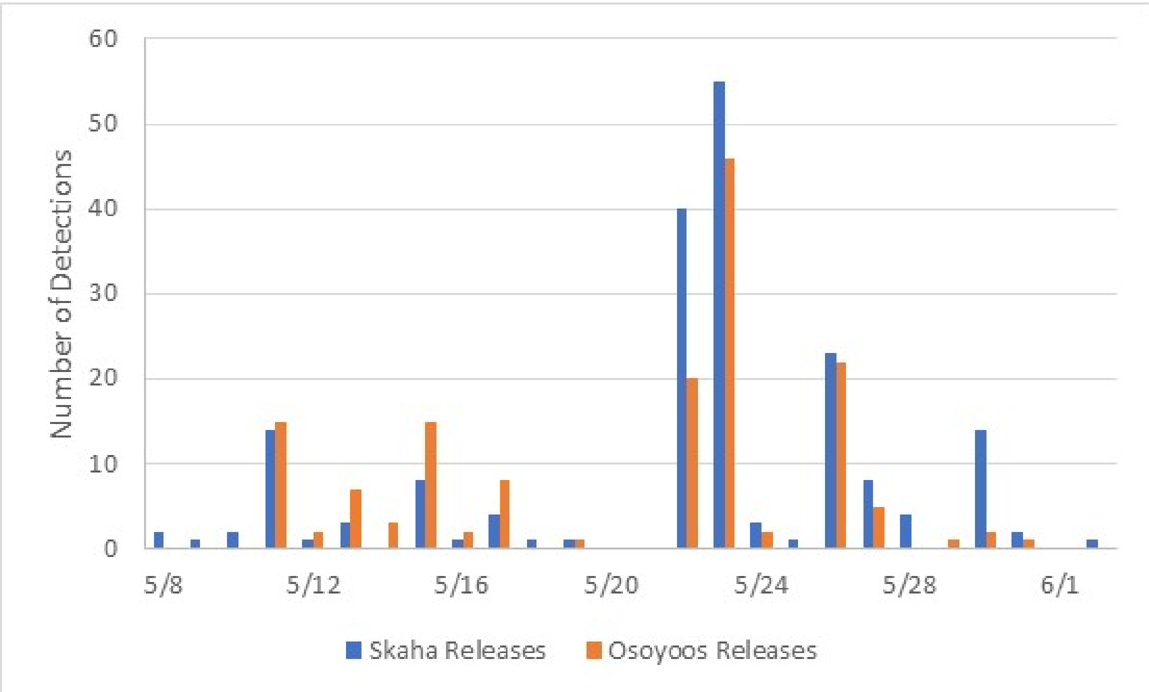


Figure 28. Number of PIT tag detections by release site for juvenile Sockeye Salmon at Zosel Dam in 2019. One Skaha released fish was also detected on June 24, 2019

In both 2017 and 2018, a “ghost” tag affected OKC antenna site performance (Fryer et al. 2020). This tag was injected into a Sockeye Salmon tagged at Wells Dam in 2011. After this Sockeye died, this tag was deposited in the gravel only to move downstream in the high 2017 flows to be deposited on top of Antenna A2 on May 11, 2017. This resulted in the tag generating near-constant detections which interfered with detections of other tagged fish passing this antenna (Figure A7 and Table A4 in Appendix A). Efforts to remove this tag by crushing or dislodging failed in 2018; however, the tag started being detected intermittently in February 2019 and detections largely stopped after April 7, 2019 with the exception of May 10, 2019 through May 17, 2019 and after December 8, 2019.

Based on upstream detections at our Skaha Dam fish ladder site, the detection rate of OKC for Sockeye in 2019 was 96.7% (Appendix A, Table A7), with five of the seven undetected Sockeye Salmon likely passing during July 2-5 and July 7-8 when the site was having power outages which were resolved when the batteries were replaced on July 8. The detection rate among all Sockeye Salmon detected at OKC (excluding detections at other sites) of the older downstream array was 99.10%, while the detection rate of the newer upstream array (the array with the ghost tag) was 75.5%. The detection rate at SKA in 2019 was 100.0%, as low flows meant all Sockeye had to use the PIT-tag monitored fish ladders rather than the unmonitored spillways which are passable at high lows (Appendix A, Table A7).

PIT tags from four adults tagged by this study at Bonneville Dam in 2019 were found at the Badger Island pelican colony and one at the Central Blalock Island tern colony (Figure 30). Last detection sites for the Badger Island recoveries were one at The Dalles, two at John Day, and one at Prosser Dam while the Central Blalock recovery was last detected at McNary Dam. The tag from the tern colony was from a 39.5 cm fork length Sockeye Salmon; those recovered from the pelican colony came from Sockeye with fork lengths of 35.5, 39.5, 52.5 and 53.5 cm. The PIT tags from 24 juvenile Sockeye tagged at Skaha and Osoyoos lakes in 2019 were detected at two different colonies, compared to 66 in 2018 and 73 in 2016 (Figure 30 and Table 41). Note that these numbers can increase over time as additional surveys detect tags deposited in prior years.

No adult Sockeye PIT tagged at Bonneville Dam were recovered in tribal fisheries between Bonneville and McNary dams in 2019.

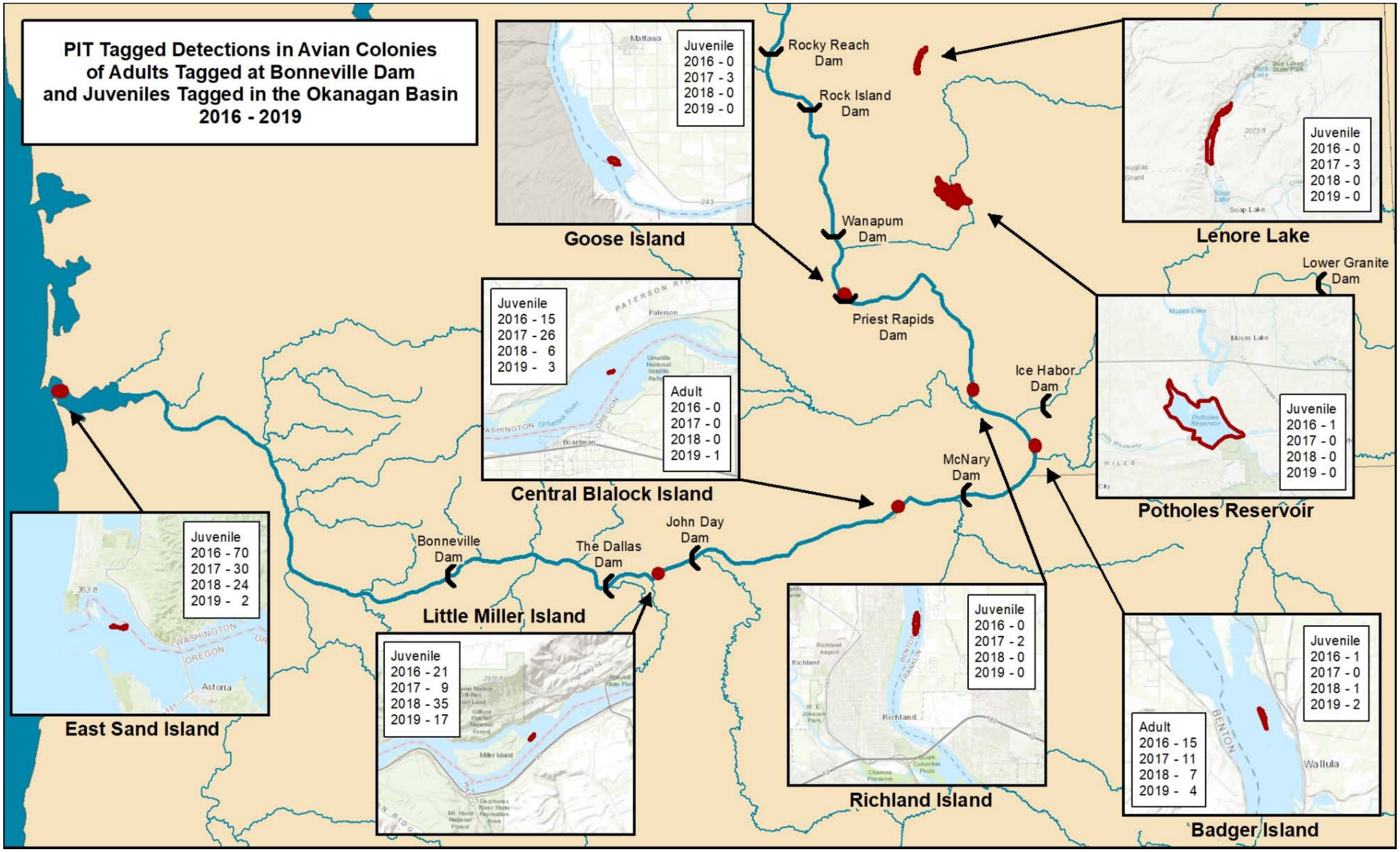


Figure 30. PIT tag detections at avian colonies of Sockeye Salmon tagged by this project in years 2016-2019.

Table 41. Number of Sockeye Salmon tagged as juveniles in the Okanagan Basin subsequently detected at avian nesting sites by year of tagging.

Avian Site	2012	2013	2014	2015	2016	2017	2018	2019	Total
Badger Island		2		5	1		1	2	11
Central Blalock Island		3	20	18	15	26	6	3	91
Crescent Island		6	5						11
East Sand Island	4	11	127	79	70	30	24	2	347
Goose Island	1					3	NA	NA	4
Lenore Lake Island						3			3
Little Miller Island	1	16	20	15	21	9	35	17	134
Potholes Reservoir,	2	3	1		1				7
Richland Island		2	1			2			5
Rock Island Forebay				1					1
Total	**8**	**43**	**174**	**118**	**108**	**73**	**66**	**24**	**614**

This project is proposed to continue and evolve over the next several years as there are several priority areas to investigate. We continue to work to improve PIT tag detection at Zosel Dam, a key point on both the upstream and downstream migration. We had a 100% detection rate on the upstream migration as low flows meant Sockeye Salmon had to pass through the fishways rather than the spillways where there is no PIT tag detection. Detection of PIT tagged juvenile Sockeye Salmon provided the most precise estimates of survival from release to Zosel Dam yet estimated. We will continue to improve PIT tag detection at Zosel Dam which also benefits steelhead and Chinook Salmon restoration activities. We will also continue opportunities to collaborate with WDFW and the Confederated Colville Tribes on in-stream arrays in the area.

Lake Wenatchee ATS are expected to continue along with limnological sampling to better estimate the annual production and future productive potential of Lake Wenatchee Sockeye Salmon. The ATS data from Skaha, Osoyoos, and Wenatchee lakes are also used in Columbia Basin run forecasting for Sockeye. There are several unanswered questions regarding Lake Wenatchee Sockeye that we are working to address under this project. A primary question is why Lake Wenatchee Sockeye, in recent years, have not increased in relative abundance as much as Okanagan Sockeye, or even Snake River Sockeye. Our limnology and ATS work described in Appendix E is suggesting that there is rearing capacity for twice as many Sockeye smolts as presently rear in the lake.

An exciting development in recent years has been the colonization of Sockeye in Skaha Lake once passage was provided at McIntyre and Skaha dams. The PIT tag arrays at SKA and OKP funded by this project have been important in assessing the success of this restoration work. With Sockeye Salmon passage

planned into Okanagan Lake in the near future, we hope to continue to work with the ONA and Canada Department of Fisheries and Oceans on expanding the system of PIT arrays to Okanagan Lake.

REFERENCES

Biomark. 2020. Fish tagging methods. Retrieved online January 2020: https://www.biomark.com/pub/media/Salmonid_Tagging_Methods.pdf

CBFWA (Columbia Basin Fish and Wildlife Authority PIT Tag Steering Committee. 1999. PIT tag marking procedures manual. CBFWA. Portland. 26 pp.

DART (Columbia River Data Access in Real Time). 2019. Online at: http://www.cbr.washington.edu/dart/dart.html

FPC (Fish Passage Center). 2019. Adult fish counts online at: http://www.fpc.org.

Fryer, J.K. 1995. Columbia Basin Sockeye Salmon: causes of their past decline, factors contributing to their present low abundance, and the future outlook. PhD dissertation. University of Washington, Seattle. 272 pp.

Fryer, J.K. 2007. Use of PIT tags to determine upstream migratory timing and survival of Columbia Basin Sockeye Salmon in 2007. Columbia River Inter-Tribal Fish Commission Technical Report. Portland.

Fryer, J.K. 2009. Use of PIT tags to determine upstream migratory timing and survival of Columbia Basin Sockeye Salmon in 2008. Columbia River Inter-Tribal Fish Commission Technical Report. Portland.

Fryer, J. K. and M. Schwartzberg. 1988. Identification of Columbia Basin Sockeye Salmon stocks based on scale pattern analysis. Columbia River Inter-Tribal Fish Commission Technical Report 89-2,

Fryer, J.K.., H. Wright, S. Folks, and K. Hyatt. 2010. Studies into factors limiting the abundance of Okanagan and Wenatchee Sockeye Salmon. Columbia River Inter-Tribal Fish Commission Technical Report for BPA Project 2008-503-00.

Fryer, J.K.., H. Wright, S. Folks, and K. Hyatt. 2011a. Studies into factors limiting the abundance of Okanagan and Wenatchee Sockeye Salmon in 2010. Columbia River Inter-Tribal Fish Commission Technical Report for BPA Project 2008-503-00.

Fryer, J. K., J. Mainord, J. Whiteaker, and D. Kelsey. 2011b. Upstream migration timing of Columbia Basin Chinook and Sockeye Salmon and steelhead in 2009. Columbia Basin Inter-Tribal Fish Commission Technical Report for BPA Project 2008-503-00.

Fryer, J.K.., H. Wright, S. Folks, and K. Hyatt. 2013. Studies into factors limiting the abundance of Okanagan and Wenatchee Sockeye Salmon in 2012. Columbia River Inter-Tribal Fish Commission Technical Report for BPA Project 2008-503-00.

Fryer, J.K.., D. Kelsey, H. Wright, S. Folks, R Bussanich, K. Hyatt and M. Stockwell. 2017. Studies into factors limiting the abundance of Okanagan and Wenatchee Sockeye Salmon in 2015. Columbia River Inter-Tribal Fish Commission Technical Report for BPA Project 2008-503-00.

Fryer, J.K., D. Kelsey, H. Wright, S. Folks, R. Bussanich, K.D. Hyatt, D. Selbie, and M.M. Stockwell. 2018. Studies into Factors Limiting the Abundance of Okanagan and Wenatchee Sockeye Salmon in 2016 and 2017. Columbia River Inter-Tribal Fish Commission for BPA Project 2008-503-00.

Fryer, J.K., D. Kelsey, H. Wright, S. Folks, R. Bussanich, K.D. Hyatt, D. Selbie, and M.M. Stockwell. 2020. Studies into Factors Limiting the Abundance of Okanagan and Wenatchee Sockeye Salmon in 2018. Columbia River Inter-Tribal Fish Commission for BPA Project 2008-503-00.

Fulton, L.A. 1970. Spawning areas and abundance of steelhead trout and coho, Sockeye, and chum Salmon in the Columbia River Basin-past and present. National Marine Fisheries Service Special Scientific Report (Fisheries) 618.

Hess, J.E., N.R. Campbell, A.P. Matala, S.R. Narum. 2013. 2012 Annual Report: Genetic Assessment of Columbia River Stocks. U.S. Dept. of Energy Bonneville Power Administration Report Project #2008-907-00.

Hyatt, K. D., D.J. Rutherford, T. Gjernes, D.P. Rankin, and T. Cone. 1984. Lake Enrichment Program: juvenile Sockeye unit survey guidelines. Can. Ms. Rep. Fish. Aquat. Sci. No. 1796.

Hyatt, K. D. and D. P. Rankin. 1999. A habitat based evaluation of Okanagan Sockeye Salmon escapement objectives. Canadian Stock Assessment Secretariat Research Document. 99/191. 59p. Available from www.dfo-mpo.gc.ca/csas/CSAS/English/Research_Years/1999/

Hyatt, K. D. and M. M. Stockwell. 2009. Okanagan fish and water management tool project assessments: Record of management strategy and decisions for the 2006-2007 fish-and-water year. Can. Ms. Rep. Fish. Aquat. Sci. No. 2913, 65p.

Keller, L. and S. Hopkins. 2020. Rock Island Dam smolt monitoring and gas bubble trauma evaluation plan 2020. Public Utility District #1 of Chelan County, 9p.

Kelsey, D., H. Ballantyne, J. Whiteaker, and J.K. Fryer. 2011. Age and length composition of Columbia Basin Chinook and Sockeye Salmon and Steelhead at Bonneville Dam in 2009. Columbia River Inter-Tribal Technical Report 11-08. Portland.

Koo, T.S.Y. 1955. Biology of the red salmon, *Oncorhynchus nerka* (Walbaum), of Bristol Bay, Alaska, as revealed by a study of their scales. Ph.D. thesis, University of Washington, Seattle.

LaHood, E.S., J.J. Miller, C. Apland, and M.J. Ford. 2008. A rapid, ethanol-free Tissue Collection Method for Molecular Genetic Analyses. Transactions of the American Fisheries Society 137:1104-1107.

Naughton, G.P., C.C. Caudill, M. L. Keefer, T.C. Bjornn, C. A. Peery, and L.C. Stuehrenberg. 2005. Late-season mortality during migration of radio-tagged adult Sockeye Salmon (*Oncorhynchus nerka*) in the Columbia River. Canadian Journal of Fisheries and Aquatic Science. 62: 30-47.

Northwest Power Planning Council (NPPC). 1986. Council staff compilation of information on Salmon and steelhead losses in the Columbia River Basin. Portland.

PTAGIS (Columbia Basin PIT Tag Information System). 2014. PIT tag marking procedures manual. Online at http://www.ptagis.org.

Quinn, T.P., Hodson, S. and Peven, C. 1997. Temperature, flow, and the migration of adult Sockeye Salmon (*Oncorhynchus nerka*) in the Columbia River. Canadian Journal of Fisheries and Aquatic Science. 54: 1349-1360.

Rundio, D. E., A.N. Montgomery, M.G. Nesbit, M.S. Morris, G.T. Brooks, G.A. Axel, J.J. Lamb, R.W. Zabel, J. Ferguson, and S.T. Lindley. 2017. Central Valley Passive Integrated Transponder (PIT) Tag Array Feasibility Study. NOAA Technical Memorandum, NOAA-TM-NMFS-SWFSC-573, 130 pp.

Whiteaker, J. and J.K. Fryer. 2008. Age and length composition of Columbia Basin Chinook and Sockeye salmon and Steelhead at Bonneville Dam in 2007. Columbia Basin Inter-Tribal Fish Commission Technical Report 08-04. Portland.

APPENDIX A

2019 Performance of Okanagan Basin PIT Tag Detection Infrastructure Funded by this Project

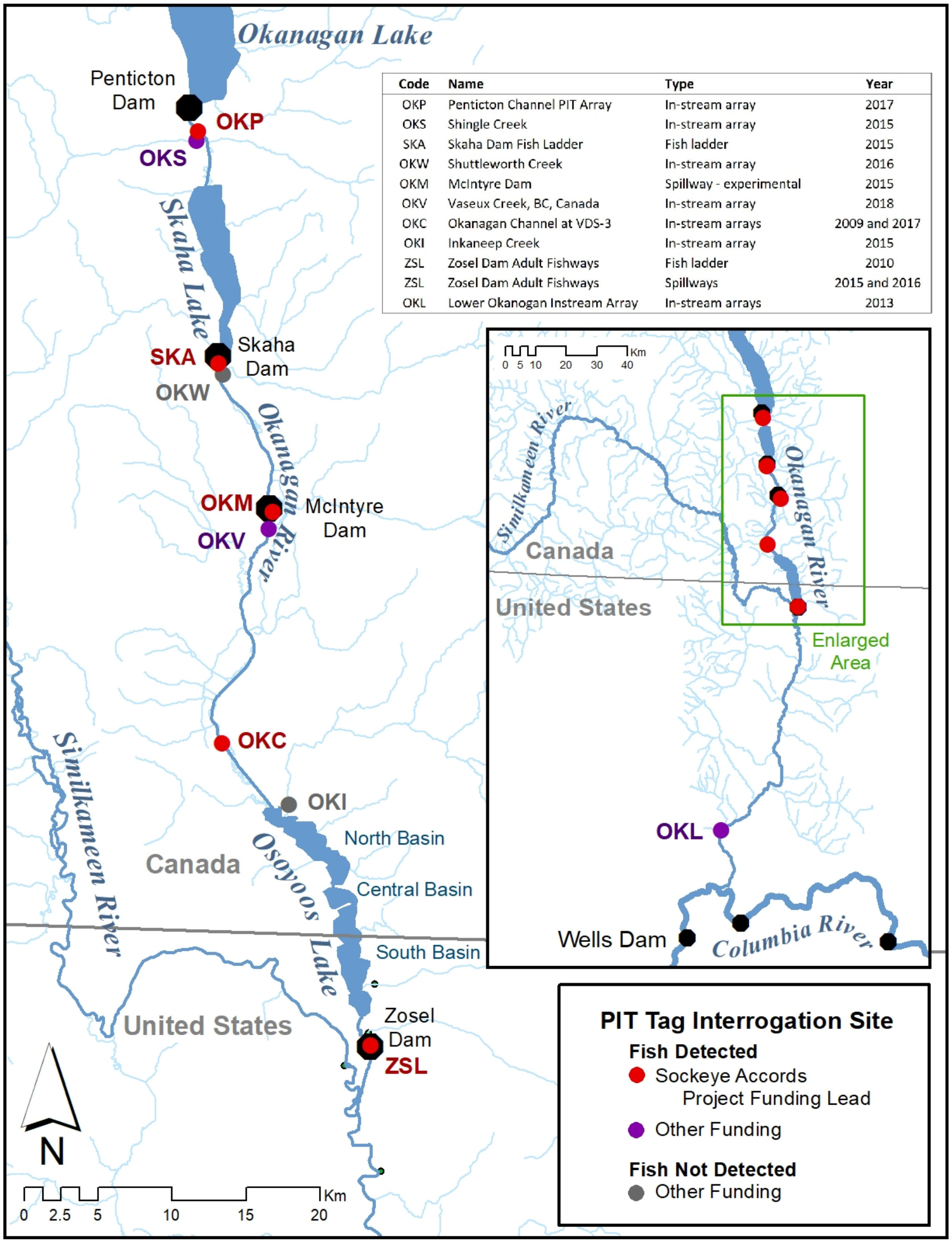
This project has funded several PIT tag antennas placements in the Okanagan Basin. Two of the early installations were arrays at both Zosel Dam fish ladders which were installed in 2010. In 2015 a floating antenna was added to detect fish moving through the east spillway and then in 2016 a second floating antenna was added to the west spillway. Neither of these were deployed in 2017 due to high flows, but new rigging was designed for one of the two floating antennas and it was deployed with the new rigging for testing with anticipated high flows in 2018. Additional arrays were installed at the Skaha Dam fish ladder (SKA, 2015) as well at McIntyre Dam spillway (OKM, 2015) and an instream array at OKC (2009 with expansion in March 2017) and another instream array in the Okanagan Channel at Penticton (OKP, installed November 2017) (Figure A1). Further details on installation, upgrades, and operating issues with OKC, OKM, SKA, and OKP can be found in Appendix F.

Zosel Dam

At Zosel Dam, PIT tags from 1002 Sockeye, 65 steelhead, 84 Chinook, and 1 Coho were detected between January 1, 2019 and December 31, 2019 (Table A1 and Figure A2). Among the Sockeye detections were 342 juveniles detected between May 8, 2019 and June 24, 2019, 53 of which were detected in Zosel fish ladders (11 east and 42 west) with the remaining 289 detected at the floating PIT tag antennas (91 left and 118 east) (Figure A3). Among the Chinook detections were 64 juveniles PIT tagged by the ONA in the Okanagan River upstream of Osoyoos Lake. Of these 64 detected Chinook, 16 were detected in the ladders (4 east, 12 west) and 48 were detected at the floating antennas (13 left, 35 right). Among the 65 steelhead detected were 10 tagged in spring 2019 that were released in the Similkameen River (PTAGIS site SIMILR) on April 11, 2019 that were then detected in Zosel Dam fish ladders between April 12, 2019 and April 14, 2019.

Sockeye Salmon tagged by CRITFC adult tagging projects at Bonneville and Wells dams comprised 641 or 61.6% of the Sockeye Salmon detected at Zosel

Dam in 2019. No adult Sockeye Salmon detected upstream of Zosel missed detection at Zosel as flows were low, the spill gates were closed, and upstream migrating salmon were forced to use the fish ladders.



Code	Name	Type	Year
OKP	Penticton Channel PIT Array	In-stream array	2017
OKS	Shingle Creek	In-stream array	2015
SKA	Skaha Dam Fish Ladder	Fish ladder	2015
OKW	Shuttleworth Creek	In-stream array	2016
OKM	McIntyre Dam	Spillway - experimental	2015
OKV	Vaseux Creek, BC, Canada	In-stream array	2018
OKC	Okanagan Channel at VDS-3	In-stream arrays	2009 and 2017
OKI	Inkaneep Creek	In-stream array	2015
ZSL	Zosel Dam Adult Fishways	Fish ladder	2010
ZSL	Zosel Dam Adult Fishways	Spillways	2015 and 2016
OKL	Lower Okanogan Instream Array	In-stream arrays	2013

Figure A1. Map of the Okanagan River showing locations of PIT tag antennas funded by this project since its inception. Zosel, Skaha, and McIntyre dams, and in-river array immediately downstream of spawning areas at OKC and an in-river array immediately downstream of Penticton Channel spawning areas at OKP.

Table A1. Number of PIT tagged Chinook, steelhead, and Sockeye detected at Zosel Dam ladders between January 1, 2019 and December 31, 2019, by release site and life stage at time of tagging.

		Detected as Juveniles			Detected as Adults				
Release Site	**Life Stage at Release**	**Chinook**	**Sockeye**	**Steelhead**	**Chinook**	**Coho**	**Sockeye**	**Steelhead**	**Total**
Columbia Estuary	Adult						379	0	379
Bonneville Dam	Adult				3		466	1	470
Priest Rapids	Adult					1		25	26
Wells Dam	Adult				15		175	11	201
Canadian Okanagan	Juvenile	64	342				12	1	419
US Okanagan	Juvenile	1		10				16	27
Methow	Juvenile				1			1	2
Rock Island	Juvenile						7	0	7
Unknown	Unknown								5[44]
Total		**65**	**342**	**10**	**19**	**1**	**1039**	**55**	**1531**

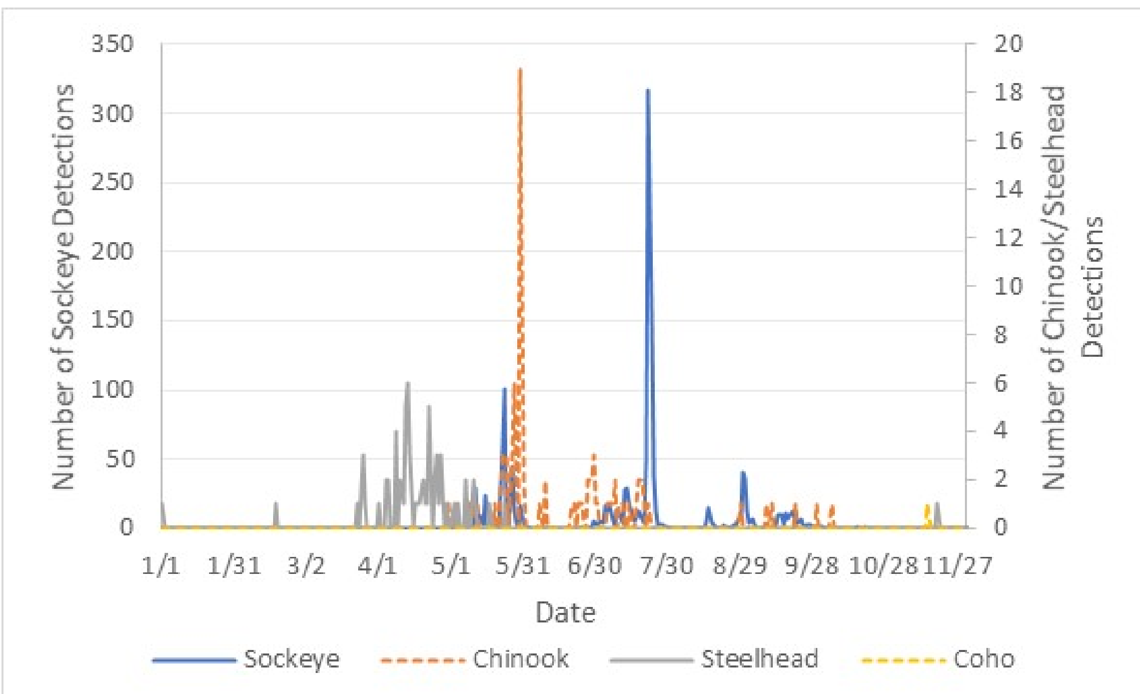


Figure A2. Number of PIT tagged Chinook, Steelhead, and Sockeye detected by date at Zosel Dam in 2019.

[44] These 5 PIT tag detections were from tags with no tag information entered into PTAGIS and are commonly referred to as orphans.

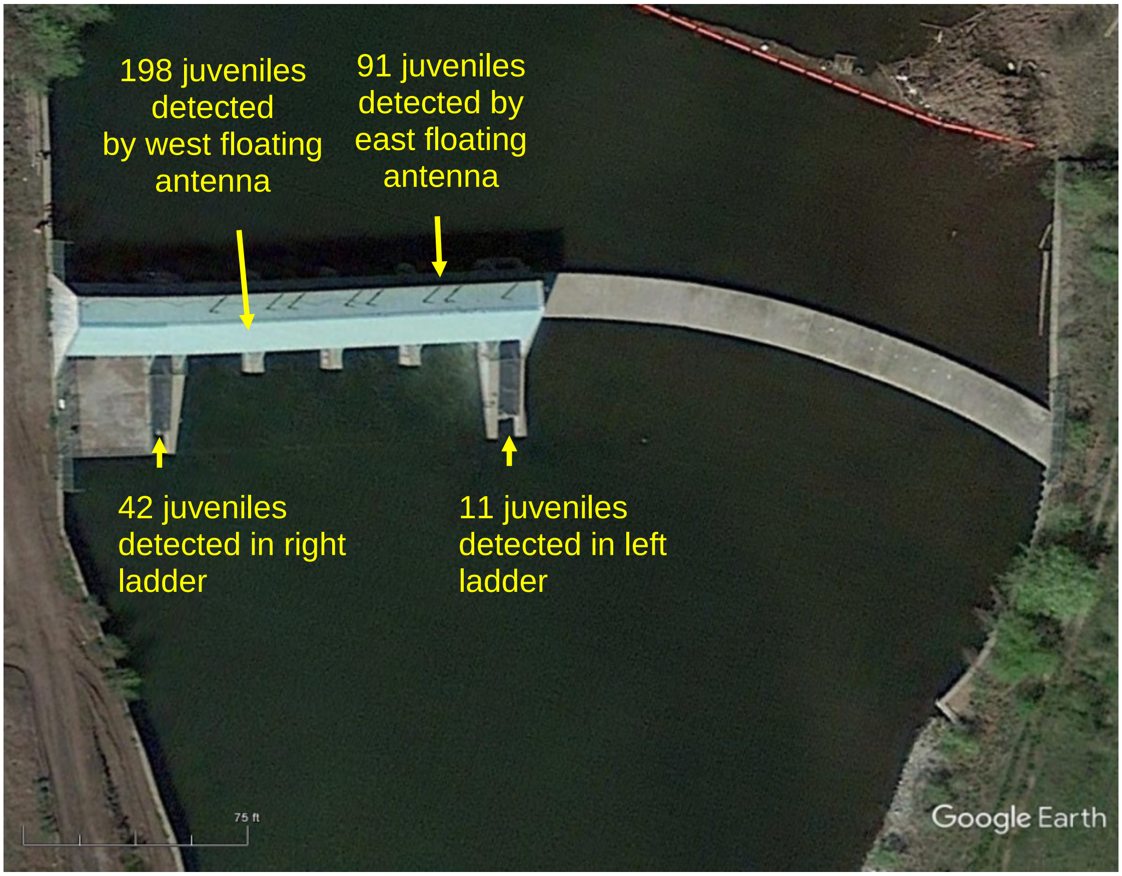


Figure A3. Zosel Dam showing a floating PIT tag array (top) and the number of Sockeye detected at each floating array and ladder in 2019 (bottom).

Okanagan Channel (OKC)

A total of 839 Sockeye Salmon, 230 Chinook Salmon and 15 steelhead were detected at OKC in 2019 (Table A2). Of these fish, 54 Sockeye and 10 Chinook were downstream migrating juveniles while the remainder were returning adults tagged on the upstream migration at Bonneville, Priest Rapids, or Wells dams or tagged as juveniles in years prior to 2019. Of the adult Sockeye detected at OKC, 0.3% passed in June, 8.7% in July, 0.9% in August, and the remainder in September (36.1%) and October (54.1%), primarily after the water temperature dropped below 15C (Figure A4). Sockeye passing OKC in July and August were generally not detected further upstream, suggesting these fish spawned primarily on the spawning grounds downstream of McIntyre Dam, while Sockeye passing in September and October were more likely to be spawning upstream of Skaha Dam in the Penticton Channel.

Table A2. Number of PIT tagged Chinook, steelhead, and Sockeye detected at OKC between January 1, 2019 and December 31, 2019, by release site and life stage at time of tagging (minus ghost tag).

		Detected as Juveniles			Detected as Adults			
Release Site	**Life Stage at Release**	**Chinook**	**Sockeye**	**Steelhead**	**Chinook**	**Sockeye**	**Steelhead**	**Total**
Columbia Estuary	Adult					288		288
Bonneville Dam	Adult				2	345	1	348
Priest Rapids	Adult						9	9
Wells Dam	Adult				8	139	5	152
Canadian Okanagan	Juvenile	220	54	33		8		315
Rock Island	Juvenile					5		5
Methow River	Juvenile			1				1
Unknown	Unknown							4
Total		**220**	**54**	**34**	**10**	**785**	**15**	**1122**

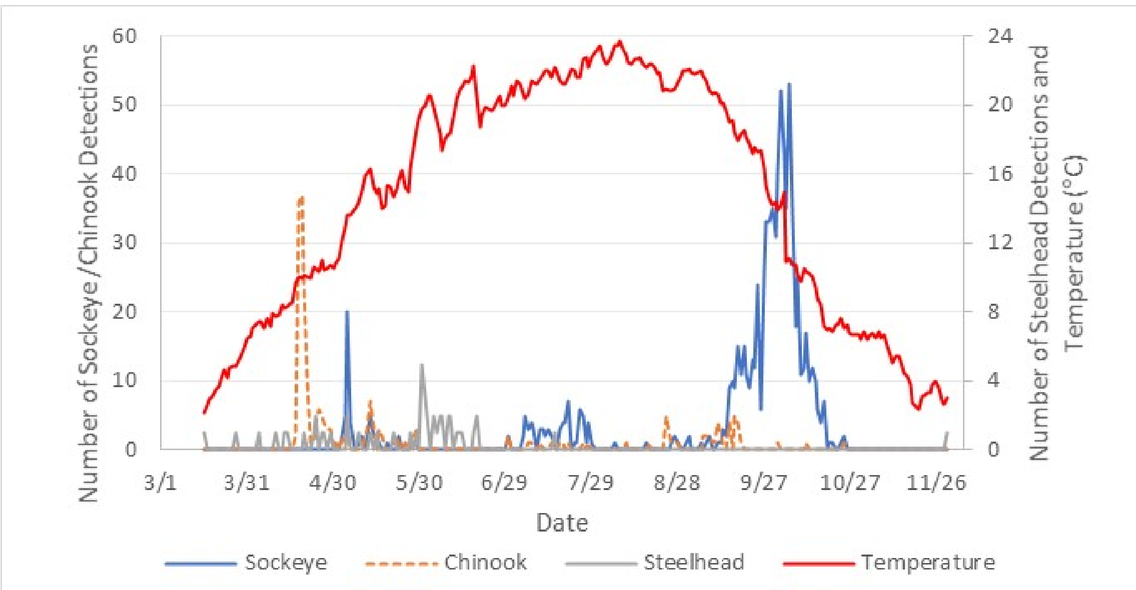


Figure A4. Number of PIT tagged salmon and steelhead detected by date at OKC and mean daily Okanagan River water temperature at OKC during the 2019 migration.

The percentage of Sockeye detected at each of the eight antennas divided by the total number of Sockeye detected at OKC shows one poorly performing antenna (antenna A6) with less than 10% of Sockeye detected at this antenna (compared to >25% at all other antennas) due to equipment problems. Antenna A3 contributed to the upper antenna array (A1-A4) detecting only 75.5% of Sockeye passing the array compared to 99.1% at the downstream array (A5-A8).

In the 2018 report for this project (Fryer et al. 2020), the performance of OKC antenna A2 was noted to be adversely impacted by a "ghost tag" from a Sockeye Salmon tagged at Wells Dam on July 11, 2011 (3D9.1C2DB01432). After this Sockeye died, this tag was deposited in the gravel only to move downstream in high 2017 flows to be deposited on top of the new antenna on May 11, 2017, and started generating near-constant detections for the rest of 2017, 2018, and early 2019 (Figure A7). High flows made it difficult to remove the tag in 2018 until the fall[45]. An effort on September 6, 2018, appeared at first to be successful, but the tag resumed transmitting on September 23, 2018. Another effort on November 26, 2018 to remove the tag failed. This tag generated detections into 2019 but then became intermittent, with no detections during the summer-fall migration period and only affecting the period between April 24-26 and May 10-17 during the 2019 spring outmigration (Figure A7). More Sockeye were detected at Antenna A2 than at any other antenna in 2019 (Table A4). Detections from the ghost tag ceased in February 2020. While the ghost tag problem receded in 2019, problems with a cable connection at Antenna A3 resulted in a low detection rate in 2019 (Table A4).

[45] Removal means trying to either crush the tag or dislodge it so that the current takes it downstream.

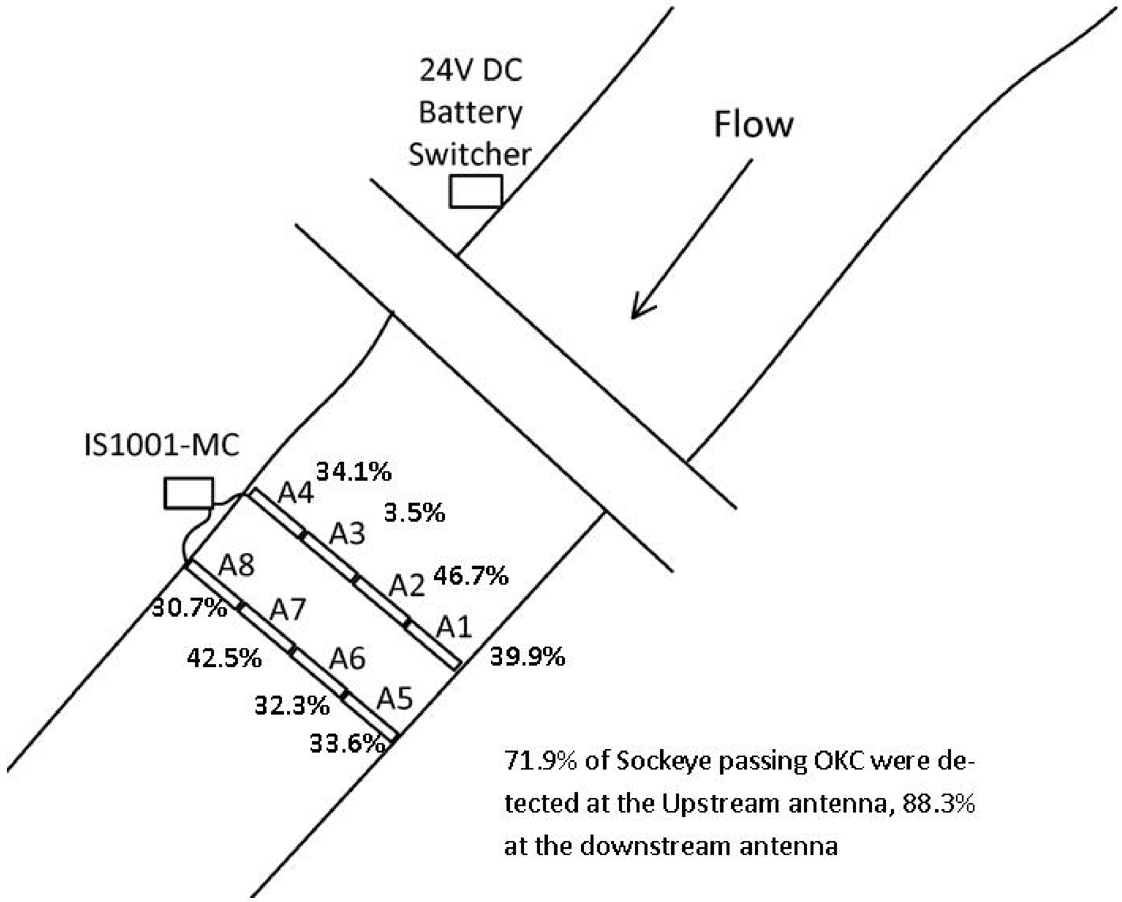


Figure A6. Percentage of Sockeye passing OKC that were detected at each individual antenna in 2019.

Table A3. Percentage of Sockeye passing OKC detected at each antenna with summaries by array in 2019[46].

Live Stage	Statistic	Upstream Array				Downstream Array				Upstream Array (A1-A4)	Downstream Array (A1-A4)
		A1	A2	A3	A4	A5	A6	A7	A8		
Adults	%	39.6	52.3	1.9	32.9	35.6	33.3	44.6	27.8	75.5	99.1
	N	235	310	11	195	277	259	347	216	593	778
Juveniles	%	66.7	22.2	0.0	11.1	32.3	12.9	25.8	35.5	50.0%	57.4
	N	18	6	0	3	10	4	8	11	27	31
Adult and Juveniles	%	41.0	51.9	1.8	32.6	35.6	33.1	44.4	28.4	73.9	96.4
	N	254	322	11	202	288	268	359	230	620	809

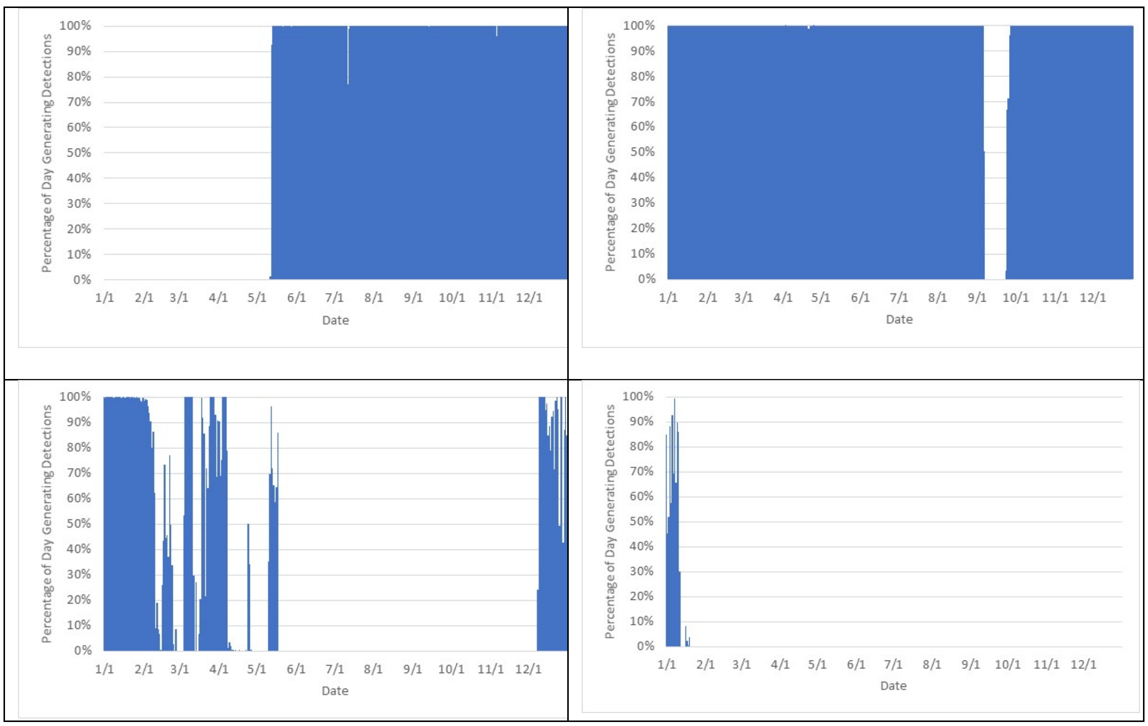


Figure A7. Percentage of each day ghost tag 3D9.1C2DB01432 was detected on antenna A2 for the years 2017-2020.

[46] Percentages were calculated within each array as the number of Sockeye detected at an antenna divided by the number of all Sockeye detected at each array. Similarly, the upstream and downstream array detections were estimated by the total number of Sockeye detected at each array divided by the number detected at both arrays. Note that sockeye missing detection at both arrays were not included in these calculations.

Table A4. Percentage of tagged Sockeye Salmon detected at OKC which were detected at each individual antenna for the years 2010-2019. Note that a new upstream array was installed in early 2017. According to PTAGIS numbering convention, the existing antenna was renumbered A5-A8 and the new antenna was numbered A1-A4.

Year	Upstream Array %				Downstream Array %				Upstream Array %	Downstream Array %
					A1	**A2**	**A3**	**A4**		
2010					14.6	33.6	52.5	34.9	100.0	0.0
2011					23.0	27.6	44.7	51.4	100.0	0.0
2012					18.1	25.1	60.5	35.3	100.0	0.0
2013					32.1	33.2	46.6	51.3	100.0	0.0
2014					22.6	37.0	42.1	34.2	100.0	0.0
2015					17.6	49.3	37.5	24.3	100.0	0.0
2016					26.9	46.1	44.2	32.8	100.0	0.0
	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**		
2017	50.7	28.4	23.6	26.2	40.6	50.8	33.7	14.0	56.7	97.0
2018	57.6	14.8	25.2	34.5	42.0	48.2	29.4	20.0	54.9	97.2
2019	41.0	51.9	1.8	32.6	35.6	33.1	44.4	28.4	73.9	96.4

Skaha Dam (SKA)

Of the 225 salmon and steelhead detected at Skaha Dam[47] (SKA), 116 were Sockeye Salmon tagged at Wells or Bonneville dams by this study (Table A5). A total of 7 returning Sockeye adults were tagged as juveniles and small numbers of returning Chinook and steelhead were also detected.

Of the Sockeye detected at SKA, 26.1% passed in late June and July, with the remainder passing after water temperatures dropped to about 20C in late August through October (Figure A8).

[47] This excludes approximately 200 adult Sockeye Salmon captured and released at the Skaha Dam fish ladder as part of another study.

Table A5. Number of PIT tagged Chinook, steelhead, and Sockeye detected at SKA between January 1, 2019 and December 31, 2019, by release site and life stage at time of tagging.

