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Studies into Factors Limiting the Abundance of Okanagan and Wenatchee Sockeye Salmon in 2018

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April 10, 2020

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EXECUTIVE SUMMARY

A total of 1,871 Sockeye Salmon, *Oncorhynchus nerka*, were sampled and 1,859 PIT tagged at the Bonneville Dam Adult Fish Facility in 2018. Sockeye PIT tagged by this project, along with previously PIT tagged Sockeye Salmon, 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 of 93.3% to The Dalles Dam, 88.9% to McNary Dam and 80.7% to Rock Island Dam in 2018.

Genetic stock identification (GSI) was used to classify the stock of 1,858 Sockeye Salmon sampled at Bonneville Dam. Concurrence between Sockeye Salmon classified both by genetics and final PIT tag detection site was 100% for the Okanagan and Wenatchee River stocks. Stock composition at Bonneville Dam in 2018 was estimated as 90.2% Okanagan, 9.0% Wenatchee, 0.6% Yakima, 0.2% Snake, and 0.0% Deschutes.

The estimated minimum fallback rates at Columbia River mainstem dams ranged from 0.1% at Bonneville Dam to 4.5% at John Day Dam.

In the Okanagan Basin, PIT tag antennas installed and maintained by this project at Zosel Dam (ZSL) and the Okanagan Channel (OKC) were operational for the entire year (Appendix A). Between January 1, and December 31, 2018, at Zosel Dam a total of 695 Sockeye, four Chinook, 19 steelhead, two Coho, and one White Sturgeon were detected. High flows in 2018 resulted in spill gates open sufficiently to allow salmon to swim upstream through the spillway without being detected by fishway PIT tag antennas. As a result, only 41.9% of passing PIT tagged Sockeye detected upstream of Zosel were detected at Zosel Dam.

At Wells Dam, 805 Sockeye Salmon were sampled, eight of which were previously PIT tagged by this project at Bonneville Dam. The remaining 797 Sockeye were PIT tagged at Wells Dam. The stock composition for Sockeye tagged at Wells Dam based on GSI and PIT tags was 97.4% Okanagan and 2.6% Wenatchee compared to 99.9% Okanagan and 0.1% Wenatchee stock for Sockeye tagged at Bonneville Dam detected at Wells Dam.

Okanagan juvenile PIT tagging resulted in 10,943 smolts being tagged between April 16 and May 9, 2018 at three sites, SKAHAL (Skaha Lake), OSOYOBR (downstream

of the Highway 3 Bridge at the Osoyoos Narrows) and OSOYOL (Osoyoos Lake North Basin) (Appendix C). Reliable estimates of survival from release to Rocky Reach Dam could be calculated for all three release groups with survival estimates ranging from 0.576 (SE=0.036) for the SKAHAL group to 0.691 (SE=0.039) for the OSOYHA group. From Rocky Reach Dam to McNary Dam, survival estimates ranged from 0.599 (se=0.144) for the OSOYOL group to 0.913 (se=0.132) for the SKAHAL group. After McNary, error associated with survival estimates for both release groups, individually and combined, was large. Travel time from release to Rocky Reach Dam ranged from 14.0 days for the SKAHAL group to 25.7 days for the OSOYOL group.

This project is proposed to continue and evolve over the next several years. One area of continuing concern is adult survival between Wells Dam and Osoyoos Lake. 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, acoustic tagging was dropped due to the large expense for the relatively small number of tags deployed, and instead focus was placed on PIT tags. 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. Of the Sockeye Salmon passing Wells Dam in 2018, only 58.5% of the Bonneville-tagged Sockeye and 51.8% of the Wells-tagged Sockeye were detected upstream. It is unknown what portion of this mortality may have been associated with migration conditions downstream of Zosel Dam or in Osoyoos Lake. PIT tag detection improvements at, or near, Zosel Dam could improve 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) are expected to continue along with limnological sampling to better estimate the annual production and future productive potential of Lake Wenatchee Sockeye Salmon (Appendices F and G). 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 may be addressed by 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. Limnology and ATS work should help to answer this question, but it is also uncertain what the optimal spawning escapement goal is for this stock. An optimal escapement analysis is being completed,

using other funding, for Osoyoos and Skaha Sockeye (Okanagan stock). A similar analysis is being considered for the Wenatchee stock.