Release Site	Life Stage at Release	Detected as Juveniles			Detected as Adults			Total
		Chinook	Sockeye	Steelhead	Chinook	Sockeye	Steelhead	
Columbia Estuary	Adult	0	0	0	0	86	0	86
Bonneville Dam	Adult	1	0	0	0	91	0	92
Priest Rapids	Adult	0	0	0	0	0	2	2
Wells Dam	Adult	0	0	0	8	25	0	33
Canadian Okanagan	Juvenile	1	7	1	0	0	0	9
Rock Island	Juvenile	0	0	0	0	3	0	3
Total		**2**	**7**	**1**	**8**	**205**	**2**	**225**

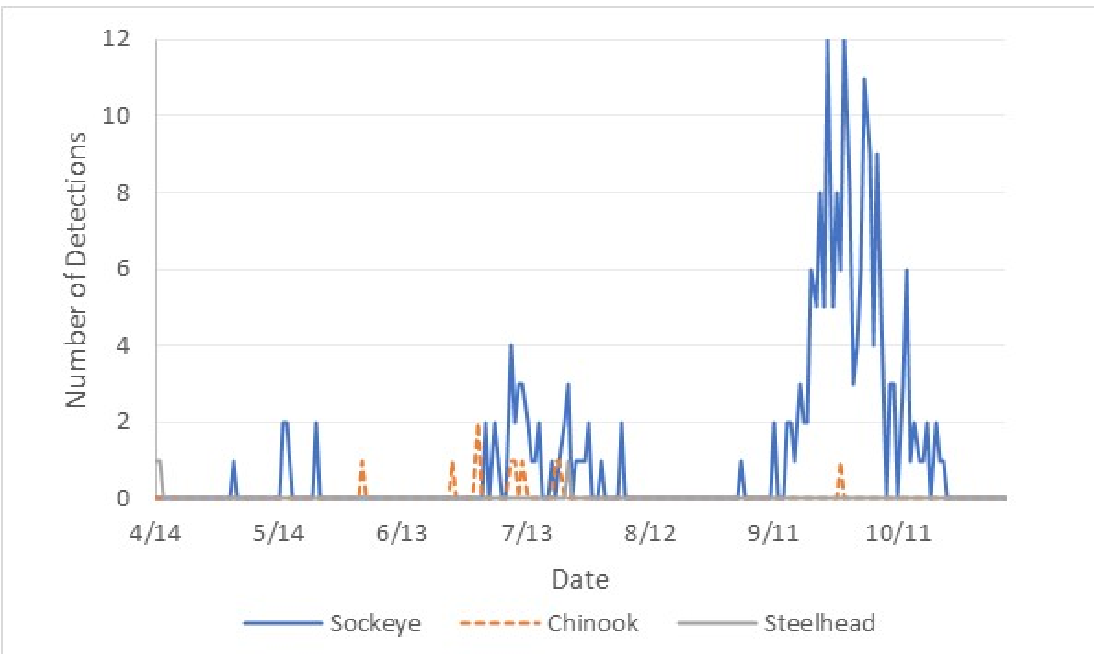


Figure A8. Number of PIT tagged Sockeye Salmon detected by date at Skaha Dam (SKA) and mean daily Okanagan River water temperature at Oliver, BC during 2019.

Penticton Channel (OKP)

Of the 171 salmon and steelhead detected at OKP, 319 were Sockeye Salmon tagged at Wells or Bonneville dams by this study and an additional 81 were tagged as adults by the ONA at Skaha Dam as part of another study (Table A6). A total of 24 returning adult Sockeye detected were tagged as juveniles as were two returning adult Steelhead.

Of the returning adult Sockeye detected at OKP, none were detected prior to July 15, 2019, with 2.8%% detected in July, 1.4% in August, 7.0% in September, 81.7% in October, and 7.0% in November (Figure A9).

Table A6. Number of PIT tagged Chinook, steelhead, and Sockeye detected at OKP between January 1, 2019 and December 31, 2019, by release site and life stage at time of tagging.

		Detected as Juveniles			Detected as Adults			
Release Site	Life Stage at Release	Chinook	Sockeye	Steelhead	Chinook	Sockeye	Steelhead	Total
Columbia Estuary	Adult					52		52
Bonneville Dam	Adult				1	66		67
Priest Rapids	Adult						2	2
Wells Dam	Adult	1			6	24	1	32
Rock Island	Juvenile		2					2
Canadian Okanogan	Juvenile		8	8				16
Total		**1**	**10**	**8**	**7**	**142**	**3**	**171**

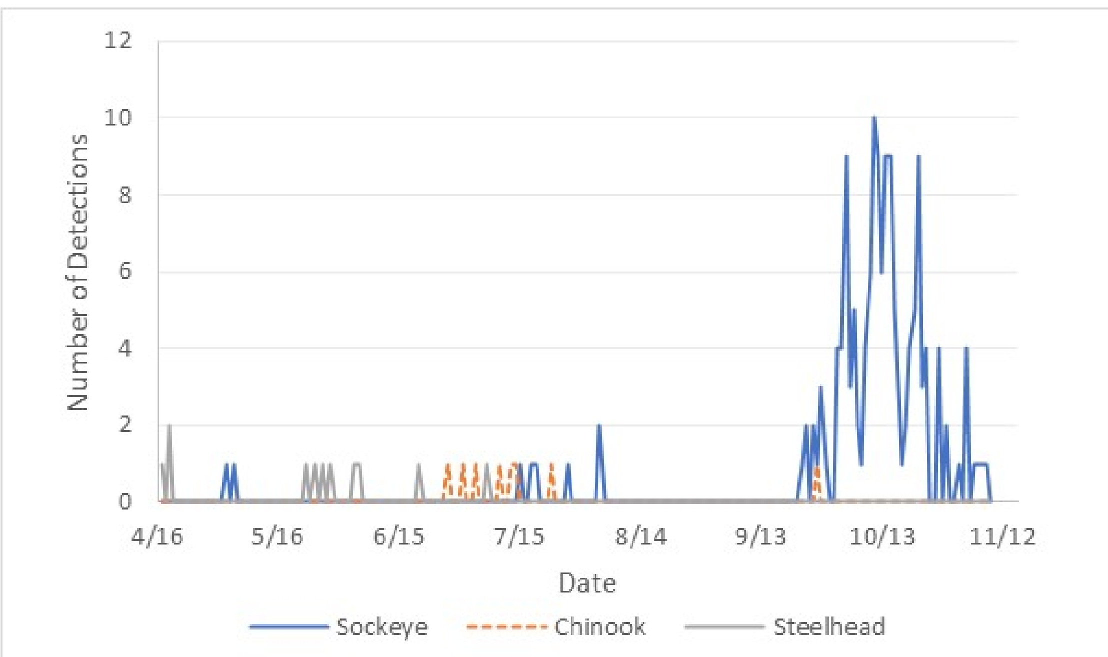


Figure A9. Number of PIT tagged Sockeye Salmon detected by date at Skaha Dam (OKP) and mean daily Okanagan River water temperature at Oliver, BC during 2019.

Sockeye Salmon Detection Rates at Okanagan River PIT Tag Arrays

Low flows resulted in high detection rates for adult Sockeye Salmon migrating at Okanagan River sites with PIT Tag antennas (Table A7). The sole exception was OKL where 61.8% of Sockeye detected upstream went undetected at OKL. A total of 8 upstream migrating Sockeye Salmon missed detection at OKC. Seven were detected passing ZSL between 7/1-7/7/2019 and their passage at OKC likely coincided with power problems at OKC. The site was down between 21:01 on 7/2 and 09:53 on 7/5 which was followed by intermittent power problems on 7/7 and 7/8. Batteries at the site were replaced on 7/8 which resolved the issue (email from Brett Turley, Biomark, May 29, 2020).

Table A7. Percentage of adult PIT tagged Sockeye passing upstream without detection at Okanagan River PIT Tag arrays by week passing Wells Dam in 2019.

Week Detected at Wells Dam	N at Wells Dam	Percentage of PIT tagged Sockeye passing upstream without being detected by PIT tag antenna site				Mean Okanagan River Weekly Flow (cms) at Gauge Stations	
		OKL	ZSL	OKC	SKA	Monse (rkm 27)	Oliver (rkm 150)
26	56	44.0%	0.0%	30.8%	0.0%	64.8	9.2
27	236	54.1%	0.0%	4.3%	0.0%	52.5	10.9
28	597	59.7%	0.0%	1.1%	0.0%	58.2	10.9
29	383	70.5%	0.0%	0.0%	0.0%	55.6	11.4
30	143	65.2%	0.0%	0.0%	0.0%	41.9	10.8
31	68	68.8%	0.0%	0.0%	0.0%	34.4	10.5
32	18	80.0%	0.0%	NA	NA	26.8	10.1
33	5	100.0%	0.0%	NA	NA	19.9	9.8
All Weeks		**61.8%**	**0.0%**	**3.3%**	**0.0%**		

APPENDIX B

Interrogation Sites in the Columbia Basin that have Detected Sockeye Salmon

Table B1. Information on interrogation sites for detection of PIT tags in the Columbia Basin that have detected Sockeye tagged and/or tracked by this project in 2019.

Site Code	Site Name	Site Description
BCC	BON PH2 Corner Collector	Bonneville Dam 2nd Powerhouse Corner Collector Outfall Channel.
BO1	Bonneville Bradford Is Ladder	Bradford Island Adult Fishway at Bonneville Dam.
BO2	Bonneville Cascades Is Ladder	Cascades Island Adult Fishway at Bonneville Dam.
BO3	Bonneville WA Shore Ladder/AFF	Washington Shore Adult Fishway and AFF at Bonneville Dam; replaces B2A and BWL.
BO4	Bonneville WA Ladder Slots	Washington Shore Fishway Vertical Slots at Bonneville Dam.
DRM	Deschutes River mouth	Mouth of the Deschutes River in the west channel at Moody Island (rkm 0.46).
DSF	Deschutes Sherars Falls	Site consists of two monitored weirs in the main fishway and two monitored weirs in the high flow fishway; one antenna per weir.
ENL	Lower Entiat River	Entiat River rkm 2, located immediately upstream of Entiat, WA.
GOA	Little Goose Fish Ladder	Adult Fishway at Little Goose Dam.
GRA	Lower Granite Dam Adult	Lower Granite Dam Adult Fishway and Fish Trap.
ICH	Ice Harbor Dam (Combined)	Ice Harbor Dam Adult Fishways (both) and Full Flow Bypass.
ICL	Lower Icicle Instream Array	Located at rkm 0.4 on Icicle Creek (Wenatchee River Basin), near Leavenworth, WA.
JDJ	John Day Dam Juvenile	John Day Dam Juvenile Fish Bypass and Sampling Facility.
JO1	John Day Dam South Fish Ladder	The interrogation site at the John Day Dam south fish ladder.
JO2	John Day Dam North Fish Ladder	The interrogation site at the John Day Dam north fish ladder.
LMA	Lower Monumental Adult Ladders	This interrogation site is in both ladders at Lower Monumental Dam.
LMR	Lower Methow River at Pateros	Lower Methow River near the WDFW 'Miller Hole' access site on the lower Methow River immediately upstream of Pateros, WA.
LRL	Lower Lochsa River Array Site	Site is located in lower 1km of the mainstem Lochsa River.
LRU	Lochsa River Upper Site	Site is located in lower 3km of the mainstem Lochsa River.
LWE	Lower Wenatchee River	Wenatchee River rkm 2.
LWN	Little Wenatchee River	Instream PIT tag interrogation site at rkm 4 located at the old fish weir.
MC1	McNary Oregon Shore Ladder	Oregon Shore Adult Fishway at McNary Dam.
MC2	McNary Washington Shore Ladder	Washington Shore Adult Fishway at McNary Dam.
MCJ	McNary Dam Juvenile	McNary Dam Juvenile Fish Bypass/Transportation Facility.
MRC	Methow River at Carlton	Located in the mainstem Methow River near the town of Carlton at rkm 45.
OKC	Okanagan Channel at VDS-3	The OKC site is located in the Okanagan (Canadian spelling) Channel at 310th Avenue/Road 18 upstream from Osoyoos Lake.
OKL	Lower Okanogan Instream Array	Site at RKM 24.9 on the mainstem Okanogan River, upstream of Chiliwist area in Okanogan County.
OKM	McIntyre Dam	Site has antennas on each side of spill bay 1 at McIntyre Dam, which is located downstream of Vaseux Lake and upstream of Okanagan Lake.
OKP	Penticton Channel PIT Array	Penticton Channel, is the channelized portion of the Okanagan River connecting Okanagan Lake with Skaha Lake, within the city of Penticton BC.
OKS	Shingle Creek	Site is on a a tributary to the Okanagan River in Canada, immediately adjacent to the Okanagan Shingle Creek Hatchery.
OKV	Vasuex Creek, BC, Canada	Instream PIT tag interrogation site located on Vasuex Creek at 200 m upstream from the confluence with the Okanagan River.
OMK	Omak Creek Instream Array	Omak Creek enters the Okanogan River at RKM 51.5, approximately 1 km upstream from the city of Omak, WA. The site is located on Omak Creek, 0.24 km from the confluence with the Okanogan River.
PRA	Priest Rapids Adult	Priest Rapids Dam Adult Fishways (both).
PRO	Prosser Diversion Dam Combined	Adult Fishways (all three) and Juvenile Bypass/Sampling Facility at Prosser Dam.
RIA	Rock Island Adult	Rock Island Dam Adult Fishways (all three).
ROZ	Roza Diversion Dam (Combined)	Roza Dam Smolt Bypass.
RRF	Rocky Reach Fishway	Rocky Reach Dam Adult Fishway.
RRJ	Rocky Reach Dam Juvenile	Juvenile Fish Bypass Surface Collector.
SKA	Skaha Dam Fish Ladder	Skaha Dam is located within the community of Okanagan Falls at the south end of Skaha Lake, BC along the Okanagan River. The fishway is at the western edge of the dam.
SW1	Lower Selway River Array	PIT tag array is located 5 rkm upstream of the mouth of the Selway River in the upper Clearwater Basin Idaho.
TD1	The Dalles East Fish Ladder	East Fish Ladder at The Dalles Dam.
TD2	The Dalles North Fish Ladder	North Fish Ladder at The Dalles Dam.
TUF	Tumwater Dam Adult Fishway	Adult Fishway at Tumwater Dam.
UWE	Upper Wenatchee River	Located at rkm 81.2 on the Wenatchee River, near Plain, WA.
WEA	Wells Dam, DCPUD Adult Ladders	Wells Dam Adult Fishways (both).
WEH	Wells Dam Hatchery	Points of detection include the adult fish handling facility, juvenile pond outflows and adult volunteer channel.
WTL	White River, Wenatchee Basin	A permanent instream PIT tag interrogation site at RKM 2.88 on the White River.
ZSL	Zosel Dam Adult Fishways	Zosel Dam is located at Okanogan River km 132, approximately 3 km downstream from the outlet of Lake Osoyoos in the town of Oroville, Washington.

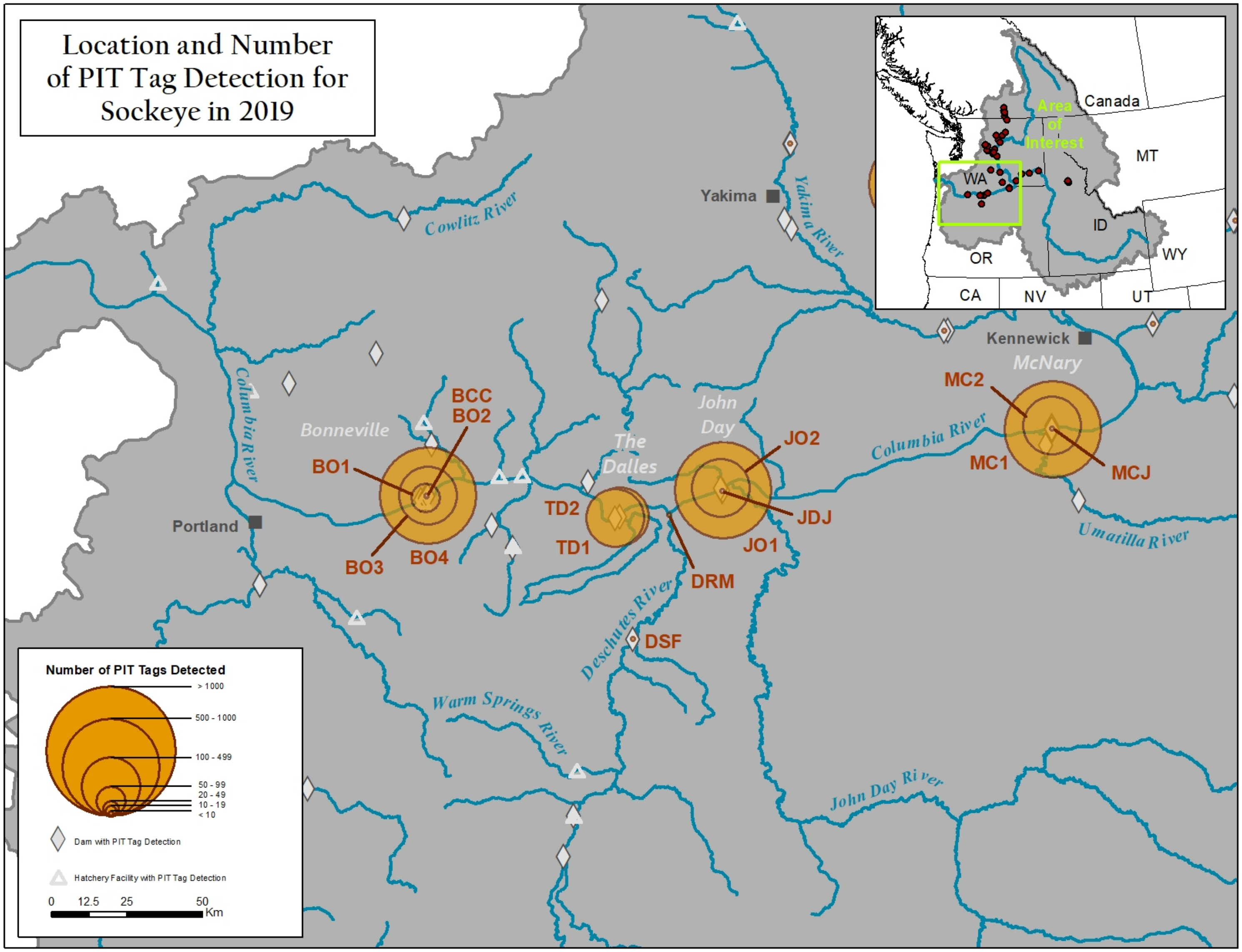


Figure B1. Map of Lower Columbia River detection sites (below Snake River) and number of Sockeye Salmon detected in 2019. Table B1 in the Appendix lists the PTAGIS sites' full name and the three-letter codes on this map.

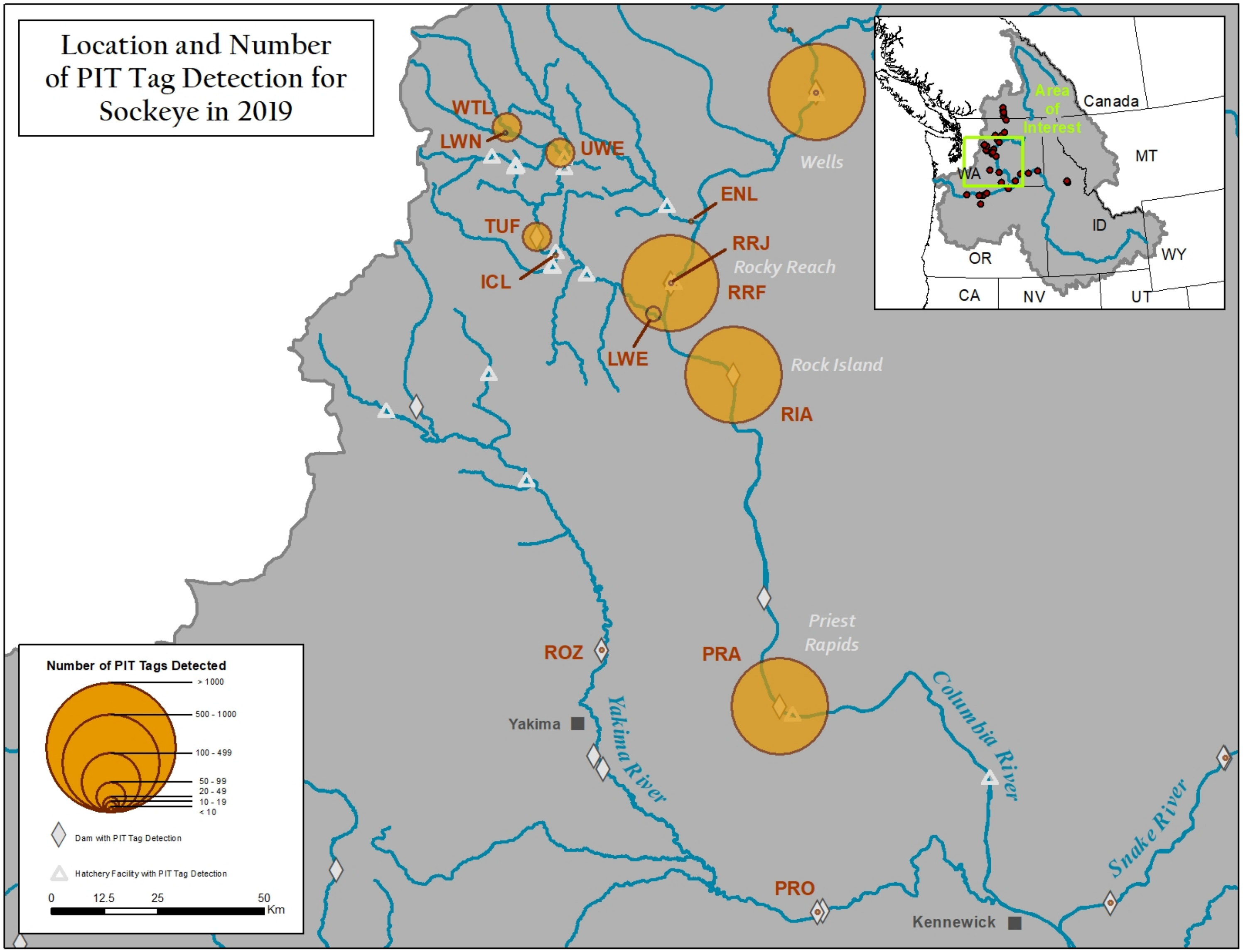


Figure B2. Map of Upper Middle Columbia River (between the Snake River and Wells Dam) detection sites and number of Sockeye Salmon detected in 2019. Table B1 in the Appendix lists the PTAGIS sites' full name and the three-letter codes on this map.

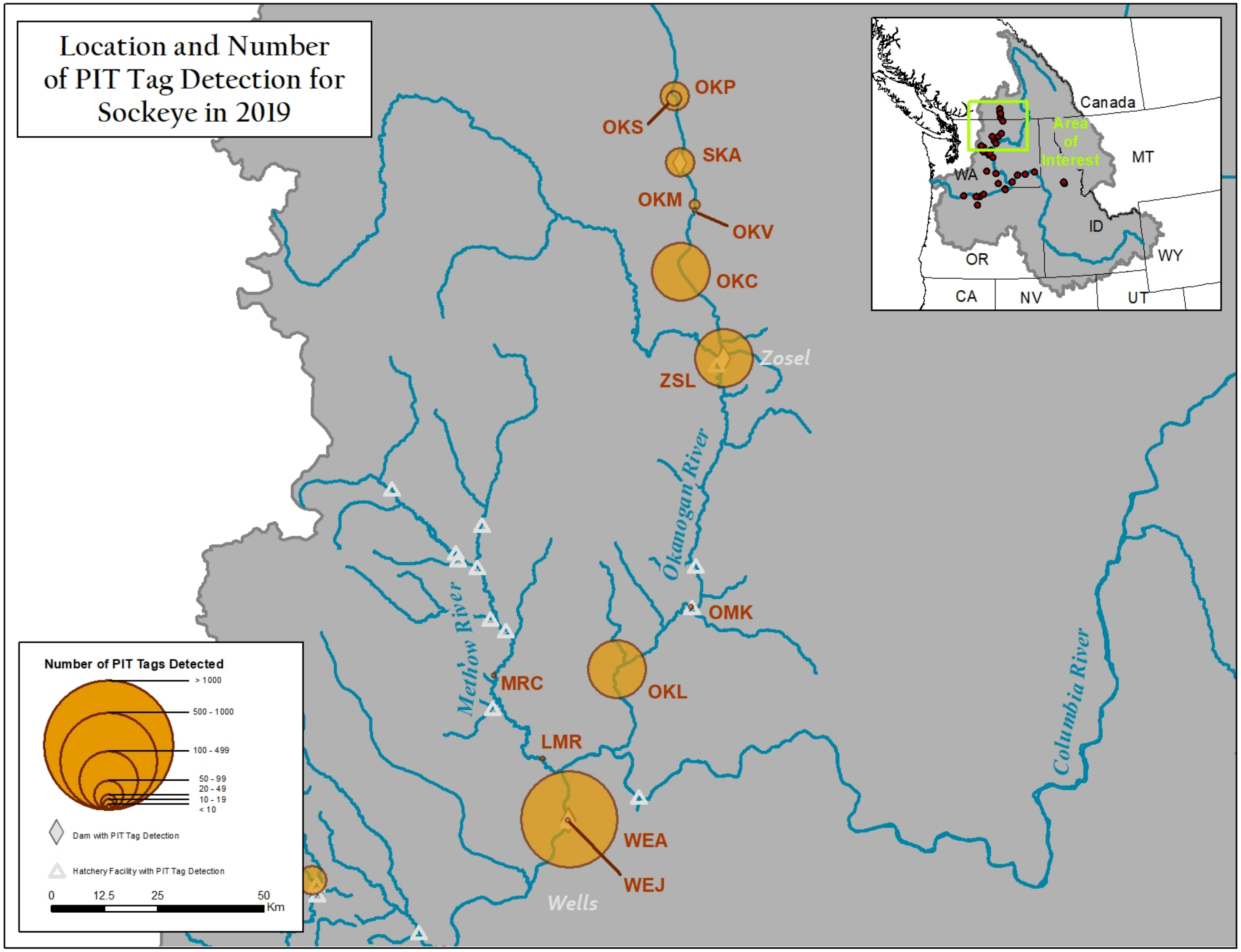


Figure B3. Map of Upper Columbia River (Wells Dam and above) detection sites and number of Sockeye Salmon detected 2019. Table B1 in the Appendix lists the PTAGIS sites' full name and the three-letter codes on this map.

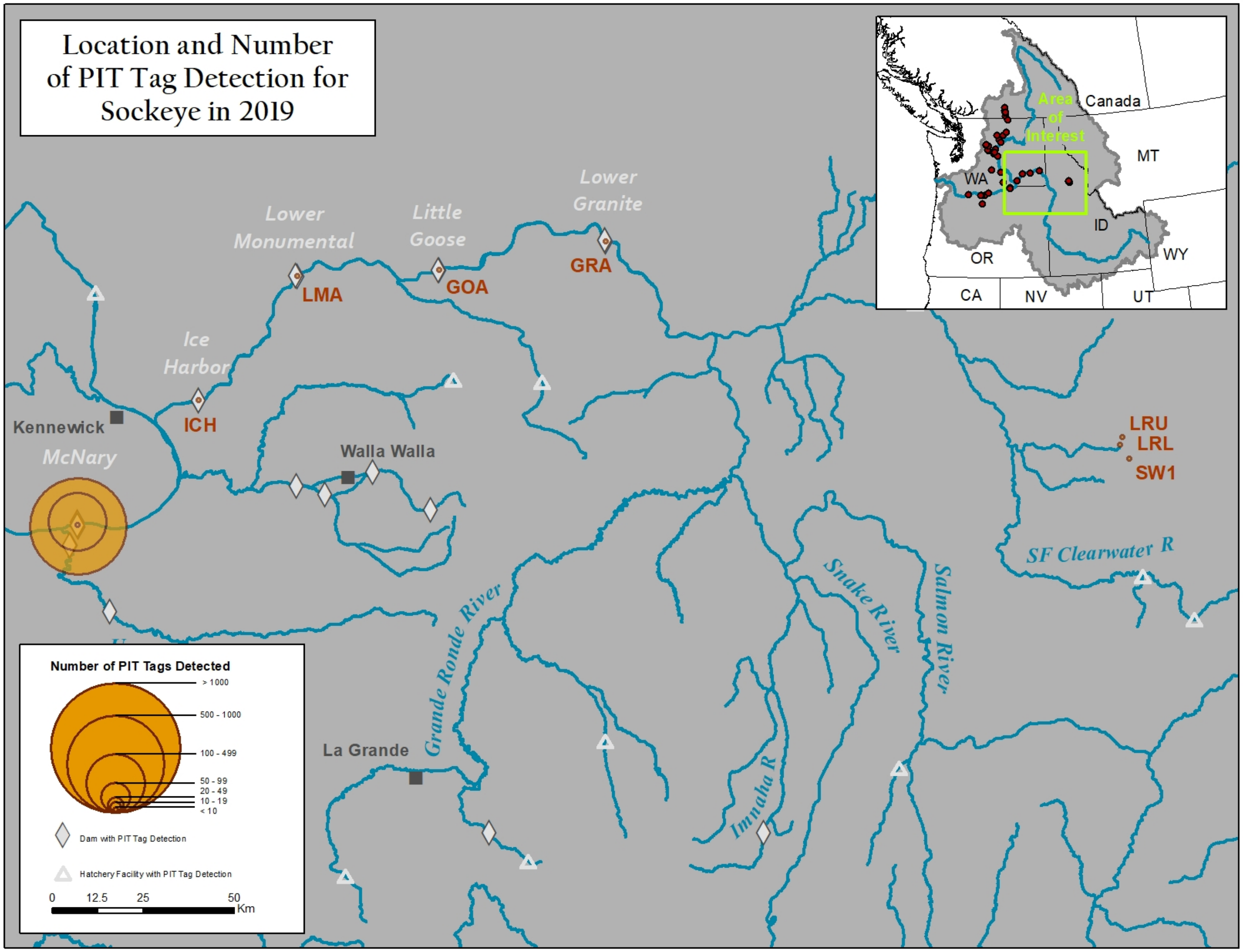


Figure B4. Map of Lower Snake River detection sites (Salmon River not included) and number of Sockeye Salmon detected in 2019. Table B1 in the Appendix lists the PTAGIS sites' full name and the three-letter codes on this map.

APPENDIX C

Q̓AWST'IK^{w} [Okanagan River] Sockeye Smolt out of Basin Survival: Purse Seining & PIT Tagging BY 2017

q̓awsitkʷ (Okanagan River) Sockeye Smolt Out of Basin Survival:
Purse Seining & PIT Tagging BY 2017

Prepared by:
Nicholas Yaniw,
Skyeler Folks, B.Sc.
Ryan Benson, M.Sc.

Okanagan Nation Aquatic Enterprises Ltd.

Prepared for:
Grant County Public Utility District, Chelan County Public Utility District,
and Columbia River Inter-Tribal Fisheries Commission

March 2020

Okanagan Nation Aquatic Enterprises Ltd.
101-3535 Old Okanagan Highway
Westbank, BC, V4T 3L7
Phone: 250-707-0095 Fax: 250-707-0166

Executive Summary

The q̓awsitkʷ[1] (Okanagan River) Sockeye Salmon (*Oncorhynchus nerka*) population is one of the last few remaining viable Sockeye Salmon stocks in the Columbia River Basin. Since 2003, the Okanagan Nation Alliance has conducted an experimental re-introduction of hatchery-reared Sockeye Salmon into q̓awst'ik'ʷt (Skaha Lake). Out of basin survival of both hatchery and natural Okanagan Sockeye smolts remains an important unanswered question. In 2012, Okanagan Nation Aquatic Enterprises (OAE) conducted a pilot study to evaluate Passive Integrated Transponder (PIT) technology to test the methodology, effectiveness, and survival and travel time of smolts as they migrate out of the Okanagan River basin. Since the initial pilot study, OAE has made improvements in both smolt capture and tagging techniques, resulting in the current smolt monitoring methodology.

In 2019, 9,082 smolts were successfully tagged and released during five tagging sessions between 25 April and 9 May. A total of 4,968 smolts were tagged at suwiw̓s. Tagging location was OSOYOL, in the north end of the lake, although fish were captured in the central basin of the lake and the area just north of the Highway 97 Bridge. Smolts were transported in fish totes on boats to the tagging location. The Osoyoos sessions lasted three days, from 25 April to 27 April. Survival probability for suwiw̓s smolts to Rocky Reach Dam was 0.66 (SE=0.04). Survival from release to Bonneville Dam was 0.34 (SE=0.07). Travel time from release to Rocky Reach Dam was approximately 21.4 days. The overall travel time (release to Bonneville) for Osoyoos smolts was 30.0 days.

An additional 4,114 smolts were successfully tagged at SKAHAL, at the southern end of q̓awst'ik'ʷt on 28 April and 9 May. Survival probability for q̓awst'ik'ʷt smolts to Rocky Reach Dam was much lower than suwiw̓s smolts at 0.33 (SE=0.03). Survival from release to Bonneville Dam was also lower at 0.24 (SE=0.11). Travel time from release to Rocky Reach Dam was approximately 19.3 days. The overall travel time (release to Bonneville) for all Skaha smolts was 27.1 days.

The aggregate population of smolts had a survival probability to Rocky Reach Dam of 0.51 (SE=0.03) and a survival probability to Bonneville Dam of 0.28 (SE=0.05). Travel time for the aggregate population averaged 20.7 days to Rocky Reach and 29.1 days to Bonneville.

Recommendations from the 2019 sampling year include the following:

- Capture smolts from both lakes. The minimum target will remain 10,000 smolts (5,000 from each lake).
- Purse seining will remain the primary capture method. The fyke net and Rotary Screw traps (RSTs) will be secondary capture methods, should the purse seine vessel be unavailable.
- McNary and John Day dam PIT detection data should continue to be excluded from future analyses. Survival and travel time estimates should only include Release to Rocky Reach Dam, Rocky Reach Dam to Bonneville Dam, and Release to Bonneville Dam intervals.
- Biosampling should only be conducted on random smolt collections from trawl catches, not smolt mortalities.

[1] throughout this report the proper Okanagan name written in N'Syilxcen will be used to identify locations

Acknowledgements

Okanagan Nation Aquatic Enterprises would like to thank the following people for their continued support:

Grant and Chelan Public Utility Districts (GCPUD and CCPUD), the Columbia River Inter Tribal Fisheries Commission (CRITFC) and the Bonneville Power Administration through the Columbia Basin Accords provided funding for this project. The Fish Passage Center, GCPUD, BPA and CRITFC were able to provide CSS PIT tags to support our efforts.

ONA staff that contributed to this project: Belinda Kruger, Sheena Hooley, Lynnea Wiens, Dave Tom, Andrew Clarke, Chelsea Mathieu, Casmir Tonasket, Edward Payne, Paul Snow, Alfred Snow, Darwyn Haller, Brenley Yuan, Samantha Davis, and Jamison Squakin. We wish to thank Osoyoos Indian Band for their support, and OIB Fisheries Technicians Lindsay George and Caine Krueger.

ONA also thanks the Baptiste Family (OIB) and Bob and Pat from the Sun & Sand RV Park (Okanagan Falls) for allowing access to private property.

Citation: Yaniw, N, S. Folks and R. Benson. 2020. q̓awsitkʷ (Okanagan River) Sockeye Smolt Out-of-Basin Survival: Purse Seining and PIT Tagging BY 2017. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 12 pp.

Table of Contents

List of Tables

List of Figures

Table of N'syilxcen Place Names

N'syilx'cin Place Name	(Okanagan-English Translation)
nx̌ʷəntkʷitkʷ	Columbia River
q̓awsitkʷ	Okanagan River
q̓awst'ik'ʷt, also known as t̓iwcən	Skaha Lake
suwiw̓s	Osoyoos Lake
sx̌wəx̌wnikw	Okanagan Falls
akspaqmix	Vaseux Lake
nʕaylintən	McIntyre Dam
akɬxʷminaʔ	Shingle Creek

1.0 Introduction

1.1 Project Background

The q̓awsitkʷ (Okanagan River) Sockeye Salmon (*Oncorhynchus nerka*) population is one of the last few remaining viable Sockeye Salmon stocks in the Columbia River Basin. In response to concerns over declining stocks in the Okanagan Basin, the Okanagan Nation Alliance (ONA) commenced Sockeye Salmon re-introduction into q’awst’ik’ʷt (Skaha Lake) beginning in 2003 (Wright and Smith 2003). Sockeye eggs collected from q’awsitkʷ broodstock are hatchery reared then released into q’awst’ik’ʷt where they rear for one year before migrating to nx̌ʷəntkʷitkʷ (Columbia River) and the Pacific Ocean as smolts (Stefanovic et al. 2019). Two main unanswered questions are out of basin survival of both hatchery and natural Okanagan smolts, and smolt-to-adult-ratios (SAR) for returning adults. The tri-partite research group comprised of the Columbia River Inter-Tribal Fish Commission (CRITFC), ONA, and the Canadian Department of Fisheries and Oceans (DFO) are mutually interested in determining the limiting factors affecting the abundance of Okanagan Sockeye. Broadly, the factors of concern are the freshwater outmigration, marine survival, and freshwater migratory return.

To determine freshwater outmigration survival, Passive Integrated Transponder (PIT) tag technology has been used by researchers and fisheries managers in the nx̌ʷəntkʷitkʷ Basin to mark and track anadromous fish since 1987. Currently, a comprehensive network of PIT arrays, tagging programs, and a data repository is operational in the Basin. The system is managed by the Pacific States Marine Fisheries Commission and funded by Bonneville Power Administration (BPA) (PTAGIS 1999). In 2009, CRITFC and ONA installed a PIT antenna in q’awsitkʷ upstream of suwiw̓s (Osoyoos Lake) to track adults tagged at Wells Dam to the spawning grounds (Fryer et al. 2012). The existing PIT network allows us to track tagged smolt survival rates and travel times during outmigration.

In 2012 Okanagan Nation Aquatic Enterprises (OAE) commenced with a trial PIT tagging program, releasing 534 tagged smolts (Benson et al. 2013). A number of logistical and operational recommendations were made, including tagging smolts from both q’awst’ik’ʷt and suwiw̓s, and a total of 4,018 tags were released in 2013 (Benson et al. 2014). PIT tagged sample sizes have increased each year: 5,054 in 2014, 7,176 in 2015; 10,241 in 2016; 11,588 in 2017; and 10,943 in 2018 (Folks et al. 2016a; 2016b; 2017; Yaniw & Benson 2018).

In 2016, OAE piloted purse seining in both lakes as a method of capturing smolts (Benson 2016; Folks et al. 2016b). Based on these results and the recommendation of the Canadian Okanagan Basin Technical Working Group (COBTWG), the direction was to rely solely on purse seining as a capture platform. As in 2018, purse seining was conducted in both suwiw̓s and q̓awst’ik’ʷt. This was based on the assumption that q’awst’ik’ʷt and suwiw̓s Sockeye populations would not be sufficiently mixed in suwiw̓s during the sampling period. One of OAE’s objectives was to tag and monitor both populations.

This report summarizes the capture and tagging program for the 2019 season (2017 Broodyear). Tagging targets of at least 10,000 (5,000 from each lake) were set to optimize survival estimates to Lower nx̌ʷəntkʷitkʷ PIT detection sites.

1.2 Study Area

q’awsitkʷ is a major tributary to nx̌ʷəntkʷitkʷ and has an approximate length of 185 km (37 km Canadian portion, 148 km US portion). q’awst’ik’ʷt smolts leave the lake and pass through Skaha Lake Outlet Dam located at sx̌wəx̌wnikw (Town of Okanagan Falls), then migrate down q’awsitkʷ through akspaqmix (Vaseux Lake), nʕaylintən (McIntyre Dam), and suwiw̓s (Figure 1). Sockeye that rear in the North Basin of suwiw̓s begin outmigration at similar times as q’awst’ik’ʷt sockeye smolts. Both travel downstream and pass through Osoyoos Lake Narrows, a feature that connects the Central and North Basin of the lake. From suwiw̓s the q’awsitkʷ flows south through Okanogan County, past the towns of Okanogan and Omak. q’awsitkʷ enters nx̌ʷəntkʷitkʷ from the north, 8 km east of Brewster, between Wells Dam (downstream) and Chief Joseph Dam (upstream). The reservoir behind Wells Dam, into which q’awsitkʷ empties, is called Lake Pateros. Smolts must migrate through nine hydroelectric dams to reach the Pacific Ocean.

For the 2017 brood year, 1,222,602 hatchery-reared fry were released into q’awst’ik’ʷt via akɬxʷminaʔ (Shingle Creek) (Stefanovic et al. 2019). In addition, an estimated 3,100 - 5,600 natural Sockeye spawned in Penticton Channel in 2017 (Yaniw and Benson 2019). Therefore, smolts outmigrating from q’awst’ik’ʷt in 2019 were of mixed natural and hatchery origin.

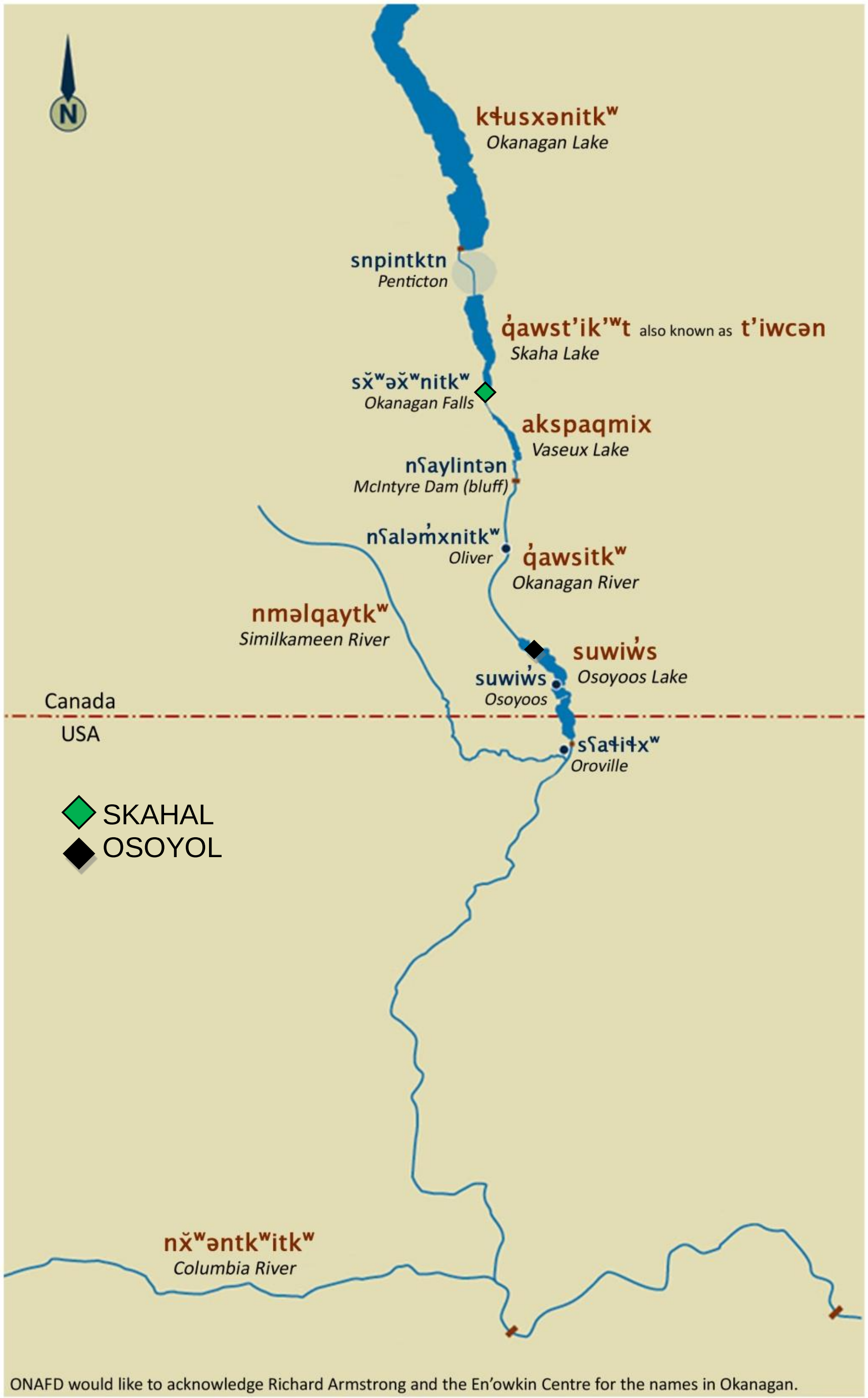


Figure 1. q'awsitkw juvenile PIT tagging locations in 2019.

1.3 Project Objectives

The main objective was to PIT tag a minimum of 5,000 smolts from each lake, q̓awst'ik'ʷt and suwiw̓s, to determine Sockeye smolt out of basin survival and travel time. Current objectives have been refined from the 2012 pilot study (Benson et al. 2013). Specific objectives included:

1. PIT tag a minimum of 5,000 hatchery- and natural-origin smolts from each lake population; q'awst'ik'ʷt and suwiw̓s, for a total of 10,000.

2. Continue to refine smolt capture techniques using a purse seine.

3. Monitor PIT tagged smolt survival and travel rates to the nx̌ʷəntkʷitkʷ estuary.

4. Synthesize an efficient study design and data management protocol that will address out of basin survival.

2.0 Methods

2.1 Smolt Capture

ONA purse seined suwiw̓s and q̓awst'ik'ʷt to capture smolts for PIT tagging. We used a 8.5 m (28') long purse seiner fishing with a 183 m (600') long seine net with 1.27 cm (1/2") knotted mesh. The purse seiner was able to fish up to a depth of 12 m (40'). Purse seining concentrated in the central basin and the southern end of the north basin of suwiw̓s where the majority of Sockeye smolts were congregating. Purse seining in Skaha Lake was concentrated in the south end of the lake, as has been done in previous years.

2.2 PIT Tagging Procedures

.

We used procedures outlined by PTAGIS (1999) and Biomark (2012) for marking smolts. We deployed Biomark HPT 12 PIT tags (134.2 kHz) measuring 12.5 mm in length. Tags were implanted with the MK-25 Rapid Implant Gun along with HPT9 pre-loaded sterile needles manufactured by Biomark. Fish were initially held in submerged net pens or oxygenated fish totes. Fish were then removed from holding pens and placed in a 45-litre cooler containing a 40 mg/l solution of tricaine methanesulfonate (MS 222). Fish were kept in the solution until they lost equilibrium (approximately 2-3 minutes), and then transferred to a smaller bin. These smaller bins contained a lower concentration of MS 222, enabling fish to partially recover. This system was an improvement on previous years; it allowed the fish to be processed with minimal handling and stress. Unlike previous years, individual smolts were not measured for fork length and general body condition/descaling. This step was eliminated in an effort to reduce sampling time and stress on the fish. Size constraints were set for tagged fish in 2019. Only fish between 70-120 mm were tagged; smaller fish would be more likely to experience tagging mortality, and larger fish were likely to be kokanee.

Tagging procedures did not change from previous years, the tagging needle was inserted on the right side between the pectoral fin and lateral line, and then the trigger was depressed until the tag was inserted into the incision hole. The tagged smolt was scanned and logged using an HPR Plus reader (Biomark®).

The HPR was connected to a Panasonic tablet, which logged and saved each tag number into a P4 software tagging session file. This configuration allowed taggers to enter bio-data and tagging comments directly into the tagging file without the need for post-season data entry. Following processing, each tagged fish was placed in a bucket of aerated water until fully recovered. All tagged smolts were returned to the holding pens and released back into the lake the same day, typically between 20:00 and 21:00 to reduce predation. Fish were released in the North Basin, at OSOYOL, in suwiw̓s. In q̓awst'ik'ʷt, smolts were also released at the tagging site, SKAHAL. All post-tagged smolt mortalities were removed and the PIT tag numbers from fish mortalities were deleted from the tagging file to improve accuracy of survival estimates.

Survival and travel time calculations were determined by tagging and observation queries through the PTAGIS database and subsequently run through version 4.19.8 of PITPro.

3.0 Results

3.1 Smolt Capture

In 2019, we captured 45.3% (n=4,114) of smolts in q̓awst'ik'ʷt and 54.7% (n= 4,968) in suwiw̓s. All suwiw̓s smolts were captured in the Central portion of the lake (the Central Basin and the area just upstream of the Highway 97 Bridge at the Narrows); all Skaha smolts were captured in the southern end of the Lake, just upstream of Skaha Dam.

Following capture and tagging, smolts were held in net pens to allow the fish to recover, monitor acute tagging mortality and to remove mortalities from the tagged population. A random sample of smolts was collected directly from purse seine catches for biosampling. In total, 749 smolts were biosampled (Skaha, n = 399; Osoyoos, n = 350). Skaha smolts had a mean fork length of 10.4 cm and mean weight of 12.4 g. Osoyoos smolts were smaller, with a mean fork length of 10.1 cm and mean weight of 11.2 g. To determine origin, thermal marks from otoliths were checked. Amongst suwiw̓s smolts, 98.6% (n=345) were natural origin. The rate of natural origin was much lower for q̓awst'ik'ʷt smolts, at 47.9% (n= 191).

3.2 PIT Tagging Results

9,082 smolts were successfully tagged and released during 5 tagging days: 25-27 April 2019 at OSOYOL (Baptiste property, north end of suwiw̓s), and 28 April and 9 May 2019 at SKAHAL (South End of q̓awst'ik'ʷt). From 28 April to 10 May, the purse seiner fished each day on in q̓awst'ik'ʷt but only successfully captured fish on 28 April and 9 May. Tagging effort has been summarized (Table 1).

Table 1. Summary of Okanagan Sockeye smolt PIT tagging effort, 2019.

Date	OSOYOOS	SKAHA
25-Apr-19	282	
26-Apr-19	4,295	
27-Apr-19	391	
28-Apr-19		3,169
9-May-18		945
TOTAL	**4,968**	**4,114**

3.2.1 Survival

Estimates of survival from release to Rocky Reach Dam, Rocky Reach to Bonneville, and Release to Bonneville were calculated for both release groups. Aggregate survival was also estimated (Table 2). Aggregate survival has been compared to previous years. Estimated survival from release to Bonneville (0.28) was the lowest since 2016 (Table 3.)

Table 2. Survival for PIT tagged q'awsitk^{w} (Okanagan River) Sockeye smolts, 2019.

River Reach Interval	Survival (Osoyoos)	SE	Survival (Skaha)	SE	Survival (Aggregate)	SE
Release to Rocky Reach	0.66	0.04	0.33	0.03	0.51	0.03
Rocky Reach to Bonneville	0.51	0.11	0.71	0.32	0.55	0.11
Release to Bonneville	0.34	0.07	0.24	0.11	0.28	0.05

Table 3. Comparison of annual survival for PIT tagged q'awsitkw (Okanagan River) Sockeye smolts, 2013-2019. Standard Errors of mean presented in brackets. Survival from Rocky Reach to Bonneville was not calculated between 2013-2018.

River Reach Interval	2013	2014	2015	2016	2017	2018	2019
Release to Rocky Reach	0.48 (0.03)	0.57 (0.08)	0.42 (0.02)	0.56 (0.02)	0.67 (0.03)	0.62 (0.02)	0.51 (0.03)
Rocky Reach to Bonneville	-	-	-	-	-	-	0.55 (0.11)
Release to Bonneville	0.48 (0.33)	0.03 (0.08)	0.44 (0.14)	0.21 (0.04)	0.35 (0.11)	0.41 (0.13)	0.28 (0.05)

* survival estimates are pooled across lakes and sites, representing an aggregate survival for all Okanagan Basin smolts.

3.2.2 Travel Time

Estimates of travel time were calculated for Osoyoos smolts, Skaha smolts and the total population. Aggregate travel time from release to Rocky Reach Dam was approximately 20.7 days (Table 4). Aggregate travel time from release to Bonneville Dam was approximately 29.1 days. Travel time to Rocky Reach was approximately 21.4 days for Osoyoos smolts and 19.3 days for Skaha smolts. Travel time to Bonneville was approximately for 30.0 days for Osoyoos smolts, and 27.1 days for Skaha smolts. This faster travel time for Skaha smolts is likely due to fish being larger than Osoyoos smolts, resulting in better swimming performance. Overall travel time from Release to Bonneville was the highest on record (Table 5).

Table 4. Mean Harmonic Travel Time for PIT tagged q'awsitk^{w} (Okanagan River) Sockeye smolts, 2019.

River Reach Interval	Osoyoos Travel Time (days)	SE	Skaha Travel Time (days)	SE	Aggregate Travel Time (days)	SE
Release to Rocky Reach	21.4	0.14	19.3	0.25	20.7	0.13
Rocky Reach to Bonneville	8.5	0.15	8.2	0.15	8.4	0.11
Release to Bonneville	30.0	0.20	27.1	0.31	29.1	0.17

Table 5. Comparison of Harmonic mean travel time for PIT tagged q'awsitkw (Okanagan River) Sockeye smolts, 2013-2019. Standard Errors of mean presented in brackets. Travel Time from Rocky Reach to Bonneville was not estimated from 2013-2018.

River Reach Interval	2013	2014	2015	2016	2017	2018	2019
Release to Rocky Reach	19.3 (0.25)	15.9 (0.19)	16.2 (0.14)	14.2 (0.13)	10.2 (0.08)	13.0 (0.13)	20.7 (0.13)
Rocky Reach to Bonneville	-	-	-	-	-	-	8.4 (0.11)
Release to Bonneville	29.0 (0.74)	23.2 (0.56)	26.6 (0.27)	23.4 (0.29)	17.7 (0.19)	19.7 (0.27)	29.1 (0.17)

* travel time estimates are pooled across lakes and sites, representing an aggregate survival for all Okanagan Basin smolts.

4.0 Discussion and Recommendations

In 2019, 4,968 smolts were tagged from suwiw̓s, and 4,114 from q̓awst'ik'ʷt. This total of 9,082 tagged smolts is slightly lower than the optimal sample size needed to estimate survival, but still provides suitable information. Overall survival to Bonneville was the lowest since 2016. Travel time (both from release to Rocky Reach and release to Bonneville) was the highest seen in any year of smolt PIT monitoring. One potential explanation for the relatively low survival is the lower than average discharge in q̓awsitkʷ. The river flow was 10 - 75 cms lower than typically measured during the same time frame, back to 2016 (Environment Canada 2020). In addition, the Okanagan Basin experienced extreme spring flooding in 2017 and 2018. The low flow likely increased smolt travel time which would increase overall mortality. Higher than average travel time supports this hypothesis.

Survival estimates are reliable from release to Rocky Reach, and release to Bonneville. However, estimates from Rocky Reach to McNary and McNary to John Day are typically unreliable, with survival probability often exceeding 1.0. Due to the configuration of PIT arrays at McNary and John Day dams, detection probabilities have been consistently low resulting in unreliable survival estimates for the associated reaches (DeHart 2018). As a result, McNary and John Day dam detection results were removed from the analysis in 2019.

In 2017, we captured solely within suwiw̓s, to test the assumption q'awst'ik'ʷt and suwiw̓s smolts would be thoroughly mixed and that at least 10% of total tagged would be q'awst'ik'ʷt origin. This assumption proved to be incorrect, possibly due to the extremely low hatchery production in BY 2015 (Folks et al. 2017; Stefanovic et al. 2016), but also because smolt capture occurred before outmigration had started, when smolts were still staging. In order to capture trends for q'awst'ik'ʷt, in 2018 we targeted smolts from both lakes equally (Yaniw & Benson 2018) and continued this approach in 2019.

Recommendations for future monitoring include:

- Capture smolts from both lakes. The minimum target will remain 10,000 smolts (5000 from each lake).

- Purse seining will remain the primary capture method. The fyke net and RSTs should be a back-up capture method, only if the purse seine vessel is unavailable.

- McNary and John Day dam PIT detection data should continue to be excluded from future analyses. Survival and travel time estimates should only include Release to Rocky Reach Dam, Rocky Reach Dam to Bonneville Dam, and Release to Bonneville Dam intervals.

- Biosampling should only be conducted on random smolt collections from trawl catches, not smolt mortalities.

5.0 References

Benson, R. 2016. Okanagan Sockeye smolt migration from suwiw̓s [Osoyoos Lake] and q̓awst'ik'ʷt [Skaha Lake] 2014 brood year. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 23 pp.

Benson, R., S. Folks, A. Stevens, and R. Bussanich. 2013. Brood year 2011 – Sockeye smolt out of basin survival pilot study in q'awsitkʷ (Okanagan River). Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 37 pp.

Benson, R., S. Folks, A. Stevens, and R. Bussanich. 2014. q̓awsitkʷ (Okanagan River) Sockeye Smolt Out-of-Basin Survival: PIT and Acoustic Tagging 2013. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 17 pp.

Biomark 2012. Fish tagging methods. Retrieved online November 2013: http://www.biomark.com/Documents%20and%20Settings/67/Site%20Documents/PDFs/Fish%20Tagging%20Methods.pdf

DeHart, M. 2018. Okanogan River sockeye passage timing, travel times, juvenile survival, and smolt-to-adult returns, migration years 2013-2018. Technical Memorandum. Fish Passage Center, Portland, OR. 13 pp.

Environment Canada. 2020. https://wateroffice.ec.gc.ca/index_e.html

Folks, S, R. Benson, A. Stevens, and R. Bussanich. 2016a. q̓awsitkʷ (Okanagan River) Sockeye Smolt Out-of-Basin Survival: PIT Tagging 2014 & 2015. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 17 pp.

Folks, S, R. Bussanich, A. Stevens, and M. Teather. 2016b. q̓awsitkʷ (Okanagan River) Sockeye Smolt Out-of-Basin Survival: PIT Tagging 2016. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 12 pp.

Folks, S, M. Teather, and R. Benson. 2017. q̓awsitkʷ (Okanagan River) Sockeye Smolt Out-of-Basin Survival: Purse Seining and PIT Tagging BY 2015. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 16 pp.

Fryer, J. K., H. Wright, S. Folks, K. D. Hyatt, and M. M. Stockwell. 2012. Limiting Factors of the Abundance of Okanagan and Wenatchee Sockeye Salmon in 2011. Columbia River Inter-Tribal Fish Commission Technical Report for BPA Project 2008-503-00

PTAGIS (1999) PIT tag Marking Procedures Manual version 2.0: Retrieved online November 2013: http://php.ptagis.org/wiki/images/e/ed/MPM.pdf

Stefanovic, D., R. Benson, C. Fuller, and L. Wiens. 2016. Collection and Rearing of Okanagan Sockeye Salmon for the Skaha Re-introduction Program: Brood Year 2015 Annual Report. Prepared as part of the Skaha Lake Sockeye Salmon Re-Introduction Monitoring and Evaluation Program: Brood Year 2015. Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC.

Stefanovic, D., Fuller, C., Benson, R., and Wiens L. 2019. Collection and Rearing of Okanagan Sockeye Salmon for the Skaha Re-introduction Program: Brood Year 2017. Prepared as part of the Skaha Lake Sockeye Salmon Re-Introduction Monitoring and Evaluation Program: Brood Year 2017. Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC.

Wright, R.H. and H. Smith (Ed). 2003. Management plan for experimental reintroduction of sockeye into Skaha Lake: Proposed implementation, monitoring and evaluation. Prepared by Okanagan Nation Alliance Fisheries Department, Westbank, BC.

Yaniw, N. and R. Benson. 2018. q̓awsitkʷ (Okanagan River) Sockeye Smolt Out-of-Basin Survival: Purse Seining and PIT Tagging BY 2016. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 13 pp.

Yaniw, N., and R. Benson. 2019. q̓awst'ik'ʷt (Skaha Lake) Nerkid Spawner Enumeration and Biological Sampling 2017. Prepared as part of the Skaha Lake Sockeye Salmon Re-Introduction Monitoring and Evaluation Program: Brood Year 2017. Okanagan Nation Alliance Aquatic Enterprises Ltd., Westbank, BC.

APPENDIX D

Fish Passage Center Memoranda regarding 2019 Okanagan Sockeye Smolt Survival

FISH PASSAGE CENTER

847 NE 19th Avenue, #250, Portland, OR 97232
Phone: (503) 833-3900 Fax: (503) 232-1259
www.fpc.org/
e-mail us at fpcstaff@fpc.org

MEMORANDUM

To: Jeff Fryer, CRITFC

From: Michele DeHart

Date: December 20, 2019

Re: Okanogan River sockeye passage timing, travel times, juvenile survival, and smolt-to-adult returns, migration years 2013-2019.

In 2013, the Comparative Survival Study (CSS) Oversight Committee was approached with a request to explore the feasibility of adding a long-term monitoring group for sockeye trapped and released from the Okanogan River. Upon the request from the Okanagan Nation Alliance (ONA) and the Columbia River Inter-tribal Fish Commission (CRITFC), the CSS Oversight Committee has transferred surplus PIT-tags to the ONA since 2013 to supplement PIT-tagging efforts at Skaha and Osoyoos lakes in the spring. Over the years, these efforts have been supported and/or funded by several agency and tribal organizations, including: Department of Fisheries and Oceans Canada, CRITFC, Chelan and Grant PUDs, and the ONA.

Based on the results from 2013 and 2014, the CSS Oversight Committee began including estimates of overall SARs from this group (Okanogan River sockeye) in their annual report. In response to your request, we have updated analyses from previous year's data requests to include estimates of juvenile survival, timing, and travel time for the 2019 PIT-tagged sockeye smolts. In addition, we provide updated estimates of overall SARs from migration years 2013-2017, with adults detected at Bonneville Dam and Wells Dam through September 15, 2019. Below are results from these updated analyses, followed by more specific details.

- Estimating juvenile survival from Release to Rocky Reach Dam (Release-RRH) has been possible for all years of tagging (2013-2019). Juvenile survival for Release-RRH in 2019 was 0.51 (95% CI: 0.47-0.55).

- Reliable estimates of juvenile sockeye survival beyond Rocky Reach Dam has not always been possible and, therefore, it has not always been possible to estimate survival from Release to McNary Dam. However, we were able to estimate survival from Release-MCN in 2019, which was 0.42 (95% CI: 0.25–0.60).
- A total of 352 PIT-tagged Okanogan River sockeye juveniles were detected at Zosel Dam and 54 were detected at the Okanogan Channel in 2019. We were able to estimate survival from release to ZSL in 2019, which was 0.92 (95% CI: 0.56-0.99). Detection probability at ZSL in 2019 was 0.04. Due to the low number of detections at OKC, we were unable to estimate survival from release to OKC in 2019.
- The 2019 CSS Annual Report provides estimates of smolt-to-adult return (SAR) rates for Rocky Reach-to-Bonneville (RRE-to-BOA) and Rocky Reach-to-Wells (RRE-to-WEA) for migration years 2013-2017 and McNary-to-Bonneville (MCN-to-BOA) and McNary-to-Wells (MCN-to-WEA) for migration years 2014-2017. The RRE-to-BOA SARs for 2013-2017 have ranged from 0.12% (95% CI: 0.05-0.19%) to 8.05% (95% CI: 6.82-9.31%). The MCN-to-BOA SARs for 2014-2017 ranged from 0.12 (95% CI: 0.05-0.20%) to 2.90 (95% CI: 2.24-3.61%).

Methods

Timing and Travel Time

Juvenile passage timing and fish travel times were estimated for 2013-2019 out-migrants based on PIT-tag detections at various dams within the Rocky Reach to Bonneville Dam reach. For each year, we estimated cumulative juvenile passage timing based on PIT-tag detections at Rocky Reach (RRE), McNary (MCN), John Day (JDA), and Bonneville (BON) dams. Daily PIT-Tag detections at each of these projects were summed and adjusted based on the average proportion of flows that passed through the powerhouse. Minimum, median, and maximum fish travel times were estimated from release to detection at each dam in the reach that has detection capabilities. Due to a high number of PIT-tag detections in 2015, 2018, and 2019, we also include estimates of travel time and passage timing to Zosel Dam on the Okanogan River for these two migration years. Finally, we provide estimates of travel time and passage timing to Okanogan Channel in 2018 and 2019.

Juvenile Survival

For each migration year, we attempted to estimate smolt survival and associated variance estimates for all PIT-tagged juvenile sockeye from their release in the Okanogan Basin to MCN. We relied on juvenile detections at RRE, MCN, JDA, and BON dams, as well as downstream of Bonneville Dam using specialized trawl equipment for PIT-tag detection. Using recapture data from fish detected at these sites, single-release mark-recapture survival estimates were generated using the Cormack-Jolly-Seber (CJS) methodology as described by Burnham et al. (1987) with the Mark program (software available free from Colorado State University) (White and Burnham 1999). In addition to estimating individual reach survivals (e.g., Release-RRE and RRE-MCN) we also attempted to estimate combined reach survival (i.e., Release-MCN) by multiplying

individual reach estimates and determining the approximate variance using the delta method (Burnham et al. 1987).

Over the years, wild Okanogan Basin sockeye have been tagged and released from various sites, including: Osoyoos Lake Narrows Highway 3 Bridge (OSOYBR), Osoyoos Lake (OSOYOL), Osoyos Lake at Haynes Point Campground (OSOYHA), Skaha Dam or just below (up to 0.5 km) (SKA or SKATAL), and Skaha Lake (SKAHAL). Using the same methodologies outlined above, we estimated individual (e.g., Release-RRE and RRE-MCN) and combined reach survivals (Release-MCN) for each of these release sites, by migration year.

Finally, in response to your request, we investigated whether there were enough PIT-tag detections of juvenile Okanogan River sockeye at Zosel Dam (ZSL) and the Okanogan Channel (OKC) to estimate survival from release to each of these two interrogation sites.

Smolt to Adult Survival (SARs)

With the complete return of adults from the 2013-2016 out-migrations and the nearly complete return from the 2017 out-migration, we were able to estimate Smolt-to-Adult Returns (SARs). Given the juvenile detection capabilities at RRE and adult detection capabilities at Bonneville Dam (BOA) and McNary Dam (MCA), we estimated SARs for four different reaches: 1) juveniles at RRE to adult returns at BON (RRE-to-BOA), 2) juveniles at RRE and adult returns at WEA (RRE-to-WEA), 3) juveniles at MCN to adult returns at BON (MCN-to-BOA), and juveniles at MCN and adult returns at WEA (MCN-to-WEA). The methodology for estimating SARs is discussed in Chapter 4 of the CSS Annual Report (McCann et al., 2019). Estimates of SARs that are provided in McCann et al. (2019) included adults detected at BOA and WEA through September 15, 2019.

Results

To put out-migration conditions into context, Table 1 and Figure 1 provide the average spring flow volumes (April 15–June 30) for the Upper Columbia River (as measured at Priest Rapids Dam), along with the average spring spill proportions at each of Wells, Rocky Reach, Rock Island, Wanapum, and Priest Rapids dams in 2013-2019.

Table 1. Average spring (April 15–June 30) flow at Priest Rapids Dam (PRD) and average spill proportion at Wells (WEL), Rocky Reach (RRH), Rock Island (RIS), Wanapum (WAN), and PRD dams in 2013-2019.

Migration Year	Average Flow at PRD (Kcfs)	Average Spill Proportion				
		WEL	RRE	RIS	WAN	PRD
2013	186.6	0.11	0.10	0.15	0.26	0.29
2014	189.4	0.13	0.10	0.21	0.31	0.35
2015	114.3	0.08	0.04	0.14	0.15	0.23
2016	156.2	0.11	0.08	0.17	0.19	0.27
2017	238.0	0.18	0.32	0.36	0.47	0.53
2018	235.5	0.27	0.28	0.32	0.41	0.43
2019	126.8	0.10	0.06	0.14	0.21	0.23

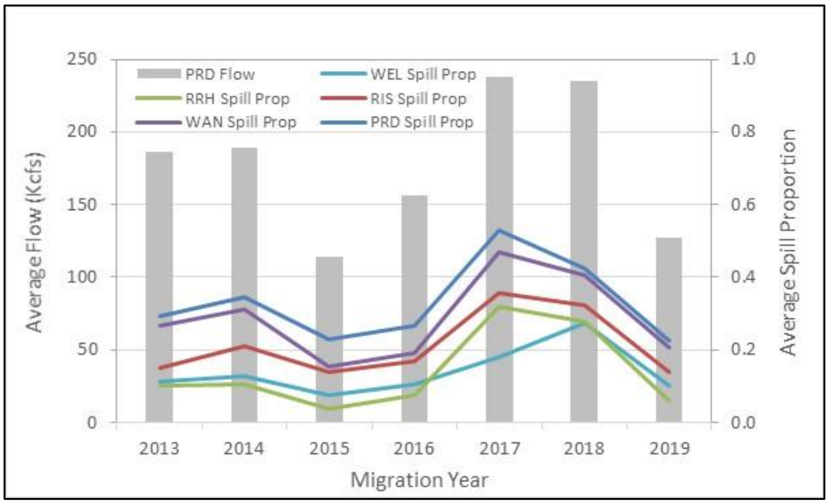


Figure 1. Average spring (April 15–June 30) flow at Priest Rapids Dam (PRD) and average spill proportion at Wells (WEL), Rocky Reach (RRH), Rock Island (RIS), Wanapum (WAN), and PRD in 2013-2019.

Travel Time and Timing

Over the years included in this analysis, PIT-tagging of juvenile sockeye in the Okanogan River Basin has varied, in both timing and the number of PIT-tags that have been released (Table 2). It is important to consider the variability in the timing of PIT-tagging efforts when assessing passage timing between years.

Table 2. Timing of PIT-tagging efforts and number of PIT-tagged Okanogan River Basin sockeye smolts released in migration years 2013-2019.

Migration Year	PIT-tagging Dates (Min and Max)	Total Tags Released
2013	Apr. 12-May 7	4,018
2014	Apr. 7-May 5	5,055
2015	Apr. 9-May 6	7,176
2016	Mar. 22-Apr. 29	10,238
2017	Apr. 26-May 3	11,588
2018	Apr. 16-18, May 2-9	10,943
2019	Apr. 25-May 9	9,082

Travel Time

Estimates of minimum, median, and maximum travel times from release to RRE, MCN, JDA, and BON dams are provided below (Table 3). These travel times are based on fish that were detected at each of the sites in their respective year of out-migration. Also provided are estimates of the 95% confidence limits around the estimated median travel time.

Due to a relatively high number of PIT-tag detections in 2015, 2018, and 2019, travel times to ZSL are also provided for these three years (Table 3). It is important to note that, in 2018, the detection system at ZSL was not installed until April 25th, a week after tagging in Osoyoos Lake concluded. Therefore, many earlier fish tagged and released from Osoyoos Lake may have been missed at this detection site. In addition, the last detection at ZSL in 2018 was May 22nd, which is around the same time that flooding impacted the antenna and ultimately led to it being partially pulled from the water. Therefore, late migrating fish may have been missed at this site.

Finally, we estimated travel times from release to OKC in 2018 and 2019, based on PIT-tag detections (Table 3). These travel time estimates are based on the fish tagged and released at Skaha Lake only, as the OKC detection site is upstream of Osoyoos Lake.

Table 3. Travel times from release to juvenile detection site of PIT-tagged Okanogan River Basin sockeye smolts from migration years 2013 to 2019. PIT-tag detection sites include: Okanogan Channel (OKC), Zosel (ZSL), Rock Reach (RRE), McNary (MCN), John Day (JDA), and Bonneville (BON) dams.

Migration Year	Detection Site	Number Detected	Release to Project Travel Time (days)			95% Confidence Limits	
			Min	Med	Max	Lower	Upper
2013	RRE	607	5.6	19.4	56.3	18.7	19.9
	MCN	181	10.0	23.7	63.7	22.1	24.7
	JDA	90	12.0	25.5	62.3	24.0	27.2
	BON	84	16.3	28.2	57.3	26.6	29.0
2014	RRE	812	4.4	16.7	40.6	16.4	17.4
	MCN	421	8.1	19.4	54.8	18.8	20.0
	JDA	155	13.0	23.0	67.5	22.1	24.0
	BON	108	11.8	22.7	59.0	20.8	24.6
2015	ZSL	63	4.7	14.2	31.0	12.0	16.0
	RRE	1,334	5.9	15.7	39.4	15.4	16.1
	MCN	143	14.0	23.2	43.0	21.6	24.0
	JDA	73	17.0	24.5	49.5	23.0	25.7
	BON	367	16.9	25.9	48.2	24.9	26.4
2016	RRE	2,632	3.8	16.7	49.5	16.4	17.4
	MCN	574	8.0	21.4	51.5	20.6	22.3
	JDA	206	11.2	22.0	71.1	21.0	23.0
	BON	511	12.4	23.7	58.9	23.3	24.6
2017	RRE	2,152	4.5	10.5	61.4	10.4	10.6
	MCN	489	8.1	15.0	31.5	14.2	15.4
	JDA	621	9.9	15.9	40.1	15.2	16.0
	BON	446	10.8	17.8	46.4	17.5	18.4
2018	OKC*	13	0.9	3.1	7.7	1.8	3.7
	ZSL	32	7.1	11.2	33.1	10.3	12.3
	RRE	1,845	4.8	14.9	54.3	14.6	15.7
	MCN	684	7.8	19.1	43.6	18.4	19.7
	JDA	289	10.1	17.1	42.5	15.7	18.3
	BON	481	11.0	21.4	46.0	20.8	21.9
2019	OKC*	54	2.6	6.5	155.9	6.5	7.2
	ZSL	342	7.9	24.4	45.3	23.7	24.5
	RRE	1,415	6.4	19.7	85.6	19.6	20.0
	MCN	190	16.0	24.1	48.1	23.8	24.8
	JDA	150	20.3	27.7	53.2	27.	29.1
	BON	666	16.6	28.5	66.9	28.0	28.7

* The OKC detection system is located upstream of Osoyoos Lake. Therefore, timing at this site is based on fish tagged and released at Skaha Lake only. Timing at the other sites includes all fish tagged in their respective years.

Timing

Overall, PIT-tagged sockeye smolts from the Okanogan River Basin passed through RRE from early to mid-May and Mid-Columbia Projects (MCN, JDA, and BON) in mid-May to early June (Table 4, Figure 2). In 2015, PIT-tagged sockeye smolts passed through ZSL Dam in late April to early May. Timing of PIT-tagged sockeye smolts at ZSL in 2018 was a bit later than 2015, with the estimated 50% and 90% passage dates occurring in mid-May (Table 4). However, it is important to note that the timing estimates at ZSL in 2018 may have been impacted by two things: 1) a later installation date and 2) flooding that caused the antenna to be partially pulled in late May. The detection system at ZSL was not installed until April 25th, a week after tagging at Osoyoos Lake had concluded. Therefore, many fish tagged and released from Osoyoos Lake may have been missed at this detection site. In addition, the last detection at ZSL was May 22nd, which is around the same time that flooding impacted the antenna and ultimately led to it being partially pulled from the water. Therefore, late migrating fish may have been missed at this site. Timing at ZSL in 2019 was the latest among the three years we have analyzed, with 50% and 90% passage dates in late May (Table 4).

As requested, we estimated juvenile timing to OKC in 2018 and 2019. As with the estimates of travel time to OKC, these timing estimates are based on fish tagged and released from Skaha Lake only, as the OKC detection site is upstream from Osoyoos Lake. Tagging efforts on Skaha Lake occurred from May 2-9 in 2018 and April 28-May 9 in 2019. Arrival timing to some of the other sites (e.g., ZSL, RRE, and MCN) may appear to be earlier than, or the same as, OKC because they are based on all fish tagged and released in 2018 and 2019, and not just those that were tagged and released from Skaha Lake in early May (Table 4).

Table 4. Migration timing of PIT-tagged Okanogan River Basin sockeye smolts detected at Zosel (ZSL), Rocky Reach (RRE), McNary (MCN), John Day (JDA), and Bonneville (BON) dams in migration years 2013 to 2019. Timing to the Okanogan River Channel (OKC) and/or Zosel (ZSL) are also provided for select years.

Migration Year	Detection Site	Number Detected	Estimated Passage Date 10%	50%	90%
2013	RRE	607	8-May	13-May	18-May
	MCN	181	11-May	17-May	25-May
	JDA	90	14-May	21-May	27-May
	BON	84	15-May	24-May	2-Jun
2014	RRE	812	10-May	14-May	22-May
	MCN	421	12-May	19-May	24-May
	JDA	155	16-May	22-May	28-May
	BON	108	16-May	21-May	28-May
2015	ZSL	63	30-Apr	4-May	9-May
	RRE	1,334	6-May	12-May	19-May
	MCN	143	13-May	18-May	26-May
	JDA	73	16-May	20-May	25-May
	BON	367	17-May	21-May	27-May
2016	RRE	2,632	24-Apr	5-May	10-May
	MCN	574	27-Apr	10-May	18-May
	JDA	206	29-Apr	10-May	20-May
	BON	511	1-May	12-May	20-May
2017	RRE	2,152	8-May	11-May	20-May
	MCN	489	12-May	14-May	23-May
	JDA	621	13-May	16-May	24-May
	BON	446	14-May	18-May	26-May
2018	OKC*	13	7-May	9-May	12-May
	ZSL	32	28-Apr	14-May	19-May
	RRE	1,845	2-May	12-May	20-May
	MCN	684	7-May	14-May	23-May
	JDA	289	10-May	17-May	24-May
	BON	481	11-May	18-May	27-May
2019	OKC*	54	4-May	5-May	23-May
	ZSL	342	12-May	23-May	27-May
	RRE	1,415	14-May	17-May	30-May
	MCN	190	19-May	21-May	1-June
	JDA	150	21-May	25-May	3-June
	BON	666	22-May	25-May	5-June

* The OKC detection system is located upstream of Osoyoos Lake. Therefore, timing at this site is based on fish tagged and released at Skaha Lake only. Timing at the other sites includes all fish tagged in their respective years.

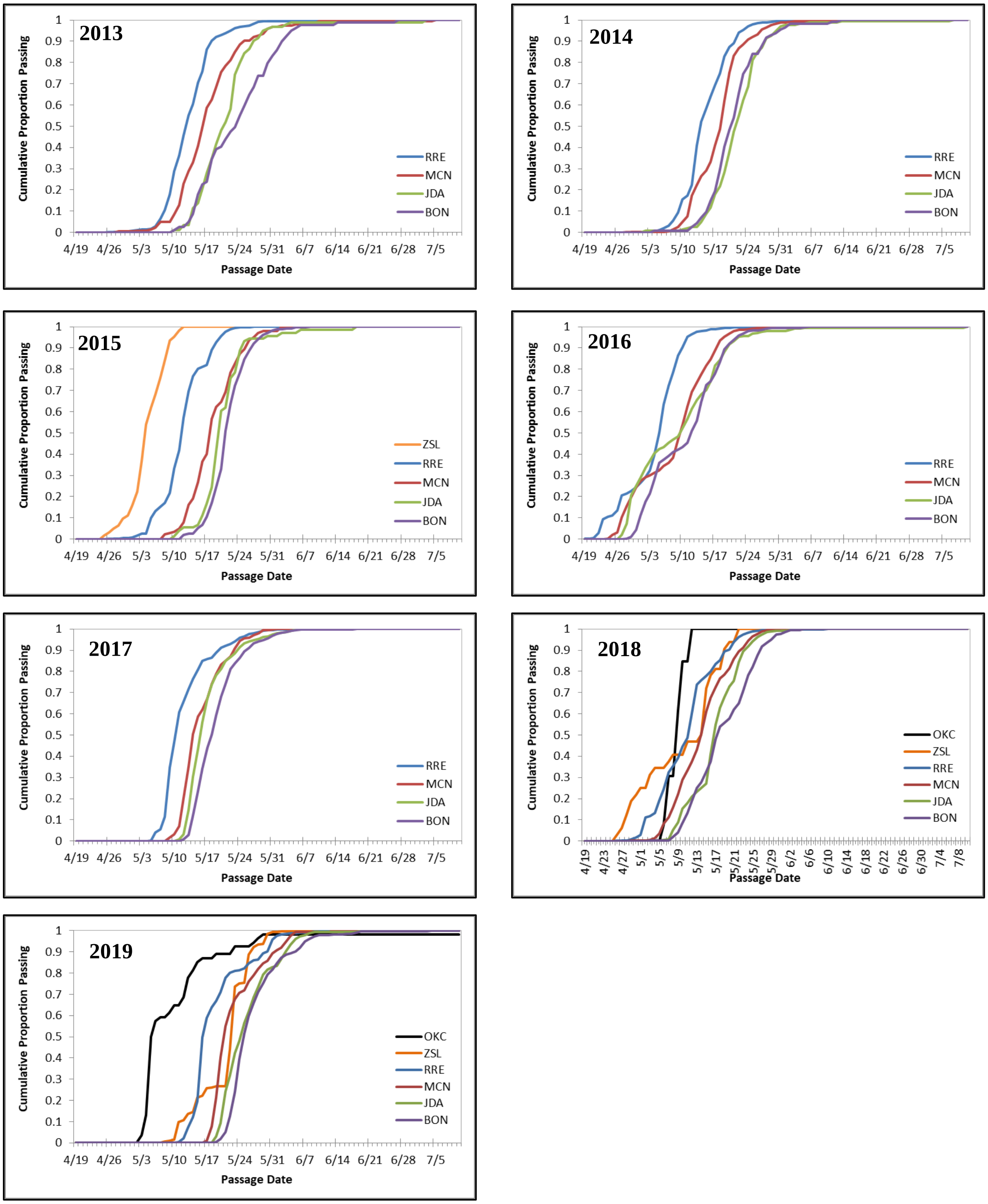


Figure 2. Cumulative passage timing of PIT-tagged wild Okanogan River basin sockeye smolts at Rocky Reach (RRE), McNary (MCN), John Day (JDA), and Bonneville (BON) dams in migration years 2013-2019. Cumulative passage timing to Zosel Dam (ZSL) is provided for MY 2015, 2018, and 2019 and the Okanogan Channel for MY 2018 and 2019. Note: the OKC detection system is located upstream of Osoyoos Lake. Therefore, timing at this site is based on fish tagged and released at Skaha Lake only. Tagging efforts on Skaha Lake occurred from May 2-9 in 2018 and April 28-May 9 in 2019. Timing to the other sites includes all fish tagged in their respective years.

Juvenile Survival

All Release Sites Combined

Estimates of individual reach survival (Release-RRE and RRE-MCN) and combined survival (Release-MCN) for each migration year (all release sites combined) are provided in Table 5. For 2013, we were only able to estimate survival from Release-RRE (0.49, 95% CI: 0.42-0.56). The total number of tags released in 2013 (4,018) was not sufficient to get reliable estimates of survival below RRE. This is largely due to low numbers of subsequent downstream detections. For example, of the 183 PIT-tagged sockeye smolts that were detected at MCN, only 19 were subsequently detected downstream of MCN. This low number of downstream detections led to an anomalous estimate of survival from RRE-MCN that was greater than 1.0 with a high standard error. Given the anomalous estimate of survival from RRE-MCN, we were also not able to estimate survival from Release-MCN for 2013.

Migration years 2014-2019 had higher total release numbers, which allowed for the estimation of not only individual reach survivals but also a combined (Release-MCN) reach survival for each year (Table 5).

Table 5. Survival of PIT-tagged sockeye juveniles tagged and released into the Okanogan River Basin in 2013-2019.

Migration Year	Number Tagged	Release-RRE (95% CI)	RRE-MCN (95% CI)	Release-MCN (95% CI)
2013	4,018	0.49 (0.42-0.56)	N/A	N/A
2014	5,055	0.57 (0.51-0.64)	0.68 (0.52-0.84)	0.39 (0.31-0.47)
2015	7,176	0.42 (0.38-0.45)	0.78 (0.53-1.03)	0.32 (0.22-0.42)
2016	10,238	0.56 (0.53-0.59)	0.80 (0.65-0.94)	0.45 (0.28-0.62)
2017	11,588	0.67 (0.62-0.72)	0.96 (0.09-1.00)	0.65 (0.51-0.78)
2018	10,943	0.62 (0.57-0.67)	0.87 (0.61-0.96)	0.54 (0.36-0.72)
2019	9,082	0.51 (0.47-0.55)	0.83 (0.60-1.06)	0.42 (0.25-0.60)

Survival by Release Site

Over the years that juvenile sockeye from the Okanogan River have been incorporated into the CSS (2013-2019), tagging and releases have occurred from several different sites, with various sites being used each year. Where possible, we have estimated survivals for each release site over several reaches: 1) release to Rocky Reach Dam (Rel-RRE), 2) Rocky Reach Dam to McNary Dam (RRE-MCN), and 3) release to McNary Dam (Rel-MCN). Summaries of these survival estimates, by release site, are provided in Table 6. Over the years, there have been a few instances when estimation of survival, either for individual reaches (e.g., 2013) or the combined reach (Rel-MCN) was not possible, generally due to low detection rates (Table 6).

It is worth noting that the different release sites utilized for Okanogan River Basin sockeye marking over the years have relied on three different capture methods: screw trap, purse seines, and fyke nets (Table 6). Unfortunately, it is not possible to isolate the effects of capture method on estimates of survival as each release site typically relied on a single capture method each year and, therefore, capture method effects would be confounded with the effects of release site. The one exception to this is OSOYBR in 2017, where both the fyke net and purse sein

methods were used. However, less than 6% of the total tags for this site were released from the fyke net capture method. This prevented us from generating reliable estimates of reach survivals for this capture method.

Table 6. Survival of PIT-tagged sockeye juveniles, by release site, tagged and released into the Okanogan River in 2013-2019.

Migration Year	Release Site	Number Tagged	Capture Method	Release-RRE (95% CI)	RRE-MCN (95% CI)	Release-MCN (95% CI)
2013	SKA-SKATAL	1,178	ST	0.46 (0.36-0.57)	N/A	N/A
	OSOYOL	57	FN	N/A	N/A	N/A
	OSOYBR	2,783	FN	0.50 (0.42-0.59)	N/A	N/A
2014	SKA-SKATAL	1,348	ST	0.41 (0.29-0.54)	0.60 (0.27-0.92)	0.25 (0.13-0.36)
	OSOYBR	3,707	FN	0.63 (0.56-0.71)	0.69 (0.52-0.87)	0.44 (0.34-0.54)
2015	SKATAL	5,435	ST	0.41 (0.37-0.45)	0.70 (0.46-0.95)	0.29 (0.19-0.38)
	OSOYBR	1,741	FN	0.44 (0.36-0.52)	N/A)	N/A
2016	SKAHAL	2,338	PS	0.48 (0.44-0.53)	0.79 (0.47-1.11)	0.38 (0.23-0.53)
	SKATAL	3,102	ST	0.47 (0.41-0.53)	0.84 (0.59-1.09)	0.39 (0.19-0.59)
	OSOYBR	1,754	FN	0.74 (0.65-0.84)	0.71 (0.41-1.02)	0.53 (0.31-0.75)
	OSOYOL	3,044	PS	0.56 (0.51-0.62)	0.91 (0.57-1.24)	0.51 (0.31-0.75)
2017	OSOYBR	2,794	PS,FN	0.82 (0.63-0.93)	N/A	N/A
	OSOYOL	8,794	PS	0.64 (0.59-0.69)	0.93 (0.31-1.00)	0.60 (0.46-0.73)
2018	OSOYOL	1,521	PS	0.59 (0.46-0.70)	0.61 (0.32-0.84)	0.36 (-0.01-0.73)
	OSOYHA	3,562	PS	0.69 (0.61-0.76)	0.89 (0.31-0.99)	0.62 (0.44-0.80)
	SKAHAL	5,860	PS	0.59 (0.51-0.66)	0.89 (0.38-0.99)	0.52 (0.39-0.66)
2019	OSOYOL	4,968	PS	0.66 (0.60-0.74)	0.82 (0.54-1.09)	0.54 (0.37-0.72)
	SKAHAL	4,114	PS	0.33 (0.28-0.37)	0.86 (0.44-1.27)	0.28 (0.14-0.42)

Release Sites: SKA-SKATAL= Skaha Dam, OSOYOL = Osoyoos Lake, OSOYBR = Osoyoos Lake Narrows Bridge, SKAHAL = Skaha Lake, OSOYHA = Osoyoos Lake at Haynes Point Campground.
Capture Methods: ST = Screw Trap, FN = Fyke Net, and PS = Purse Seine

Survival to Zosel Dam (ZSL) and Okanogan Channel (OKC)

In 2018, there were a total of 32 detections of PIT-tagged Okanogan River sockeye at ZSL and only 13 at OKC. In 2019, there were a total of 342 detections at ZSL and 54 detections at OKC. This number of detections allows us to estimate travel times and timing to these two sites in both 2018 and 2019. However, there were not enough detections in 2018 to allow for the estimation of survival from release to ZSL or OKC. For 2019, we were able to estimate survival from release to ZSL and ZSL to RRE (Table 7). There were not enough detections at OKC (and downstream) to get reliable estimates of survival from release to OKC in 2019. However, we were able to estimate survival from OKC to RRE in 2019 (Table 7). Finally, the estimated detection probability at ZSL for 2019 was 0.04, while that for OKC was 0.005.

Table 7. Survival from release to Zosel Dam (Rel-ZSL), Zosel Dam to Rocky Reach Dam (ZSL-RRE), Release to Okanogan Channel (Rel-OKC), and Okanogan Channel to Rocky Reach Dam (OKC-RRE) of PIT-tagged sockeye juveniles tagged and released into the Okanogan River in 2019.

Migration Year	Rel-ZSL (95% CI)	ZSL-RRE (95% CI)	Rel-OKC (95% CI)	OKC-RRE (95% CI)
2019	0.92 (0.56-0.99)	0.56 (0.44-0.66)	N/A	0.49 (0.26-0.72)

Smolt to Adult Survival (SARs)

To date, the CSS Annual Report has provided SARs for Okanogan River Basin sockeye for both the Rocky Reach-to-Bonneville (RRE-to-BOA) and McNary-to-Bonneville (MCN-to-BOA) reaches for migration years 2013-2017. In 2019, SARs for the Rocky Reach-to-Wells (RRE-to-WEA) and McNary-to-Wells (MCN-to-WEA) were added to the CSS Annual Report. These estimates of SARs are based on all release sites combined and are summarized below (Tables 8 and 9). In addition, the SARs for adults returning to Bonneville (RRE-to-BOA and MCN-to-BOA) are provided in Figure 3.

Table 8. Overall McNary-to-Bonneville (MCN-to-BOA) and Rocky Reach-to-Bonneville (RRE-to-BOA) SARs for Okanogan River wild sockeye, 2013-2017.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA			Smolts arriving RRE[B]	RRE-to-BOA		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2013[B,C]	---	---	---	---	2,012	8.05	6.82	9.31
2014[B]	2,170	2.90	2.24	3.61	2,937	2.15	1.72	2.63
2015	2,538	1.58	1.04	2.16	3,064	1.31	0.97	1.66
2016[B]	4,501	1.76	1.35	2.14	5,782	1.30	1.06	1.55
2017[B,D]	5,842	0.12	0.05	0.20	5,956	0.12	0.05	0.19

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and the Logit link.
[B] PIT-tagged sockeye were coded as "unknown" rearing type. Some PIT-tagged smolts may have been hatchery sockeye released into Skaha Lake as fry.
[C] Due to an unreliable survival estimate in the RRH-MCN reach, SAR (MCN-BOA) was not possible.
[D] Incomplete, 2-salt returns through Sept. 15, 2019.

Table 9. Overall McNary-to-Wells (MCN-to-WEA) and Rocky Reach-to-Wells (RRE-to-WEA) SARs for Okanogan River wild sockeye, 2013-2017.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-WEA			Smolts arriving RRE[B]	RRE-to-WEA		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2013[B,C]	---	--	--	--	2,012	4.32	3.50	5.24
2014[B]	2,170	2.35	1.75	2.94	2,937	1.74	1.36	2.16
2015	2,538	1.22	0.79	1.71	3,064	1.01	0.72	1.32
2016[B]	4,501	1.31	0.99	1.62	5,782	0.97	0.78	0.18
2017[B,D]	5,842	0.12	0.05	0.20	5,956	0.12	0.05	0.19

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and the Logit link.
[B] PIT-tagged sockeye were coded as "unknown" rearing type. Some PIT-tagged smolts may have been hatchery sockeye released into Skaha Lake as fry.
[C] Due to an unreliable survival estimate in the RRH-MCN reach, SAR (MCN-WEA) was not possible.
[D] Incomplete, 2-salt returns through Sept. 15, 2019.

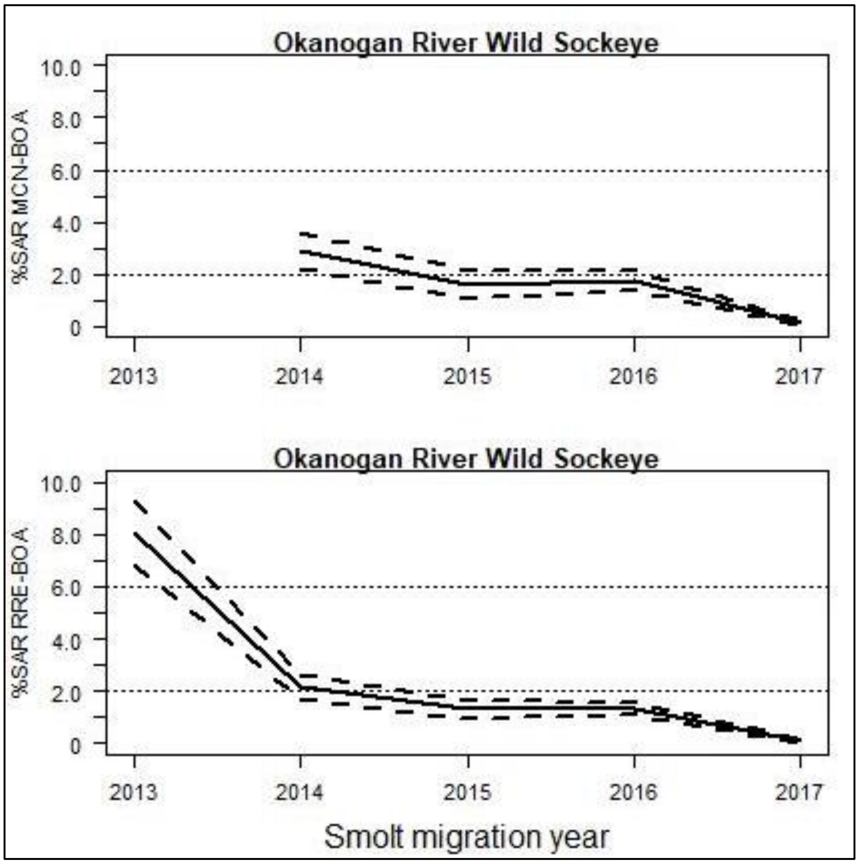


Figure 3. Bootstrapped SAR (MCN-to-BOA and RRE-to-BOA) and upper and lower CI for Okanogan River sockeye, 2013-2017 migration years. The NPCC (2014) 2%-6% SAR objective for listed wild populations is shown for reference. Figure adapted from Figure 4.24 of McCann et al. (2019)

Conclusions

The CSS Oversight Committee continues to believe that a long-term monitoring group for wild sockeye from the Okanogan Basin would be valuable. Results from the last five years of tagging indicate that, with a minimum of 5,000 PIT-tags released per year, the CSS will continue to be able to estimate juvenile survival from release to MCN and SARs for the RRE-to-BOA, RRE-to-WEA, MCN-to-BOA, and MCN-to-WEA reaches. The CSS Oversight Committee plans to continue to incorporate results from this group into future annual reports.

References

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph 5. Bethesda, MD. 437 pp.

McCann, J., B Chockley, E. Cooper, B. Hsu, S. Haeseker, R. Lessard, T. Copeland, E. Tinus, A. Storch, and D. Rawding. 2019 (in preparation). Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye: 2019 Annual Report. BPA Contract #19960200. http://www.fpc.org/documents/CSS.html

White, G.C. and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 Supplement, 120–138.

APPENDIX E

Lake Wenatchee and Osoyoos Lake Juvenile Sockeye Salmon and Limnology Comparison Brood Years 2009-2018 (in-lake 2010-2019)

don.mcqueen1943@gmail.com

LAKE WENATCHEE
JUVENILE SOCKEYE SALMON AND LIMNOLOGY STATUS REPORT
BROOD YEARS 2009-2018 (IN-LAKE 2010-2019)

D.J. McQueen
Emeritus Research Professor, York University, Toronto.

January 2021

Editorial note: Sockeye Salmon from Brood Years BY2009-18 were sampled in-lake during 2010-19. Because these and associated limnological data were recorded during the summer following egg deposition (for example BY2018 is followed by inlake 2019) this document reports data in terms of in-lake years.

REPORT SUMMARY

The goals of the Lake Wenatchee Sockeye Salmon (*Oncorhynchus nerka*) research program are to quantify life history parameters for the Lake Wenatchee Sockeye Salmon population, investigate the physical, chemical and biological factors that may be regulating population growth in freshwater, and to estimate lake-carrying capacity for this species. The in-lake program began in 2010 with a single acoustic and trawl survey. This was expanded to two acoustic and trawl surveys in 2011 and in 2012, the program was expanded to include a full limnological assessment including estimates of lake-turnover, oxygen-temperature profiles, water chemistry, phytoplankton, zooplankton and Sockeye fry abundance. Between 2012 and 2019, survey intensity has increased with the 2017 - 2019 programs being especially exemplary.

The 2012-19 results suggest that Lake Wenatchee provides excellent habitat for Sockeye fry. Although the lake is oligotrophic and Sockeye fry growth is expected to be limited, a unique mix of physical and biological conditions permits unusually high rates of Sockeye growth and production. These factors include (i) a well oxygenated, cold water hypolimnion, (ii) a ratio of edible to total phytoplankton which is exceptionally high suggesting that most of the algal species found in Lake Wenatchee have sizes, shapes and digestibility that make them excellent food sources for freshwater zooplankton, and (iii) a zooplankton community that includes two large bodied species (*Daphnia schodleri* and *Hesperodiaptomus kenai*) which provide excellent food sources for Sockeye fry.