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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-1800s, however, the Sockeye Salmon run has severely declined, reaching a low of fewer than 9200 fish in 1995 before rebounding in recent years reaching 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 past three years has been 342,498 in 2016, 87,693 in 2017, and 193,816 in 2018.

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 reintroduce 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. 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 Stockwell 2009).

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

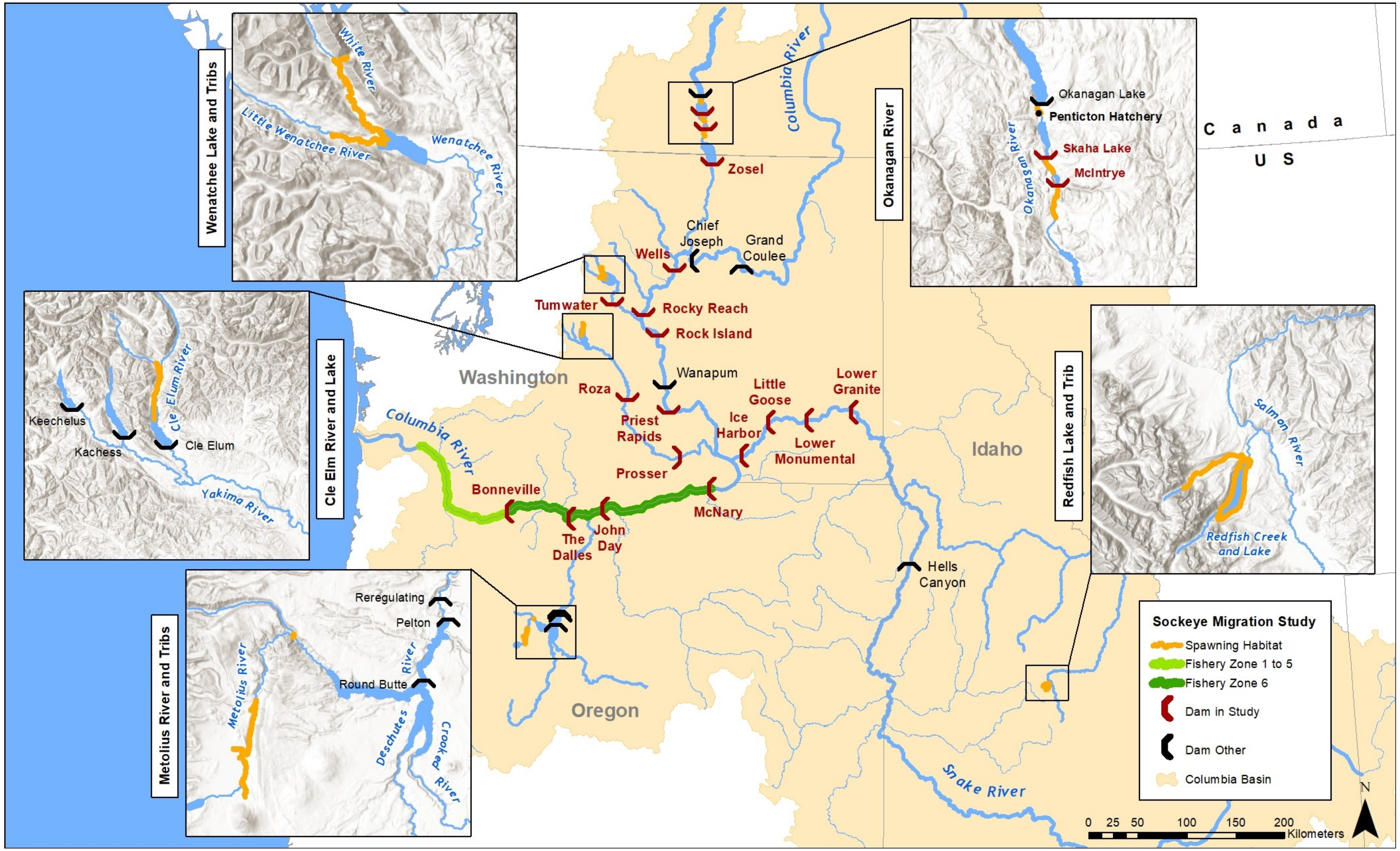

Figure 1. Map of the Columbia Basin showing fishery Zones 1-5 and 6, the major and minor Sockeye Salmon production areas and significant dams on their migration route.