Through the period 2010-19, the fall population density for Lake Wenatchee Sockeye fry averaged 2121 ha^{-1}. Age-0 Sockeye fry growth rates were about equal in all years and were higher than expected when compared to similar data from Osoyoos Lake. Year 2017-19 bioenergetics-based production and consumption analysis showed that the percentage of prey production that was consumed per day by Sockeye fry was always much lower than the carrying capacity (i.e. 2017 = average 6.0% of prey production consumed per day, 2018 = 8.3% and 2019 = 14.7%). In no case was there any indication that consumption by age-0 and age-1 fry was capable of limiting prey availability. We conclude that for the summer-early fall period, Lake Wenatchee has unused zooplankton production capacity that could be consumed by Sockeye fry. We suggest that over the next few years Sockeye fry population densities might be increased to achieve September densities of 4000 ha^{-1} (i.e current 2012-19 September average = 2121 ha^{-1}). But see Appendix 1 (Page 64) for some cautions and caveats.

Suggestions for future additions to the Lake Wenatchee Sockeye Salmon research program are provided in Appendices 1, 2 (pages 64 and 65).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure 16: Left panel - average June-September zooplankton biomass with respect to average spring-summer fry density; middle panel - average June-September *Hesperodiaptomus* biomass with respect to spring-summer fry density; right panel - average June-September *Daphnia* biomass with respect to spring-summer fry density.

Figure 17: Year 2011-19 age-0 Sockeye fry weights and lengths from June through to the winter.

Figure 18: Lake Wenatchee 2019 zooplankton production from 27 June 2019 to 07 November 2019; (133 days).

Figure 19: Lake Wenatchee 2019 age-0 and age-1 field weights and simulated weights with respect to date.

Figure 20: Lake Wenatchee 2019 bioenergetics-based estimates of consumption rates (µg L^{-1} d^{-1} dry weight) by age-0 plus age-1 Sockeye fry.

Figure 21: Lake Wenatchee 2019 bioenergetics-based estimates of consumption (µg L^{-1} d^{-1} dry weight) by age-0 plus age-1 Sockeye fry.

Figure 22: Lake Wenatchee 2019 comparison of zooplankton biomass and zooplankton production with consumption of zooplankton by fish.

Figure 23: Lake Wenatchee 2017 comparison of zooplankton biomass and zooplankton production with consumption of zooplankton by fish.

Figure 24: Lake Wenatchee 2018 comparison of zooplankton biomass and zooplankton production with consumption of zooplankton by fish.

METHODS AND SITE DESCRIPTION

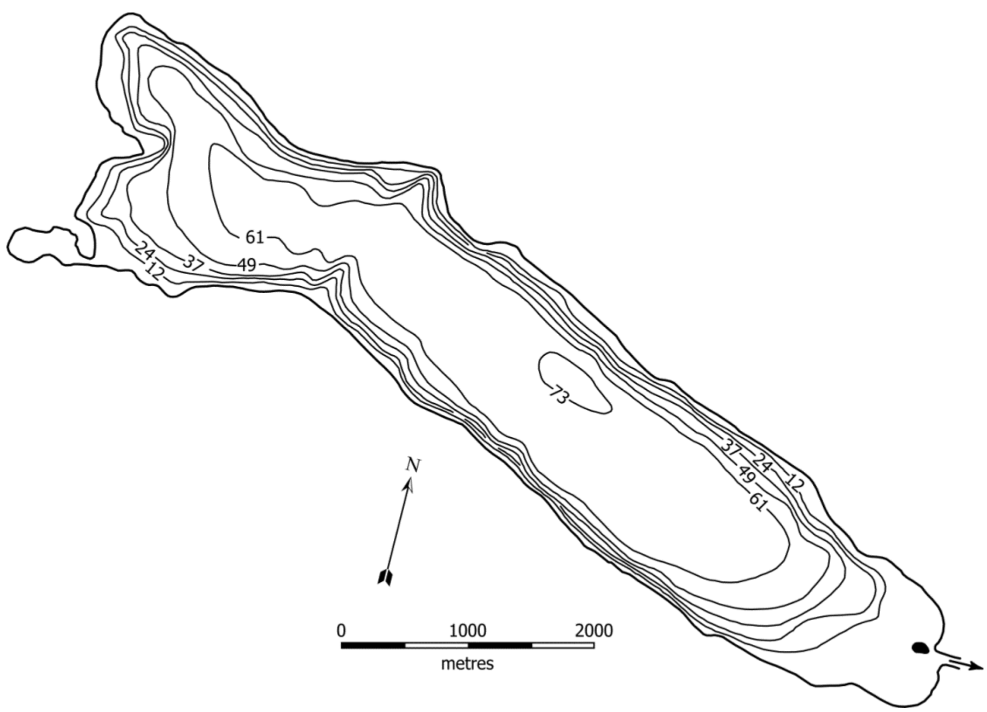
Site Description

Lake Wenatchee WA is a deep, moderately large, Sockeye Salmon nursery lake flowing into the Wenatchee River and ultimately into the Columbia River. Physical characteristics are summarized in Figure 1 and Table 1

Table 1: Lake Wenatchee physical characteristics. The data source for this Table 1 is: *Dion, N.P., G.C. Bortleson, J.B. McConnell, and J.K. Innes. 1976. Data on selected lakes in Washington, Part 5. Water-Supply Bulletin 42, Part 5. State of WA, Dept. of Ecology*.

	Units USA		Units metric	
Location 47.823^{O}N, 120.778^{O}W				
Elevation	1,872	ft	570	m
Area	2,500	acre	1,011	ha
Volume	360,000	acre feet	444,052,800	cubic m
Average depth	150	feet	45	m
Maximum depth	244	feet	74	m

Figure 1: Bathymetric map of Lake Wenatchee, WA. Depths are in metres (original map in feet). Adapted from: Dion, N.P., G.C. Bortleson, J.B. McConnell, and J.K. Innes. 1976. Data on selected lakes in Washington, Part 5. Water-Supply Bulletin 42, Part 5. State of WA, Dept. of Ecology.

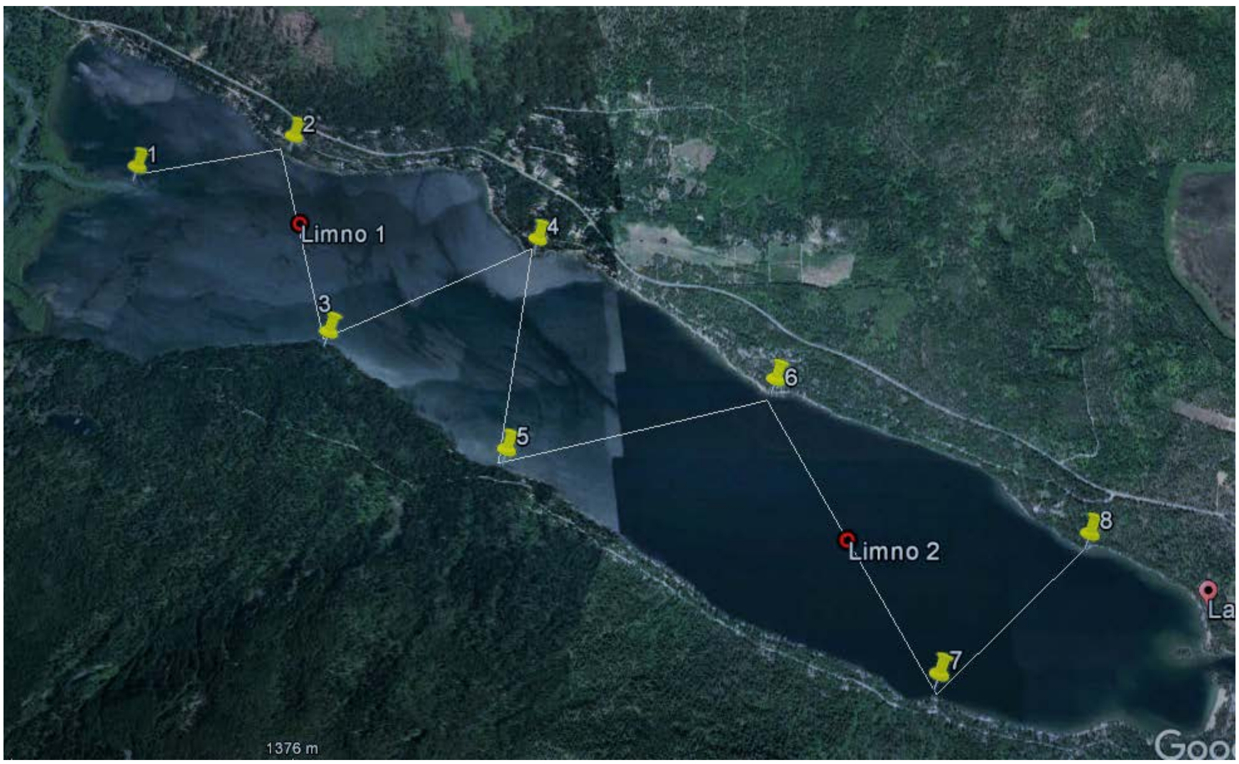


Lake Wenatchee Sampling and Data Processing

Two sampling sites (**Limno 1**: N 47^{O}49.394 W 120^{O}47.170) (**Limno 2**: N 47^{O}48.590 W 120^{O} 45.190) were used for water chemistry, phytoplankton and zooplankton; and seven transects were used for acoustic and trawl surveys of juvenile Sockeye Salmon (Figure 2). Details regarding sample timing and frequency are summarized in Table 2.

Figure 2: Location of acoustic and trawl transects and two sampling stations (Limno 1 and Limno 2) in Lake Wenatchee.

.



Oxygen and temperature were recorded at both Limno 1 and Limno 2. Sampling depths were at 1 meter intervals (1-20 m) and at 4 meter intervals (24-52 m) thereafter.

Water chemistry samples were collected at both Limno 1 and Limno 2. During 2012-13, total phosphorus (TP) samples were stored in screw-cap test-tubes in the dark until analysis. $NO_3 + NO_2$ samples were passed through an acrodisk filter, placed in screw-cap plastic bottles, and frozen until analysis. Chlorophyll a samples were filtered (47 mm Millipore) and frozen until analysis. Samples were analyzed at the Cultus Lake laboratory of Fisheries and Oceans Canada. Additional samples were sent to Vancouver Island University where they were analyzed for Na, Mg, and Ca (ppm) and for $CaCO_3$ alkalinity (ppm).

During 2017, two water chemistry stations (Limno 1 and 2) were sampled as described above. Sampling dates are shown in Table 2. During daylight hours, Secchi depth was recorded

at each limnological station. During periods of night sampling, Secchi depth was not recorded. In the epilimnion, water chemistry samples were collected using a Van Dorn bottle at 1, 5, 10 m depths. Water from the three depths was integrated and then sub-sampled to yield: 1 nutrient (nitrogen) sample stored in a clear 250 mL bottle, 1 TP sample stored in a clear 250 mL bottle, 1 alkalinity and calcium sample stored in a clear 250 mL bottle, and 1 phytoplankton sample stored in a 500 mL clear plastic bottle and treated with Lugol's solution. During collection, all water samples were held in coolers in the dark. Hypolimnetic samples were averaged from samples collected at 20, and 34 or 45 m (depending on lake depth). Details are in Lawrence et al. (2007). All samples were couriered to the provincial water chemistry laboratories in Burnaby, B.C. (PSC Analytical Services laboratory, Burnaby, British Columbia). The analytical protocol followed the methods of Bran and Luebbe Inc. (1987), Eaton et al (1995, 1998). Water chemistry samples were not collected during 2014-16 and 2018-19.

During 2012-19, phytoplankton biomasses were sampled at two stations (Limno 1 and 2). At each station, water was combined from depths of 1, 5, and 10m and samples were drawn from the mixture. In the laboratory the samples were settled and densities, cell sizes, cell shapes, and biovolumes were recorded. One of the objectives of the phytoplankton counting procedure was to assess the relative availabilities of edible (grazable) and non-edible (non-grazable) algae. We quantified "edibility" based on size, toxicity, and digestibility. Single cells or colonies ≤ 30 μm width or length were considered edible (Cyr 1998; Cottingham 1999) unless they were classified as being either "toxic" or "digestion-resistant". *Microcystis* was always classified as being "toxic". Other genera were assumed to be non-toxic. Algae with thick gelatinous sheaths can pass through *Daphnia* guts undigested (Stutzman 1995) and were considered to be digestion-resistant, independent of size. Additional detail with respect to methods is available in Hyatt et al. (2005) and McQueen et al. (2007). During 2012-17, samples were analyzed by Elaine Carney. During 2018-19, samples were analyzed by Biologica Environmental Services, Ltd. using the protocol developed by Ms. Carney.

During 2012-19, zooplankton were sampled at night at the two limnological stations (Limno 1 and 2) (Figure 1) via metered vertical net hauls (Rigosha meter, 100 µm mesh, 0.5 m net diameter, net length 3 m). Samples were collected approximately every 4-6 weeks (see sample schedule Table 2). Each sample was washed out of the plankton net using water saturated with carbon dioxide and was then preserved in 5.5% buffered and sugared formalin and shipped to the laboratory. In the laboratory, individual samples from each of 2 stations were combined to produce one volume-weighted "combined" sample for each sampling date (McQueen et al. 2007). Because each of the samples had different sampling efficiencies (measured with a Rigosha flow meter), each station sample was suspended in water so that each one mL of sample contained water from 10 L of lake water. For each station, 10 mL (containing plankton from 100 L of lake water) from each sample jar was then added to a "combined" sample jar. Since there were 2 stations the combined sample jar contained 20 mL of sample representing the zooplankton found in 200 L of lake water. The original samples were then re-filtered to remove excess water, re-suspended in 5.5 % formalin and relabelled to record the loss of a certain percentage of the sample. During counting, Cladocerans and copepods (adults and copepodids) were identified to species. Nauplii were identified as either *Diacyclops thomasi* or *Hesperodiaptomus kenai.* Edmondson (1959) was the principal taxonomic reference, but also Dussart and Fernando (1990) for Cyclopoids, and Lieder (1983) for Bosminids. Eggs per female were counted for all species. To calculate biomass, body lengths of all animals were measured using an image-based, semi-automated, counting and measuring system. Animal weights were

estimated using length-weight regressions summarized in Girard and Reid (1990). If preserved animals were used to develop these regressions, a 39% correction for weight loss in formalin was applied (Giguère et al. 1989).

During 2010-19, juvenile Sockeye Salmon (*Oncorhynchus nerka*) densities were assessed 1-5 times per year (depending on the lake-year; see sample schedules in Table 2) using a Biosonics DT-X echosounder (200 kHz sounder, pulse width at 0.4 ms and a 6.6° transducer). More details are available in (MacLellan and Simmons 1992, Hyatt et al. 2011). The acoustics transducer was towed at night over 7 transects (Figure 2). During each sampling trip, samples of pelagic fish were collected using a 3m x 7m mid-water trawl designed by Enzenhofer and Hume (1989). When the fish samples were collected by Fisheries and Oceans Canada, juvenile Sockeye were preserved in 95% ethanol. Fish samples were then transported to the laboratory, where the preservative was changed twice over six weeks. They were then removed from the preservative, blotted dry, measured (total length), and weighed. Weights were corrected for the effects of ethanol using the expression (fresh weight = preserved weight/0.868429; P. Rankin, Pacific Biological Station, unpublished data). When samples were collected by the Okanagan Nation Alliance, they were kept on ice and transported back to the laboratory where fresh lengths and weights were recorded.

During 2012-19, fish stomachs were processed on one date in 2013 (13 July, number of stomachs =30), three dates in 2017 (29 June, age-0 n=40, age-1 n=1; 31 August, age-0 n=30, age-1 n=1; and 15 September age-0 n=30, age-1 n=1), two dates in 2018 (14 August, age-0 n=30; age-1, n=30 and 07 November age-0, n=30) and on 3 dates in 2019 (28 July 2019, 30 Sept 2019, and 24 Oct 2019). Prey identified included *Diacyclops*, *Hesperodiaptomu*s, *Daphnia, Bosmina* and adult dipterans. The stomach data became inputs for bioenergetics modeling.

Bioenergetics-based production and consumption analysis was used to estimate daily rates of consumption by both age-0 and age-1 Sockeye fry consuming each of the main species of zooplankton, chironomids and adult dipterans. Consumption rates of prey by Sockeye fry were compared with rates of production by each of the major zooplankton species. If consumption > production we would conclude that density-dependent growth suppression was occurring. If production > consumption we would conclude that the fish were not affecting zooplankton biomass and that density-dependent growth suppression due to prey removal was not expected.

Samples appropriate for bioenergetics analysis were collected during 2012, 2013, 2017, 2018 and 2019 and bioenergetics-based consumption rates were estimated for each of these years. The data required for the analysis included: (1) weights and densities of age-0 and age-1 Sockeye fry with respect to date, (2) diets for Sockeye fry, (3) Sockeye fry vertical distribution in the water column with respect to date, (4) water temperatures with respect to date and depth, (5) zooplankton species-specific biomass and energy content, and (6) estimates of zooplankton species-specific rates of production. All of these data are summarized in the following pages of this report.

Lake Wenatchee fish bioenergetics models were run for 2012, 2013, 2017, 2018 and 2019. In 2012-13, the ages of the Sockeye fry were unknown and bioenergetics-based consumption rates included both age-0 and age-1 fry together. In 2013, fish diets were not sampled and the diet data from 2012 were used. For 2017, 2018 and 2019, consumption rates were calculated separately for age-0 and age-1 Sockeye fry. In all years, the assumptions and input data were as follows. (1) Water temperatures occupied by the fish were based on the Sockeye depth distributions observed during each survey. Residence temperature was based on

the average temperature of the volume of water occupied by >90% of the fish population. (2) Fish diets were translated to percent biomass as described above. (3) For each of the fish groups, model inputs included starting and ending mean weight (g wet weight), starting density (ha^{-1}), and mortality expressed as mortality suffered by each fish group between each known census period. (4) Energy densities (J/g wet weight) were set at 5233 J/g for Sockeye. Energy densities for prey were set at: copepods 3000 J/g, cladocerans 2500 J/g, adult dipterans 1500 J/g.

Lake Wenatchee 2012-18 Inventory of Samples Collected

An inventory of the samples collected in each year and sample timing and frequency is provided in Table 2. The most complete sample sets were collected in 2017–19.

Table 2: Samples collected at Lake Wenatchee during 2012-19. Black x's indicate that the samples were collected, processed, analyzed and included in this report. Blank = samples were not collected.

In-Lake 2012

Date Surveyed	Discharge from Wenatchee River at Plain Washington	Water chemistry average 1,3,5 and 25 m	Temperature and Oxygen	Secchi Depth m	Phytoplankton average 1,3,5 m water depth	Zooplankton 0-30 m water depth	Acoustic sampling	Fish trawling	Fish lengths	Fish weights	Fish Ages	Fish stomachs
May-July	x											
04-Jun-12			x	x	x	x						
25-Jun-12		x	x	x	x		x	x	x	x		
05-Jul-12			x	x	x	x						
13-Jul-12												x
08-Aug-12			x	x	x	x						
10-Sep-12					x	x						
18-Sep-12			x	x	x		x	x	x	x	x	
06-Oct-12		x	x	x	x	x						

In-Lake 2013

Date Surveyed	Discharge from Wenatchee River at Plain Washington	Water chemistry average 1,3,5 and 25 m	Calcium and Alkalinity	Temperature and Oxygen	Secchi Depth m	Phytoplankton average 1,3,5 m water depth	Zooplankton 0-30 m water depth	Acoustic sampling	Fish trawling	Fish Lengths	Fish Weights	Fish Ages	Fish stomachs
May-September	x												
25-Jun-13				x	x	x	x						
10-Jul-13			x					x	x	x	x		
30-Jul-13				x	x		x						
26-Aug-13				x	x		x						
23-Sep-13				x	x		x	x	x	x			

In-Lake 2014

Date Surveyed	Discharge from Wenatchee River at Plain Washington	Water chemistry average 1,3,5 and 25 m	Calcium and Alkalinity	Temperature and Oxygen	Secchi Depth	Phytoplankton average 1,3,5 m water depth	Zooplankton 0-30 m water depth	Acoustic sampling	Fish trawling	Fish lengths	Fish weights	Fish Ages	Fish stomachs
May-September	x												
5-Jun-2014				x	x	x	x						
23-Jun-2014				x	x								
26-Jun-2014							x						
14-Jul-2014				x	x	x	x						
11-Aug-2014				x			x						
4-Sep-2014				x	x	x	x						
29-Sep-2014						x	x						
8-Oct-2014				x	x								
27-Oct-2014								x	x	x	x		
23-Feb-2015								x	x	x	x		

In-Lake 2015

Date Surveyed	Discharge from Wenatchee River at Plain Washington	Water chemistry average 1,3,5 and 25 m	Calcium and Alkalinity	Temperature and Oxygen	Secchi Depth)	Phytoplankton average 1,3,5 m water depth	Zooplankton 0-30 m water depth	Acoustic sampling	Fish trawling	Fish lengths	Fish weights	Fish Ages	Fish stomachs
May-September	x												
01-Jun-15				x		x							
4-Jun-2015					x		x						
25-Jun-2015				x			x						
14-Jul-2015				x	x	x	x						
5-Aug-2015				x			x						
25-Aug-2015					x	x							
27-Aug-2015				x			x						
16-Sep-2015				x	x	x	x						
21-Sep-2015								x	x	x	x		
11-Mar-2016								x	x	x	x	x	x

In-Lake 2016

Date Surveyed	Discharge from Wenatchee River at Plain Washington	Water chemistry average 1,3,5 and 25 m	Calcium and Alkalinity	Temperature and Oxygen	Secchi Depth	Phytoplankton average 1,3,5 m water depth	Zooplankton 0-30 m water depth	Acoustic sampling	Fish trawling	Fish lengths	Fish weights	Fish Ages	Fish stomachs
May-September	x												
08-Jun-16				x	x								
09-Jun-16							x						
29-Jun-16				x			x						
20-Jul-16				x	x		x						
10-Aug-16				x			x						
31-Aug-16				x	x		x						
01-Sep-16								x	x	x	x	x	
29-Sep-16				x	x								
03-Nov-16								x	x	x	x	x	
12-Apr-17								x	x	x	x	x	

In-Lake 2017

Date Surveyed	Discharge from Wenatchee River at Plain Washington	Water chemistry average 1,3,5 and 25 m	Calcium and Alkalinity	Temperature and Oxygen	Secchi Depth	Phytoplankton average 1,3,5 m water depth	Zooplankton 0-30 m water depth	Schindler zooplankton samples 0-40 m	Acoustic sampling	Fish trawling	Fish lengths	Fish weights	Fish Ages	Fish stomachs
May-September	x													
12-Apr-17				x	x				x	x	x	x	x	x
14-Jun-17						x	x							
28-Jun-17				x	x				x	x	x	x	x	x
06-Jul-17							x							
27-Jul-17						x	x							
08-Aug-17								x						
21-Aug-17				x	x									
08-Sep-17						x								
21-Aug-17							x		x	x	x	x	x	x
23-Aug-17		x	x											
31-Aug-17								x						
14-Sep-17							x	x						
15-Sep-17				x	x				x	x	x	x	x	x
21-Sep-17		x	x											
04-Oct-17						x	x							
20-Nov-17									x	x	x	x	x	x

In-Lake 2018

Date Surveyed	Discharge from Wenatchee River at Plain Washington	Water chemistry average 1,3,5 and 25 m	Calcium and Alkalinity	Temperature and Oxygen	Secchi Depth	Phytoplankton average 1,3,5 m water depth	Zooplankton 0-30 m water depth	Schindler zooplankton samples 0-40 m	Acoustic sampling	Fish trawling	Fish lengths	Fish weights	Fish Ages	Fish stomachs
May-September	x													
15-Mar-18				x										
13-Jun-18				x					x	x	x	x	x	
14-Jun-18							x							
15-Jun-18				x	x	x								
11-Jul-18				x			x							
01-Aug-18							x							
04-Aug-18				x		x								
13-Aug-18				x	x				x	x	x	x	x	x
22-Aug-18				x			x							
10-Sep-18				x	x	x	x							
03-Oct-18				x	x	x								
04-Oct-18							x							
09-Oct-18				x					x	x	x	x	x	
06-Nov-18				x					x	x	x	x	x	x

In-Lake 2019

Date Surveyed	Discharge from Wenatchee River at Plain Washington	Water chemistry average 1,3,5 and 25 m	Calcium and Alkalinity	Temperature and Oxygen	Secchi Depth	Phytoplankton average 1,3,5 m water depth	Zooplankton 0-30 m water depth	Schindler zooplankton samples 0-40 m	Acoustic sampling	Fish trawling	Fish lengths	Fish weights	Fish Ages	Fish stomachs
May-September	x													
19-Mar-19							x							
17-Apr-19							x							
21-May-19				x			x							
05-Jun-19				x	x	x								
27-Jun-19							x							
25-Jul-19				x			x							
28-Jul-19				x					x	x	x	x	x	x
08-Aug-19				x	x	x								
15-Aug-19							x							
18-Sep-19				x			x							
30-Sep-19				x					x	x	x	x	x	x
03-Oct-19				x		x	x							
24-Oct-19				x					x	x	x	x	x	x
07-Nov-19							x							
11-Nov-19				x										
23-Nov-19				x					x	x	x	x	x	
29-Feb-20				x										

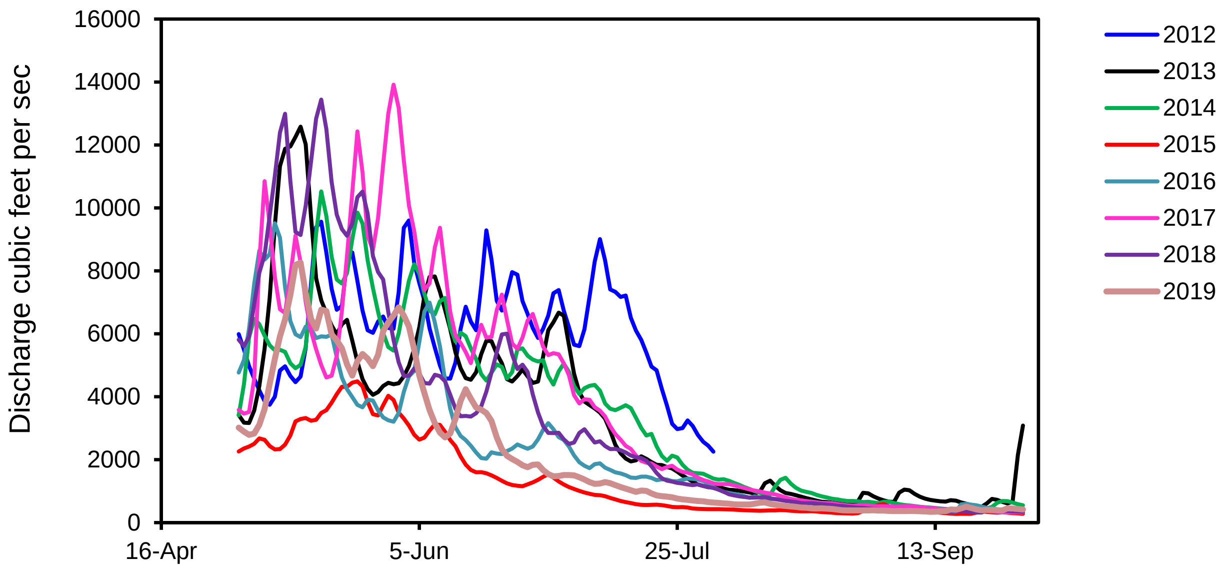
RESULTS AND DISCUSSION

Rates of Wenatchee River Discharge and Lake-Turnover

Although annual estimates of lake-turnover have hydrological value, they do not capture the very dynamic changes in rates of water loading that occur in Lake Wenatchee during the spring-summer. This is illustrated by the Wenatchee River flow rates recorded by the USGA at Plain WA, located about 15km downriver from Lake Wenatchee (Figure 3).

These river flow data show that during the 92 day May-July period, when juvenile Sockeye were recruiting to the lake and when their zooplankton prey were reaching peak population abundances; rates of Wenatchee River flow were exceptionally variable (Figure 3).

Figure 3: Rates of Wenatchee River discharge recorded at Plain Washington during May-September 2012-2019. (Reference gauge USGS 12457000 Wenatchee River at Plain, WA).



But note that the Plain WA estimates (Figure 3, Table 3) include contributions from the Chiwawa River which flows into the Wenatchee River between Lake Wenatchee and Plain WA. To account for this extra contribution we have subtracted the Chiwawa flow from the flow recorded at Plain WA. This has the effect of reducing the flows based on estimates from Plain WA and therefore increasing Wenatchee Lake water residence and turnover times (Table 3).

Table 3: May-July estimates of rates of water flow in the Wenatchee River exiting Lake Wenatchee. These estimates are based on the flow measured at Plain WA minus the flow form the Chiwawa River.

Year	Flow (01 May- 31 July) Wenatchee River at Plain Washington cubic feet per second	Flow (01 May - 31 July) Chiwawa River cubic feet per second	Net flow cubic feet per second (Plain minus Chiwawa)	Net flow cubic meters per second	Net flow per day cubic meters	May-July Lake Wenatchee turnover time days
2012	6,141	1,614	4,527	128	11,077,375	40
2013	4,972	1,247	3,725	105	9,114,606	49
2014	5,244	1,301	3,943	112	9,647,943	46
2015	2,014	604	1,410	40	3,449,164	129
2016	3,580	1,128	2,452	69	5,999,671	74
2017	5,846	1,589	4,257	121	10,416,232	43
2018	5,245	1456	3,789	107	9,271,144	48
2019	3,260	852	2,408	68	5,893,021	75
Average	4,538	1,224	3,314	94	8,108,645	63

It should be noted that the net discharge estimates (Table 3) and resultant turnover times do not account for inputs from Nason Creek which flows into the Wenatchee River south of the lake and upstream from the USGS gauge at Plain WA. The implication is that net flows recorded in Table 3 are overestimates and that lake-turnover times are likely higher than shown. However, because Nason and other smaller creeks are not gauged our current estimates are the best available. These turnover times are very similar to spring-summer turnover times recorded in Osoyoos Lake (Hyatt et al. 2018). Later in this report we will investigate the effects that high turnover times can have on lake temperature, phytoplankton and zooplankton.

Lake Wenatchee 2012-18 Water Temperature and Oxygen Concentrations

Juvenile Sockeye salmon prefer water temperatures $<17^{O}$ C and oxygen concentrations >4 ppm. Through the summer and fall of 2012-19, this optimal mix of temperature and oxygen conditions was available to Sockeye fry at all times (Tables 4, 5). Year 2015, was exceptional because the epilimnetic temperatures exceeded the optimum during both July and August, but even in that year, cool (i.e. $<17^{O}$ C) oxygenated water was available throughout the hypolimnion. In all other years, warm (i.e. $>17^{O}$ C) epilimnetic water was observed only during August and early September, and throughout those time periods, well oxygenated hypolimnetic water was available to Sockeye fry.

Table 4: Lake Wenatchee 2012-19 water temperatures. Shaded areas represent water temperatures >17^{O} C.

Water depth (m)	04-Jun-12	25-Jun-12	05-Jul-12	09-Aug-12	18-Sep-12	06-Oct-12
1	8.1	8.2	10.6	14.2	16.4	13.8
2	7.7	8.2	10.2	14.2	16.1	13.8
3	7.6		10.0	14.2		13.7
4	7.5	8.0	9.5	14.2	15.6	13.7
5	7.3		9.3	14.2		13.7
6	7.3	8.1	9.2	14.2	15.5	13.7
7	7.2		9.1	14.0		13.7
8	7.2	8.1	9.0	13.9	15.3	13.6
9	7.2		8.8	13.7		13.6
10	7.1	8.0	8.6	13.6	15.1	13.6
11	7.1		8.6	13.5		13.6
12	7.1	7.7	8.5	13.5	14.8	13.6
13	7.0		8.4	13.4		13.6
14	6.9	7.4	8.4	13.4	14.5	13.6
15	6.9		8.3	13.3		13.6
16	6.8	7.4	8.2	12.9	14.2	13.6
17	6.8		8.0	12.8		13.6
18	6.7	7.4	7.9	12.8	14.0	13.6
19	6.7		7.8	12.7		13.5
20	6.7	7.4	7.8	12.3	13.8	13.4
24	6.5	7.2	7.5	10.5	12.3	13.2
28	6.4	7.1	7.4	9.5	11.6	11.1
32	6.3		7.2	8.9		8.6
36	6.3		7.1	8.5		7.9
40	6.2		7.0	7.9		7.5
44	6.1		6.9	7.6		7.4
48	6.1		6.8	7.3		7.2
52	6.0		6.7	7.1		7.1
Average temperature 0-20 m	7	8	9	14	15	14

Water depth (m)	25-Jun-13	30-Jul-13	26-Aug-13	23-Sep-13
1	11.2	18.0	18.6	16.1
2	10.5	17.5	18.4	16.2
3	10.5	17.2	18.1	16.2
4	10.4	17.0	18.0	16.2
5	10.3	16.9	18.0	16.2
6	10.3	16.7	17.8	16.3
7	10.2	16.6	17.8	16.3
8	10.2	16.5	17.7	16.3
9	10.1	16.2	17.7	16.3
10	10.0	16.1	17.7	16.3
11	9.9	16.1	17.6	16.3
12	10.0	15.9	17.5	16.3
13	9.4	15.7	17.3	16.3
14	9.2	15.4	17.0	16.3
15	9.1	14.9	17.3	15.8
16	8.9	13.3	16.5	15.5
17	8.8	12.7	15.5	14.9
18	8.7	11.4	14.9	14.6
19	8.6	11.1	14.0	13.6
20	8.5	11.0	13.3	12.6
24	8.4	10.5	10.7	10.6
28	8.2	9.7	9.9	9.5
32	8.1	8.9	9.0	8.8
36	7.9	8.4	8.6	8.4
40	7.6	8.0	8.2	8.0
44	7.4	7.6	7.8	7.7
48	7.2	7.4	7.5	7.5
52	7.0	7.2	7.3	7.3
Average temperature 0-20 m	10	15	17	16

Water depth (m)	05-Jun-14	23-Jun-14	14-Jul-14	11-Aug-14	04-Sep-14	08-Oct-14
1	9.4	11.6	15.3	19.0	17.7	15.5
2	9.3	11.6	15.0	18.6	17.6	15.4
3	9.3	11.1	15.0	18.1	17.4	15.4
4	9.1	10.9	14.8	17.8	17.3	15.4
5	9.1	10.9	14.7	17.6	17.2	15.4
6	9.0	10.8	14.5	17.3	17.2	15.4
7	9.0	10.7	14.4	17.1	17.1	15.4
8	8.9	10.6	14.2	16.9	17.1	15.4
9	8.8	10.6	14.2	16.4	17.0	15.4
10	8.7	10.4	14.0	16.0	17.0	15.3
11	8.7	10.2	13.5	15.8	16.9	15.3
12	8.6	10.1	13.0	15.7	16.4	15.3
13	8.6	10.0	12.7	15.5	16.3	15.2
14	8.5	10.0	12.4	15.3	16.2	15.1
15	8.5	9.6	12.1	15.1	16.0	15.0
16	8.4	9.4	11.8	15.0	15.4	14.9
17	8.4	9.3	11.6	13.9	14.5	14.7
18	8.3	9.2	11.4	13.0	14.1	14.6
19	8.3	9.1	11.2	12.5	13.5	14.5
20	8.3	9.0	10.8	11.9	12.8	14.4
24	8.2	8.9	10.3	10.6	11.6	13.2
28	8.1	8.7	9.9	9.7	10.6	11.4
32	7.9	8.5	9.4	9.0	9.7	9.6
36	7.6	8.2	8.9	8.6	9.0	9.1
40	7.3	8.0	8.6	8.2	8.6	8.9
44	7.0	7.8	8.2	7.9	8.2	8.2
48	6.8	7.6	7.9	7.7	7.9	8.0
52	6.7	7.4	7.7	7.5	7.7	7.8
Average temperature 0-20 m	9	10	13	16	16	15

Water depth (m)	01-Jun-15	25-Jun-15	14-Jul-15	05-Aug-15	28-Aug-15	16-Sep-15
1	13.3	16.6	19.2	18.5	17.8	16.5
2	13.2	16.6	19.1	18.5	17.9	16.4
3	13.1	16.6	18.9	18.5	18.0	16.2
4	12.8	16.5	18.8	18.5	18.0	16.1
5	12.3	16.3	18.8	18.5	18.0	16.1
6	11.8	16.1	18.7	18.5	18.0	16.0
7	11.5	15.5	18.6	18.4	18.0	16.0
8	11.2	15.1	18.6	18.4	18.0	16.0
9	11.0	14.9	18.5	18.4	18.0	15.9
10	10.7	14.7	18.3	18.4	18.0	15.9
11	10.4	14.5	17.9	18.4	18.0	15.9
12	10.4	14.2	17.0	18.4	18.0	15.9
13	10.3	14.0	15.8	18.2	18.0	15.9
14	10.1	13.8	15.2	18.1	18.0	15.9
15	10.0	13.4	14.4	17.8	18.0	15.8
16	9.8	13.0	13.5	17.8	18.0	15.8
17	9.8	12.9	12.7	17.7	18.0	15.8
18	9.7	12.5	12.3	17.7	17.6	15.8
19	9.5	12.3	12.2	16.5	17.5	15.7
20	9.4	12.1	11.9	15.2	17.2	15.7
24	8.9	10.8	10.4	11.3	13.3	14.9
28	8.6	9.8	9.6	10.1	10.2	10.2
32	8.0	8.8	8.7	9.2	9.2	9.0
36	7.5	8.1	8.1	8.4	8.5	8.4
40	7.1	7.7	7.7	8.0	7.9	7.9
44	6.8	7.2	7.2	7.6	7.5	7.4
48	6.6	7.0	7.0	7.4	7.2	7.2
52	6.5	6.8	6.8	7.2	7.0	7.0
Average temperature 0-20 m	11	15	16	18	18	16

Table 4 continued: Lake Wenatchee 2012-19 water temperatures. Shaded areas represent water temperatures >17^{O} C.

Water depth (m)	08-Jun-16	29-Jun-16	20-Jul-16	10-Aug-16	31-Aug-16	29-Sep-16
1	11.8	13.4	16.4	16.6	18.8	15.5
2	11.8	13.3	16.2	16.5	18.6	15.5
3	11.6	13.2	16.1	16.5	18.4	15.4
4	11.4	13.0	15.9	16.5	18.3	15.4
5	11.1	12.8	15.7	16.5	18.2	15.4
6	10.8	12.8	15.4	16.5	18.1	15.4
7	10.7	12.8	15.2	16.5	18.1	15.3
8	10.6	12.7	15.1	16.5	18.1	15.3
9	10.5	12.7	14.9	16.5	18.0	15.3
10	10.3	12.6	14.8	16.5	18.0	15.3
11	10.2	12.6	14.6	16.5	17.8	15.3
12	10.0	12.5	14.4	16.5	17.7	15.3
13	9.8	12.4	14.2	16.5	17.6	15.3
14	9.6	12.3	14.0	16.5	17.5	15.3
15	9.3	12.2	13.7	16.5	17.5	15.2
16	9.2	12.2	13.5	16.5	17.3	15.2
17	9.1	12.1	13.3	16.4	16.7	15.1
18	9.0	12.1	13.2	15.9	16.4	15.1
19	8.9	12.0	13.1	15.8	15.5	15.0
20	8.8	11.7	13.0	15.8	14.7	14.9
24	8.7	10.7	11.2	13.3	13.0	14.0
28	8.4	9.6	10.4	11.8	11.0	11.4
32	8.2	9.0	9.5	10.2	9.6	9.6
36	7.9	8.4	8.6	9.1	8.9	8.8
40	7.6	8.0	8.1	8.6	8.5	8.3
44	7.4	7.7	7.8	8.2	8.2	8.0
48	7.3	7.5	7.6	7.9	7.8	7.8
52	7.2	7.5	7.5	7.7	7.6	7.6
Average temperature 0-20m	10	13	15	16	18	15

Water depth (m)	12-Apr-17	28-Jun-17	21-Aug-17	15-Sep-17
1	4.1	8.7	18.3	17.1
2	4.1	8.7	18.1	17.2
3	4.0	8.7	17.7	17.1
4	4.0	8.6	17.6	17.1
5	4.0	8.6	17.5	17.1
6	3.9	8.5	17.4	17.0
7	3.9	8.5	17.2	17.0
8	3.9	8.5	17.0	16.9
9	3.9	8.5	16.9	16.8
10	3.9	8.5	16.7	16.7
11	3.9	8.5	16.6	16.7
12	3.9	8.5	16.5	16.6
13	3.9	8.5	16.2	16.5
14	3.9	8.5	15.9	16.3
15	3.9	8.5	15.4	16.3
16	3.9	8.5	15.1	16.2
17	3.9	8.5	14.4	16.0
18	3.9	8.5	13.8	15.0
19	3.9	8.5	12.9	13.5
20	3.9	8.5	12.6	12.4
24	3.9	8.4	10.9	10.1
28	3.9	8.4	9.4	9.0
32	3.9	8.1	8.9	8.4
36	3.9	7.9	8.4	8.0
40	3.9	7.7	8.0	7.7
44	3.9	7.6	7.8	7.5
48	3.9	7.5	7.6	7.3
52	3.9	7.0	7.5	7.2
Average temperature 0-20m	4	9	16	16

Water depth (m)	15-Mar-18	13-Jun-18	15-Jun-18	11-Jul-18	04-Aug-18	13-Aug-18	22-Aug-18	10-Sep-18	03-Oct-18	09-Oct-18	06-Nov-18
1	4.1	9.8	10.5	14.7	17.6	18.9	18.7	16.2	14.2	13.4	10.7
2	4.1	9.8	10.4	14.6	17.6	18.6	18.7	16.2	14.2	13.5	10.7
3	4.0	9.8	10.3	14.5	17.6	18.5	18.7	16.2	14.3	13.6	10.7
4	4.0	9.8	10.3	14.3	17.5	18.4	18.7	16.2	14.4	13.6	10.8
5	3.9	9.8	10.2	14.0	17.5	18.2	18.7	16.2	14.4	13.6	10.8
6	3.8	9.8	10.2	13.5	17.3	17.9	18.5	16.2	14.4	13.6	10.8
7	3.5	9.7	10.1	13.1	17.2	17.5	18.1	16.2	14.4	13.7	10.8
8	3.4	9.7	10.0	12.8	17.1	17.1	17.7	16.3	14.4	13.7	10.8
9	3.4	9.6	9.8	12.7	17.0	17.0	17.3	16.3	14.4	13.7	10.8
10	3.3	9.5	9.5	12.6	16.8	16.7	17.2	16.3	14.4	13.7	10.8
11	3.3	9.5	9.4	12.5	16.8	16.5	16.9	16.3	14.4	13.7	10.8
12	3.3	9.4	9.3	12.4	16.5	16.3	16.4	16.3	14.4	13.7	10.8
13	3.3	9.3	9.3	12.3	15.9	16.2	16.7	16.3	14.4	13.7	10.8
14	3.3	9.3	9.3	12.2	14.6	16.1	16.6	16.2	14.4	13.7	10.8
15	3.3	9.3	9.2	11.9	14.3	15.6	16.4	16.2	14.4	13.7	10.8
16	3.2	9.3	9.1	11.8	14.1	14.8	16.1	16.2	14.4	13.7	10.8
17	3.2	9.3	9.1	11.7	13.6	14.3	15.5	16.1	14.4	13.7	10.8
18	3.2	9.3	9.0	11.5	13.3	13.5	14.4	16.0	14.4	13.7	10.7
19	3.2	9.2	9.0	11.4	12.7	12.8	14.0	15.5	14.3	13.6	10.7
20	3.2	9.2	9.0	11.3	12.2	12.3	13.3	15.0	14.3	13.6	10.7
24	3.2	8.7	9.0	10.8	10.6	11.1	11.6	11.6	12.8	12.6	10.2
28	3.2	8.4	8.7	9.9	10.1	10.2	10.8	10.4	10.4	10.3	9.9
32	3.2	8.1	8.5	9.3	9.4	9.5	10.0	9.7	9.7	9.4	9.7
36	3.2	7.9	8.3	9.0	8.9	8.9	9.3	9.2	9.1	8.8	9.4
40	3.2	7.6	8.3	8.6	8.5	8.5	8.7	8.8	8.7	8.4	8.9
44	3.2	7.5	8.0	8.4	8.3	8.1	8.3	8.4	8.4	8.1	8.3
48	3.2	7.3	7.9	8.0	8.0	7.9	8.1	8.2	8.2	7.9	8.0
52	3.2	7.2	7.8	7.7	7.9	7.7	7.9	7.9	8.0	7.7	7.7
Average temperature 0-20m	3	10	10	13	16	16	17	16	14	14	11

Table 4 continued: Lake Wenatchee 2012-19 water temperatures. Shaded areas represent water temperatures >17^{O} C.

Water depth (m)	21-May-19	05-Jun-19	25-Jul-19	28-Jul-19	08-Aug-19	18-Sep-19	30-Sep-19	03-Oct-19	24-Oct-19	11-Nov-19	23-Nov-19	29-Feb-20
1	8.3	10.8	16.8	17.8	20.7	16.8	14.7	14.4	11.9	9.7	8.5	3.5
2	8.2	10.6	16.8	17.6	20.2	16.9	14.8	14.5	11.8	9.7	8.5	3.5
3	8.2	10.4	16.7	17.5	19.7	16.9	14.8	14.5	11.8	9.7	8.5	3.5
4	8.2	10.3	16.7	17.5	19.5	16.9	14.8	14.5	11.8	9.7	8.5	3.5
5	8.2	10.2	16.6	17.0	19.4	16.9	28.3	14.5	11.8	9.7	8.5	3.5
6	8.2	10.2	16.1	17.0	19.2	16.9	14.8	14.5	11.8	9.7	8.5	3.5
7	8.2	10.1	15.8	16.2	18.8	16.9	14.8	14.5	11.8	9.8	8.5	3.5
8	8.2	10.0	15.7	15.9	18.2	16.9	14.8	14.5	11.8	9.7	8.5	3.5
9	8.0	9.8	15.4	15.8	17.9	16.9	14.8	14.6	11.8	9.7	8.5	3.5
10	8.0	9.6	15.2	15.5	17.5	16.9	14.8	14.6	11.7	9.7	8.5	3.5
11	7.9	9.5	15.0	15.3	17.2	16.9	14.8	14.6	11.7	9.7	8.4	3.5
12	7.8	9.4	14.9	15.2	16.9	16.9	14.8	14.6	11.7	9.7	8.4	3.5
13	7.7	9.3	14.7	15.1	16.7	16.9	14.8	14.6	11.8	9.7	8.4	3.5
14	7.6	9.2	14.6	15.3	16.0	16.9	14.8	14.5	11.7	9.7	8.4	3.5
15	7.5	9.2	14.6	15.0	15.4	16.9	14.8	14.5	11.7	9.7	8.4	3.5
16	7.4	9.1	14.5	14.9	15.1	16.9	14.8	14.5	11.7	9.7	8.4	3.5
17	7.4	9.0	14.4	14.7	14.8	16.9	14.8	14.5	11.7	9.7	8.4	3.5
18	7.2	8.7	14.1	14.5	14.2	16.7	14.8	14.5	11.6	9.7	8.4	3.5
19	7.1	8.7	14.0	14.2	14.1	16.4	14.8	14.5	11.5	9.7	8.4	3.5
20	7.1	8.6	13.6	13.8	13.9	16.0	14.8	14.5	11.4	9.7	8.4	3.5
24	6.8	8.3	12.8	12.4	12.6	14.0	14.7	14.1	11.3	9.7	8.4	3.5
28	6.7	8.0	11.5	11.4	11.1	11.9	12.4	12.8	11.0	9.5	8.4	3.5
32	6.5	7.6	10.2	10.0	9.8	10.5	10.1	10.6	10.7	9.4	8.3	3.5
36	6.4	7.3	9.0	8.4	8.9	9.3	8.7	9.3	10.2	9.1	8.2	3.5
40	6.3	7.1	8.2	7.9	8.0	8.5	8.2	8.4	9.1	8.8	8.1	3.4
44	6.2	6.9	7.8	7.4	7.5	7.8	7.5	7.9	7.5	8.1	7.9	3.4
48	6.2	6.7	7.4	7.0	7.1	7.5	7.1	7.5	7.0	7.5	7.4	3.4
52	6.1	6.4	7.1	6.7	7.0	7.1	6.8	7.2	6.8	7.2	7.2	3.4
Average temperature 0-20 m	7.8	9.6	15.3	15.8	17.2	16.8	15.5	14.5	11.7	9.7	8.4	3.5

Table 5: Lake Wenatchee 2012-19 oxygen concentrations (ppm).