The 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 detection capability (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; 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 a PIT tag study. 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. 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 between 2006 and 2010 (Fryer 2007, 2009, Fryer et al. 2010, 2011A) 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 funded installation of antennas at both Zosel Dam fishways (ZSL) in 2010, 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. This data is used to estimate juvenile survival and compared to Wenatchee River smolt trap smolt estimates. Since 2012, this project has also funded limnology 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 consists 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 as well as upstream of a second spillway in 2016 and both were operational in 2018. An experimental PIT tag antenna was added to one spillway at McIntyre Dam as well two antennas in 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. A summary of 2018 detection data at these sites is 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 234) 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 between April 25, to October 12, 2018. 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. Fish not selected and fish that have recovered from sampling then migrate back to the Washington Shore fish ladder above the picket weir.

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. PIT tags were inserted into the body cavity (if not already present) of the Sockeye Salmon using standard techniques (CBFWA 1999) and the fish scanned again for PIT tags. 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; Prosser and Roza dams on the Yakima River; and Tumwater Dam on the Wenatchee River (array configurations are available at www.ptagis.org) as well as at numerous 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.

Migratory characteristics of Sockeye Salmon PIT tagged as juveniles were calculated for comparison with 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.

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 5.4 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 and bubbled oxygen until they were partially recovered; they were then placed back into the fish ladder 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 was used to classify those mixed-stock samples. With the widespread deployment of PIT tag infrastructure at Columbia, in 2006 PIT tagging Sockeye Salmon began at Bonneville Dam and these fish tracked through PIT tag antennas located in upstream dam fish ladders and in-stream arrays and classifying stock by location of last detection. In 2012, we began also collecting genetics samples from Sockeye sampled to classify Sockeye Salmon using Genetics Stock Identification.

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: 70°C for 30 min, 25°C for 10 minutes, and 95°C for one minutes, followed by 50 cycles of 95°C for 5 seconds, and 50°C for 25 seconds, and a final cool down step of 25°C 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 2018, Sockeye Salmon samples were classified using GSI to the four stocks: Wenatchee, Okanagan, Snake, and Deschutes (Figure 1).

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. In 2018, those individuals last observed in the Okanagan Basin were classified as being Okanagan stock. Individuals that were last observed at in the Wenatchee Basin were classified as Wenatchee stock. Sockeye that were last observed at or upstream of Ice Harbor Dam were classified as being Snake River stock. Sockeye Salmon last detected in the Yakima Basin were classified as being Yakima stock and Sockeye last detected at other sites 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, we have done GSI on virtually all Sockeye sampled at Bonneville Dam. In 2018 we again completed GSI analysis on virtually all Sockeye sampled at Bonneville Dam as well as Sockeye PIT tagged at Wells Dam that were not detected in the Okanagan River.

Final Stock Classification Rules

In 2018 a combination of GSI 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, 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 indicates Yakima Sockeye, we classified as Yakima. Also, if Sockeye were last detected in the Yakima Basin, they are classified as Yakima unless fish were 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. In this case, we used the PIT tag stock classification.

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, prevents age determination in all 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 exceptions of Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, 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) visual count passing Bonneville Dam in week i (DART 2019, Fish Passage Center 2019), T_i is the number of fish PIT tagged at Bonneville Dam 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 missed passing 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 missed 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 PIT detection capability while all four dams in the Snake River have juvenile detection. Furthermore, there is no detection at any dam for fish falling back over the spillway 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 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 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. 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

Night-time juvenile Sockeye Salmon densities in Wenatchee, Osoyoos, and Skaha lakes[2] 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 (Simrad or Biosonics sounders operating at 70-200 kHz) deployed from a boat at night (Hyatt et al. 1984). Acoustic signal returns from juvenile Sockeye were digitally 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) information 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 (2 x 2m 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.