Water depth (m)	04-Jun-12	05-Jul-12	09-Aug-12	06-Oct-12
1	10.2	12.8	9.9	10.0
2	10.2	13.0	10.0	10.0
3	10.2	13.1	10.0	10.0
4	10.2	13.2	10.0	9.9
5	10.2	13.3	10.0	9.8
6	10.2	13.3	10.0	9.8
7	10.3	13.4	10.0	9.7
8	10.3	13.5	10.0	9.7
9	10.3	13.5	10.0	10.2
10	10.3	13.5	10.0	9.7
11	10.3	13.6	10.0	9.7
12	10.3	13.6	10.0	9.6
13	9.4	13.6	10.0	9.6
14	10.5	13.4	9.9	9.6
15	10.4	13.7	9.9	9.6
16	10.3	13.7	10.0	9.6
17	10.2	13.8	10.0	9.6
18	10.3	13.8	10.0	9.5
19	10.2	13.8	9.9	9.5
20	10.0	13.9	10.0	9.5
24	6.0	13.9	10.2	9.4
28	6.6	14.0	10.3	9.8
32	6.9	14.0	10.3	10.1
36	7.1	14.0	10.3	9.9
40	7.1	14.0	10.4	9.8
44	7.1	14.2	10.4	9.7
48	7.1	14.2	10.4	9.7
52	7.2	14.2	10.4	9.7

Water depth (m)	25-Jun-13	30-Jul-13	26-Aug-13	23-Sep-13
1	11.3	9.0	9.0	9.3
2	11.3	9.1	9.0	9.3
3	11.3	9.1	9.0	9.3
4	11.3	9.1	9.0	9.2
5	11.2	9.1	9.0	9.2
6	11.2	9.1	9.0	9.1
7	11.2	9.2	9.0	9.1
8	11.1	9.2	9.0	9.1
9	11.1	9.2	9.0	9.1
10	11.0	9.2	9.0	9.0
11	11.0	9.2	8.9	9.0
12	10.9	9.2	8.9	9.0
13	10.9	9.2	8.9	9.0
14	10.9	9.1	8.8	8.9
15	10.9	9.3	8.7	8.7
16	10.9	9.3	8.7	8.6
17	10.8	9.5	8.7	8.6
18	10.8	9.5	8.7	8.5
19	10.8	9.5	8.7	8.5
20	10.8	9.5	9.2	8.6
24	10.7	9.5	9.1	8.8
28	10.7	9.6	9.3	8.9
32	10.6	9.5	9.3	8.8
36	10.5	9.5	9.3	8.9
40	10.5	9.4	9.3	8.9
44	10.4	9.3	9.2	8.9
48	10.3	9.2	9.1	8.9
52				

Water depth (m)	05-Jun-14	23-Jun-14	14-Jul-14	11-Aug-14	04-Sep-14	08-Oct-14
1	10.9	10.4	10.0	9.1	9.1	9.3
2	10.9	10.4	10.0	9.1	9.1	9.4
3	10.9	10.5	10.0	9.2	9.1	9.4
4	10.9	10.5	10.0	9.3	9.1	9.4
5	10.9	10.5	10.0	9.3	9.1	9.4
6	10.9	10.5	10.0	9.3	9.1	9.4
7	10.9	10.5	10.0	9.3	9.1	9.3
8	10.9	10.5	10.1	9.3	9.1	9.3
9	10.9	10.5	10.0	9.3	9.1	9.3
10	10.9	10.5	10.0	9.3	9.0	9.3
11	10.9	10.5	10.0	9.2	9.0	9.3
12	10.9	10.4	10.1	9.2	8.9	9.2
13	10.8	10.4	10.1	9.2	8.9	9.2
14	10.8	10.4	10.1	9.2	9.3	9.2
15	10.8	10.3	10.1	9.1	8.8	9.1
16	10.8	10.3	10.1	9.1	8.8	9.1
17	10.8	10.3	10.1	9.1	8.8	9.0
18	10.8	10.3	10.0	9.2	8.8	9.0
19	10.8	10.3	10.0	9.2	8.7	8.9
20	10.8	10.3	10.0	9.2	8.7	8.9
24	10.7	10.3	10.0	9.4	8.8	8.6
28	10.6	10.2	10.0	9.4	8.9	8.4
32	10.6	10.2	9.9	9.5	9.1	8.5
36	10.5	10.1	9.9	9.5	9.2	8.6
40	10.5	10.1	9.9	9.4	9.2	8.8
44	10.5	10.0	9.8	9.4	9.2	8.7
48	10.4	10.0	9.8	9.3	9.1	8.7
52	10.4	9.9	9.6	9.2	9.0	8.6

Water depth (m)	01-Jun-15	25-Jun-15	14-Jul-15	05-Aug-15	28-Aug-15	16-Sep-15
1	10.5	9.7	8.8	9.2	9.1	9.1
2	10.5	9.7	8.8	9.2	9.1	9.2
3	10.5	9.7	8.8	9.2	9.0	9.2
4	10.5	9.8	8.8	9.1	9.5	9.2
5	10.5	9.7	8.8	9.1	9.5	9.2
6	10.6	9.7	8.8	9.1	9.5	9.2
7	10.7	9.8	8.8	9.1	9.0	9.1
8	10.6	9.8	8.8	9.1	8.9	9.1
9	10.7	9.8	8.8	9.1	8.9	9.1
10	10.6	9.8	8.8	9.1	8.9	9.1
11	10.6	9.8	8.8	9.0	8.9	9.1
12	10.6	9.8	8.9	9.0	8.9	9.0
13	10.6	9.8	9.0	9.0	8.8	9.0
14	10.5	9.8	9.1	9.0	8.8	9.0
15	10.5	9.7	9.2	9.0	8.8	9.0
16	10.5	9.8	9.2	9.0	8.8	9.0
17	10.5	9.8	9.3	9.0	8.7	8.9
18	10.5	9.7	9.3	9.0	8.7	8.9
19	10.5	9.7	9.3	8.9	8.6	8.9
20	10.4	9.7	9.3	8.8	8.5	8.9
24	10.4	9.8	9.3	8.9	8.3	8.6
28	10.4	9.8	9.4	9.0	8.4	8.4
32	10.4	9.8	9.5	9.2	8.6	8.4
36	10.3	9.8	9.5	9.3	8.7	8.4
40	10.3	9.8	9.5	9.3	8.8	8.4
44	10.2	9.8	9.5	9.3	8.9	8.4
48	10.1	9.7	9.5	9.3	8.9	8.4
52	10.1	9.6	9.5	9.3	8.9	8.4

Table 5 continued: Lake Wenatchee 2012-19 oxygen concentrations (ppm)

Water depth (m)	08-Jun-16	29-Jun-16	20-Jul-16	10-Aug-16	31-Aug-16	29-Sep-16
1	10.7	10.4	9.5	9.2	8.8	9.4
2	10.7	10.5	9.7	9.2	8.9	9.4
3	10.7	10.4	9.7	9.2	8.9	9.4
4	10.7	10.4	9.7	9.2	8.9	9.4
5	10.7	10.5	9.8	9.2	8.9	9.4
6	10.7	10.5	9.8	9.1	8.9	9.4
7	10.8	10.4	9.8	9.1	8.9	9.3
8	10.8	10.4	9.8	9.1	8.9	9.3
9	10.8	10.4	9.8	9.1	8.9	9.3
10	10.8	10.4	9.8	9.1	8.9	9.3
11	10.7	10.4	9.8	9.1	8.8	9.3
12	10.7	10.4	9.7	9.1	8.8	9.2
13	10.7	10.4	9.7	9.1	8.8	9.2
14	10.7	10.4	9.7	9.0	8.8	9.2
15	10.7	10.4	9.7	9.0	8.8	9.2
16	10.7	10.4	9.7	9.0	8.7	9.1
17	10.7	10.4	9.7	9.0	8.7	9.1
18	10.7	10.4	9.6	9.0	8.6	9.0
19	10.7	10.3	9.6	8.9	8.4	9.0
20	10.7	10.3	9.6	8.9	8.4	9.0
24	10.6	10.2	9.7	8.9	8.5	8.7
28	10.6	10.1	9.6	8.9	8.5	8.4
32	10.5	10.1	9.6	9.0	8.7	8.4
36	10.4	10.0	9.6	9.1	8.8	8.5
40	10.4	10.0	9.6	9.1	8.8	8.5
44	10.3	9.9	9.5	9.1	8.8	8.5
48	10.3	9.9	9.4	9.1	8.9	8.4
52	10.2	9.9	9.3	9.1	8.7	8.2

Water depth (m)	12-Apr-17	28-Jun-17	21-Aug-17	15-Sep-17
1	10.9	10.5	9.1	9.5
2	10.9	10.6	9.1	9.4
3	10.9	10.6	9.1	9.4
4	10.9	10.7	9.1	9.4
5	10.8	10.7	9.1	9.4
6	10.8	10.7	9.1	9.4
7	10.8	10.7	9.1	9.4
8	10.8	10.7	9.1	9.4
9	10.8	10.7	9.1	9.3
10	10.9	10.7	9.1	9.3
11	10.9	10.7	9.1	9.3
12	10.9	10.7	9.0	9.3
13	10.8	10.7	9.0	9.2
14	10.8	10.7	9.5	9.2
15	10.8	10.7	9.0	9.1
16	10.8	10.7	9.0	9.1
17	10.7	10.7	9.1	9.0
18	10.7	10.7	9.0	8.9
19	10.7	10.6	9.0	8.8
20	10.7	10.6	9.6	8.8
24	10.7	10.6	9.3	9.0
28	10.6	10.6	9.5	9.2
32	10.6	10.5	9.5	9.3
36	10.6	10.5	9.5	9.4
40	10.5	10.6	9.5	9.5
44	10.5	10.6	9.4	9.5
48	10.5	10.5	9.4	9.6
52	10.4	10.4	9.5	9.6

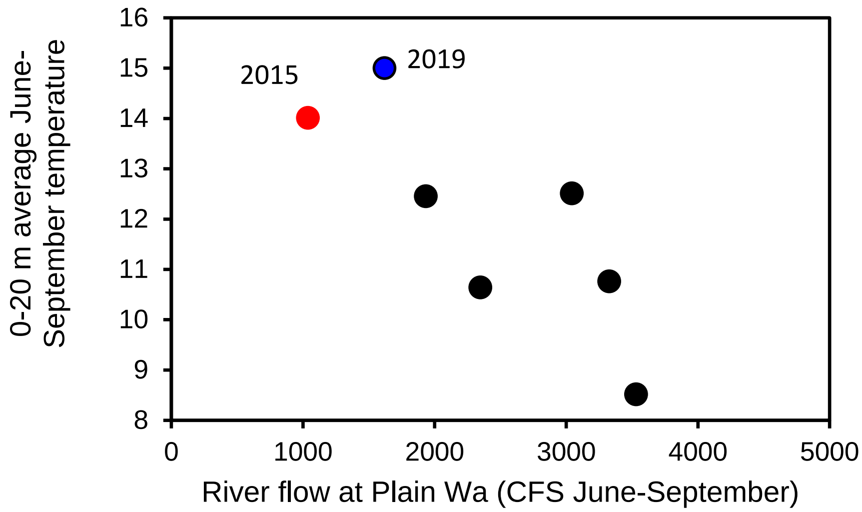
Water depth (m)	15-Mar-18	15-Jun-18	11-Jul-18	04-Aug-18	22-Aug-18	10-Sep-18	13-Aug-18	03-Oct-18	09-Oct-18	06-Nov-18
1	12.5	10.8	10.1	9.2	9.2	9.3	9.7	9.7	10.1	17.4
2	12.5	11.0	10.1	9.1	9.2	9.3	9.8	9.7	9.9	17.0
3	12.6	11.0	10.1	9.1	9.2	9.3	9.8	9.6	9.8	16.9
4	12.6	11.0	10.2	9.1	9.2	9.3	9.8	9.6	9.8	16.7
5	12.6	11.0	10.1	9.1	9.2	9.3	9.8	9.5	9.7	16.6
6	12.7	11.0	10.2	9.1	9.2	9.2	9.8	9.5	9.7	16.6
7	12.8	11.0	10.2	9.1	9.2	9.2	9.8	9.5	9.7	16.5
8	12.8	11.0	10.2	9.1	9.1	9.2	9.8	9.4	9.7	16.5
9	12.8	10.9	10.2	9.1	9.1	9.2	9.8	9.4	9.7	16.4
10	12.9	11.0	10.2	9.1	9.1	9.2	9.8	9.4	9.6	16.4
11	12.8	11.0	10.1	9.1	9.0	9.1	9.9	9.4	9.6	16.4
12	12.8	11.0	10.1	9.1	9.0	9.1	9.8	9.3	9.6	16.4
13	12.8	11.0	10.1	9.2	8.9	9.1	9.8	9.3	9.6	16.4
14	12.8	11.0	10.1	9.2	8.9	9.1	9.8	9.3	9.6	16.4
15	12.8	10.9	10.1	9.3	8.8	9.1	9.7	9.3	9.6	16.3
16	12.8	10.9	10.1	9.3	8.8	9.1	9.7	9.2	9.5	16.3
17	12.8	10.9	10.0	9.3	8.8	9.0	9.7	9.2	9.5	16.2
18	12.8	10.9	10.0	9.3	8.8	9.0	9.7	9.2	9.5	16.2
19	12.8	10.9	10.0	9.3	8.8	8.9	9.8	9.2	9.5	16.1
20	12.8	10.9	10.0	9.3	8.8	8.8	9.8	9.1	9.4	16.1
24	12.8	10.8	9.9	9.4	8.9	8.7	9.9	8.8	9.4	15.9
28	12.8	10.8	9.9	9.4	9.0	8.8	9.9	8.7	9.0	15.9
32	12.8	10.7	9.8	9.5	9.0	8.9	10.0	8.6	8.9	15.9
36	12.8	10.7	9.8	9.5	9.0	8.9	10.0	8.6	8.8	15.8
40	12.7	10.6	9.7	9.5	9.1	8.9	10.0	8.6	8.9	15.3
44	12.7	10.5	9.7	9.4	9.0	8.8	10.1	8.6	8.9	14.6
48	12.7	10.5	9.6	9.2	9.0	8.7	10.0	8.5	8.8	14.2
52	12.7	10.4	9.6	9.1	8.9	8.6	10.0	8.4	8.8	13.7

Table 5 continued: Lake Wenatchee 2012-19 oxygen concentrations (ppm)

Water depth (m)	21-May-19	05-Jun-19	25-Jul-19	28-Jul-19	08-Aug-19	18-Sep-19	30-Sep-19	03-Oct-19	24-Oct-19	11-Nov-19	23-Nov-19	29-Feb-20
1	11.2	10.4	9.5	9.3	8.5	9.4	10.3	9.3	9.4	10.5	10.9	12.2
2	11.2	10.6	9.6	9.5	8.5	9.4	10.2	9.2	9.4	10.4	10.8	12.1
3	11.2	10.6	9.6	9.6	8.6	9.3	10.2	9.2	9.4	10.5	10.7	12.0
4	11.2	10.7	9.6	9.7	8.6	9.3	10.2	9.2	9.4	10.3	10.6	12.0
5	11.2	10.7	9.6	9.8	8.7	9.3	10.2	9.1	9.4	10.3	10.5	12.0
6	11.2	10.7	9.6	9.7	8.7	9.3	10.1	9.1	9.4	10.3	10.4	11.9
7	11.2	10.7	9.6	9.8	8.7	9.2	10.1	9.1	9.4	10.2	10.3	11.9
8	11.2	10.7	9.6	9.8	8.8	9.2	10.1	9.0	9.3	10.2	10.2	11.8
9	11.2	10.7	9.6	9.8	8.9	9.2	10.1	9.0	9.3	10.2	10.2	11.8
10	11.2	10.7	9.6	9.8	8.9	9.2	10.1	9.0	9.3	10.2	10.1	11.8
11	11.1	10.7	9.6	9.8	8.9	9.2	10.1	9.0	9.3	10.1	10.1	11.7
12	11.2	10.7	9.5	9.8	8.8	9.1	10.1	9.0	9.3	10.1	10.1	11.7
13	11.1	10.7	9.5	9.8	8.8	9.1	10.1	9.0	9.3	10.1	10.0	11.7
14	11.1	10.7	9.5	9.8	8.6	9.1	10.0	8.9	9.3	10.1	10.0	11.7
15	11.1	10.7	9.5	9.8	8.6	9.0	10.0	8.9	9.3	10.1	10.0	11.7
16	11.1	10.7	9.5	9.8	8.6	9.0	10.0	8.9	9.2	10.1	10.0	11.7
17	11.1	10.7	9.5	9.8	8.6	9.0	10.0	8.9	9.2	10.0	9.9	11.6
18	11.1	10.7	9.5	9.7	8.6	8.9	10.0	8.9	9.2	10.0	9.9	11.7
19	11.1	10.7	9.4	9.8	8.6	8.9	10.0	8.8	9.2	10.0	9.9	11.6
20	11.1	10.7	9.4	9.8	8.6	8.7	10.0	8.9	9.2	10.0	9.9	11.6
24	11.0	10.7	9.4	9.7	8.6	8.5	9.9	8.6	9.2	9.8	9.8	11.5
28	10.9	10.6	9.4	9.7	8.6	8.6	9.6	8.4	9.2	9.7	9.4	11.5
32	10.9	10.6	9.5	9.7	8.7	8.7	9.4	8.2	9.2	9.6	9.8	11.4
36	10.8	10.5	9.5	9.8	8.8	8.9	9.4	8.3	9.1	9.4	9.7	11.4
40	10.8	10.5	9.5	9.8	8.9	8.9	9.4	8.3	8.8	9.0	9.6	11.3
44	10.7	10.4	9.6	9.8	8.9	8.9	9.5	8.3	8.6	8.5	9.5	11.3
48	10.7	10.4	9.5	9.9	8.9	9.0	9.5	8.2	8.4	8.4	9.2	11.3
52	10.6	10.3	9.5	9.9	8.9	8.9	9.4	8.2	8.4	8.1	8.9	11.2

There was a strong (R^2=0.66, p=0.02, n=7) (Figure 4) correlation between average June-September discharge rate from Lake Wenatchee and June-September water temperature averaged over 0-20 m water depth. Later in this report we will investigate the effects that this may have had on phytoplankton, zooplankton and fish.

Figure 4: Average Lake Wenatchee 0-20 m water temperatures recorded during June-September 2012-19, with respect to average rates of river flow (2012-19 cubic feet per second) recorded at Plain WA.



Lake Wenatchee 2012-19 Secchi Depths

In all years Secchi depths were typically greater than 5 m suggesting oligotrophic water quality conditions suitable for juvenile Sockeye Salmon. During 2017 and on some dates during 2018 and 2019, samples were taken at night and Secchi depths were recorded on only one and four dates respectively (Table 6).

Table 6: Lake Wenatchee Secchi depths

	Secchi Depths (m)		Secchi Depths (m)
04-Jun-12	5.8	01-Jun-15	5.7
25-Jun-12	5.5	14-Jul-15	7.8
05-Jul-12	5.9	28-Aug-15	7.9
09-Aug-12	4.3	16-Sep-15	7.0
18-Sep-12	6.5		
06-Oct-12	7.2	08-Jun-16	5.5
		20-Jul-16	4.9
25-Jun-13	5.6	31-Aug-16	7.1
30-Jul-13	5.4	29-Sep-16	10.5
26-Aug-13	6.6		
23-Sep-13	6.9	12-Apr-17	6.8
05-Jun-14	7.5	15-Jun-18	6.0
23-Jun-14	7.7	01-Aug-18	5.9
14-Jul-14	5.3	10-Sep-18	9.8
04-Sep-14	8.0	03-Oct-18	10.5
08-Oct-14	9.2		
		05-June-19	6.7
		08- Aug-19	7.6

Lake Wenatchee 2012-18 Water Chemistry

During 2012, nutrient chemistry was recorded on two dates and calcium concentrations were recorded on one date (Table 7). During 2013, alkalinity and calcium concentrations were recorded on one date. During both 2012 and 2013, samples were processed at the laboratories used by Fisheries and Oceans, (see methods). During 2017, nutrient chemistry, alkalinity and calcium concentrations were recorded on two dates and processed at the laboratory used by the Okanagan Nation (see methods). Despite this change in analytical methods, concentrations of various elements were remarkably consistent. During other years, water chemistry parameters were not measured.

During 2012, 2013 and 2017, total epilimnetic phosphorus averaged 5-6 µg L^{-1} suggesting oligotrophic conditions. Alkalinity varied from 9-13 mg L^{-1}, which is considered to be near the lower end of the normal alkalinity scale, but not unusual and not limiting to most fish and plankton.

In the 2016 version of the Lake Wenatchee Report we noted that low alkalinity and low concentrations of calcium have been shown to inhibit chitin formation in *Daphnia* and that lower limits for calcium limitation range from 1-3 mg Ca L^{-1}. We suggested that in Lake Wenatchee, low calcium concentrations might limit *Daphnia*. Now, a more comprehensive review of the literature suggests that daphnid survival thresholds tend to be species-specific. For *Daphnia magna* the reproductive threshold is 0.1-0.5 mg L^{-1} Ca (Alstad, et al. 1999, Hessen et al. 2000). For *Daphnia galeata* the thresholds for survival lie between 0 and 2 mg Ca (Rukke 2002). For *Daphnia pulex* the survival threshold is 0.1-0.5 mg L^{-1} and reproduction rates were reduced at concentrations less than 1.5 mg L^{-1} Ca (Ashforth and Yan 2008). For *Daphnia pulex x Daphnia pulicaria* hybrid, survival and reproduction decreased at Ca concentrations < 1.0 mg/L (Goodberry 2013). Tessier and Horwitz (1990) surveyed 146 lakes in the eastern United States and found that larger *Daphnia pulex/pulicaria*, *Daphnia galeata mendotae,* and *Daphnia schodleri* were found in high calcium lakes, and smaller *Daphnia catawba, Daphnia ambigua, Daphnia retrocurva, Daphnia parvula* were found in low Ca lakes.

Samples from 2012, 2013 and 2017 (Table 7) show that in Lake Wenatchee, calcium varied from 1.5-2.7 mg L^{-1}, which is low compared to Okanagan Lakes, but still high enough to support the species (i.e. *Daphnia schodleri.)* found in Lake Wenatchee. In the future, calcium monitoring should be continued.

Table 7: Lake Wenatchee 2012, 2013 and 2017 water chemistry. Water chemistry data were not collected during 2018 and 2019.

Lake Wenatchee 2012		Station 1	Station 1	Station 2	Station 2		Average	
Date		Epilimnion	Hypolimnion	Epilimnion	Hypolimnion		Epilimnion	Hypolimnion
12-Jun-12	Phosphorus (total µg L-1)	6.5	7.4	nd	nd		6.5	7.4
	Alkalinity (total mg L-1)	12.8	nd	nd	nd		12.8	
	Calcium (Ca total mg L-1)	2.5	nd	nd	nd		2.5	
18-Sep-12	Phosphorus (total µg L-1)	5.3	9.8	5.0	5.2		5.2	7.5

Lake Wenatchee 2013		Station 1	Station 1	Station 2	Station 2		Average	
Date		Epilimnion	Hypolimnion	Epilimnion	Hypolimnion		Epilimnion	Hypolimnion
10-Jul-13	Alkalinity (total mg L-1)	7.2	nd	5.4	nd		6.3	nd
	Calcium (Ca total mg L-1)	2.0	nd	1.5	nd		1.8	nd

Lake Wenatchee 2017		Station 1	Station 1	Station 2	Station 2		Average	
Date		Epilimnion	Hypolimnion	Epilimnion	Hypolimnion		Epilimnion	Hypolimnion
23-Aug-17	Nitrogen (total µg L-1)	75.0	71.0	65.0	65.0		70.0	68.0
	Phosphorus (total µg L-1)	5.0	5.0	5.0	5.0		5.0	5.0
	Alkalinity (total mg L-1)	9.4	8.1	8.9	8.8		9.2	8.5
	Calcium (Ca total mg L-1)	2.6	2.5	2.6	2.5		2.6	2.5
21-Sep-17	Nitrogen (total µg L-1)	64.0	63.0	43.0	75.0		53.5	69.0
	Phosphorus (total µg L-1)	5.6	5.0	5.0	5.5		5.3	5.3
	Alkalinity (total mg L-1)	9.8	9.4	9.5	9.7		9.7	9.6
	Calcium (Ca total mg L-1)	2.7	2.6	2.7	2.6		2.7	2.4

Lake Wenatchee 2012-19 phytoplankton

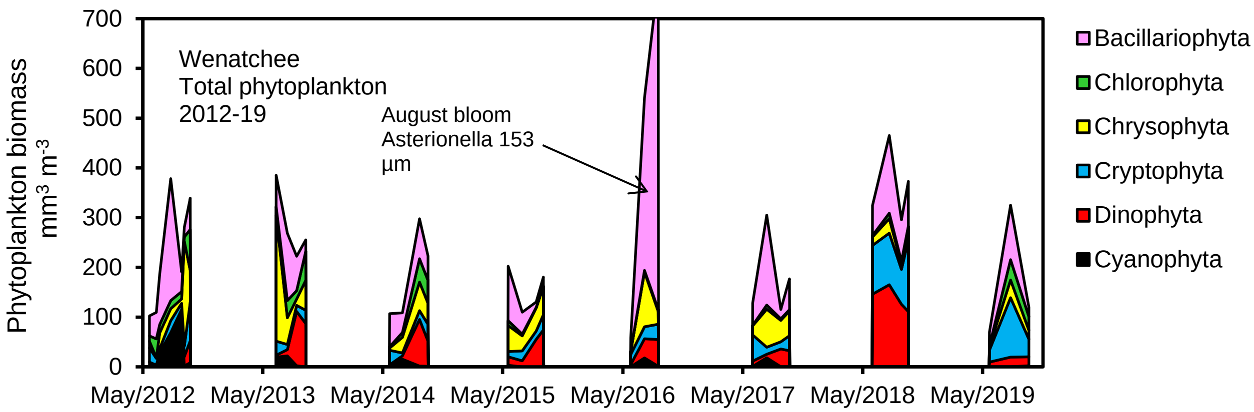
Phytoplankton were collected on seven dates during 2012, four dates during 2013-15, three dates during 2016, 4 dates during 2017-18 and 3 dates during 2019 (Figure 5, Tables 8, 9). Samples taken at 1,5,10 m were combined. Densities, cell sizes, cell shapes and biovolumes were recorded. One of the objectives of the phytoplankton counting procedure was to assess the relative availabilities of edible (grazable) and non-edible (non-grazable) algae. We quantified "edibility" based on size, toxicity and digestibility (see Methods for details).

In Lake Wenatchee during most years, total phytoplankton biovolume averaged 273 $mm^3 m^{-3}$ and the edible biovolume averaged 179 $mm^3 m^{-3}$. As a point of reference, Osoyoos Lake 2005-13 total phytoplankton biovolume averaged 1120 $mm^3 m^{-3}$ and the edible biovolume averaged 322 $mm^3 m^{-3}$. Although the total biovolume in Lake Wenatchee was lower than in Osoyoos Lake, the percentage that was edible was much higher (Wenatchee 65%, Osoyoos 28%). Detailed count data are provided in Tables 8, 9. Additional Lake Wenatchee vs. Osoyoos Lake comparisons are available in the 2018 ONA-DFO-CRITFC report titled: Lake Wenatchee and Osoyoos Lake Juvenile Sockeye Salmon and Limnology Comparison - Brood Years 2009-2016 (In-Lake 2010-2017).

Throughout 2012-19 (Figure 5, Tables 8, 9) there was considerable year to year variability in phytoplankton biovolume. During 2012 there was a bloom of *Cyclotella stelligera* (now *Discostella stelligera*) a small disk-shaped diatom that is thought to be a good food source for zooplankton. *Cyclotella* also appeared in the edible fraction of the phytoplankton sampled in 2016. During that year there was also a very large bloom of *Asterionella* a star-shaped diatom colony (Figure 6) that is too large for consumption by zooplankton.

During 2015, phytoplankton biovolumes, especially edible phytoplankton biovolumes, were lower than in the other years. Edible phytoplankton was also somewhat lower in 2019. The most likely correlates could be (1) higher rates of river flow into Lake Wenatchee and therefore higher rates of phytoplankton washout during 2015 and 2019, and (2) higher rates of predation by the 2015 and 2019 zooplankton population. This is discussed in more detail in the section titled "Analysis of between-year differences in phytoplankton and zooplankton biomass:" on pages 36-39.

Figure 5: Lake Wenatchee 2012-19, total and edible phytoplankton biovolume as $mm^3\ m^{-3}$ which approximates $\mu g \bullet L^{-1}$ wet weight.



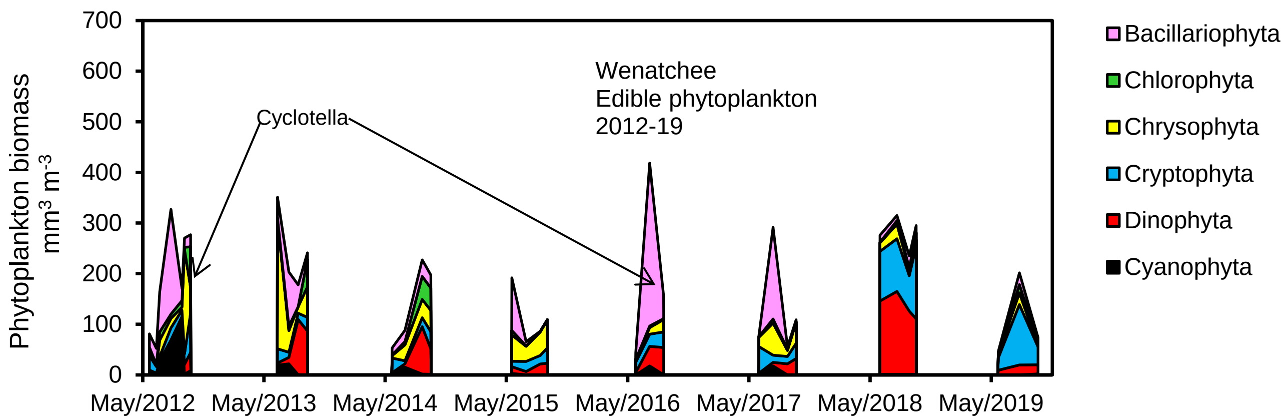


Figure 6: Asterionella measuring 153 x 102 x 3 µm.

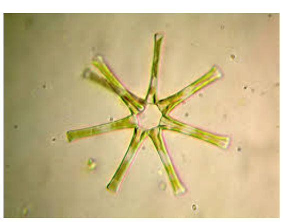


Table 8: Lake Wenatchee 2012-19, total phytoplankton biovolume as mm^3 m^{-3} which approximates µg L^{-1} wet weight

Date	Cyanophyta	Dinophyta	Cryptophyta	Euglenophyta	Chrysophyta	Haptophyta	Tribophyta	Chlorophyta	Raphidophyta	Bacillariophyta	**TOTAL**
04-Jun-12	10	0	29	0	13	1	0	11	0	40	**103**
25-Jun-12	3	1	13	0	1	0	0	38	0	53	**110**
05-Jul-12	25	3	8	0	32	2	0	16	0	101	**188**
08-Aug-12	63	6	24	0	24	0	0	16	0	245	**378**
10-Sep-12	105	10	13	0	8	0	0	15	0	39	**191**
18-Sep-12	2	19	21	0	210	1	0	9	0	20	**282**
6-Oct-12	8	44	78	0	63	2	0	83	0	63	**342**
25-Jun-13	19	4	28	0	254	0	0	17	0	63	**385**
29-Jul-13	22	12	10	0	54	2	0	35	0	135	**271**
26-Aug-13	2	109	12	0	13	11	1	17	0	69	**235**
23-Sep-13	0	87	27	0	60	4	0	58	0	23	**259**
5-Jun-14	4	0	29	0	5	9	0	2	0	66	**116**
14-Jul-14	15	7	6	0	31	8	0	10	0	40	**116**
4-Sep-14	2	94	18	0	57	2	0	47	0	80	**300**
30-Sep-14	1	50	34	0	42	8	1	46	0	49	**231**
1-Jun-15	3	17	11	0	52	3	0	10	0	110	**206**
14-Jul-15	0	12	20	0	30	0	0	3	0	44	**110**
25-Aug-15	0	55	17	0	46	1	0	1	0	11	**131**
16-Sep-15	0	74	30	0	56	1	0	2	0	18	**181**
8-Jun-16	0	5	20	0	6	2	0	1	0	26	**60**
20-Jul-16	18	39	24	0	110	4	0	3	0	347	**545**
31-Aug-16	1	54	31	0	26	1	0	4	0	664	**780**
14-Jun-17	1	10	53	0	18	3	0	1	0	45	**131**
27-Jul-17	18	7	14	0	76	8	0	8	0	181	**313**
8-Sep-17	0	36	14	0	43	1	0	3	0	19	**116**
4-Oct-17	0	32	30	0	50	4	0	3	0	62	**181**
14-Jun-18	1	145	98	0	17	0	0	3	0	60	**324**
04-Aug-18	1	164	104	0	29	0	0	11	0	156	**465**
10-Sep-18	1	125	70	0	11	0	0	5	0	84	**296**
01-Oct-18	1	110	144	0	12	0	0	16	0	90	**373**
05-Jun-19	0	9	24	0	7	0	0	2	0	28	**70**
08-Aug-19	0	19	119	0	36	0	0	41	0	109	**325**
03-Oct-19	2	18	35	0	18	0	0	27	0	19	**120**

Table 9: Lake Wenatchee 2012-19, <u>edible</u> phytoplankton biovolume as mm^3 m^{-3} which approximates µg L^{-1} wet weight.

Date	Cyanophyta	Dinophyta	Cryptophyta	Euglenophyta	Chrysophyta	Haptophyta	Tribophyta	Chlorophyta	Raphidophyta	Bacillariophyta	**TOTAL**
04-Jun-12	10	0	29	0	13	1	0	3	0	26	**82**
25-Jun-12	3	1	13	0	1	0	0	2	0	32	**53**
05-Jul-12	25	3	8	0	32	2	0	16	0	79	**166**
08-Aug-12	63	6	24	0	19	0	0	9	0	207	**327**
10-Sep-12	105	10	13	0	6	0	0	13	0	24	**171**
18-Sep-12	2	19	21	0	205	1	0	5	0	18	**271**
6-Oct-12	8	36	78	0	50	2	0	81	0	24	**279**
25-Jun-13	19	4	28	0	254	0	0	5	0	41	**351**
29-Jul-13	22	12	10	0	43	2	0	8	0	107	**206**
26-Aug-13	1	109	12	0	13	11	1	0	0	43	**191**
23-Sep-13	0	87	27	0	60	4	0	54	0	13	**245**
5-Jun-14	4	0	29	0	5	9	0	2	0	14	**62**
14-Jul-14	15	7	6	0	31	8	0	7	0	22	**96**
4-Sep-14	2	94	18	0	36	2	0	45	0	33	**229**
30-Sep-14	1	50	34	0	42	8	1	45	0	25	**206**
1-Jun-15	3	13	11	0	52	3	0	9	0	104	**195**
14-Jul-15	0	7	20	0	30	0	0	1	0	8	**66**
25-Aug-15	0	22	17	0	46	1	0	1	0	1	**87**
16-Sep-15	0	23	30	0	55	1	0	1	0	0	**110**
8-Jun-16	0	5	20	0	5	2	0	1	0	14	**46**
20-Jul-16	18	39	24	0	13	4	0	3	0	322	**423**
31-Aug-16	0	54	31	0	24	1	0	2	0	45	**157**
14-Jun-17	1	2	53	0	18	3	0	1	0	1	**80**
27-Jul-17	18	7	14	0	63	8	0	8	0	181	**299**
8-Sep-17	0	22	14	0	12	1	0	3	0	5	**56**
4-Oct-17	0	32	30	0	42	4	0	1	0	3	**113**
14-Jun-18	1	145	98	0	17	0	0	1	0	14	**276**
04-Aug-18	1	164	104	0	29	0	0	7	0	10	**315**
10-Sep-18	1	125	70	0	11	0	0	4	0	24	**235**
01-Oct-18	1	110	144	0	12	0	0	14	0	14	**295**
05-Jun-19	0	9	24	0	7	0	0	1	0	6	**46**
08-Aug-19	0	19	119	0	23	0	0	16	0	23	**202**
03-Oct-19	2	18	35	0	2	0	0	7	0	9	**74**

Lake Wenatchee 2012-19 zooplankton

The Lake Wenatchee zooplankton community comprises a very small number of species. There are two dominant copepods (*Diacyclops thomasi, Hesperodiaptomus kena*i), and two bosminids (*Bosmina longirostris, Eubosmina coregoni*) which were counted separately but grouped together in this report (Figure 7, Table 10). The remaining cladocerans are *Daphnia schodleri* and *Leptodora kindtii*. Note that in earlier reports we used the name *Daphnia thorata*, but after considerable taxonomic work we have changed the name to *Daphnia schodleri*. However, even now the taxonomists are unsure. We know that there is only one *Daphnia* species, but individual specimens don't key exactly to either *thorata* or *schodleri*. This is probably not unusual as *Daphnia* are known to hybridize and *Daphnia* taxonomy is sometimes uncertain. Based on current evidence, the Lake Wenatchee *Daphnia* species is likely to be *Daphnia schodleri* and since there is only one species, henceforth we will simply use the term *Daphnia*. Most of the other Lake Wenatchee zooplankton species are typical of those found in the Okanagan lakes. The exception is *Hesperodiaptomus kenai* which is extremely large, typically brightly coloured and an excellent food source of juvenile Sockeye Salmon.

Through 2012-19, there was considerable variation in zooplankton biomass (Figure 7). During 2012, the rotifer *Kellicottia* was abundant and accounted for the unusually high zooplankton biomasses recorded in the fall. During 2013 and 2014, from August through to the end of sample collection in October, there was a decline in total zooplankton biomass (Figure 7, Table 10). During 2015, there was an unusually large *Daphnia* population which persisted through the summer until September. During spring-summer 2016, zooplankton biomasses were lower than normal and all species appeared to be equally affected, but during the fall of 2016, *Daphnia* and *Bosmina* biomasses increased (Table 10). During 2017, *Hesperodiaptomus* densities were very high during the spring, and were lower during the summer when *Bosmina* and *Daphnia* became more abundant. During 2018, zooplankton biomass was the lowest recorded since the study began.

During 2019, *Daphnia* was the dominant species. Also during 2019, we extended our sampling interval to the early spring (March-April) and the late fall (October-November). (Figure 7, Table 10). Our goal was to improve our life history data for *Hesperodiaptomus*. This is discussed in the section titled "The importance of *Hesperodiaptomus*" on page 41.

Figure 7: Year 2012-19 zooplankton biomass (µg L^{-1} dry weight).

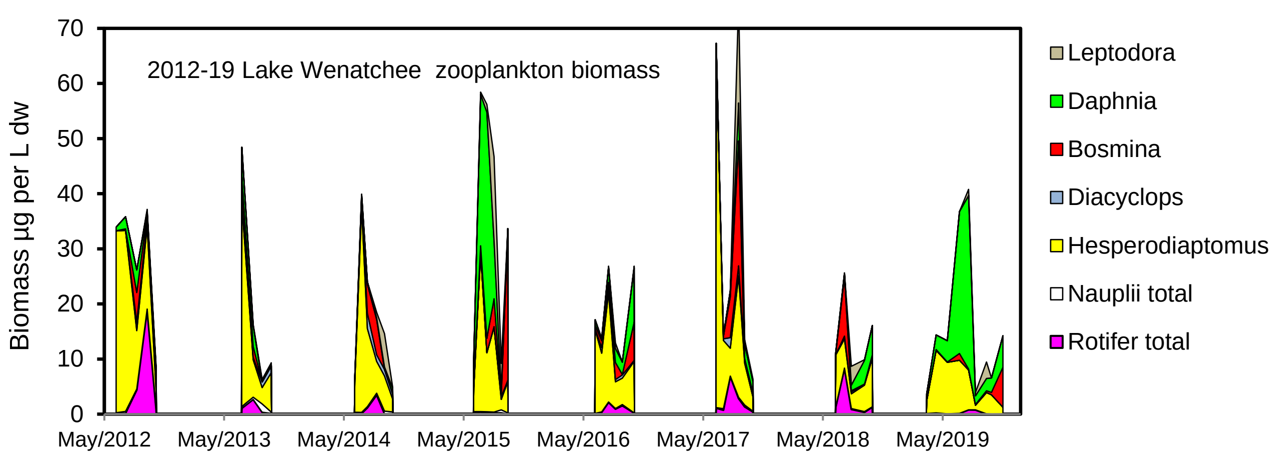


Table 10: 2012-19 Lake Wenatchee zooplankton biomasses (µg L^{-1} dry weight)

Date	Rotifer total	Nauplii total	Diacyclops adults & cop	Hesperodiaptomus kenai adults & cop	Epischura	Bosmina	Daphnia	Diaphanosoma	Leptodora	Total
06-Jun-12	0.14	0.13	0.04	32.97	0.00	0.00	0.65	0.00	0.00	**33.93**
05-Jul-12	0.18	0.30	0.06	32.84	0.00	0.23	2.20	0.00	0.00	**35.82**
08-Aug-12	4.40	0.15	1.45	10.61	0.00	5.46	4.11	0.00	0.00	**26.17**
09-Sep-12	19.00	0.09	1.05	15.07	0.00	1.24	0.34	0.00	0.36	**37.15**
06-Oct-12	0.97	0.03	1.00	3.32	0.00	2.65	0.18	0.00	0.57	**8.71**
25-Jun-13	1.09	0.30	0.64	36.93	0.00	4.07	5.38	0.00	0.04	**48.45**
30-Jul-13	2.68	0.40	0.46	6.78	0.00	1.96	3.76	0.00	0.27	**16.30**
26-Aug-13	0.34	1.52	1.02	2.96	0.00	0.00	0.07	0.00	0.39	**6.30**
23-Sep-13	0.15	0.23	1.21	7.14	0.00	0.00	0.17	0.00	0.42	**9.32**
05-Jun-14	0.07	0.26	0.38	5.43	0.00	0.08	0.23	0.00	0.00	**6.45**
26-Jun-14	0.15	0.17	1.26	37.35	0.00	0.45	0.49	0.00	0.00	**39.88**
14-Jul-14	1.17	0.18	2.78	14.19	0.00	5.29	0.39	0.00	0.01	**24.01**
11-Aug-14	3.47	0.34	1.17	5.79	0.00	6.39	0.34	0.00	0.97	**18.46**
04-Sep-14	0.07	0.49	1.16	6.38	0.00	0.04	0.43	0.00	6.04	**14.60**
29-Sep-14	0.10	0.29	0.89	2.34	0.00	0.16	0.88	0.00	0.24	**4.91**
04-Jun-15	0.22	0.26	0.12	4.20	0.00	0.26	5.13	0.00	0.00	**10.18**
25-Jun-15	0.41	0.04	0.13	28.80	0.00	1.17	27.46	0.00	0.44	**58.46**
14-Jul-15	0.20	0.24	0.08	10.68	0.00	2.57	41.05	0.00	1.39	**56.19**
05-Aug-15	0.26	0.11	0.07	15.44	0.00	5.07	10.49	0.00	15.29	**46.73**
27-Aug-15	0.26	0.52	0.49	1.88	0.00	0.39	0.81	0.00	4.86	**9.21**
16-Sep-15	0.03	0.19	0.25	5.67	0.00	26.84	0.70	0.00	0.00	**33.67**
09-Jun-16	0.12	0.03	0.15	15.16	0.13	0.70	0.95	0.00	0.00	**17.24**
29-Jun-16	0.35	0.05	1.00	10.67	0.00	1.23	0.38	0.00	0.08	**13.74**
20-Jul-16	2.14	0.08	1.04	19.91	0.00	0.76	2.76	0.00	0.18	**26.85**
10-Aug-16	0.93	0.08	0.40	4.86	0.00	3.11	2.55	0.00	1.00	**12.92**
31-Aug-16	1.55	0.18	0.57	4.81	0.00	0.10	2.22	0.00	0.00	**9.42**
06-Oct-16	0.19	0.05	0.17	9.34	0.00	6.96	9.86	0.00	0.30	**26.86**
14-Jun-17	1.10	0.09	0.02	65.80	0.00	0.03	0.27	0.00	0.00	**67.31**
6-Jul-17	0.72	0.25	0.26	12.42	0.00	0.44	0.12	0.00	0.00	**14.22**
27-Jul-17	6.84	0.06	1.91	5.05	0.00	7.44	1.05	0.00	0.12	**22.48**
21-Aug-17	2.84	0.21	1.84	22.04	0.00	22.67	6.88	0.00	18.56	**75.02**
9-Sep-17	1.35	0.29	0.77	7.58	0.00	0.15	2.54	0.00	0.82	**13.49**
4-Oct-17	0.42	0.11	0.29	2.57	0.00	0.45	1.99	0.00	0.52	**6.33**
14-Jun-18	1.24	0.06	0.04	9.41	0.00	0.16	0.20	0.00	0.00	**11.11**
11-Jul-18	8.35	0.01	0.50	5.30	0.00	10.87	0.57	0.00	0.00	**25.60**
01-Aug-18	0.87	0.15	0.34	2.67	0.00	0.21	1.01	0.00	3.42	**8.68**
10-Sep-18	0.34	0.12	0.16	4.79	0.00	0.06	4.29	0.00	0.11	**9.87**
04-Oct-18	1.28	0.05	0.15	8.83	0.00	0.42	5.33	0.00	0.00	**16.07**

Continued

Table 10 continued

Date	Rotifer total	Nauplii total	Diacyclops adults & cop	Hesperodiaptomus kenai adults & cop	Epischura	Bosmina	Daphnia	Diaphanosoma	Leptodora	Total
19-Mar-19	0.01	0.10	0.00	2.33	0.00	0.03	1.23	0.00	0.00	**3.70**
17-Apr-19	0.00	0.24	0.00	11.33	0.00	0.16	2.62	0.00	0.00	**14.36**
21-May-19	0.01	0.04	0.00	9.34	0.00	0.08	3.85	0.00	0.00	**13.33**
27-Jun-19	0.14	0.01	0.01	9.62	0.00	1.22	25.75	0.00	0.00	**36.75**
25-Jul-19	0.79	0.00	0.00	7.23	0.00	0.15	31.48	0.00	1.15	**40.79**
15-Aug-19	0.76	0.02	0.00	0.85	0.00	0.09	1.59	0.00	0.59	**3.91**
18-Sep-19	0.02	0.03	0.01	3.87	0.00	0.31	2.25	0.00	2.99	**9.47**
03-Oct-19	0.00	0.00	0.00	3.52	0.00	0.42	2.60	0.00	0.00	**6.55**
07-Nov-19	0.03	0.00	0.00	1.22	0.00	7.27	5.72	0.00	0.00	**14.23**

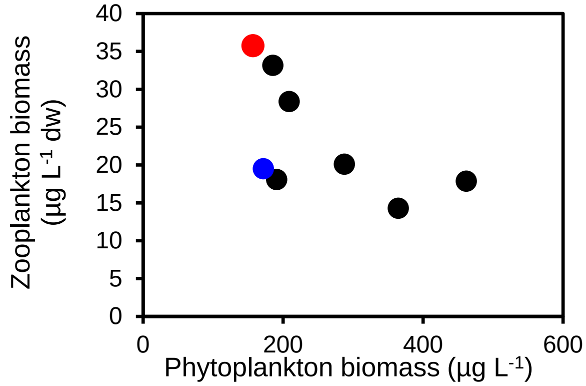
Analysis of between-year differences in phytoplankton and zooplankton biomass

Here we investigate three possible hypotheses for the observed between-year differences in species-specific zooplankton biomasses (Figure 7, Table 10). We also investigate potential relationships between zooplankton and phytoplankton.

Working Hypothesis 1 – There is a negative correlation between phytoplankton and zooplankton biomass.

A comparison of Figure 5 (phytoplankton biomass) and Figure 7 (zooplankton biomass) shows that when zooplankton biomasses were highest (2015 and 2017), phytoplankton biomasses were lowest and conversely, when zooplankton biomasses were lowest (2016 and 2018) phytoplankton biomasses were highest. This suggests a negative correlation between zooplankton and phytoplankton and when the entire 2012-19 data set is plotted (Figure 8) higher phytoplankton biomasses are associated with lower zooplankton biomasses and there is a negative but not significant (R^2=0.37, p=0.10) relationship between zooplankton and phytoplankton biomass. From this we conclude that a bottom-up phytoplankton-zooplankton relationship is unlikely and that year to year changes in phytoplankton biomass do not limit zooplankton biomass. However, we also note that in some years, higher zooplankton biomasses were associated with lower phytoplankton biomasses. Could zooplankton limit phytoplankton? This will be discussed in the section titled "Working Hypothesis 4" on page 40.