[2] 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.

Juvenile PIT Tagging

Skaha and Osoyoos lakes were seined using a 183 m long seine 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. Due to the success of the purse seine operation in 2017, the fyke net was not deployed in Osoyoos Narrows nor were any rotary screw traps used in juvenile collection.
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We used procedures outlined by PTAGIS (2014) and Biomark (2020) 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 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 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 bio-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; the resulting memo is Appendix D.

RESULTS

Upstream Migration Analysis

Mixed Stock Sample Size and Age Composition

In 2018 a total of 1,871 Sockeye Salmon were sampled for this project at the Bonneville Dam Adult Fish Facility between May 31 and July 26 (Table 1). Of these, 1,859 were tagged while there were two recaptures of Sockeye previously PIT tagged by this project. Both of recaptures dropped downstream after the first tagging event and were recaptured two days later. These recapture events were removed from subsequent analysis. Eleven Sockeye were not detected after release, resulting in a total of 1848 Sockeye tracked upstream. In 2018, sampling restrictions resulting in raised picket leads affected this project on 22 sampling days through July 26, 2018, 19 due to high shad abundance as well as three days due to high water temperatures (21.1-22.2C, Table 1)[3]. Temperatures reached or exceeded 22.2°C from July 27 through August 19, 2019, resulting in no sampling during a period when 0.3% of the Sockeye run passed Bonneville Dam (as estimated using visual fish counts).

The Sockeye not detected after tagging may have shed their tags, had defective tags, or died. It is also possible that these Sockeye Salmon passed downstream without being detected as Sockeye often pass over the top of weirs in the fish ladder rather than through the underwater slots where PIT tag antennas are located in the lower portions of Bonneville Dam fish ladders. It is unlikely that Sockeye Salmon pass upstream through Bonneville Dam fish ladders undetected since they pass 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. However, at Bonneville Dam (as well as The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams) fish can pass upstream (or downstream) through the navigation locks without being detected at PIT tag antennas. All other dams with PIT tag detection have antennas in fish ladders that Sockeye Salmon must pass, though data from 2006-2018 indicate that, even at those dams without navigation locks, PIT tagged Sockeye occasionally escape detection as they migrate upstream (Table 2).

[3] 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).

Table 1. Number of Sockeye Salmon sampled, and PIT tagged at Bonneville Dam and tracked upstream by date and statistical week in 2018.

									Days Sampling Restrictions in Effect		
Sampling Dates	Statistical Week[4]	% of Run	Sampled (N)	Tagged	Previously Tagged At AFF[5]	Mortalities	Not Detected after Tagging	Detected After Tagging and Tracked	Reduced Sampling Temperature	Reduced Sampling Shad or Salmon Abundance	No Sampling Temperature
5/31,6/4-6/8	22-23	1.7	86	86	0	0	1	85	0	1	0
6/11-6/15	24	9.2	233	232	0	0	2	230	0	5	0
6/18-6/22	25	30.6	353	352	1	0	2	350	0	5	0
6/25-6/29	26	32.5	463	456	1	0	1	455	0	5	0
7/2-7/4,7/6	27	17.6	310	307	0	0	0	307	0	3	0
7/9-7/13	28	5.6	222	222	0	0	0	222	0	1	0
7/16-7/20	29	1.7	114	114	0	0	4	110	0	0	0
7/23-7/26	30	1.2	90	90	0	0	1	89	3	0	1
Total			**1871**	**1859**	**2**	**0**	**11**	**1848**	**3**	**20**	**1**

Table 2. Number and percentage of Bonneville Dam PIT tagged fish not detected at detection sites as estimated from upstream detections for 2006-2018. Okanagan and Wenatchee in-stream antenna sites (LWE, UWE, OKL, and OKC) are also included in recent years[6].