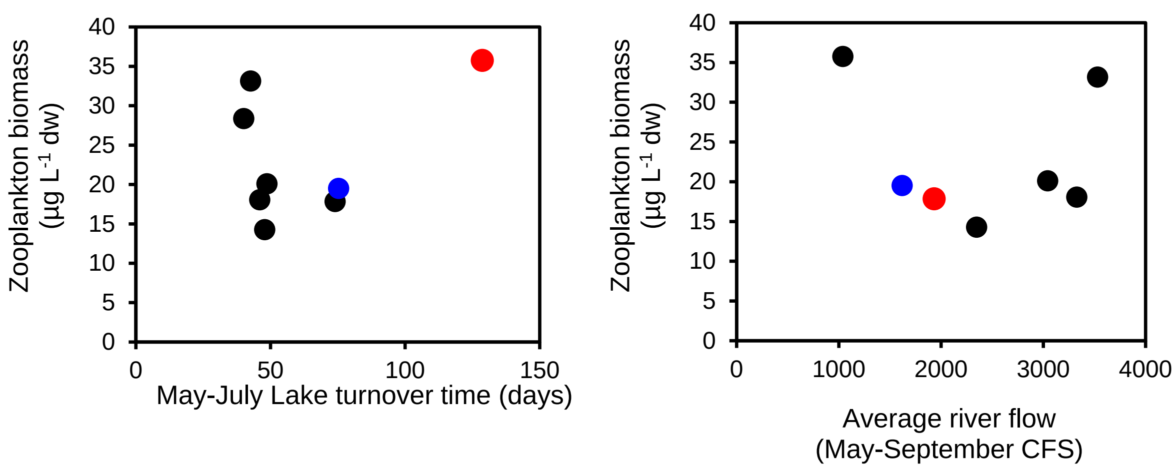
Figure 8: Year 2012-19 June-September phytoplankton biomass with respect to zooplankton biomass. Year 2015 is shown in red, 2019 in blue.



Working Hypothesis 2 - There is an inverse relationship between the volume of water flowing through Lake Wenatchee and zooplankton biomass.

This hypothesis is based on observations in the Okanagan valley where there were strong negative relationships between discharge from the Okanagan River and mean summer zooplankton biomasses in Osoyoos ($p=.004$) and Skaha ($p=.008$) lakes. However in Lake Wenatchee (Figure 9), there is no obvious relationship between rates of lake-turnover or rates of river flow and average summer zooplankton biomass.

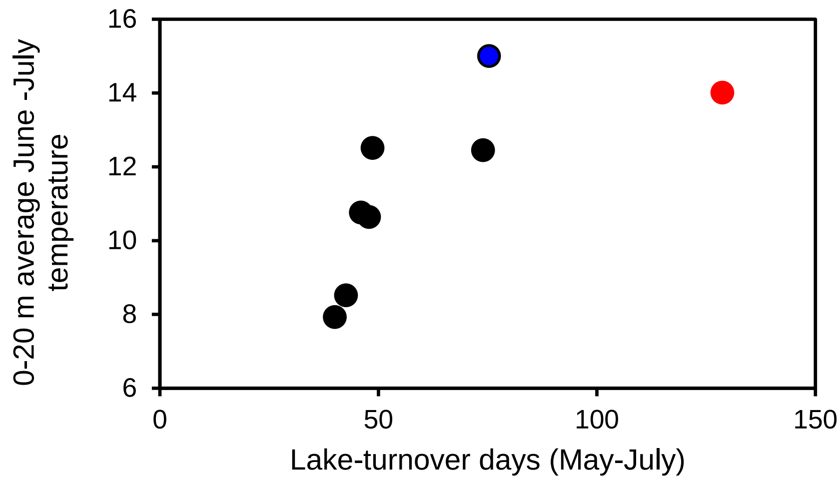
Figure 9: Year 2012-19 average spring-summer (May-September) zooplankton biomass with respect to average (May-July) rate of lake-turnover and average rate of flow in the Wenatchee River recorded at Plain Washington. Red data point = year 2015, blue = 2019.



<u>Working Hypothesis 3</u> - There is a relationship between lake temperature and zooplankton biomass.

There was a significant negative (R^2=0.65, p=0.027) correlation between discharge rate from Lake Wenatchee and average (0-20m) water temperature (Figure 4). There was also a significant (R^2=0.51, p=0.046) relationship between lake-turnover and water temperature (Figure 10). The conclusion is that average 0-20 m water temperature is positively associated with lake-turnover time. The longer the water remains in the lake, the warmer it becomes.

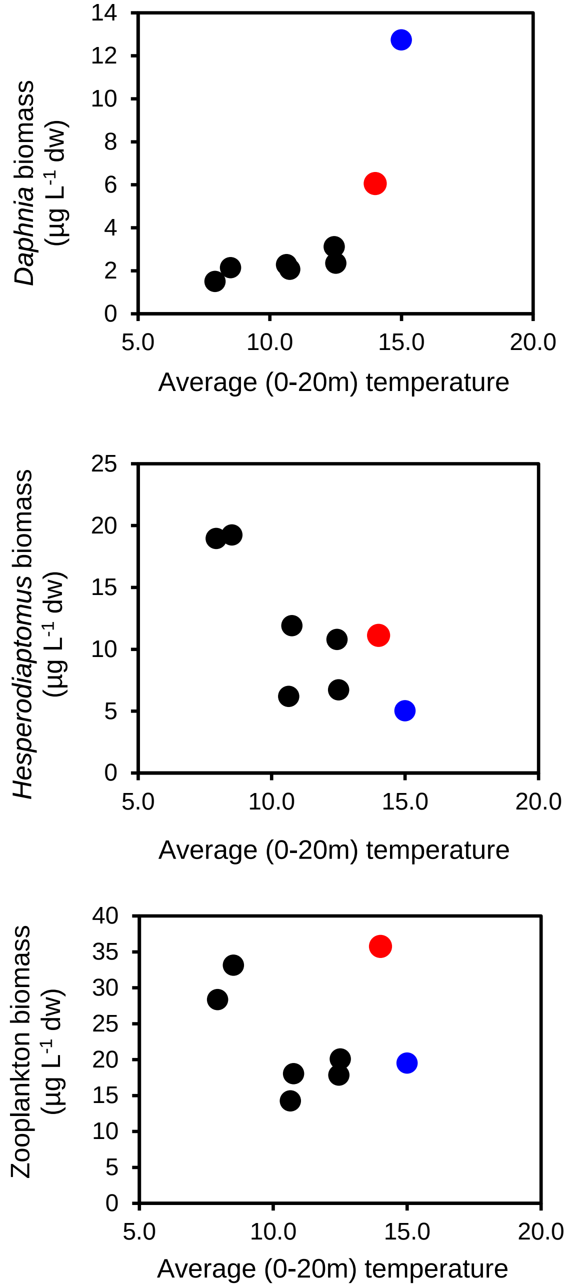
Figure 10: Year 2012-19 average (0-20 m water depth) June-July water temperature with respect to average (May-July) rate of lake-turnover. Red data point = year 2015, blue = 2019.



We conclude that zooplankton biomass, lake turnover and water temperature are related as follows: (i) There was no relationship between zooplankton biomass and river flow and no relationship between zooplankton biomass and lake-turnover (Figure 9). Unlike the Okanagan lakes, there appears to be no significant washout of Lake Wenatchee zooplankton. (ii) There was a significant negative relationship between discharge rate from Lake Wenatchee and average (0-20m) water temperature (Figure 4) and also a significant positive relationship between lake-turnover and water temperature (Figure 10). Longer residence times were associated with higher water temperatures. (iii) Was there a relationship between zooplankton biomass and water temperature? The answer is both yes and no (Figure 11).

Daphnia biomass was <u>positively</u> (R^2=0.59, p=0.027) associated with water temperature (Figure 11 top panel) and *Hesperodiaptomus* biomass was negatively (R^2=0.62, p=0.021) associated with water temperature (Figure 11 middle panel), but there was no relationship between average (June-September) total zooplankton biomass and average (June-September) 0-20 m water temperature (Figure 11 bottom panel). It appears that the two species-specific relationships cancel each other so that <u>total</u> zooplankton biomass is not correlated with water temperature. It also seems likely that during warm summer *Daphnia* will dominate the plankton and during cool summers *Hesperodiaptomus* will dominate. There is more about this in the next section (page 40).

Figure 11: Year 2012-19 average June-September (0-20 m) water temperature and average June -September *Daphnia* biomass (top panel), average June -September *Hesperodiaptomus* biomass (middle panel) and average June -September total zooplankton (bottom panel).

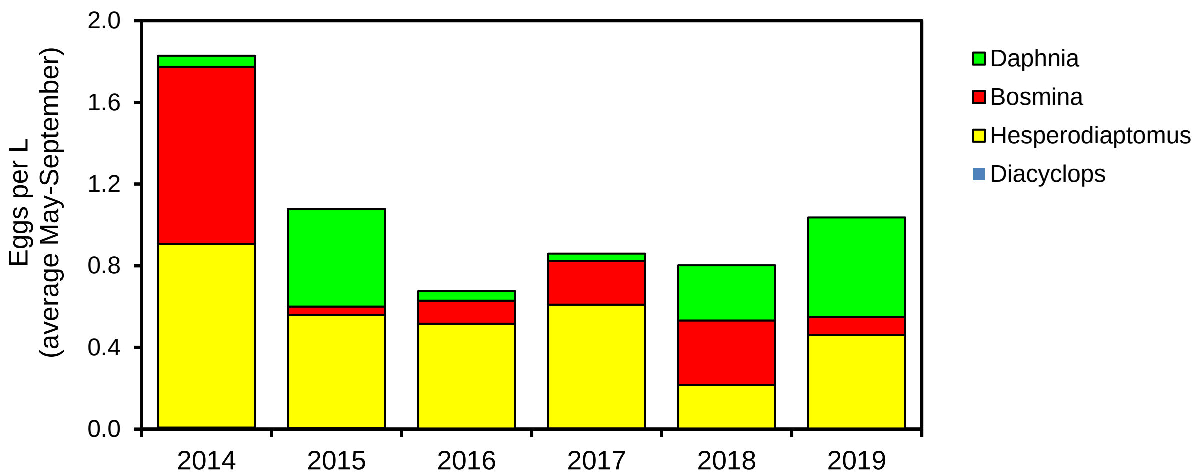


Working Hypothesis 4 - There is a top-down relationship between zooplankton biomass and phytoplankton biomass.

In 2015 river flow was the lowest recorded and 2015 was the year with the highest recorded rate of lake-turnover (Table 3). During that year, *Daphnia* biomass was the highest recorded (Figure 7) and *Daphnia* egg counts were the highest recorded (Figure 12). In 2015, during late-June and early-July, the epilimnion warmed to $19^{O}C$ (Table 4) and epilimnetic water warmer than $17^{O}C$ persisted through to late August - early September. Also in 2019 river flow was low and during July, August and early September, epilimnetic water temperatures reached record highs and remained $>17^{O}C$ for more than two months. Because juvenile Sockeye Salmon are known to avoid water temperatures $>17^{O}C$, it seems likely that the warm epilimnetic water acted as a refuge for *Daphnia* and stimulated unusually high egg production. During 2015 and 2019, high *Daphnia* biomasses and high grazing rates by *Daphnia* may have been associated with the record low phytoplankton biomasses recorded in those two years.

We conclude that during 2015 and 2019, low rainfall → low rates of river flow into Lake Wenatchee → longer water residence times and lake turnover, → warm epilimnetic water → avoidance of warm epilimnetic water by Sockeye plus high rates of *Daphnia* reproduction → high *Daphnia* densities and high grazing rates → low phytoplankton densities. During 2015 and 2019, food web dynamics were strongly influenced by climate.

Figure 12: Year 2014-18 average (June-September) zooplankton eggs counts per L of lake water.



Note however, that 2016 was also a low flow year (Table 3), but the 0-20 m water strata did not warm to the high temperatures recorded during 2015 and 2019 (Table 4). We note that summer river flows were higher in 2016 than they were in 2015 and 2019, but we can offer no other documented explanations for the low *Daphnia* biomasses observed in 2016.

The importance of *Hesperodiaptomus*

In the Lake Wenatchee vs. Osoyoos Lake comparison (McQueen et al. 2018) we noted that Lake Wenatchee average (May-August) zooplankton biomass (25 µg L^{-1}) was much lower

than average zooplankton biomass in Osoyoos Lake (67 µg L^{-1}). Among the cladocerans, both lakes had *Daphnia* and *Bosmina* but, *Diaphanosoma* was found only in Osoyoos Lake. Among the copepods, both lakes had *Diacyclops bicuspidatus*, but Osoyoos Lake had *Leptodiaptomus ashlandi* while Lake Wenatchee had *Hesperodiaptomus kenai*. This single species substitution (*Hesperodiaptomus* vs *Leptodiaptomus*) represents a major difference in the availability of zooplankton for fish. On average, *Leptodiaptomus* copepodids and adults weigh 2.5 µg dry weight and measure less than 1 mm in body length. On average *Hesperodiaptomus* copepodids and adults weigh >20 µg dry weight and the average body length is about 2 mm. This makes *Hesperodiaptomus* an important target as prey for juvenile Sockeye.

As noted, Lake Wenatchee total zooplankton biomasses were lower than they were in Osoyoos Lake. This suggests that Lake Wenatchee Sockeye should have grown at about half the rate of Osoyoos Lake juvenile Sockeye. However, the presence of *Hesperodiaptomus* likely allowed Lake Wenatchee Sockeye to hunt with greater efficiency (energy return per feeding strike was higher), resulting in a smaller than expected difference in Sockeye growth rates. In fact during 2012, 2013 and 2014, both Wenatchee and Osoyoos Juvenile Sockeye had similar lengths and weights (Table 11).

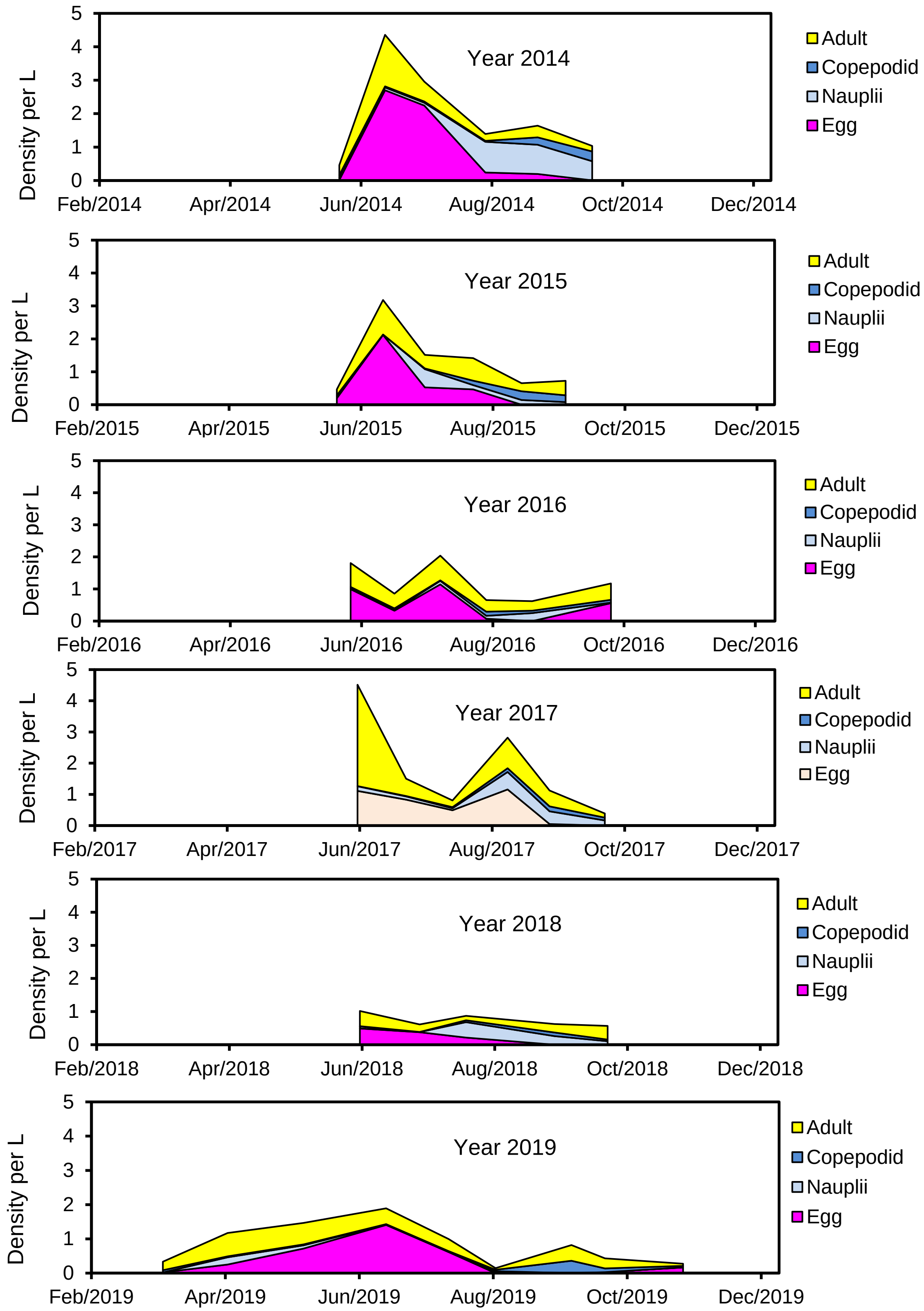
Table 11: Comparisons of Lake Wenatchee and Osoyoos Lake age-0 Sockeye lengths and weighs.

Lake Wenatchee			Osoyoos Lake		
Date	Length (mm)	Weight (g)	Date	Length (mm)	Weight (g)
18-Sep-12	56	1.9	11-Sep-12	61	2.3
23-Sep-13	60	nd	10-Oct-13	74	4.1
23-Feb-14	74	4.2	27-Feb-14	75	4.5

Hesperodiaptomus egg, nauplii, copepodid and adult counts from 2014-18 (Figure 13), suggested that there was a single period of reproduction in the spring and early summer. However, the May-October sampling regime that we used in those years introduced some uncertainty about the exact extent of the reproductive cycle. During 2019, we increased sampling to include most of the ice-free season (i.e. March-April and November) (Figure 13), and we found that most egg production occurred during March-August, with perhaps a small reproductive period under the ice during the winter. This winter reproductive period may prove to be very important.

Hesperodiaptomus and *Daphnia* are a primary prey for Sockeye fry. During 2010-19 fry densities have usually ranged from 1000-2000 ha^{-1} (Table 12). These are modest densities and future enhancement may produce much larger population densities with associated increases in rates of consumption by fish. A possible concern is that consumption by higher densities of Sockeye fry may exceed the productive capacity of *Hesperodiaptomus* which has a fixed life cycle with most reproduction in the spring and early summer. *Hesperodiaptomus* adults and copepodids consumed in the fall will not be replaced. Our bioenergetics work in the section titled "Lake Wenatchee 2019 bioenergetics-based estimates of consumption by fish compared to production by zooplankton" on page 48 will address this issue.

Figure 13: *Hesperodiaptomus kenai* egg, nauplius, copepodid and adult density



Lake Wenatchee 2012-18 Juvenile Sockeye Salmon

Table 12: Year 2010-19 Lake Wenatchee juvenile Sockeye numbers (lake area 1004 ha), densities, lengths, weights and where available; ages and sample sizes.

Brood year	sample year	Fish age	Sample date	Number per lake	Mean density per ha	Mean Length mm	Mean Weight g	Sample size	Percent population	Provenance
2009	**2010**	nd	21-Sep-10	1,637,000	1600	58	2.02	—	—	DFO JSIDS SRe01-2013
2010	**2011**		20-Sep-11	2,300,000	2300	56	1.74	—		DFO JSIDS SRe01-2013
2010	**2011**	nd	1-Nov-11	2,000,000	2000	62	2.69	—	—	DFO JSIDS SRe01-2013
2011	**2012**	0	25-Jun-12	1,666,000	1666	31	0.27	—	98%	DFO JSIDS SRe01-2013
2011	**2012**	nd	18-Sep-12	2,847,909	2837	56	1.89	*105	—	DFO JSIDS SRe01-2013
2011	**2012**	1	25-Jun-12	34,000	34	nd	4.02	—	2%	DFO JSIDS SRe01-2013
2012	**2013**	nd	10-Jul-13	2,778,381	2767	38	0.66	102	—	DFO echosound (length, weight DFO)
2012	**2013**	nd	23-Sep-13	2,650,400	2640	60	nd	89	—	DFO echosound (no weight)
2013	**2014**	nd	27-Oct-14	1,774,238	1767	58	2.06	178	—	DFO echosound (length, weight DFO)
2013	**2014**	nd	23-Feb-15	1,519,873	1514	74	4.15	102	—	ONA echosound (length, weight ONA)
2014	**2015**	nd	21-Sep-15	2,451,535	2442	59	2.11	146	—	DFO echosound (length, weight DFO)
2014	**2015**	0	11-Mar-16	2,136,833	2,128	70	3.67	102	96%	ONA echosound (length, weight ONA)
2014	**2015**	1	11-Mar-16	89,035	89	117	13.90	4	4%	ONA echosound (length, weight ONA)
2015	**2016**	0	01-Sep-16	1,272,472	1,268	60	2.40	115	84%	ONA echosound (length, weight ONA)
2015	**2016**	0	03-Nov-16	1,205,735	1,129	73	4.20	106	94%	ONA echosound (length, weight ONA)
2015	**2016**	0	12-Apr-17	600,817	598	72	4.01	120	92%	ONA echosound (length, weight ONA)
2015	**2016**	1	01-Sep-16	242,376	241	105	13.80	22	16%	ONA echosound (length, weight ONA)
2015	**2016**	1	03-Nov-16	72,344	79	109	13.40	7	6%	ONA echosound (length, weight ONA)
2015	**2016**	1	12-Apr-17	50,068	50	113	12.30	10	8%	ONA echosound (length, weight ONA)
2016	**2017**	0	28-Jun-17	3,499,286	3,485	35	0.31	158	99%	ONA echosound (length, weight ONA)
2016	**2017**	0	22-Aug-17	2,948,267	2,936	54	1.57	155	99%	ONA echosound (length, weight ONA)
2016	**2017**	0	15-Sep-17	2,541,623	2,532	56	1.81	100	99%	ONA echosound (length, weight ONA)
2016	**2017**	0	20-Nov-17	2,111,701	2,103	72	3.80	138	100%	ONA echosound (length, weight ONA)
2016	**2017**	0	15-Mar-17	1,909,917	1,903	72	3.75	37	97%	ONA echosound (length, weight ONA)
2016	**2017**	1	28-Jun-17	43,741	44	65	2.67	2	1%	ONA echosound (length, weight ONA)
2016	**2017**	1	22-Aug-17	18,899	19	77	5.00	1	<1%	ONA echosound (length, weight ONA)
2016	**2017**	1	15-Sep-17	25,165	25	93	9.30	1	<1%	ONA echosound (length, weight ONA)
2016	**2017**	1	20-Nov-17	0	0	—	—	0	0%	ONA echosound (length, weight ONA)
2016	**2017**	1	15-Mar-17	50,261	50	98	8.64	1	3%	ONA echosound (length, weight ONA)

Table 14 Continued…..

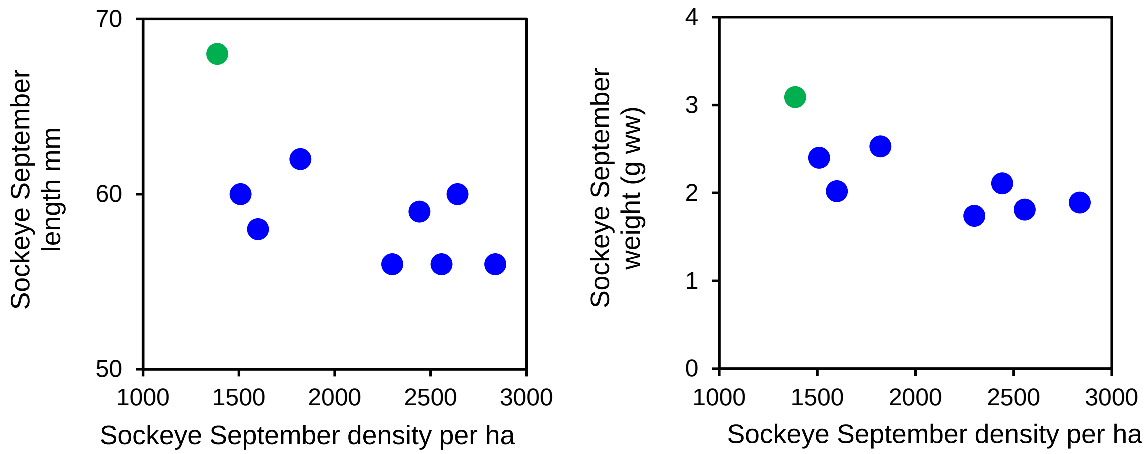
Brood year	sample year	Fish age	Sample date	Number per lake	Mean density per ha	Mean Length mm	Mean Weight g	Sample size	Percent population		Provenance
2017	**2018**	0	13-Jun-18	1,638,528	1632	3.03	0.24	487	96%		ONA echosound (length, weight ONA)
2017	**2018**	0	13-Aug-18	1,244,960	1240	5.38	1.60	112	94%		ONA echosound (length, weight ONA)
2017	**2018**	0	09-Oct-18	1,290,140	1285	6.75	3.09	148	93%		ONA echosound (length, weight ONA)
2017	**2018**	0	06-Nov-18	1,031,108	1027	6.84	3.31	56	94%		ONA echosound (length, weight ONA)
2016	**2018**	1	13-Jun-18	69,276	69	7.16	3.70	14	4%		ONA echosound (length, weight ONA)
2016	**2018**	1	13-Aug-18	74,296	74	10.39	12.42	38	6%		ONA echosound (length, weight ONA)
2016	**2018**	1	09-Oct-18	102,408	102	10.88	13.83	5	7%		ONA echosound (length, weight ONA)
2016	**2018**	1	06-Nov-18	63,252	63	-	-	0	6%		ONA echosound (length, weight ONA)
2018	**2019**	0	28-Jul-19	1,660,302	1655	5.22	1.50	123	96%		ONA echosound (length, weight ONA)
2018	**2019**	0	30-Sep-19	1,695,341	1690	6.19	2.53	106	93%		ONA echosound (length, weight ONA)
2018	**2019**	0	24-Oct-19	1,093,888	1091	6.47	2.92	100	95%		ONA echosound (length, weight ONA)
2018	**2019**	0	29-Feb-20	436,914	436	nd	nd	0	96%	§	ONA echosound (length, weight ONA)
2017	**2019**	1	28-Jul-19	71,471	71	11.81	19.53	7	4%		ONA echosound (length, weight ONA)
2017	**2019**	1	30-Sep-19	131,243	131	15.30	39.91	1	7%		ONA echosound (length, weight ONA)
2017	**2019**	1	24-Oct-19	54,065	54	14.15	28.82	2	5%		ONA echosound (length, weight ONA)
2017	**2019**	1	29-Feb-20	18,627	19	nd	nd	0	4%	§	ONA echosound (length, weight ONA)

§ There was no trawling in February 2020. The data shown here are based on 2018 age breaks

Do Wenatchee Lake juvenile Sockeye exhibit density-dependent growth? A common hypothesis is that juvenile Sockeye feed primarily on zooplankton, therefore increased Sockeye densities should be associated with reduced biomasses of zooplankton and this will result in reduced availability of food which feeds back to reduce juvenile Sockeye growth. If this scenario is true, we should find (i) a negative relationship between age-0 Sockeye density (x variable) and age-0 Sockeye growth rate (y variable), (ii) a positive relationship between zooplankton biomass (x variable) and age-0 Sockeye growth rate (y variable) and (iii) a negative relationship between age-0 Sockeye density (x variable) and zooplankton biomass (y variable). These three sub-hypotheses are tested in the sections that follow.

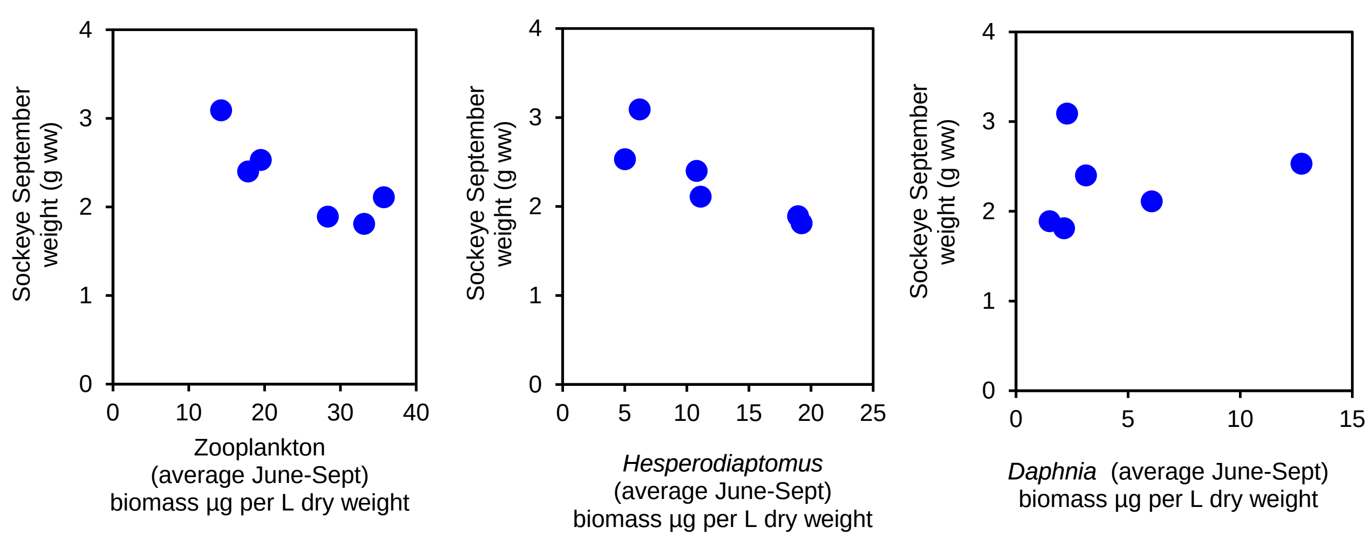
(i) Under the “density dependent” hypothesis we expect to find a negative relationship between Sockeye density and growth. Data from 2010-13 and 2015-19 showed significant negative relationships between age-0 Sockeye September density (x variable) and September age-0 Sockeye length (Figure 14 left panel, $R^2 = 0.53$, p=0.04) and weight (Figure 14 right panel, $R^2 = 0.55$, p=0.04). From this we conclude that Lake Wenatchee age-0 Sockeye have density-dependent rates of summer growth. We must now investigate the mechanism.

Figure 14: Sockeye fry September-October length (left figure) and weight (right figure) with respect to September fry density. The green data are from 2018.



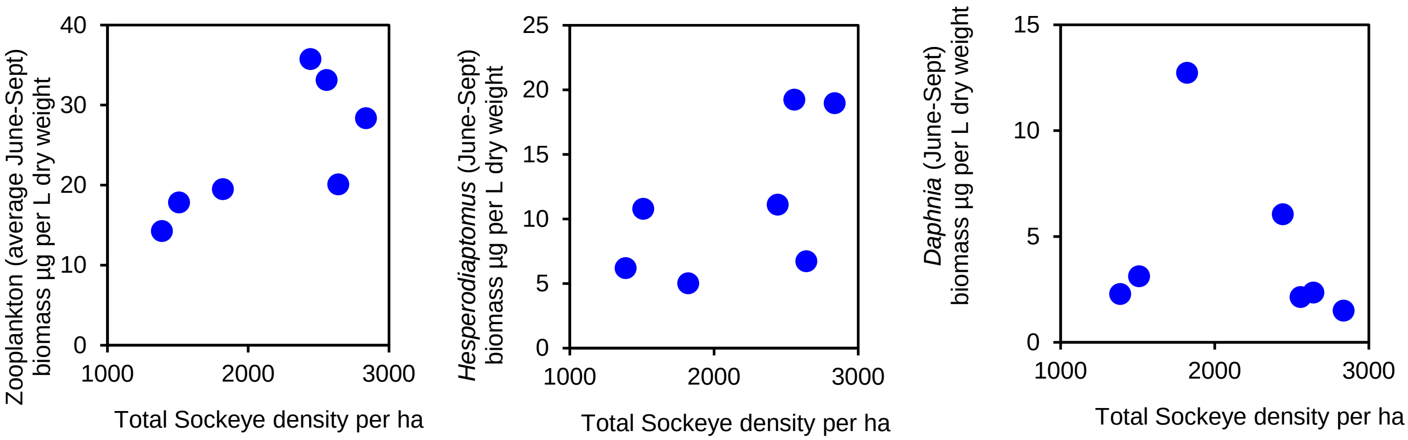
(ii) Under the food-based density-dependent hypothesis we expect positive relationships between zooplankton biomass (x variable) and age-0 Sockeye growth rate (y variable). Based on data from 2010-13 and 2015-19, we found no such relationships (Figure 15) for age-0 Sockeye September-weight with respect to total zooplankton biomass, *Hesperodiaptomus* biomass or *Daphnia* biomass (Figure 15). Contrary to expectations, the relationships between Sockeye weight and the biomass of total zooplankton and *Hesperodiaptomus* were negative rather than positive. The relationship between Sockeye weight and *Daphnia* biomass was positive but not significant.

Figure 15: Left panel – September juvenile Sockeye mean weight with respect to average June-September zooplankton biomass; middle panel - September juvenile Sockeye mean weight with respect to average June-September *Hesperodiaptomus* biomass; right panel - September juvenile Sockeye mean weight with respect to average June-September *Daphnia* biomass.



(iii) The density dependent hypothesis states that increased Sockeye densities should result in the consumption of more zooplankton and that subsequent reduced biomasses of zooplankton should feed-back to reduce juvenile Sockeye growth. Data from 2012-13 and 2015-19, show that the relationships between age-0 Sockeye density (x variable) and total zooplankton biomass (y variable Figure 16 left panel) is positive rather that negative and the relationship between age-0 Sockeye density (x variable) and *Hesperodiaptomus* biomass (y variable Figure 16 middle panel) is also positive. There was no relationship for *Daphnia* biomass and juvenile Sockeye density and all three relationships are not statistically significant.

Figure 16: Left panel - average June-September zooplankton biomass with respect to average spring-summer fry density; middle panel - average June-September *Hesperodiaptomus* biomass with respect to spring-summer fry density; right panel - average June-September *Daphnia* biomass with respect to spring-summer fry density.

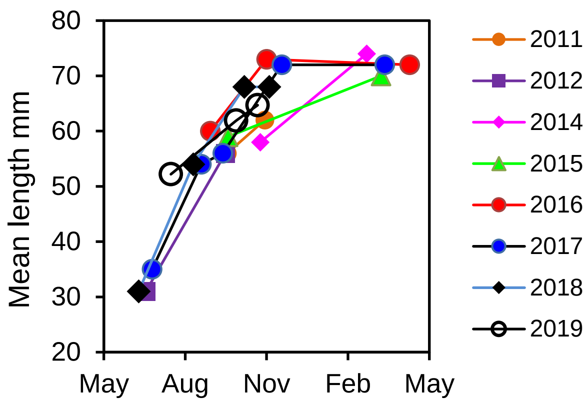


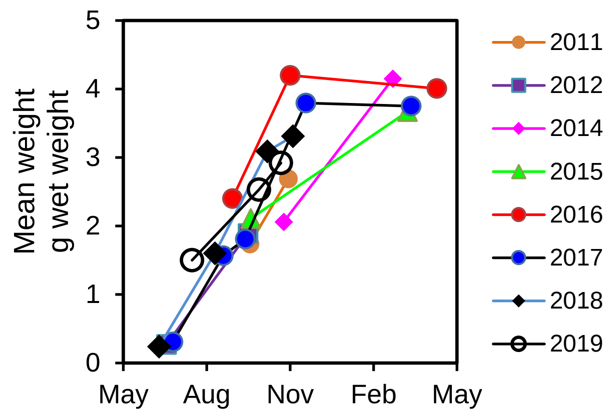
Given that there was a negative relationship between age-0 Sockeye density and September Sockeye length and weight (Figure 14), but no relationship between zooplankton biomass and age-0 Sockeye September weight (Figure 15) and no relationship between zooplankton density and Sockeye density (Figure 16), there appears to be a logical inconsistency in the data. In Figure 14, the 2018 data point is an outlier and when the 2018 data are removed from the regressions, the negative relationships between age-0 Sockeye September weight and total Sockeye density became non-significant ($p = 0.10$). Also the “September” 2018 Sockeye data were actually measured on 09 October 2018 when the fish were larger than they would have been in September which was the date used for all of the other years (Table 12). In addition, the 2018 age-0 fry that were again recorded in November 2018, were the same length that they were in October (Figure 18) and their November lengths and weights were lower than the lengths and weights of age-0 fry recorded in November 2016 and 2017 (Figure 18). We conclude that the apparent correlation between Sockeye density and age-0 September weight is spurious and exemplifies the problems encountered when using single length-weight measures to represent seasonal growth rates.

A comparison of von Bertalanffy growth curves would provide a more appropriate analysis, but there were insufficient data in many of the years. Visual inspection of the growth curves plotted in Figure 17 makes the point.

Juvenile Sockeye growth: The Lake Wenatchee growth patterns are similar to the patterns observed (during 2005-17) in Osoyoos Lake where late-June age-0 Sockeye averaged 35 mm length, grew rapidly through the summer-fall reaching average lengths of 70 mm (65-75 mm) in late November and then grew more slowly through the winter. Osoyoos age-0 Sockeye weights showed the same pattern (i.e. average 0.5 g in June, 4 g in later November and then variable growth during the winter). As noted earlier (Table 11, page 41) despite the fact that Lake Wenatchee zooplankton biomasses are much lower than they are in Osoyoos Lake, age-0 Sockeye achieve fall weights that are very similar to the weights achieved by age-0 Sockeye in Osoyoos Lake (Figure 17) thus reinforcing the importance of the Lake Wenatchee *Daphnia* and especially *Hesperodiaptomus*, as superior food sources for age-0 Sockeye.

Figure 17: Year 2011-19 age-0 Sockeye fry weights and lengths from June through to the winter.





Lake Wenatchee 2019 bioenergetics-based estimates of consumption by fish compared to production by zooplankton

Bioenergetics-based production and consumption analysis allows us to estimate daily rates of consumption by both age-0 and age-1 Sockeye fry consuming each of the main species of zooplankton, and to compare these with rates of production by each of the major zooplankton species. If consumption > production we might conclude that density-dependent growth suppression in Sockeye fry is occurring. If production > consumption we might conclude that the fish are not affecting zooplankton biomass and that density-dependent growth suppression is not expected.

In previous reports, Lake Wenatchee fish bioenergetics was analyzed in 2012, 2013 and 2017, 2018 and 2019. In those reports we provided full details for the bioenergetics simulations that were run for each year (see list of previous reports on page 69). In this 2019 report, we will detail the 2019 bioenergetics data, and we will make comparisons with bioenergetic simulations from 2017 and 2018.

Bioenergetics simulations require 7 data sets. Some are shown in earlier portions of this report and others will be calculated in the sections that follow. The required data which are; (1) diets for Sockeye fry (Table 13 to follow), (2) vertical distribution of Sockeye fry with respect to date and temperature (Table 14 to follow), (3) zooplankton species-specific rates of production (Figure 18 to follow), (4) weights and densities of age-0 and age-1 Sockeye fry with respect to date (shown previously Table 12), (5) water temperatures with respect to date and depth (shown previously Table 4), (6) zooplankton biomass and species-specific mean weight (shown previously Table 10), and (7) fish and zooplankton energy density (in the methods).

(1) Sockeye diets. Sockeye fry stomachs were collected on three dates, species-specific prey were identified, enumerated and averaged (per fish) (Table 13). Prey numbers where then multiplied by average prey weights (from zooplankton samples) and proportions by weight were used in the bioenergetics model.

Table 13: Year 2019, average number of prey per fish gut. N = the number of fish in each sample.

	Age	N	*Cyclops*	*Hesperodiaptomus*	*Daphnia*	*Bosmina*	Adult fly
28-Jul-19	0	35	0.0	5.5	171.6	0.0	0.0
30-Sep-19	0	30	0.8	7.5	171.7	9.2	0.0
24-Oct-19	0	30	0.0	0.0	744.3	120.2	0.0
28-Jul-19	1	7	0.0	105.8	2203.1	0.0	0.0
30-Sep-19	1	1	0.0	16.0	10.0	1.0	1.0
24-Oct-19	1	3	0.0	2.3	2957.3	389.3	42.7

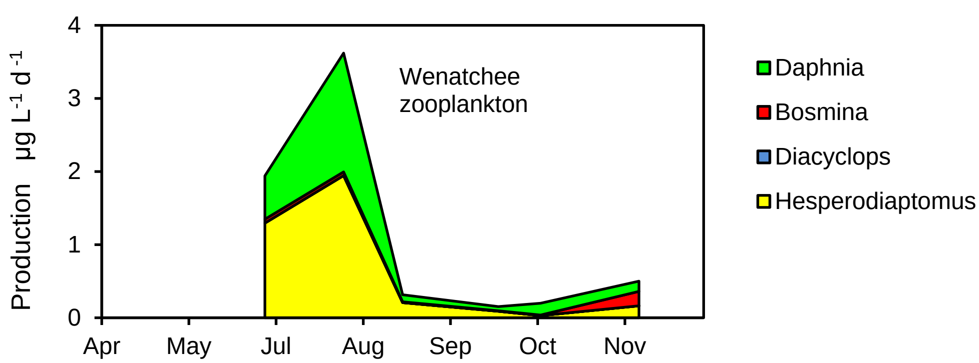
(2) Vertical distribution of Sockeye fry: On each sampling date, acoustic samples for Sockeye fry were used to estimate fry densities with respect to depth (Table 14). These data were combined with water temperatures (Table 4) to estimate the average temperature experienced by >90% of the fish on each sample date. Specifically, the water depths included in each of the depth intervals shown in yellow in Table 14, were averaged to produce the average temperature experienced by fry on each date.

Table 14: Percent of Sockeye fry observed at each depth interval on each acoustic assessment date. The yellow highlight denotes depths that include >90% of the population.

Depth	28-Jul-19	30-Sep-19	24-Oct-19	29-Feb-20
2-5	nd	nd	nd	nd
5-10	3	1	1	1
10-15	5	2	1	4
15-20	12	1	1	0
20-30	64	15	13	2
30-40	14	56	56	13
40-50	1	20	24	31
50-60	0	5	5	49

(3) Zooplankton species-specific rates of production: Production rates for each species of zooplankton were calculated using the method of Cooley et al. (1986) (Figure 18). These data show that *Daphnia* and *Hesperodiaptomus* accounted for most of the zooplankton production in the spring and that *Daphnia* were more productive during the late summer-fall. During 2019, percent P/B (production/biomass) per day for *Daphnia*, *Bosmina* and *Hesperodiaptomus* were 3.4%, 14.5% and 12.2% respectively. These values are within the range found in the published literature (i.e. Stockwell and Johannsson 1997).

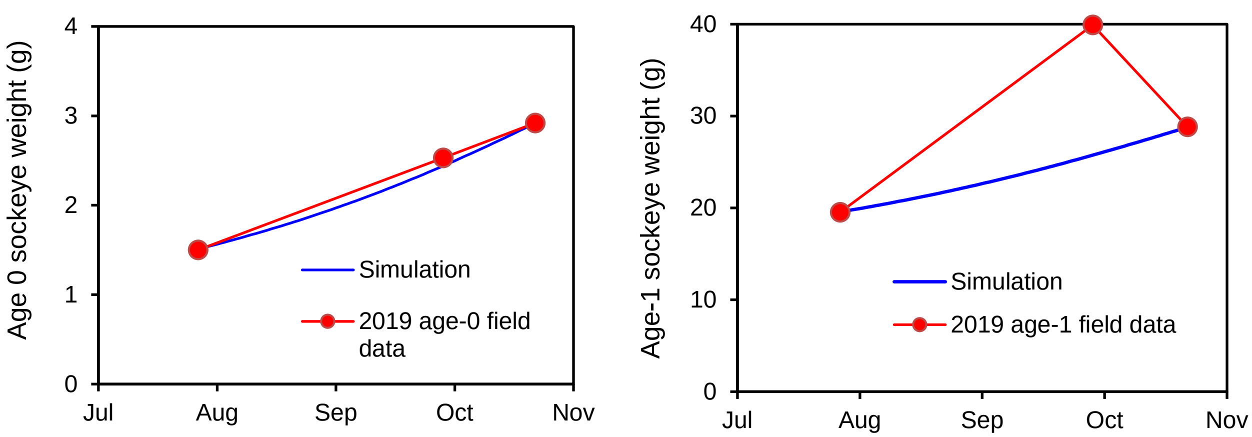
Figure 18: Lake Wenatchee 2019 zooplankton production from 27 June 2019 to 07 November 2019; (133 days).



Year 2019 fish bioenergetics calculations: Lake Wenatchee fish bioenergetics models were run for 2019 age-0 and age-1 Sockeye fry. The assumptions and input data were as follows. (i) Through the simulation period (28 July to 24 October 2019)(89 days), water temperatures occupied by the fish were based on the depth distributions observed during each survey (Table 14). Between-survey temperatures were interpolated from the known sample values. (ii) Through the simulation period, fish diets changed in accordance with the data shown in Table 13. (iii) For each of the fish groups; model inputs included starting and ending mean weight (g wet weight), starting density (ha^{-1}), and mortality expressed as mortality suffered by each fish group between each known census period (Table 12). (iv) Through an iterative process, the model estimated the amount of food average fish from each age class would need to eat in order to grow as fast as observed in the field. Knowing fish density, we were able to combine these data to calculate the quantity of each prey species consumed per litre per day. These prey species-specific daily consumption rates were then compared with daily rates of prey production.

In order to achieve a good fit between field and simulated mean fish weights-at-age, outputs from the model were compared with field measured weights-at-age. For 2019, the standard Sockeye Salmon bioenergetics model parameters produced good fits for the age-0 fry (Figure 19), but very poor fits for the age-1 fry. This “poor fit” was almost certainly due to very low sample sizes (28 July = 7, 30 September = 1, and 24 October = 2) and therefore sparse information for age-1 fry lengths and weights. In addition the single age-1 Sockeye fry captured on 30 September 2019, was exceptionally large when compared to age-1 fry from previous years (Table 12). It is difficult to know what to make of these data. Consumption rates for age-1 fry were calculated using the 24 October age-0 fry weights (N=2) and are discussed below (Figure 20).

Figure 19: Lake Wenatchee 2019 field measured age-0 and age-1 weights with respect to date and simulated weights with respect to date.



The 2019 fish bioenergetics simulations were run from 28 July 2019 (the first diet sample available) to 24 October 2019 (89 days). On an individual basis, age-1 fry were large and consumed substantial weights of prey, but their population densities were relatively low (Table

12). The result was that age-1 fry accounted for 23% of the total prey consumption and age-0 fry accounted for 77% (Figure 20).

Both age-0 and age-1 Sockeye had similar diets, but the age-1s were larger and the stomachs contained many more prey (Table 13). *Daphnia* were the preferred prey for both age groups, followed by *Hesperodiaptomus*. In the fall, both age classes consumed *Bosmina* which had higher rates of reproduction and higher biomasses in the fall (Figures 7 and 18) and age-1 Sockeye also consumed higher numbers of dipterans (adult fly – Table 13) during late September-October. These diet trends are reflected in the bioenergetics-based consumption estimates (Figure 21) which show that the primary food types consumed by Sockeye fry were *Daphnia* and *Hesperodiaptomus* throughout, and *Bosmina* and dipterans in the fall. In previous years, Sockeye Salmon fry have consumed *Diacyclops*, *Bosmina* and dipterans, but in 2019, *Diacyclops* was almost completely absent from the zooplankton community (Figure 7). Field abundances of dipterans were unknown.

Figure 20: Lake Wenatchee 2019 bioenergetics-based estimates of consumption rates (µg L^{-1} d^{-1} dry weight) by age-0 plus age-1 Sockeye fry.