	Percentage by Year and Mean of All Years													
Dam/Array	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	Mean
Bonneville (BO1 & BO4)	1.1	0.2	2.8	1.6	0.7	0.4	1.8	0.5	0.7	0.6	0.4	2.1	0.2	1.0
The Dalles	0.9	2.1	0.4	0.6	0.3	1.6	--	--	--	--	--	--	--	1.0
John Day	2.8	--	--	--	--	--	--	--	--	--	--	--	--	2.8
McNary	2.9	5.2	2.4	1.1	3.8	2.1	12.1	1.6	3.8	5.0	10.1	6.5	3.1	4.6
Priest Rapids	0.1	0.0	0.3	0.4	0.2	0.0	0.4	0.2	0.6	0.3	0.3	0.8	0.0	0.3
Rock Island	28.3	5.9	2.9	10.2	41.5	4.4	5.4	4.4	6.2	2.6	6.9	6.8	1.3	9.7
Rocky Reach	0.2	0.7	0.0	0.0	0.3	0.0	1.4	0.7	0.5	0.0	0.2	0.7	12.3	1.3
Wells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	--	--	--	--	0.0
Ice Harbor	0.0	0.0	0.0	0.0	12.5	--	0.0	--	0.0	20.0	0.0	--	--	3.6
Lower Monumental	0.0	0.0	0.0	0.0	--	--	--	--	--	--	--	--	--	0.0
Little Goose	0.0	0.0	0.0	0.0	--	--	--	--	--	--	--	--	--	0.0
Lower Granite	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
Zosel	57.5	74.5	1.6	0.0	0.9	87.3	83.0	98.6	--	--	--	--	--	50.4
LWE	68.4	49.6	54.7	17.9	48.0	--	--	--	--	--	--	--	--	47.7
UWE	9.9	9.3	9.7	24.6	52.7	--	--	--	--	--	--	--	--	21.2
OKL	50.1	47.4	59.4	13.8	68.9	--	--	--	--	--	--	--		47.9
OKC	7.7	NA	16.9	--	--	--	--	--	--	--	--	--	--	16.9

[4] 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 2018, for instance, Statistical Week 24 began on June 10 and ended on June 16.

[5] These were fish that were tagged by CRITFC and, after tagging, moved downstream in the fish ladder only to be recaptured by CRITFC later. These second capture events were excluded from further analyses of upstream migrating Sockeye.

[6] No data indicates there were either no antennas installed at the site, or there were no detections upstream of the site.

Based on Sockeye PIT tagged at Bonneville Dam by this study, the dam with the highest percentage passing upstream undetected in 2018 was Zosel Dam (57.5%) due to high flows resulting in Sockeye Salmon going through the Zosel Dam spillways rather than using the fish ladder. Rock Island Dam has had the highest percentage of Sockeye passing upstream undetected among mainstem Columbia River dams every year since 2013, likely due to electrical noise adversely affecting the ability of PIT tag antennas to detect PIT tags (Fryer et al. 2017). See also Appendix B for detection site information and maps showing sites Sockeye were detected.

The predominant age group in 2018, at 94.2% of the run, was estimated to be Age 1.2 (Table 3). All the other age groups observed individually comprised 2% or less of the run.

Table 3. Weekly and total age composition of Sockeye Salmon at Bonneville Dam as estimated from scale patterns in 2018. (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	2.1	1.2	1.3	2.2	3.1
22-23	1.7	83	0.0%	6.0%	89.3%	2.4%	2.4%	0.0%
24	9.2	232	0.0%	3.0%	91.3%	3.0%	0.9%	1.7%
25	30.6	345	0.3%	2.0%	94.0%	2.0%	1.1%	0.6%
26	32.5	453	0.7%	1.5%	96.0%	0.9%	0.4%	0.4%
27	17.6	308	0.3%	1.6%	93.9%	1.0%	2.3%	1.0%
28	5.6	214	0.9%	3.2%	93.5%	0.0%	1.9%	0.5%
29	1.7	110	0.9%	1.8%	92.8%	0.9%	3.6%	0.0%
30	1.2	90	0.0%	0.0%	89.9%	2.2%	7.9%	0.0%
Composite	**100.0**	**1835**	**0.4%**	**2.0%**	**94.2%**	**1.4%**	**1.3%**	**0.7%**

Upstream Recoveries, Mortality, and Escapement:

Survival rates to upstream dams, as estimated from detections of Sockeye PIT tagged by this study at Bonneville Dam in 2018 can be found in Figure 2 with annual data since 2006 in Table 4. Survival to upstream dams in 2018 was higher than the mean rate reported by this study for all dams except The Dalles and Tumwater dams.

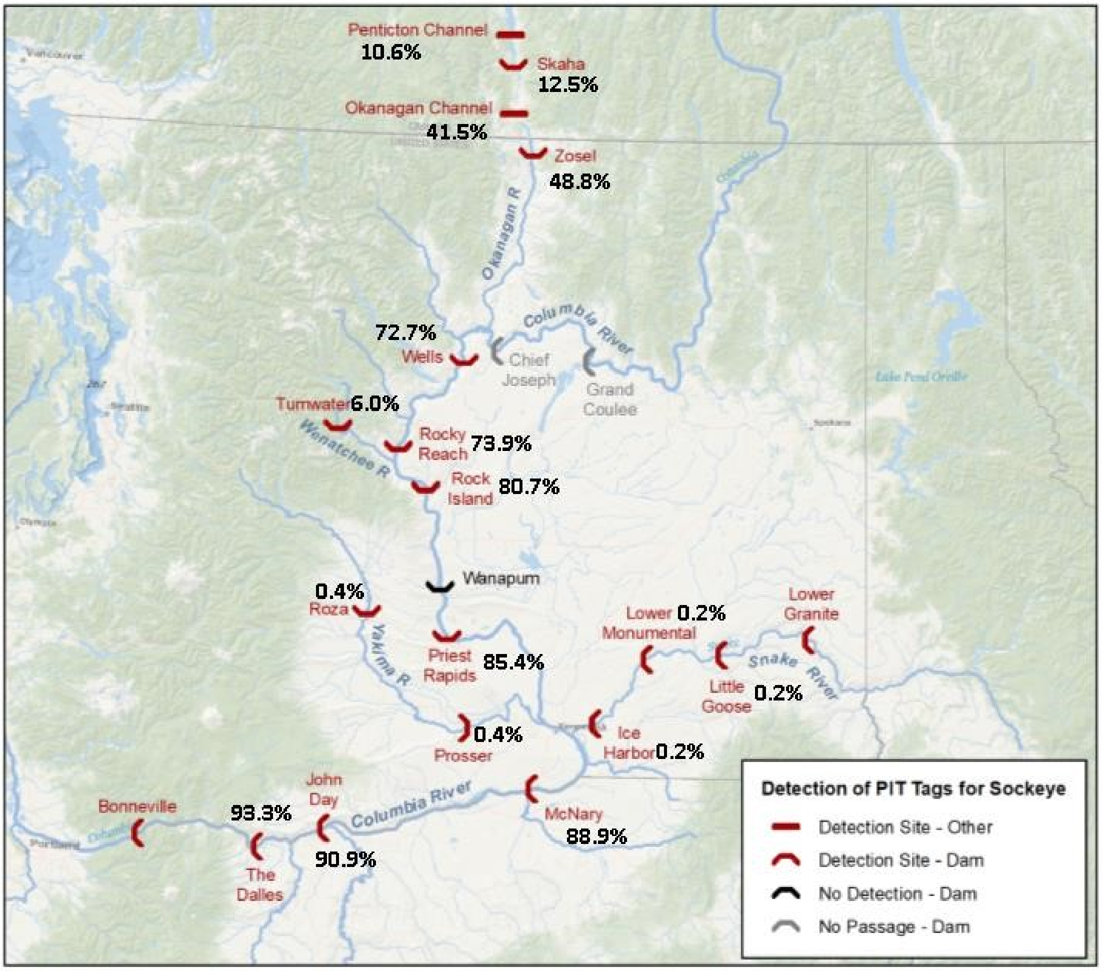

Figure 2. Map of the Columbia River Basin from Bonneville to Wells and Lower Granite dams showing the number of fish PIT tagged at Bonneville Dam, and the percentage of the run estimated to pass upstream dams and upstream detection sites in 2018.