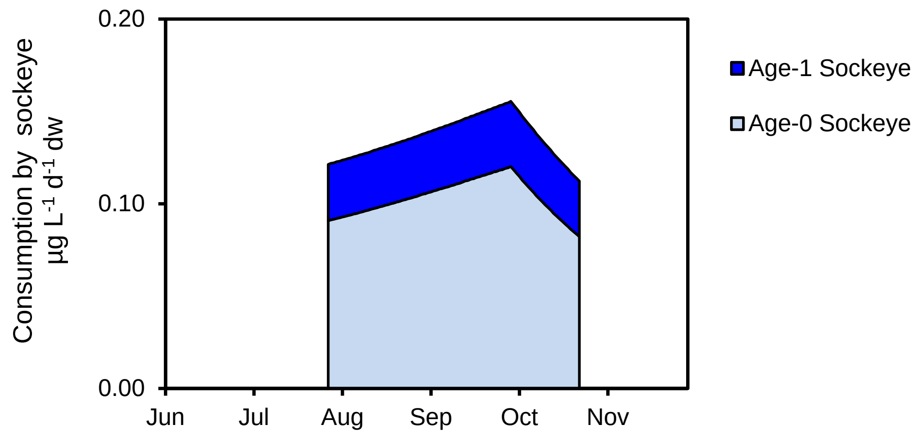
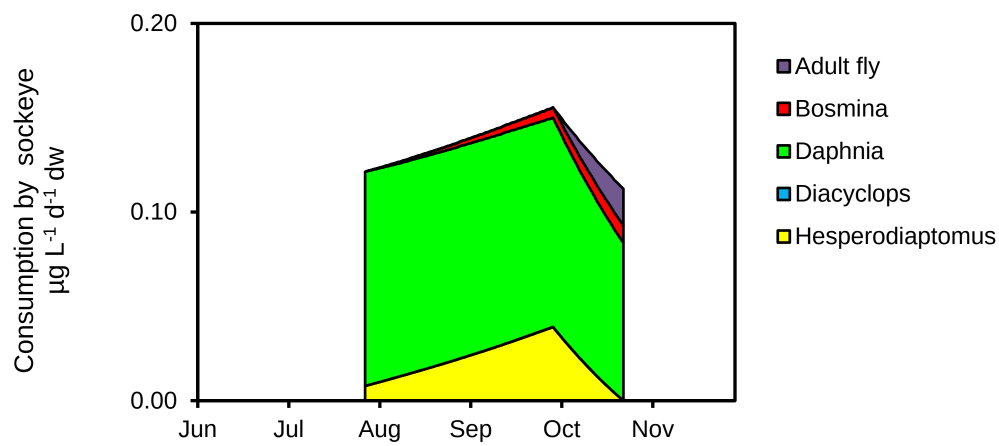
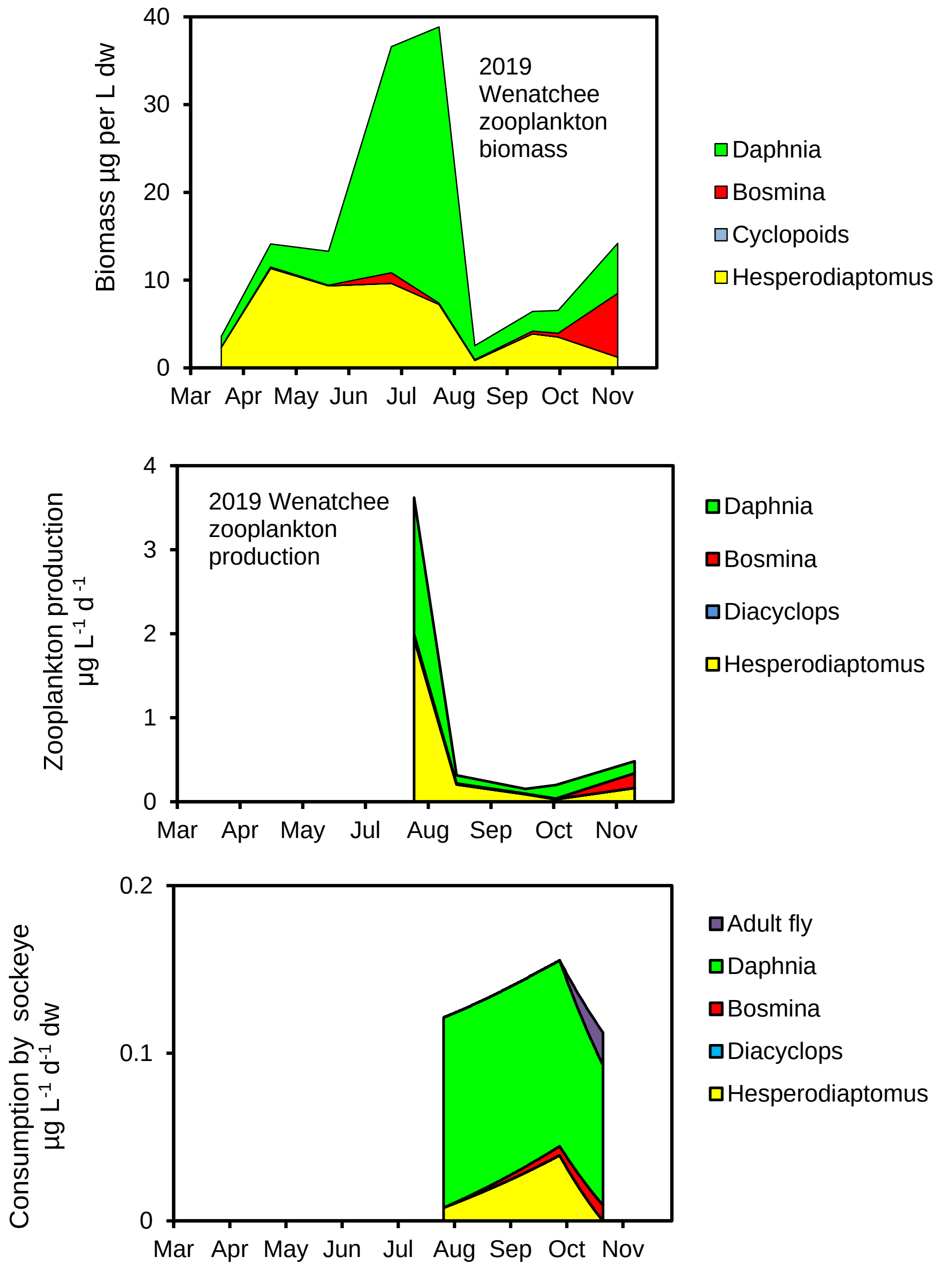


Figure 21: Lake Wenatchee 2019 bioenergetics-based estimates of consumption (µg L^{-1} d^{-1} dry weight) by age-0 plus age-1 Sockeye fry feeding on four species of zooplankton plus dipterans.



Year 2019 consumption by fish vs. production by zooplankton: Fish bioenergetics simulations allow us to directly compare rates of consumption by fish with rates of production by their prey. The assumption is that when consumption<production, prey should remain plentiful and when consumption>production we should observe declining field abundances of prey and we might conclude that lake carrying capacity has been reached.

Figure 22: Lake Wenatchee 2019 comparison of zooplankton biomass, zooplankton production (from Figure 18) and consumption of zooplankton by fish (from Figure 21).



During the simulation period (29 July to 24 October 2019) daily consumption by age-0 and age-1 Sockeye Salmon averaged 0.14 µg L^{-1} d^{-1} dw, and daily production by *Daphnia* and *Hesperodiaptomus* was about 7 times greater averaging 0.95 µg L^{-1} d^{-1} dw (Figure 22, Table 15). From this we might assume that Sockeye Salmon fry could not consume enough prey to influence zooplankton population densities (Table 15).

However in August-September, population densities for both *Daphnia* and *Hesperodiaptomus* suddenly declined and remained low for the rest of the sampling and simulation period (Figure 7, 22). The period from late-July to August-September was a period of change. (1) The lake rapidly warmed and stratified (i.e. the depth of water > 17 C^{O} fell from 0 m on 25 July, to 7 m on 28 July, to 11 m on 08 August to 17 m on 18 September, Table 4). (2) *Daphnia* egg counts fell from 0.3 per individual on 27 June to <0.1 eggs per individual during July and August. (3) *Hesperodiaptomus* egg counts fell from 3 per individual on 27 June to 1.7 eggs per individual on 27 July to 0 per individual during August and September. (4) This was associated with substantial reductions in zooplankton production which fell from 3.6 µg L^{-1} d^{-1} dw on 27 July to 0.3 µg L^{-1} d^{-1} dw on 15 August (Figure 22). The factors that resulted in the observed changes in egg numbers and zooplankton production remain unexplained. Perhaps they were related to the observed changes in lake stratification or to undetected changes in phytoplankton, or to some other event that we failed to monitor. What is clear however, is that after the late-July early-August transition, the production-consumption dynamic changed significantly.

During mid-July to September, consumption by age-0 plus age-0 Sockeye Salmon remained relatively constant at 0.14 µg L^{-1} d^{-1} dw. On 25 July, production by zooplankton averaged 3.6 µg L^{-1} d^{-1} dw. Therefore on 25 July consumption equalled only 4% of zooplankton production and we assume that consumption by fish had minimal effects on zooplankton biomass. However after the July-August transition, production by zooplankton fell to 0.23 µg L^{-1} d^{-1} dw, consumption remained at 0.14 µg L^{-1} d^{-1} dw. The result was that consumption equalled 60% of zooplankton production. Given that zooplankton die for many reasons other than from predation by fish, we might conclude that at Lake Wenatchee during the late summer and fall, predation by fish held zooplankton biomass at low levels.

It is most important to note however, that predation by Sockeye Salmon could not have caused the substantial reductions in zooplankton biomass that were observed during the late-July to mid-August transition. It was only after that period that predation by fish held zooplankton biomasses to low levels.

Table 15: Summary of 2019 bioenergetics input and output data.

Year 2019	
Simulation dates	28 July - 24 October 2019
Duration	89 days
Average age-0 density in simulation	1549 ha^{-1}
Age-0 density in the field	28 July 2019 = 1655 ha^{-1}; 30 Sept = 1690 ha^{-1}; 24 Oct = 1091 ha^{-1}
Average age-0 weight in simulation	2.1 g ww
Average age-1 density in simulation	68 ha^{-1}
Age-1 density in the field	28 July 2019 = 71 ha^{-1}; 30 Sept = 131 ha^{-1}; 24 Oct = 54 ha^{-1}
Average age-1 weight in simulation	23.6 g ww (sample sizes 28 July 2019 = 7; 30 Sept = 1; 24 Oct = 2)
Average temperature at fish depth	11.0^{O}
Diet collection dates	28 July 2019, 30 Sept 2019, and 24 Oct 2019
Average prey biomass in field (by species)	*Daphnia* = 8.7 µg L^{-1} dw; *Bosmina* = 1.6; *Diacyclops* = 0.0; *Hesperodiaptomus* = 3.3
Average total zooplankton biomass in simulation	13.7 µg L^{-1} dw
Average zooplankton production (by species)	*Daphnia* = 0.42 µg L^{-1} d^{-1} dw; *Bosmina* = 0.05, *Diacyclops* = 0.00; *Hesperodiaptomus* = 0.49
Average total zooplankton production	0.95 µg L^{-1} d^{-1} dw
Average consumption by fish (by prey species)	*Daphnia* = 0.11 µg L^{-1} d^{-1} dw; *Bosmina* = 0.004, *Diacyclops* = 0.00004; *Hespero.* = .02, Adult fly = 0.0028
Average total consumption by fish	0.14 µg L^{-1} d^{-1} dw
Percent prey biomass consumed (by species)	*Daphnia* = 1.3%; *Bosmina* = 0.24%, *Diacyclops* = 0.00%; *Hesperodiaptomus* = 061%
Percent of total prey biomass consumed	1.02 % d^{-1}
Percent prey production consumed (by species)	*Daphnia* = 26.4% d^{-1}; *Bosmina* = 8.2%, *Diacyclops* = 0.0%; *Hesperodiaptomus* = 4.2%
Percent of total prey production consumed	14.73% d^{-1}

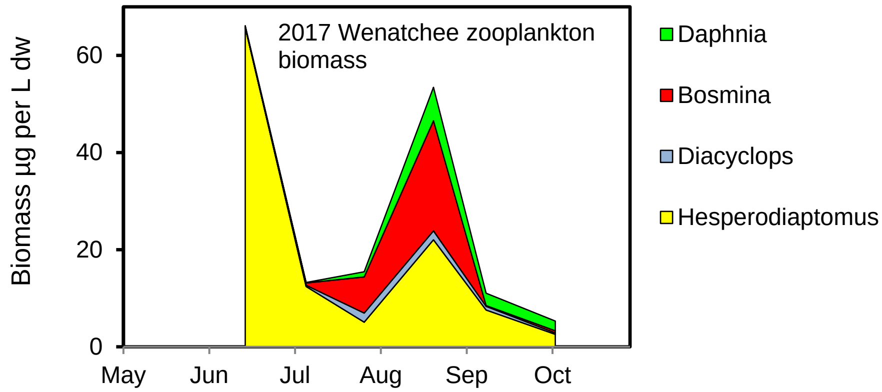
Between-year comparison of production-consumption data 2017, 2018 and 2019:

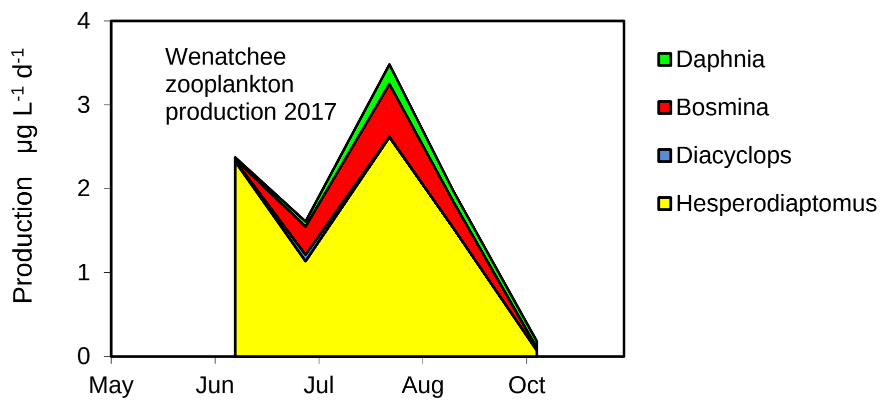
In this section we will compare the 2019 bioenergetics outcomes with bioenergetics data from 2017 (Table 16), 2018 (Table 17). In earlier reports from 2012 and 2013 we also provided bioenergetics estimates, but during those early years, fish data were collected only twice per year (Table 12) and diet data were limited to a single collection from July 2013. As the study progressed, we gradually increased the number of fish and diet collections that were made each year so that during 2017, 2018 and 2019, fish data were collected 4-5 times per year (Table 12) and diet data were collected 2-3 times per year.

Year 2017 (Figure 23, Table 16) was very different from 2019. During 2017, the primary prey were *Hesperodiaptomus* (Figure 23) and during 2019 the primary prey were *Daphnia* (Figure 22). This is a direct reflection of prey availability in the field (Figure 7, Table 10). Earlier we showed that the biomass of *Hesperodiaptomus* biomass was negatively (R^2=0.62, p=0.021) (Figure 11 middle panel) with water temperature and we also showed that the biomass of *Daphnia* was positively (R^2=0.59, p=0.027) associated with water temperature (Figure 11 top panel). During 2017, water temperatures were the second lowest recorded in this study, *Hesperodiaptomus* biomass was the highest recorded and *Daphnia* biomass among the lowest. Both *Hesperodiaptomus* and *Daphnia* are large and likely to be primary prey, and the Sockeye fry simply consumed the prey that was most available.

Bioenergetics estimates from 2017, suggest that together, age-0 and age-1 Sockeye fry were able to consume only 0.3% of prey biomass per day and 5% of prey production per day (Figure 23). Even near the end of the simulation period (September) when zooplankton biomass and production had fallen to very low levels, zooplankton prey production was 5 times higher than consumption by Sockeye fry. During 2017, Lake Wenatchee Sockeye fry had no discernible impact on their food supply and Sockeye growth rates were not mediated by prey availability.

Figure 23: Lake Wenatchee 2017 comparison of zooplankton biomass, zooplankton production and consumption of zooplankton by fish.





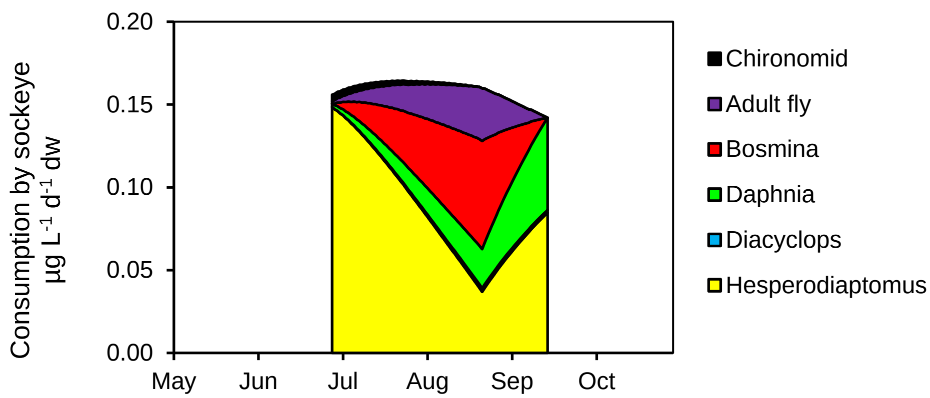


Table 16: Summary of 2017 bioenergetics input and output data.

Year 2017	
Simulation dates	28 June 2017 - 15 Sept 2017
Duration	80 days
Average age-0 density in simulation	3063 ha^{-1}
Age-0 density in the field	28 June 2017 = 3485 ha^{-1}; 22 Aug = 2936 ha^{-1}; 15 Sept = 2532 ha^{-1}
Average age-0 weight in simulation	1.1 g ww
Average age-1 density in simulation	23 ha^{-1}
Age-1 density in the field	28 June 2017 = 44 ha^{-1}; 22 Aug = 19 ha^{-1}; 15 Sept = 25 ha^{-1}
Average age^{-1} weight in simulation	4.9 g ww
Average temperature at fish depth	9.8^{O}
Diet collection dates	28 June 2017; 22 Aug 2017; 15 Sept 2017
Average prey biomass in field (by species)	*Daphnia* = 2.1 µg L^{-1} dw; *Bosmina* = 6.1, *Diacyclops* = 1.0; *Hesperodiaptomus* = 22.6
Average total zooplankton biomass in simulation	31.8 µg L^{-1} dw
Average zooplankton production (by species)	*Daphnia* = 0.11 µg L^{-1} d^{-1} dw; *Bosmina* = 0.32, *Diacyclops* = 0.024; *Hesperodiaptomus* = 1.90
Average total zooplankton production	2.36 µg L^{-1} d^{-1} dw
Average consumption by fish (by prey species)	*Daphnia* = 0.02 µg L^{-1} d^{-1} dw; *Bosmina* = 0.03, *Diacyclops* = 0.001; *Hesperodiaptomus* = .09
Average total consumption by fish	0.14 µg L^{-1} d^{-1} dw ; 0.14 µg L^{-1} d^{-1} dw (includes dipterans),
Percent prey biomass consumed (by species)	*Daphnia* = 1%; *Bosmina* = 0.5%, *Diacyclops* = 0.1%; *Hesperodiaptomus* = 0.4%
Percent of total prey biomass consumed	0.4% d^{-1}
Percent prey production consumed (by species)	*Daphnia* = 18% d^{-1}; *Bosmina* = 9%, *Diacyclops* = 4%; *Hesperodiaptomus* = 5%
Percent of total prey production consumed	6.0% d^{-1}

Year 2018 (Figure 24, Table 17) was also different from 2019. During 2018, rates of lake turnover and water temperatures were about average (2012-2019) but year 2018, stands out as a year with the lowest zooplankton biomasses recorded since the study began in 2012 (Figure 7 on page 34, Figure 24). *Hesperodiaptomus* and *Daphnia* were the primary prey consumed by Sockeye fry (Figure 24) and the total rates of zooplankton consumption averaged 0.1 µg L^{-1} d^{-1} dry weight. Even in the fall when zooplankton production was the lowest recorded, consumption was 3-4 times less. Again these data suggest that during 2018, Lake Wenatchee Sockeye fry could not have significantly influenced zooplankton biomass.

Figure 24: Lake Wenatchee 2018 comparison of zooplankton biomass, zooplankton production and consumption of zooplankton by fish.

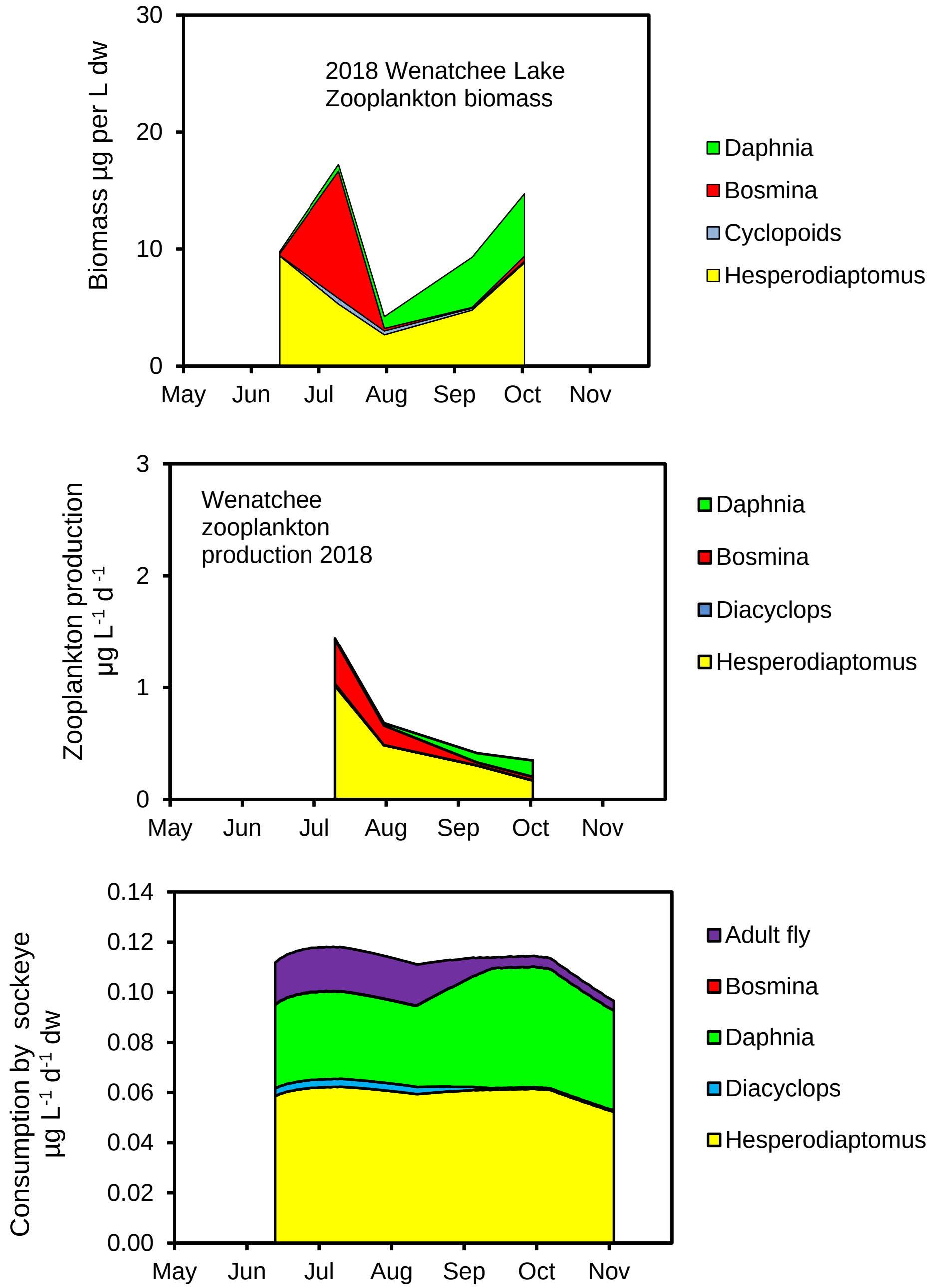


Table 17: Summary of 2018 bioenergetics input and output data.

Year 2018	
Simulation dates	13 June - 05 Nov 2018
Duration	146 days
Average age-0 density in simulation	1294 ha^{-1}
Age-0 density in the field	13 June 2018 = 1632 ha^{-1}; 13 Aug 1240 ha^{-1}; 09 Oct = 12851 $ha^{-1;}$ 06 Nov = 1027 ha^{-1}
Average age-0 weight in simulation	1.9 g ww
Average age-1 density in simulation	68 ha^{-1}
Age-1 density in the field	13 June 2018 = 69 ha^{-1}; 13 Aug 74 ha^{-1}; 09 Oct = 102 $ha^{-1;}$ 06 Nov = 63 ha^{-1}
Average age-1 weight in simulation	10 g ww
Average temperature at fish depth	10.5^{O}
Diet collection dates	13 Aug 2018; 06 Nov 2018
Average prey biomass in field (by species)	*Daphnia* = 2.3 µg L^{-1} dw; *Bosmina* = 2.4; *Diacyclops* = 0.2; *Hesperodiaptomus* = 6.2
Average total zooplankton biomass in simulation	11.1 µg L^{-1} dw
Average zooplankton production (by species)	*Daphnia* = 0.07 µg L^{-1} d^{-1} dw; *Bosmina* = 0.16, *Diacyclops* = 0.004; *Hesperodiaptomus* = 0.49
Average total zooplankton production	0.72 µg L^{-1} d^{-1} dw
Average consumption by fish (by prey species)	*Daphnia* = 0.02 µg L^{-1} d^{-1} dw; *Bosmina* = 0.00, *Diacyclops* = 0.001; *Hesperodiaptomus* = .04
Average total consumption by fish	0.06 µg L^{-1} d^{-1} dw (zooplankton only); 0.07 µg L^{-1} d^{-1} dw (includes dipterans),
Percent prey biomass consumed (by species)	*Daphnia* = 1.0%; *Bosmina* = 0.00%, *Diacyclops* = 0.5%; *Hesperodiaptomus* = 0.6%
Percent of total prey biomass consumed	0.5 % d^{-1}
Percent prey production consumed (by species)	*Daphnia* = 36% d^{-1}; *Bosmina* = 0%, *Diacyclops* = 25%; *Hesperodiaptomus* = 8%
Percent of total prey production consumed	8.3% d^{-1}

Many of the preceding conclusions are based on the assumption that the bioenergetics-based production and consumption values accurately reflect estimates based on field and laboratory work. Comparisons with laboratory studies show that the Lake Wenatchee fish consume more food and grow faster than expected. (1) Brett et al. (1969) and Brett and Blackburn (1981) measured the growth rates of juvenile Sockeye with respect to temperature, oxygen concentrations and food availability. For Sockeye 5-7 months old they found that maximum growth rates were 2.6 % of body weight gained per day. For Lake Wenatchee Sockeye, the average 2017 weight gain was about 5.5 % per day for very small (age 3-5 months) age-0 Sockeye and 3.1% per day for larger age-1 Sockeye. (2) In the experiments noted above, Brett et al. (1969) showed that maximum growth rates for juvenile Sockeye were obtained when daily ration equalled 6% of body weight per day. For Lake Wenatchee age-0, and age-1 Sockeye, the average % of body weight consumed per day was 11% for age-0 Sockeye and 5% for age-1 Sockeye fry. From this we conclude that the growth and consumption rates estimated using bioenergetics methods, are even higher than what we would expect based on laboratory experiments using artificial food, but it should be noted that the fish used by Brett et al. (1969) were larger (5-30 g) than the Lake Wenatchee Sockeye and smaller fish are known to grow more quickly and consume larger portions of the body weight per day. (3) Bevelhimer and Adams (1993) used a bioenergetics model to simulate diel vertical migration by kokanee and found that they consumed 4.5% body weight per day and grew at a rate of about 1% body weight per day. Again the 2017 Lake Wenatchee Sockeye out perform these juvenile kokanee.

Together these data reinforce the conclusion that Lake Wenatchee provides excellent habitat for juvenile Sockeye. Collectively, the limnology and fisheries data assembled during 2012-19, suggest that Lake Wenatchee has surplus zooplankton production capacity and could support Sockeye fry populations having spring-fall population densities roughly twice the average (Table 12) observed during 2012-19.

ACKNOWLEDGEMENTS

This report had been prepared in support of a program of ongoing collaborative work among the Columbia River Intertribal Fisheries Commission (CRITFC), the Okanagan Nation Alliance (ONA), Canada’s Department of Fisheries and Oceans (DFO) and the Washington State Department of Fish and Wildlife (WDFW).

LITERATURE CITED

Alstad NEW, Skardal L, Hessen DO (1999) The effect of calcium concentration on the calcification of *Daphnia magna*. Limnol. Oceanogr. 44: 2017–2023.

Ashforth D, Yan ND (2008) The interactive effects of calcium concentration and temperature on the survival and reproduction of *Daphnia pulex* at high and low food concentrations. Limnol. Oceanogr. 53: 420–432.

Bevelhimer MS, Adams SM (1993) A bioenergetic analysis of diel vertical migration by kokanee salmon, *Oncorhynchus nerka*. Canadian Journal of Fisheries and Aquatic Sciences 50: 2336-2349.

Bran and Luebbe Inc. (1987) Nitrite/Nitrate in waste water, Technicon TrAAcs 800Industrial Methods No. 824-87T July 1987.

Brett JR, Shelbourn JE, Shoop CT (1969) Growth rate and body composition of fingerling Sockeye salmon *Oncorhynchus nerka*, in relation to temperature and ration size. J. Fish. Res. Bd. Canada 26: 2363-2394.

Brett JR, Blackburn JM (1981) Oxygen requirements for growth of young coho (*Oncorhynchus kisutch*) and Sockeye (*O. nerka*) salmon at 15° C. Canadian Journal of Fisheries and Aquatic Sciences 38: 399-404.

Cooley J M, Moore JE, Geiling WT (1986) Population dynamics, biomass, and production of the macrozooplankton in the Bay of Quinte during changes in phosphorus loading. *In* Project Quinte: point source phosphorus control and ecosystems response in the bay of Quinte, Lake Ontario. *Edited by* Minns CK, Hurley DA, Nichols KH. Canadian Special Publication Fisheries and Aquatic Sciences 86. pp166-176.

Cottingham KL (1999) Nutrients and zooplankton as multiple stressors on phytoplankton communities: evidence from size structure. Limnol.Oceanog. 44: 810-827.

Cyr H (1998) Cladoceran- and copepod-dominated zooplankton communities graze at similar rates in low-productivity lakes. Canadian Journal of Fisheries and Aquatic Sciences 55: 414-422.

De Bernardi, R (1984) Chapter 3. Methods for the estimation of zooplankton abundance. *In* A Manual on methods for assessment of secondary productivity in fresh waters. *Edited by* Downing, JA, Rigler FH. Blackwell Scientific.

Dion NP, Bortleson GC, McConnell JB, Innes JK (1976) Data on selected lakes in Washington, Part 5. United States Geological Survey. Water-Supply Bulletin 43, Part 5.

Dussart BH, Fernando CH (1990) A review of the taxonomy of five Ontario genera of freshwater cyclopoid Copepoda (Crustacea). Can. J. Zool. 68: 2594-2604.

Eaton A, Clesceri LS, Greenberg AE *(Editors*) (1995). Standard methods for the Examination of Water and Wastewater, Section 4500PE. APHA-AWWA-WPCF. 20th edition.

Eaton A, Clesceri LS, Greenberg AE *(Editors*) (1998) Standard methods for the Examination of Water and Wastewater, Section 4500NC. APHA-AWWA-WPCF. 20th edition.

Edmondson WT (1959) Fresh-water biology. J. Wiley & Sons, Chichester.

Enzenhofer HJ, Hume JMB (1989) Simple closing midwater trawl for small boats. N. Am. J. Fish Manage. 9: 372-377.

Giguère LA, St. Pierre JF, Bernier B, VIzina A, Rondeau JG (1989) Can we estimate the true weight of zooplankton samples after chemical preservation? Canadian Journal of Fisheries and Aquatic Sciences 46: 522-527.

Girard R, Reid RA (1990) Dorset Research Centre study lakes: sampling methodology (1986 - 1989) and lake morphometry - Ont. Min. Environ. Report, 33 pp + appendices.

Goodberry F (2013) The effects of calcium concentration and food levels on the growth and reproduction of *Daphnia*. MA thesis. State University of New York College at Buffalo Department of Biology. 58pp.

Hessen DO, Alstad NEW, Skardal L (2000) Calcium limitation in *Daphnia magna*. Journal of Plankton Research 22: 553–568.

Hyatt KD, McQueen DJ, Cooper KL (2005) Competition for food between juvenile Sockeye salmon and the macroinvertebrate planktivore *Neomysis mercedis*, in Muriel Lake, British Columbia, Canada. Ecoscience 12:11-26.

Hyatt KD, McQueen DJ, Rankin DP, Demers E (2011) Density-dependent growth in juvenile Sockeye salmon (*Oncorhynchus nerka*). The Open Fish Science Journal 4: 49-61.

Hyatt KD, McQueen DJ, Ogden, A (2018) Have invasive mysids (*Mysis diluviana*) altered the capacity of Osoyoos Lake, British Columbia to produce Sockeye salmon (*Oncorhynchus nerka*)? The Open Fish Science Journal 11: 1-26

Lawrence S, Wright H, Hyatt KD, McQueen DJ, Rankin DP (2007) Sockeye salmon restoration in Skaha and Osoyoos lakes: Summary of biomonitoring sampling protocol for water chemistry, phytoplankton, zooplankton and juvenile fish. Okanagan Nation Alliance, 3255 C Shannon Lake Road, Westbank, BC V4T 1V4

Lieder U (1983) Revision of the genus *Bosmina* Baird, 1845 (Crustacea, Cladocera). -Int. Revue. ges. Hydrobiol 68: 121-139.

MacLennan DN, Simmonds EJ (1992) Fisheries Acoustics. Fish and Fisheries Series 5: ix + 325p. Chapman and Hall, London.

McQueen DJ, Hyatt KD, Rankin DP, Ramcharan CJ (2007) Changes in algal species composition affected juvenile Sockeye salmon production at Woss Lake, British Columbia: a lake fertilization and food web analysis, N. Amer. J Fish. Manage. 27: 369-389.

McQueen, DJ (2018) Lake Wenatchee and Osoyoos lake juvenile Sockeye salmon and limnology comparison brood years 2009-2016 (in-lake 2010-2017). Available From Okanagan Nation Alliance. Okanagan Nation Aquatic Enterprises Ltd. #106-3500 Carrington Rd. Westbank, BC V4T 3C1

Stockwell JD, Johnson BM (1997) Refinement and calibration of a bionergetics-based foraging model for kokanee (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 54: 2659-2676.

Rukke NA (2002) Tolerance to low ambient calcium shows interpopulation differences in *Daphnia galeata*. J. Plankton Res. 24: 527–531

Stutzman P (1995) Food quality of gelatinous colonial chlorophytes to the freshwater zooplankters *Daphnia pulicaria, Diaptomus oregonensis*. Freshwater Biol. 34: 149-153.

Tessier AJ, Horwitz RJ (1990) Influence of water chemistry on size structure of zooplankton assemblages. Canadian Journal of Fisheries and Aquatic Sciences 47: 1937–1943

Walters CJ, Juanes F (1993) Recruitment limitations as a consequence of natural selection for use of restricted feeding habitats and predation risk taking by juvenile fishes. Canadian Journal of Fisheries and Aquatic Sciences 50: 2058-2070.

Walters CJ, Martell SD (2004) Fish. Ecol. Manag., Princeton University Press, Princeton, New Jersey.

APPENDIX 1

Suggestions for the 2021 Lake Wenatchee sampling program

Since fish sampling began in 2010 a substantial body of high quality research data has been gathered. Going forward it will be possible to reduce sampling in some areas and it will be necessary to continue and expand a little, in others.

(1) Oxygen and temperature should be sampled at least 6 times (i.e. once per month)
(2) Secchi depth measurements could be discontinued.
(3) Water chemistry could be discontinued, but if funding allows, calcium concentrations should be assessed twice during July and September.
(4) Phytoplankton should be sampled 3 times during May, July and September.
(5) Zooplankton should be sampled 6 times once per month May-October, but see below for special samples collected in late-November and after ice-out. .
(6) Fish should be sampled (trawl and echosounder) 5 times during early-July, mid-August, mid-September, November and winter (after ice-out).
(7) Our data from 2012-19 suggest that for the summer to early-fall period, Lake Wenatchee has unused zooplankton production capacity and we suggest that over the next few years Sockeye fry population densities might be increased so that average September densities equal 4000 ha^{-1} (note that the current 2012-19 September average = 2121 ha^{-1}). However, there is a caveat. To date our bioenergetics data include samples collected during June-October, and the age-0 Sockeye length-weight data (Figure 17) suggest that between November and February (ice-out) there is very little growth. We have seen similar patterns in Osoyoos and Skaha lakes (Hyatt et al. 2018, 2021) and have also found that year to year variability in winter growth rates is very high. In future years zooplankton sampling should be extended to include November and February and the addition of winter diet data would also make it impossible to assess the possibility that poor growth rates are the direct result of reduced winter food supply. Should this prove to be the case, then the growth bottleneck will be during the winter, higher fry densities may exacerbate an already difficult situation and the correct management decision might be to limit the density of Sockeye fry.
(8) In 2019, for the first time, we extended zooplankton sampling to include samples from March and April. We found that during April, *Hesperodiaptomus* egg numbers began to increase (Figure 13), and *Hesperodiaptomus* densities began to increase. This sampling program should be continued. Because *Hesperodiaptomus* are very important food sources for Sockeye fry, there is some concern that if this is the only period of egg production, high summer densities of Sockeye fry may be capable of high levels of consumption during the fall which would seriously damage the *Hesperodiaptomus* population. To find out more about this potentially existential threat, zooplankton sampling should begin earlier and end later in the season.
(9) During three of the fish sampling periods (early-July, mid-August, mid-September), Schindler-Patalas zooplankton trap samples and temperature profiles must be taken, (see Appendix 2).

APPENDIX 2

More about sampling errors

On Three occasions throughout the study we have observed strong reductions in lake-turnover. In two of the three years (detailed on page 40) low turn-over was accompanied by lake warming and by increased *Daphnia* populations. We speculated that during those years, fish were unable to spend much time in the warm epilimnion, and that this allowed the *Daphnia* to thrive, reduce algal biomass and potentially increase lake clarity. The problem with these interesting arguments is that we lack depth distribution data for zooplankton.

In addition, we really know very little about the relationship between the vertical distributions of Sockeye fry and their zooplanktonic prey. Our bioenergetics-based consumption estimates assume that fish and zooplankton are perfectly mixed. However, we know that this is not true and data from vertical plankton hauls which are averaged over the entire water column, may fail to describe true prey availability at fine spatial scales (Walters and Juanes, 1993; Walters and Martell, 2004). In addition, Sockeye fry are known to aggregate at specific water depths which typically become deeper through the summer and fall (Table 16). The implication is that average zooplankton standing stocks measured in aerial units may not be representative of the prey actually available for consumption by individual fish. The fish and the zooplankton may be aggregated at different depths.

In 2017, we attempted to deal with this problem by using echosounder data to quantify the Sockeye aggregation depths and Schindler-Patalas plankton-trap data to quantify the depths of their primary prey (i.e. *Hesperodiaptomus* and *Daphnia*).

The plankton trap data were collected at night. They show that (Figure A2.1) on 08 August and 14 September 2017, both *Hesperodiaptomus* and *Daphnia* were most abundant below the thermocline. On August 31 2017, they were slightly more abundant above the thermocline. The Sockeye acoustic data were also gathered at night, but on different dates (Table A2.1). They show that during late August and September, the Sockeye fry were aggregated below the thermocline. From this we might conclude that both the Sockeye and their prey were at roughly the same water depths and that the densities of zooplankton available to Sockeye fry exceeded the 0-30 m average. It follows that we might conclude that the use of average zooplankton biomasses in was acceptable. However, the experiment was flawed.

Figure A2.1: Top panels - depth distribution for Lake Wenatchee *Hesperodiaptomus* on three dates during 2017. Bottom panels - depth distribution for Lake Wenatchee *Daphnia* on three dates during 2017.

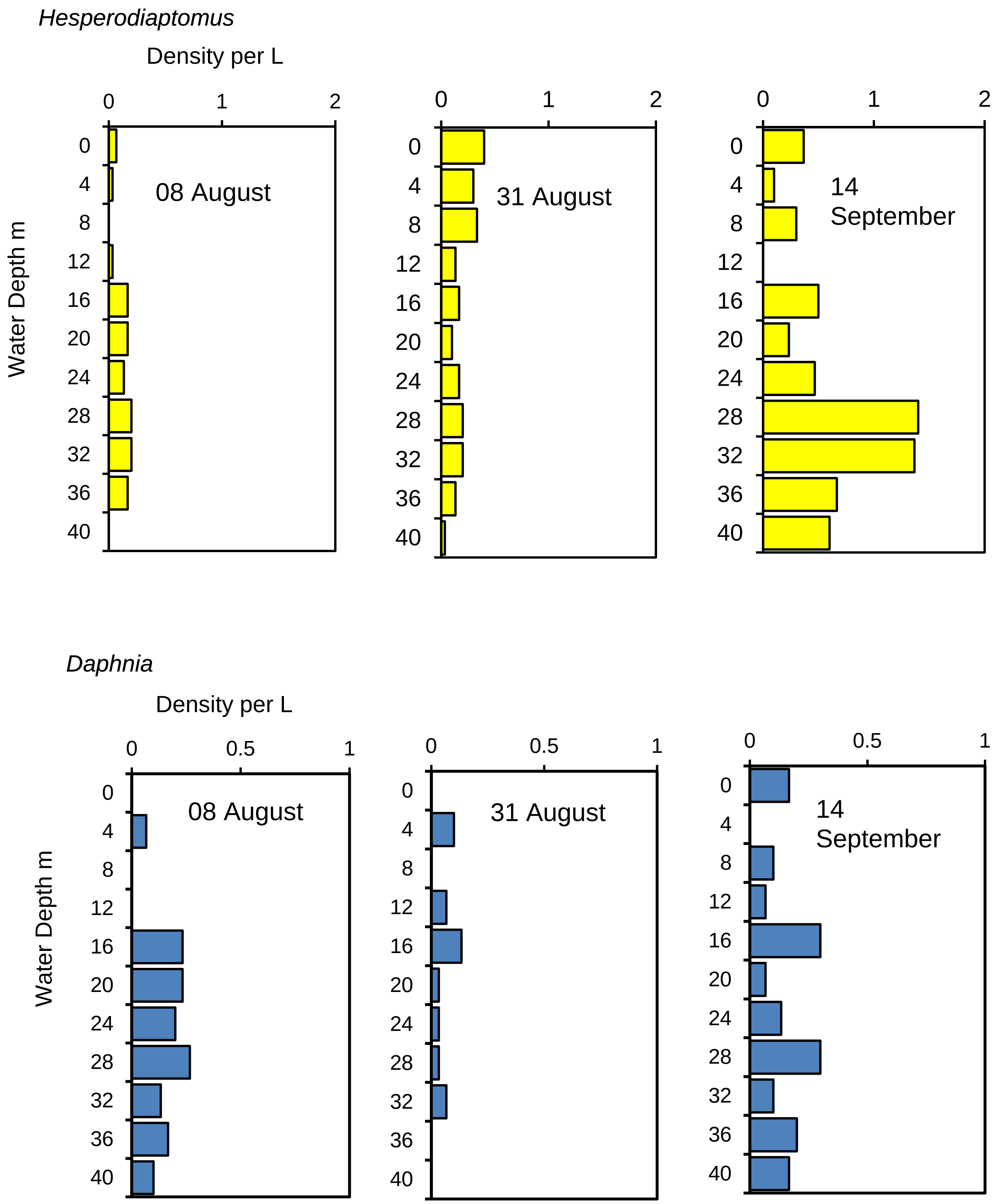
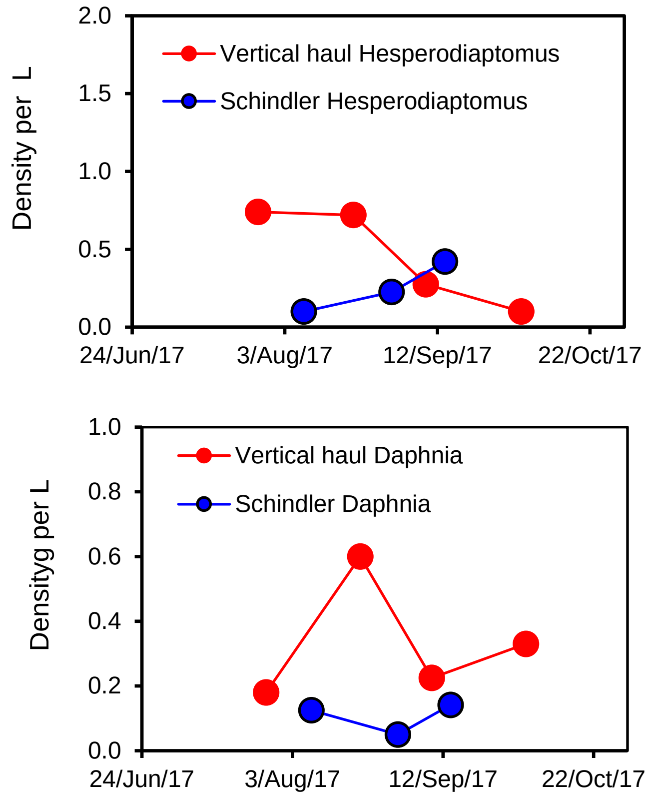


Table A2.1: Water temperatures with respect to depth. The shaded area includes the depths were acoustic sampling showed that >90% of the Sockeye fry population was aggregated.

Water depth (m)	21-Aug-17	15-Sep-17
1	18.3	17.1
2	18.1	17.2
3	17.7	17.1
4	17.6	17.1
5	17.5	17.1
6	17.4	17.0
7	17.2	17.0
8	17.0	16.9
9	16.9	16.8
10	16.7	16.7
11	16.6	16.7
12	16.5	16.6
13	16.2	16.5
14	15.9	16.3
15	15.4	16.3
16	15.1	16.2
17	14.4	16.0
18	13.8	15.0
19	12.9	13.5
20	12.6	12.4
24	10.9	10.1
28	9.4	9.0
32	8.9	8.4
36	8.4	8.0
40	8.0	7.7
44	7.8	7.5
48	7.6	7.3
52	7.5	7.2

There are three problems with the Schindler-Patalas trap data. (i) There was an unexpected shift in zooplankton depth distribution during 31 August 2017. (ii) Between-sample variation in zooplankton density was unexpectedly high. This was especially true for *Hesperodiaptomus* on 14 September 2017. Both problems suggest that there may have been sampling errors. (iii) Throughout the study we have used a metered vertical haul net to assess zooplankton density. We chose this gear because it is technically straight forward to deploy in the field at night and because it provides vertically integrated samples that yield sample averages from only one count. The Schindler-Patalas trap is generally considered to be equally or more efficient (De Bernardi 1984) than the vertical haul, so our expectation was that average (0-30m) zooplankton densities from the vertical haul net and Schindler-Patalas trap should be about the same. That is not what we found (Figure A2.2). On all but one date, plankton densities from the vertical hauls were substantially higher than they were from the plankton trap. This suggests that there must have been an unknown sampling error associated with trap use.

Figure A2.2: Comparison of *Hesperodiaptomus* and *Daphnia* densities from the vertical hauls and the plankton-traps.



If funding allows, during 2021 or 2022, we suggest that (1) Sockeye fry samples, (2) Schindler trap samples and (3) temperature profiles should be taken all together on three dates: early-July, mid-August and mid-September.