Table 4. Survival of Sockeye PIT tagged at Bonneville Dam to upstream dams 2006-2018 with the mean June 15-July 14 water temperature at Bonneville Dam.

	Percentage by Year and Mean of All Years													
Dam	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**	**2009**	**2008**	**2007**	**2006**	**Mean**
The Dalles	93.3	89.3	94.0	82.8	93.1	89.5	--	--	--	--	--	--	--	90.3
John Day	90.9	--	--	--	--	--	--	--	--	--	--	--	--	90.9
McNary	88.9	81.7	89.2	54.0	88.3	83.6	82.4	76.1	81.5	85.7	89.4	84.0	88.4	82.6
Priest Rapids	85.4	74.6	85.3	44.9	84.5	78.6	77.3	71.9	78.4	82.1	86.3	77.4	84.8	77.8
Rock Island	80.7	70.8	81.6	40.6	79.5	74.2	75.0	68.9	76.3	80.2	85.8	73.4	81.1	74.5
Rocky Reach	73.9	43.7	60.5	31.6	65.3	52.4	62.1	55.3	63.7	67.1	73.7	62.2	58.8	59.3
Wells	72.7	42.5	59.3	29.4	64.2	50.5	60.8	53.9	62.6	65.2	71.1	60.9	53.8	57.5
Tumwater	6.0	25.8	20.8	8.3	13.6	20.9	12.9	14.2	13.3	12.2	9.4	NA	NA	14.3
Bonneville Dam mean water temp 6/15-7/14	18.5	18.1	18.8	21.3	17.9	18.2	16.4	15.8	16.6	17.9	17.0	18.2	18.3	17.8

Survival rates were also calculated since the 2008 return year for a group of approximately 3000 juvenile Sockeye captured and PIT tagged annually at the Rock Island Dam juvenile bypass (Table 5). Both Wenatchee and Okanagan juvenile Sockeye Salmon pass this site, making the mixed stock composition relatively similar to that of Sockeye tagged as adults at Bonneville Dam. However, sample sizes of returning adults from the Rock Island tagging program tend to be small, with only 32 returns to Bonneville Dam in 2018. These Sockeye survived at high rates in 2018; 100% to Rock Island Dam and a combined 87.5% 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 3.

Table 5. Survival of Sockeye PIT tagged as smolts at Rock Island Dam, on their adult upstream migration from Bonneville Dam to upstream dams 2008-2018[7].

	Percentage by Year and Mean of All Years											
Dam	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**	**2009**	**2008**	**Mean**
# at Bonneville	**32**	**16**	**35**	**128**	**155**	**66**	**121**	**125**	**130**	**33**	**38**	**80**
The Dalles	100.0	87.5	82.9	85.9	92.9	87.9	--	--	--	--	--	89.5
John Day	100.0	--	--	--	--	--	--	--	--	--	--	100.0
McNary	100.0	81.3	74.3	60.2	87.1	80.3	74.4	74.4	82.3	100.0	89.5	82.2
Priest Rapids	100.0	68.8	74.3	54.7	83.9	74.2	71.9	73.6	81.5	93.9	89.5	78.8
Rock Island	93.9	68.8	68.6	46.9	77.4	68.2	69.4	68.8	79.2	90.9	81.6	74.0
Rocky Reach	65.6	68.8	45.7	36.7	60.0	56.1	48.8	55.2	70.0	87.9	55.3	59.1
Wells	62.5	62.5	42.9	32.8	58.7	56.1	43.8	52.8	68.5	87.9	55.3	56.7
Zosel	46.9	18.8	37.1	7.0	39.4	3.0	0.8	1.6	--	--	--	19.3
Tumwater	25.0	6.3	22.9	13.3	16.1	10.6	23.1	14.4	10.0	3.0	26.3	15.5