LIST OF LAKE WENATCHEE REPORTS

(1) Rankin, D, P., R. Ferguson and K.D. Hyatt. 2011. Wenatchee Lake, WA: Juvenile Nerkid Abundance and Lake Survey Status Report. Report to file: JSIDS - SRe 04-2010. Salmon and Regional Ecosystems Division, Fisheries and Oceans Canada, Nanaimo, B.C., V9T 6N7

(2) Ferguson, R. and K.D. Hyatt. 2013. Wenatchee Lake, WA: Juvenile Nerkid Abundance Status Report. Report to file: JSIDS - SRe 01-2013. Salmon and Regional Ecosystems Division, Fisheries and Oceans Canada, Nanaimo, B.C., V9T 6N7

(3) Wenatchee Lake Sockeye salmon and limnology status report BY2011 (in-lake 2012) and BY2012 (in-lake 2013). D.J. McQueen, Emeritus Research Professor, York University, Toronto. Available From Okanagan Nation Alliance. Okanagan Nation Aquatic Enterprises Ltd. #106-3500 Carrington Rd. Westbank, BC V4T 3C1

(4) Lake Wenatchee juvenile Sockeye salmon and limnology status report Brood years 2011-2015. D.J. McQueen, Emeritus Research Professor, York University, Toronto. Available From Okanagan Nation Alliance. Okanagan Nation Aquatic Enterprises Ltd. #106-3500 Carrington Rd. Westbank, BC V4T 3C1

(5) Lake Wenatchee juvenile Sockeye salmon and limnology status report brood years 2011-2016 (in lake 2012-2017). D.J. McQueen, Emeritus Research Professor, York University, Toronto. Available From Okanagan Nation Alliance. Okanagan Nation Aquatic Enterprises Ltd. #106-3500 Carrington Rd. Westbank, BC V4T 3C1

(6) Lake Wenatchee juvenile Sockeye salmon and limnology status report brood years 2009-2017 (in-lake 2010-2018). D.J. McQueen, Emeritus Research Professor, York University, Toronto. Available From Okanagan Nation Alliance. Okanagan Nation Aquatic Enterprises Ltd. #106-3500 Carrington Rd. Westbank, BC V4T 3C1

(7) Lake Wenatchee juvenile Sockeye salmon and limnology status report brood years 2009-2018 (in-lake 2010-2019). D.J. McQueen, Emeritus Research Professor, York University, Toronto. Available From Okanagan Nation Alliance. Okanagan Nation Aquatic Enterprises Ltd. #106-3500 Carrington Rd. Westbank, BC V4T 3C1

(8) Lake Wenatchee and Osoyoos lake juvenile Sockeye salmon and limnology comparison brood years 2009-2016 (in-lake 2010-2017). 2018 ONA-DFO-CRITFC report. D.J. McQueen, Emeritus Research Professor, York University, Toronto. Available From Okanagan Nation Alliance. Okanagan Nation Aquatic Enterprises Ltd. #106-3500 Carrington Rd. Westbank, BC V4T 3C1

End of last page

APPENDIX F

Passive Integrated Transponder (PIT) Tag Interrogation Array Sites and Operations in the Okanagan, BC, Canada

Passive Integrated Transponder (PIT) Tag Interrogation Array Sites and Operations in the Okanagan, BC, Canada

Okanagan Nation Alliance

Prepared for:
Columbia River Inter-Tribal Fisheries Commission

March 2018

Okanagan Nation Alliance
101-3535 Old Okanagan Highway
Westbank, BC, V4T 3L7
Phone: (250) 707-0095 Fax: (250) 707-0166

Disclaimer: Okanagan Nation Alliance reports frequently contain preliminary data, and conclusions based on these may be subject to change.

Citation: ONA 2018. Passive Integrated Transponder (PIT) Tag Interrogation Array Sites and Operations in the Okanagan, BC, Canada. Prepared by Okanagan Nation Alliance., Westbank, BC. 16 pp.

Executive Summary

As part of the Sockeye Limiting factors Study initiated by the Columbia River Inter – Tribal Fish Commission (CRITFC), funded by BPA Accords, this project since inception (2009) has installed and operated a number of Passive Integrated Transponder (PIT) tag interrogation arrays throughout the Canadian Okanagan. These interrogation arrays have been vital for stock assessment objectives for the recovery of the Okanagan Sockeye population.

The installation of PIT arrays in the Okanagan Basin commenced in 2009 with the installation of OKC, a mainstem array downstream of Road 18 in Oliver BC. This site has quickly become a keystone detection point for determination of escapement returns to the Okanagan basin. Following the installation of OKC, the PIT array infrastructure has quickly expanded with the installations of temporary floating PIT arrays upstream of OKC, trial PIT installation at McIntyre Dam, fishway installations at Skaha Dam, the addition of a second array at OKC, and finally the installation of the Northernmost mainstem PIT array at OKP in the Penticton Channel.

This document serves as a brief description of each of these sites, a description of the site location, operations to date, along with challenges and successes at each.

Acknowledgements

Okanagan Nation Alliance would like to thank the following people for their continued support: Richard Bussanich, and Ryan Benson for leadership and project support. Nick Yaniw, Casimir Tonasket, Saul Squakin, Paul Snow, Dave Tom, Andrew Clarke, Chelsea Mathieu, Lynnea Wiens, Sheena Hooley, Amanda Stevens, and other ONA staff that have supported this project over the years. This project is supported by Dr Kim Hyatt, DFO Pacific Biological Station, and Dr. Daniel Selbie, DFO Cultus Lake. Dr Jeffery Fryer, Columbia River Inter-Tribal Fish Commission

Table of Contents

List of Tables

List of Figures

Table of N’syilxcen Place Names

N’syilx’cin Place Name	(Okanagan-English Translation)
nx˘ʷəntkʷitkʷ	Columbia River
q̓awsitkʷ	Okanagan River
q̓awst’ik’ʷt, also known as t̓iwcən	Skaha Lake
suwiw̓s	Osoyoos Lake

Indigenous Peoples of the Okanagan are the exclusive owners of their cultural and intellectual properties.

1.0 Introduction

1.1 Project Background

The q̓awsitkʷ (Okanagan River) Sockeye Salmon (*Oncorhynchus nerka*) population is one of the last few remaining viable Sockeye Salmon stocks in the Columbia River Basin. In response to concerns over declining stocks in the Okanagan Basin, the Okanagan Nation Alliance (ONA) commenced Sockeye Salmon re-introduction into q’awst’ik’ʷt (Skaha Lake) beginning in 2003 (Wright and Smith 2003). Also starting in 2009 the Columbia Inter-Tribal Fish Commission (CRITFC), funded via a BPA accords project, initiated a study to examine factors limiting the success of Okanagan Sockeye. Since inception, this project has been a collaborative effort by three parties; the ONA, CRITFC, and the Canadian Federal Department of Fisheries and Oceans (DFO). As part of an assessment of limiting factors this project has included monitoring of adult migratory returns via acoustic tagging and deployment of Passive Integrated Transponder (PIT) tags. In order to detect PIT tags, the expansion of PIT array network into the Canadian portion of the Okanagan River was required.

Starting in 2009 the Northernmost PIT array (OKC) in the Columbia River Basin was installed downstream of Road 18 in Oliver BC. This site was upgraded from a MUX FS1001 to an MSC IS1001 in 2015, along with the most recent upgrade adding four (4) additional antennas upstream of the original location in the fall of 2016. Other project sites have followed; the installation and operation of McIntyre Dam in 2014, Skaha Dam in 2015, and most recently the installation of a mainstem PIT array in Penticton Channel in the fall of 2017. This report is a descriptive document of each of the sites and presents a history of the operations of each along with the challenges and successes at each of the sites.

1.2 Study Area

q’awsitkʷ is a major tributary to nx̌ʷəntkʷitkʷ and has an approximate length of 185 km (37 km Canadian portion, 148 km US portion). Sockeye that rear in the North Basin of suwiẁs begin outmigration at similar times as q’awst’ik’ʷt sockeye smolts. Both travel downstream and pass through the Osoyoos Lake Narrows, a part of the lake that connects the Central and North Basin of the lake. From suwiẁs the q’awsitkʷ flows south through the Okanogan County, past the towns of Okanogan and Omak. q’awsitkʷ enters nx̌ʷəntkʷitkʷ from the north, 8 km east of Brewster, between the Wells Dam (downstream) and the Chief Joseph Dam (upstream). The reservoir behind Wells Dam, into which q’awsitkʷ empties, is called Lake Pateros. Smolts must migrate through nine hydroelectric dams to reach the Pacific Ocean. Similarly adult Sockeye

returning to the Okanagan endure the same migration in reverse working upstream through the many Hydro electric dams on the nx̌ʷəntkʷitkʷ.

Figure 1. Okanagan Basin Map with Nsyilxcen site names

2.0 Sites

2.1 OKC

2.1.1 Site Description

OKC was the first PIT detection array installed in the Canadian portion of the q'awsitkʷ in the fall of 2009. At the time of installation this was the first PIT tag array to be installed within the transboundary portion of the nx˘ʷəntkʷitkʷ Basin and was the Northernmost PIT array within the entire basin.The site was chosen based on proximity downstream of the natal spawning areas of the Okanagan Sockeye, while being upstream of suwiẁs. The site is located downstream of Vertical Drop Structure number 3 at Road 18 in Oliver BC.

The OKC site is located in the Okanagan (Canadian spelling) Channel at 310th Avenue/Road 18 upstream from suwiẁs. The river in this section is channelized and Vertical Drop Structures (n=17) are used to control the river gradient. The array is located approximately 130 ft downstream of VDS-3. The river at this location is approximately 80 ft wide, enabling nearly full coverage of the width with four 20-ft antennas. Detection of adult sockeye salmon (Oncorhynchus nerka) is the primary focus of the array. Water depth during the sockeye salmon migration ranges from 10 to 24 inches. Optimal read range of 12-mm TX1411SST PIT tags in pass-by orientation ranges between 18 and 20 inches resulting in high detection efficiency. Four new antennas were added to the site in a second array in March 2017.

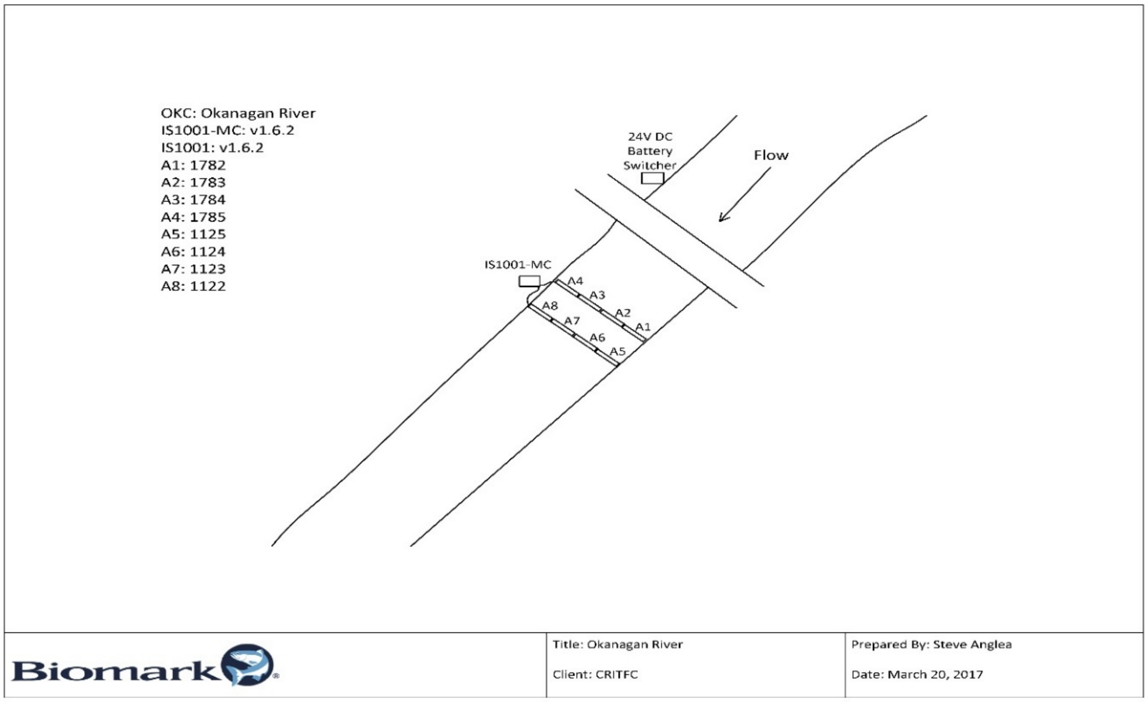


Figure 2 Site map of OKC configuration

Figure 3 Google Earth Image of OKC downstream of VDS 3 at Road 18, Oliver BC

The site location (Figure 2 & 3) was chosen due to its proximity both upstream of suwiẇs while still being downstream of the spawning grounds upstream. The channelized section of river at the location of OKC both upstream and downstream is not suitable spawning substrate. Therefore better suited for PIT detection as fish move through the area and are less likely to mill around. The location 45ft downstream of the VDS structure was chosen as a function of distance from the nearest power lines as well as Provincial permitting available at the time (2009).

OKC was installed initially with three (3) antennas in November 2009 covering 75% of the wetted width due to a miscalculation of available area for the antennas. It was soon decided to add a 4th antenna in the winter of 2010 to provided 100% wetted width coverage. A FS1001 MUX powered the unit, connected via 100ft of underground cable to the power supply North Road 18 at the site of the Water Survey of Canada hydrometric station. A dedicated 120v power outlet was connected to the electrical panel already in place to provide power to a battery switcher and batteries connected in two banks of two 12V batteries connected in series to provide 24v of DC power to OKC. The battery switcher was timed to charge the battery banks in 3 hour intervals before switching to the alternate bank.

Figure 4 Photos of OKC installation November 2009

2.1.2 Operations

OKC since installation has operated well. The site has had remote access and connection to a 4G Telus network for remote polling and downloading of data for auto uploading of data files to PTAGIS. Biomark has been retained by CRITFC to monitor and auto load the data files generated by OKC into the PTAGIS database. Key points in the operation history are noted in table 1.

Upon installation in 2009 the site was operated to ensure functional, however was powered down through the winter of 2009 into 2010 in an effort to save budget during a time of no expected PIT detections. The site was powered on in the spring to ensure functionality, operated for a week to ensure noise levels and power levels appropriate and powered down again until May 2010. The site has had continuous operation since this date and has not been powered down through winter months. The site between 2010 and 2014 operated well with regular and routine maintenance site visits.

Table 1 Operational dates for OKC since installation

Year	Start Date	End Date	Notes
2009	6/11/2009	11/19/2009	First year of operation. Three antennas cover ~75% of the channel width.
2010	3/18/2010	1/1/2011	Interrogation activities were suspended from November 19, 2009 through March 18, 2010, and again from March 27 through May 14.
2011	1/1/2011	1/1/2012	Functional year round
2012	1/1/2012	1/1/2013	Functional year round
2013	1/1/2013	1/1/2014	Functional year round
2014	1/1/2014	1/1/2015	Site down July 5-7. Tags with 3DD prefix were not recorded prior to October 22.
2015	1/1/2015	1/1/2016	Mux replaced with IS1001 master controller and readers August 25.
2016	1/1/2016	1/1/2017	Functional year round
2017	1/1/2017	1/1/2018	Added a second array of 4 antennas upstream of OKC. Antennas labelled 1-8.
2018	1/1/2018	Present	Operating as normal, has a pit tag lodged on antenna 2

Through 2014 OKC experienced an issue with detecting tags with a sub mask 3DD between July 5 and October 22, 2014. This was a programming issue due to the firmware and was not detected by Biomark. The issue became apparent as very few sockeye were detected during this period, despite good numbers of fish observed at other sites downstream (Wells, Zosel Dams), as well as upstream enumeration counts. The issue was rectified in the fall of 2014, however, late and missed a cohort worth of detections during the migratory year of 2014. Approaching 5 years in age, and with PIT technology improvements it was thereafter

recommended that OKC be upgraded from the aging FS1001MUX to the new IS1001 MC standard.

During August of 2015 OKC was upgraded to an IS1001 master controller. As a result, the PIT antennas were also upgraded by modifying the existing antennas amperage calibrations and connecting IS1001 nodes to each of the antennas. This upgrade provided an increase in read range from 8-12inches to 16-18 inches vertically in the water column. The move to the new IS1001 platform also allowed for optimizing the effieciency of individual antenna tuning as each of the nodes attached to each antenna operate independent of the others with respect to power, noise, and tuning.

The most recent update to OKC has been the installation of a secondary array upstream of the original location. Four new 20ft Biomark HDPE IS1001 antennas were installed 30 ft upstream the first antennas (Figure 2 & 5). With changes in technology Biomark altered the design of the stout antennas. The original antennas are encased in rigid FRP channel, while the new antennas are attached to the river bed via duckbill anchors with no external casing. Figure 5 shows the antennas getting prepared for install long with the IS1001 nodes attached to the downstream side of the antenna.

Figure 5 IS1001 HDPE antennas installed at OKC

2.1.3 Next steps

OKC has quickly become a keystone to our monitoring efforts for the Okanagan populations of anadromous fish. Recently the Fish Passage Centre (FPC) has recommended the Okanagan Sockeye population be added as an annual mark group for continued monitoring and be included with the Salmon Coordinating Committee (SCC). Next steps for OKC are to continue the operations and maintenance of the site and repair as required. Two of eight antennas are the original installed in 2009 and may soon need replacing – as has already been completed with the remaining antennas.

Also, as PIT technology advances, updates where required should be considered to improve read range and detection of all life stages (smolt – adult).

2.2 OKC Upstream floating Array Trials

2.1.1 Site Description

One of the initial issues with the original installation of 4 antennas at OKC was the lack of a secondary array – to provide site redundancy, detection efficiency determination, and more importantly directionality. In an effort to provide additional detection and directionality at OKC a trial effort using floating PIT arrays was attempted in 2014. The site location for the floating antennas was just upstream of Road 18 adjacent to the Water Survey of Canada site that powers OKC.

Figure 6 Trial floating PIT antennas in place upstream of Road 18 and OKC

2.1.2 Operations

Floating antennas (v1.0) were acquired from Biomark and installed upstream of VDS 3 on March 18, 2014. These antennas were an initial design and a first effort by Biomark to produce a floating PIT antenna. They were made with a soft fabric used for construction of river rafts surrounding a dense foam and measured 10ft x 3ft with a leading edge oriented at 45 degrees to the surface of the water and held in place with 1 inch irrigation pipe attached to the matting to hold the leading edge upright (Figure 6).

Two 200lb concrete lock blocks were installed along the banks of the river that formed that anchors for the aircraft cable to span the river crossing. The antennas attached to the aircraft cable via a series of cam straps. The cam straps were attached to a separate smaller diameter aircraft cable that was connected in a loop similar to a clothes line to facilitate deploying and holding the antennas in place. Each antenna was connected in series to the adjacent antenna via a ridged flexible conduit. The antennas weighed approximately 70lbs and connected to an IS1001 Canbus via a pig tail connector at the downstream end.

In 2015 four (4) additional 10 foot floating PIT arrays were installed to increase the wetted with of detection. About 60ft was covered via the antennas covering approximately 75% of the channel.

The antennas were powered by a dedicated 120V electrical outlet installed adjacent to the WSC station and the battery bank powering OKC. A SolaHD isolation transformer was installed to clean up the incoming AC power to provide noise free 120V AC power to the IS1001MC powering the floating antennas.

The floating anntennas appeared to operate well, until freshet of 2015 during which a large rootwad and tree debris entangled the aircraft cable and dragged the lock blocks into the river. ONA staff were able to recover the antennas, cabling, and lock blocks. However installation and operations at this site has not resumed since.

2.1.3 Next steps

The floating antennas trials at OKC failed. The floating antennas are still functional and are in inventory awaiting their next deployment. However the IS1001 nodes and the IS1001 MC have been re-purposed and relocated to the installation within Penticton Channel in 2017

2.3 McIntyre Dam

2.3.1 Site Description

McIntyre dam, along with the vertical drop structures along the Okanagan River, form part of the water management system operated by the Province of British Columbia Water Stewardship Devision of the Ministry of Forests, Lands, Natural resource Operations, and Rural Development FLNRORD). McIntryre Dam is a small non-power generating facility that was originally constructed in 1954 with undershot gates that were considered not fish passable to upstream migration. In 2009 ONA working with many agency partners work to retrofit these gates to fish friendly overshot gates. The fish passage efficiency of these gates is still being determined, and as such on March 31, 2015 we installed trial PIT antennas to the walls of one of the 5 bays at McIntyre Dam.

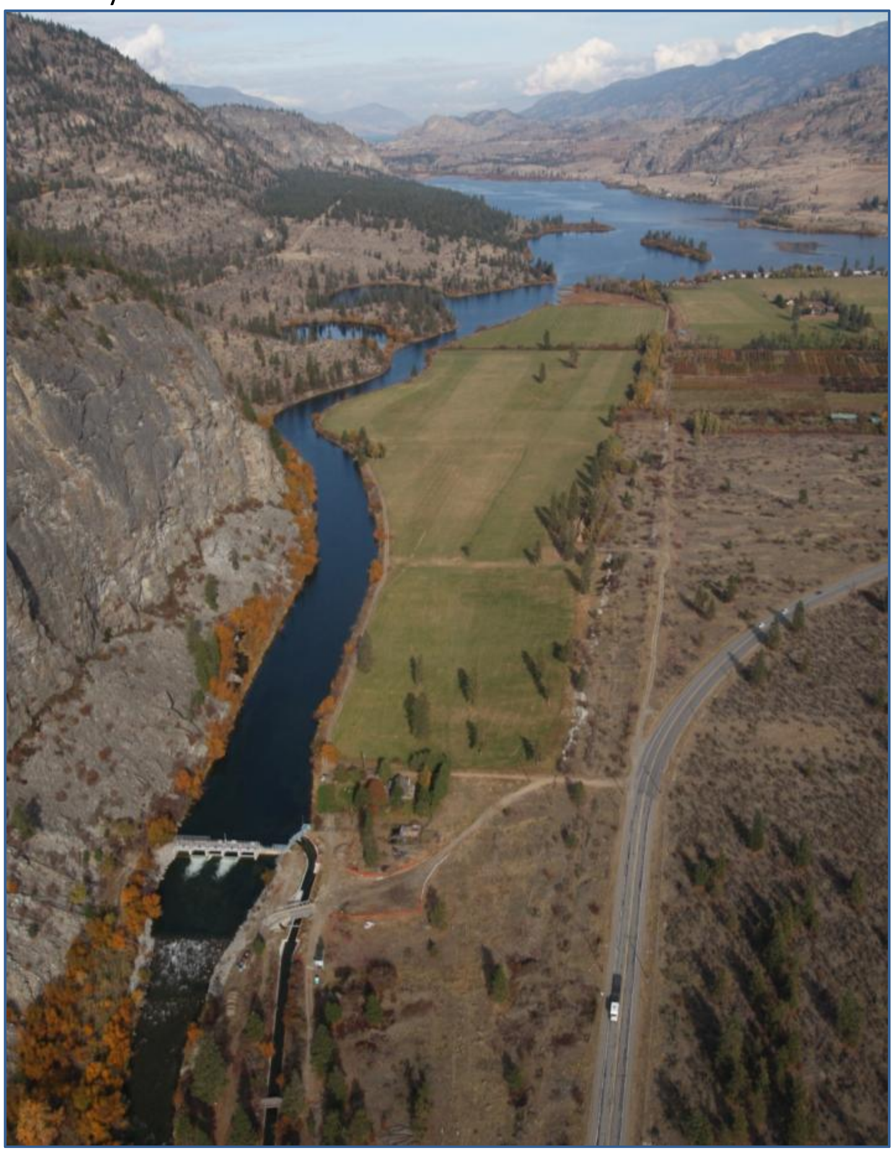


Figure 7 McIntyre Dam downstream of Vaseux Lake with two of the 5 bays spilling water

Figure 8 Wall mounted PIT antenna trials in Bay 1 McIntyre Dam

With the failure of the floating antenna trials at OKC, a different approach was developed for McIntyre Dam. As the overshot gates at McIntyre Dam, by design they spill a laminar homogenous flow over the gates into the plunge pool downstream of the structure. The bubble curtain that is created discourages fish jumping efforts. In video enumeration trials to determine fish passage efficiency of the newly installed gates it has been demonstrated that the majority of fish jump attempts occurs downstream of the new wing walls of each of the gates. Figure 8 shows one of these concrete walls that the PIT array was attached to. Our hypothesis for these trials was that fish jumping upstream would follow or be near the concrete walls on the upstream side of the dam. Therefore we trialed the installs of two biolite IS1001 antennas with a custom ferrous mounting plate – to limit background noise for the antenna.

The antennas are installed in bay 1, the Eastern most, river left bay. The antennas are installed at the base of the gate on each of the walls and have a read range of 18 inches from either side horizontally into the bay. Figure 9 is a view looking upstream to the dam from downstream showing the 5 gates – the PIT arrays are located to the bay on the right. This location was chosen based on video work being conducted by ONA to determine the overall fish passage efficiency of the gates – suggesting that the majority of sockeye fish jumping effort occurs within this bay.

The antennas are connected to the power supply on the dam, with a dedicated 120V outlet connected to a SolaHD isolation transformer. Stand alone IS1001s are encased within a small enclosure mounted adjacent to the control tower on the upstream side of the dam.

Figure 9 McIntyre Dam post gate modifications in 2009.

2.3.2 Operations

Data collection commenced as soon as the site was installed. However, as no cell service or modem was part of the install – data collection is conducted via downloading data files manually. As a trial operation downloads of data initially commenced weekly decreasing to monthly once a data processing system was established. The data has not been uploaded to PTAGIS nor has the site been registered as an interrogation site within the PTAGIS database. The intention here is to demonstrate the proof of concept prior to officially requesting a site.

Operations of the site also requires communications within the dam operators as not all gates are open at all times depending on flows. Typically gate 1 is operating at all times, however during the fall of 2015 the gate was sporadically operated. Efforts have been made to continue the working relationship with dam operators to ensure a line of communication for operating

times. In December of 2015 the site was powered down as dam operators had a planned closure of the gate through the winter. Operations resumed in the spring of 2016 – since this date a power supply issue causes the IS1001s to turn off. This issue remains unsolved as PIT priorities have moved to other sites. However, revisiting McIntyre Dam PIT detection will add strength to the PIT detection network in the Canadian Okanagan.

2.3.3 Next steps

Issues pertaining to the power supply require solving, in addition to continued communication with dam operators for bay operation. A cell modem and extender would also serve the site well to remotely view and troubleshoot from a desktop space. Funds allocated to a modem and retrofit would likely be recovered in the first year saving personnel travel and site visit time to manually download, upload, and troubleshoot on site.

.

2.2 Skaha Dam

2.3.1 Site Description

Skaha Dam is a non power generating facility that forms part of the water management system operated by FLNRORD located within the community of Okanagan Falls at the south end of Skaha Lake, BC along the Okanagan River. The fishway is a small weir-pool fishway at the western edge of the dam that was only recently opened to fish passage – allowing anadromous fish free access into Skaha Lake. Installing a PIT array here was a logical choice based on location and proximity to upstream spawning locations, as well as being a fishladder – providing easy access and installation options.

Two custom built Biomark IS1001 PIT antennas (182.88cm L x 81.28cm W x 12.7cm H) designed to exactly fit the fishway were installed on May 13, 2015 (Figure. 10). The antennas have IS1001 master controllers, stand-alone units. Many PIT interrogation sites across the Columbia basin have upgraded to the new IS1001 standard (Fryer, J. Pers Comm 2015) "The IS1001 is a high performance, ISO- compliant stationary RFID transceiver designed for detecting, storing and transmitted FDX (Full duplex) and HDX (Half Duplex) PIT tag ID's in permanently installations. It is specifically designed for applications that require low power consumption and a large detection area" (Biomark 2012). In field testing at Skaha Dam and at VDS 3 OKC in Oliver BC, upgrading to the IS1001 system has shown improved detection range over the older MS1001 MUX system (ONA unpublished data).

The PIT antennas were installed at the entrance and exit to the fishway to attempt to determine fish migration timing, delay, and direction of travel within the fishway as well as to provide an additional opportunity for detection at the site. The lower most antenna was installed within bay 2 on the upstream side of jump 2 of the fishway. The upstream antenna, was located upstream of jump 6 within Skaha Lake, until low water levels in 2015 necessitated the installation of the antenna just downstream of jump 6. Moving the antenna to the downstream end of the stoplogs required the installation of a wooden support, which lowered the antenna below the jump 6 nappe depth. The success of this modification in 2015 resulted in the refitting of the lower antenna to below the nappe depth of jump #2 in August, 2016. Figure 10 shows the view of the two PIT antennas installed at Skaha Dam fishway in 2015. The first photo (L) shows the placement of the upstream antenna above the 6th stoplog at the top of the fishway and (R) shows the placement of the lower antenna above the 2nd stoplog.

Figure 10 View of the two PIT antennas installed at Skaha Dam fishway in 2015.

The IS1001 unit was installed within a 24’ x 24’ enclosure and secured to the steel perimeter fence of Skaha Dam. The units have also been connected to the electrical power grid and are now autonomously powered eliminating the need for batter swaps as per previous years. As a means to reduce the electrical noise inherent to 120V AC power, a SOLA HD Isolation transformer was installed and connected to buffer the incoming power supply for the antennas (Figure 11).

Data from the antennas was managed by the data logger board within the IS1001 logger board. Data was stored on an external portable USB drive that was downloaded on a regular basis. On site visits data was downloaded to a Yuma 2 Trimble tablet and was then transferred to our ONA offices for data management. The data was managed and manipulated using Biomark Log File Viewer Version 1.0.1 and exported to excel for further analysis.

Figure 11 View of the master control IS1001 unit outside and inside of its enclosure.

2.3.2 Operations

In 2016, 3349 adult sc̓win were PIT tagged at Bonneville, Priest Rapids, and Wells dams in the Columbia River through funding from Columbia River Inter-Tribal Fish Commission (CRITFC) projects examining limiting factors affecting the abundance of Columbia River sc̓win. 1657 were tagged at Bonneville Dam between May 26 and August 18, 2016. 894 were tagged at Priest Rapids Dam between June 29th and July 22, 2015, while finally 798 were tagged at Wells Dam between June 27 and July 28, 2016.

Of the fish tagged at lower Columbia River dams, 993 were detected at OKC – the mainstem PIT array within the lower Okanagan River at Road 18, Oliver BC. Of these, 114 PIT tags were detected within the Skaha Dam Fishway between June 24th and October 22nd, 2016 (Appendix B).

Four (4) scenarios can describe the detections for the 114 unique PIT tagged sockeye within the fishway;

1) the fish were successfully detected by the downstream antenna, followed shortly by the upstream antenna,
2) the fish were only detected by the downstream antenna,
3) the fish were only detected by the upstream antenna, and
4) the fish were detected first by the upstream antenna, followed shortly by the downstream antenna.

The first scenario is ideal and lends to calculating upstream transit time through the fishway. Calculated as time of last detection by the upstream antenna – (minus) the first time of detection by the downstream antenna. This was the case for only 79 of the 114 fish detected within the fishway. These fish were detected between June 29th and October 22nd, 2016. The average travel time, calculated as first time detected at the downstream array within the fishway and the last time detected by the upstream array, was 4:55:29hrs (hrs:minutes:seconds). The range of timing of these tags varied from short times 2 minutes and 56 seconds, to longest durations of 29 hours, 17minutes, 11 seconds.

The second scenario, of fish being only detected by the downstream antenna occurred for 21 fish occurring between June 24th and October 12th, 2016. Average time from first detection at the downstream antenna to last time detected by the downstream antenna was 4:44:21 (hrs:minutes:seconds). The range in timing of these tags varied from short times of 51 seconds, to longer durations of 30 hours, 41 minutes, and 42 seconds.

The third scenario occurred for fish only detected by the upstream antenna occurred for 4 fish between July 26th and September 29th, 2016. Average time from first detection at the upstream antenna to last time detected by the upstream antenna was 3:19:21 (hrs:minutes:seconds). The range in timing varied from one single detection to 13 hours, 3 minutes, 21 seconds.

The fourth scenario occurred for 10 fish in which the direction of travel appeared to be downstream by being first detected by the upstream antenna, then shortly thereafter by the downstream antenna. The timing of these fish occurred between August 13th and August 29th, 2016. The range in timing is narrow for this scenario (range: 31 seconds to 6 minutes) with an average downstream travel time of 3mins 3 seconds.

Detection and operation of the PIT arrays for the 2016 season was improved over previous years, however presented operation issues with installation mechanisms within the fishway itself. Figure 18 demonstrates the *in situ* modifications with wooden bracing to attach the PIT arrays in a manner that permitted flow through the fishway. As a result of these modifications, we observed an increasing number of fish striking the downstream antenna due to the placement of the antenna within the jump path of sockeye. The video analysis of this confirms an increased number of attempts in order to pass this antenna.

Detection of sockeye within the PIT array, correlates with the upstream enumerations of sockeye within Penticton Channel. An AUC estimate of spawners entering and successfully spawning within Penticton Channel for 2016 is 75,200 nerkids, with early estimates of 4000 sockeye (ONA unpublished data, 2016).

Figure 12 View of the wooden PIT antenna support and PIT antenna installed below the level of the stoplogs.

By contrast to the success of 2016 and the possible PIT scenarios of fish movement through the fishway, the 2017 season observed no PIT detections. This is likely due to modifications as noted in Figure 12 that were required to brace the PIT antennas dislodged from debris entering the fishway. Metal pipeclamps were used by ONA staff unfamiliar with PIT operations to secure the antenna to the modified bracing for the antennas. Additionally freshet of 2017 dislodged the lower most antenna necessitating an emergency rescue of the antenna. ONA staff were able to recover the antenna and secure to the walls of the fishway. Due to a number of circumstances the antenna remains in this place at time of writing (April 2018). High water through most of 2017, and staffing and budgetary constraints through the fall and winter of 2017 and 2018 followed by a high freshet in the spring of 2018.

2.3.3 Next steps

Following freshet of 2018, repairs will be required for the Skaha Dam PIT arrays. Not only will the downstream array require re-installation, the braces used to attach the PIT arrays to the fishway walls and weirs will require modifications. These repairs will improve the PIT detection of the fishway and hopefully return PIT interrogation events to the site missing in 2017. Continuation of the cell service and modem added in 2017 will be vital to the monitoring and operation of the PIT array.

2.2 Penticton Channel

2.3.1 Site Description

Penticton Channel, is the channelized portion of the q̓awsitkʷ connecting Okanagan Lake with Skaha Lake, within the city of Penticton BC. This represents the upstream most accessible portion of mainstem river for Columbia River anadromous fish. The channel was constructed in the 1950's in an effort to control flooding and irrigation, as well as to dewater a portion of land adjacent to the airport in Penticton to land larger planes. Recently however, the ONA have been actively involved in habitat projects to improve spawning habitat within the channel. The Okanagan River Restoration Initiative (ORRI) has taken action to install spawning platforms in the upstream most sections of the Penticton Channel.

The sections of river suitable for spawning are upstream of the Green Mountain Road Bridge – where downstream the channel is low gradient and a backwatered portion of Skaha Lake pending flows. In the upstream section of the channel, while downstream of the spawning platforms we installed a mainstem PIT array in November 2017. The site is just upstream of the old KVR bridge abutment.

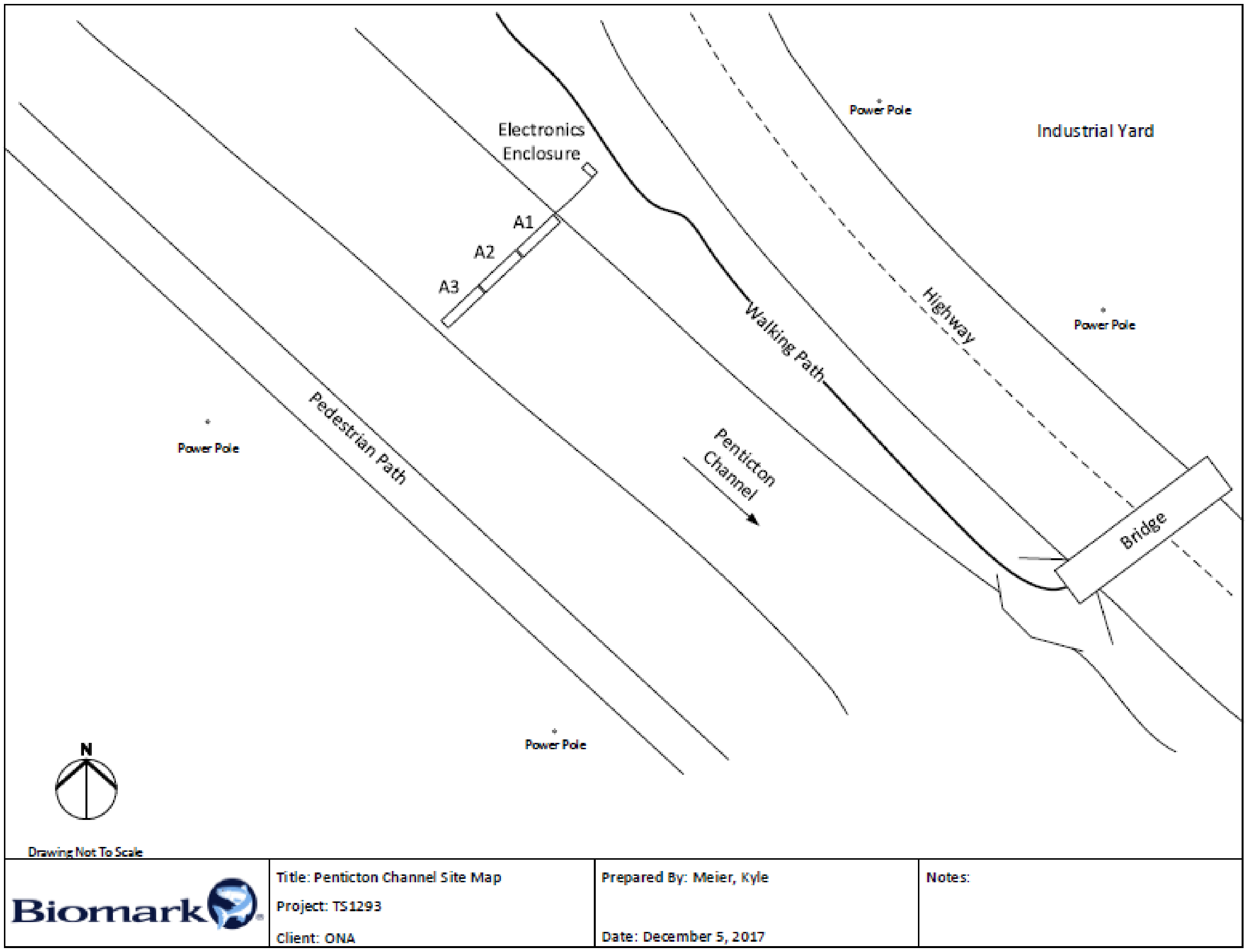


Figure 13 Site map of OKP within the Penticton channel, upstream of the KVR bridge

2.3.2 Operations

The site is currently powered by an enclosure originally designed for Biomark Biolite antennas. It contains 4 12v batteries connected in series, attached to a DC-DC power supply box connected to a IS1001MC. Rigid flexible conduit is buried subsurface and runs from the box located on the river left bank (East) side of the river connecting 3 20ft ABS Biomark PIT anntenas, with IS1001 nodes. Upon installation, staff made every effort to fully conceal the PIT array as public and recreational use of both the pathway and river channel is extremely busy in summer months with thousands of tubers floating the channel daily. It is expected that this site will greatly improve our estimates of terminal spawning ground counts of sockeye.

INSERT Jeff'S photo of site

2.3.3 Next steps

As the site is powered by 12v batteries, the next logical installation upgrade for the site is to connect to the power grid to ensure seamless, autonomous operation – similar to OKC. The intention for this site would be to operate authomously as a mainstem river PIT array – as OKC. Additionally, as there is much traffic passing the site effort made to communicate the project to the broader public – a permanent information panel should be created and installed.

5.0 Supporting Projects References

Benson, R. (2014). Okanagan Sockeye smolt migration from suwiw̓s [Osoyoos Lake] and q̓awst’ik’ʷt [Skaha Lake] 2012 brood year. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 28 pp.

Benson, R. 2016. Okanagan Sockeye smolt migration from suwiw̓s [Osoyoos Lake] and q̓awst’ik’ʷt [Skaha Lake] 2014 brood year. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 23 pp.

Benson, R., & A. Stevens. 2014. Okanagan Sockeye smolt migration from suwiw̓s [Osoyoos Lake] and q̓awst’ik’ʷt [Skaha Lake] 2011 brood year. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 24 pp.

Benson, R., & A. Warman. 2012. Okanagan Sockeye smolt migration from suwiw̓s [Osoyoos Lake] and q̓awst’ik’ʷt [Skaha Lake] 2010 brood year. Prepared by Okanagan Nation Alliance Fisheries Department, Westbank, BC. 27 pp.

Benson, R.L., A. Warman, and R. Bussanich. 2011. Okanagan sockeye smolt migration from suwiw̓s (Osoyoos Lake) and q’awst’ik’ʷt (Skaha Lake) 2009 brood year. Prepared by Okanagan Nation Alliance Fisheries Department, Westbank, BC. 36 pp.

Benson, R., S. Folks, A. Stevens, and R. Bussanich. 2013. Brood year 2011 – Sockeye smolt out of basin survival pilot study in q’awsitkʷ (Okanagan River). Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 37 pp.

Benson, R., S. Folks, A. Stevens, and R. Bussanich. 2014. q̓awsitkʷ (Okanagan River) Sockeye Smolt Out-of-Basin Survival: PIT and Acoustic Tagging 2013. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 17 pp.

Biomark (2012) Fish tagging methods. Retrieved online November 2013: http://www.biomark.com/Documents%20and%20Settings/67/Site%20Documents/PDFs/Fish%20Tagging%20Methods.pdf

Folks, S, R. Benson, A. Stevens, and R. Bussanich. 2016a. q̓awsitkʷ (Okanagan River) Sockeye Smolt Out-of-Basin Survival: PIT Tagging 2014 & 2015. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 17 pp.

Folks, S, R. Bussanich, A. Stevens, and M. Teather. 2016b. q̓awsitkʷ (Okanagan River) Sockeye Smolt Out-of-Basin Survival: PIT Tagging 2016. Prepared by Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC. 12 pp.

Fryer, J. K., H. Wright, S. Folks, K. D. Hyatt, and M. M. Stockwell. 2012. Limiting Factors of the Abundance of Okanagan and Wenatchee Sockeye Salmon in 2011. Columbia River Inter-Tribal Fish Commission Technical Report for BPA Project 2008-503-00

Lady, J.M., P. Westhagen, and J.R. Skalski. 2003. SampleSize 1.1. Sample size calculations for fish and wildlife survival studies. School of Aquatic and Fishery Sciences, University of Washington. Seattle, WA.

PTAGIS (1999) PIT tag Marking Procedures Manual version 2.0: Retrieved online November 2013: http://php.ptagis.org/wiki/images/e/ed/MPM.pdf

Stefanovic, D., R. Benson, C. Fuller, and L. Wiens. 2016. Collection and Rearing of Okanagan Sockeye Salmon for the Skaha Re-introduction Program: Brood Year 2015 Annual Report. Prepared as part of the Skaha Lake Sockeye Salmon Re-Introduction Monitoring and Evaluation Program: Brood Year 2015. Okanagan Nation Aquatic Enterprises Ltd., Westbank, BC.

Wright, R.H. and H. Smith (Ed). 2003. Management plan for experimental reintroduction of sockeye into Skaha Lake: Proposed implementation, monitoring and evaluation. Prepared by Okanagan Nation Alliance Fisheries Department, Westbank, BC.

Yaniw, N., and R. Benson. 2017. q̓awst’ik’ʷt (Skaha Lake) Nerkid Spawner Enumeration and Biological Sampling 2015. Prepared as part of the Skaha Lake Sockeye Salmon Re-Introduction Monitoring and Evaluation Program: Brood Year 2015. Okanagan Nation Alliance Aquatic Enterprises Ltd., Westbank, BC.

6.0 Appendix

OKC Site Log

Date	Comments	Who
3/16/2017	Installed four new 20' antennas and IS1001 readers upstream of the existing array. New antennas are A1-A4 and existing antennas were renamed to A5-A8.	sanglea
10/26/2016	A new modem was installed by Skyeler Folks and the site is now automatically uploading data again. I turned on site checking	bturley
9/21/2016	Master Controller and IS-1001 firmware was updated from version 1.6.0 to 1.6.1	bturley
9/20/2016	I changed the exciter voltage level on all antennas from 4 to 3.	bturley
11/7/2016	Switcher batteries were swapped out on Saturday 7/9. I increased the input voltage level to 3 on Monday 7/11.	bturley
4/6/2016	The input voltage at the site dropped below 18V on Saturday morning at about 07:45 am PST. This caused the readers to automatically go into standby. I put the readers back into scan mode on 6/6 at about 05:45 am. The input voltage is currently about 22V. One of the switcher batteries has possibly gone bad causing the input voltage to drop.	bturley
4/26/2016	The Master Controller and reader firmware were upgraded to version 1.6.0. After the upgrade the Master Controller reverted back to it's default ID of 01 instead of the correct A0. This caused a couple of rejected files last night. I changed the ID back to the correct one and will manually repair the rejected files and re submit them.	bturley
9/15/2015	Site file checking has been temporarily disabled.	bturley
9/15/2015	A new cell modem was installed at OKC. I configured the modem and downloaded the MC buffer and uploaded the buffer to PTAGIS.	bturley
9/15/2015	I reset the MC time, changed the noise alarm threshold to 50% and set the tag unique delay to 1 minute.	bturley
9/15/2015	On 8/25 and 8/26, the mux reader was replaced with a Master Controller and four IS-1001's.	bturley
9/15/2015	Site checking enabled on 9/15/2015 at 1300 hrs.	bturley
8/25/2015	OKC site is down during reader upgrade since 8/25 a.m. We are replacing the mux with a Master Controller and IS1001 readers. Site checking is off until installation is complete.	bturley
1/6/2015	Installed new CR1000 program ver 9.01 which eliminates the manufacturer tag prefix filter.	bturley
12/3/2015	O&M visit on 3/12/15. I changed the lithium battery on the mux and re-tuned.	bturley
12/15/2014	Tags with the 3DD prefix were not recorded before 10/22 because the datalogger had incorrect software that did not recognize tags with the 3DD prefix. The correct program was loaded on 11/19 and the mux buffer - which contained tags going back to 10/22 - was uploaded to PTAGIS on files OKC14295.ALL.	bturley

8/7/2014	Site went down on 7/5 due to dead batteries. Possible power outage disabled the battery charger? Skyeler Folks replaced batteries on site on 7/7 and got the site back up and running.	bturley
3/2/2014	Battery bank B was swapped out with new batteries on 1/31 at 1300 hours.	bturley
08/20/2013	On 7/25 at around 00:00 PST, the current of antenna 2 dropped from @ 4.20A to 3.33 A. On 8/7, the current dropped to @ 2.73A. On 8/9 at about 17:30, the current returned to about 4.00 A.	Bturley
2/1/2013	annual log file initiation for OKC	POC Bot
1/1/2012	annual log file initiation for OKC	POC Bot
1/1/2011	annual log file initiation for OKC	POC Bot
09/15/2010	Replaced faulty exciter cable for Antenna 1. At this point, the entire array is functioning and interrogation is finally consistent and continuous and numerous sockeye salmon Oncorhynchus nerka are being detected.	sanglea
05/14/2010	Problem with power solved - faulty relay in battery switcher. Relay replaced. Interrogation is continuous and consistent at this point.	sanglea
03/27/2010	Something is up with Antenna 1 - high noise. Antenna removed from sampling sequence until problem is resolved.	sanglea
03/27/2010	Power issues again. Power not being provided to transceiver enclosure consistently. Interrogation interrupted from March 27, 2010 through May 14, 2010.	sanglea
03/18/2010	Fourth antenna installed at the OKC array. Batteries in battery switcher replaced.	sanglea
11/19/2009	Based on the lack of test tag detections, interrogation was interrupted from November 19, 2009 through March 18, 2010.	sanglea
11/19/2009	Power to transceiver is intermittent. Based on the lack of test tag detections, interrogation was interrupted from November 19, 2009 through March 18, 2010.	sanglea
6/11/2009	Installation in-stream PIT-tag detection array 130' downstream of VDS-3 on the Okanagan River is complete. Array consists of 3-20' Biomark pass-by antennas. Array extends out from right-bank.	sanglea
6/11/2009	Biomark, with the cooperation and assistance of the Columbia RiverInter-Tribal Fish Commission and the Okanagan Nation Alliance, installed an instream PIT-tag detection array in the Okanagan River, upstream of Lake Osoyoos, British Columbia, CA in fall 2009. Three antennas were installed in November 2009 and a fourth antenna wasinstalled in March 2010. Opportunistic detections occurred during this time period due to issues with consistent power and communication. The system is powered using a Biomark battery switcher and data is transmitted using Campbell Scientific data collection and monitoring hardware and software.	sanglea

SKA SITE Log

Date	What	Who		
3/24/2017	Swapped Reader IDs, so now 01 is the upstream reader/antenna and 02 is the downstream reader/antenna.	sanglea	Upstream Antenna	1
12/5/2015	Site became fully operational	mteather	Downstream Antenna	2