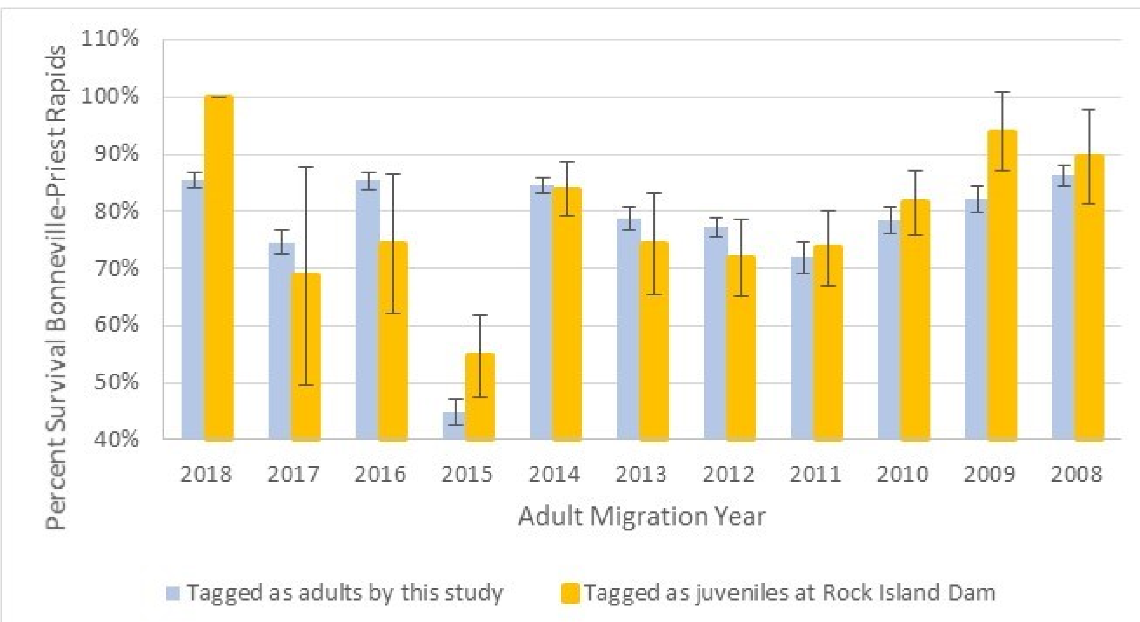

Figure 3. Annual percentage survival with 90% CI from Bonneville Dam to Priest Rapids Dam for adult Sockeye Salmon tagged by this study at Bonneville Dam and for returning Sockeye Salmon tagged as juveniles at Rock Island Dam 2008-2018.

[7] Years prior to 2008 were not included due to low sample sizes. From 2002-2007, the number of Sockeye PIT tagged as juveniles detected at Bonneville ranged between one and eight fish annually. Year 2011 was the first with PIT tag detection at Zosel Dam, 2013 the first year for detection at The Dalles Dam.

The estimated escapement based on upstream PIT tag detections was greater than the number of Sockeye counted at The Dalles, John Day, and McNary dams, but less than at Priest Rapids, Rock Island, Rocky Reach, Wells, and Tumwater dams (Table 6, Figure 4). The PIT tag estimates show a consistent decrease in Sockeye counts as the run progresses upstream, which is to be expected as Sockeye die on the upstream migration due to fisheries and natural mortality. However, the visual dam counts show an irregular pattern of increases and decreases with Priest Rapids counting, where almost as many Sockeye (189,884) were counted as at Bonneville Dam (193,816), while the number of Sockeye counted at The Dalles Dam (152,101) was less than at any other dam on the Columbia River.

Table 6. Percentage of PIT tagged Sockeye Salmon detected at upstream dams subsequent to tagging at Bonneville Dam, estimated escapement from both PIT tags and visual means, and the difference between the PIT tag and visual escapement estimate in 2018.

Dam	Estimated Percentage Reaching Dam	Escapement Estimate Using Bonneville PIT Tagged Sockeye	Visual Dam Count	Difference Between Bonneville PIT Tag and Visual Estimate
Bonneville	--	--	193,816	--
The Dalles	93.3%	180,667	152,101	+18.8%
John Day	90.9%	175,979	168,469	+4.5%
McNary	88.9%	172,219	155,480	+10.8%
Priest Rapids	85.4%	165,434	189,884	-12.9%
Rock Island	80.7%	156,180	172,009	-9.2%
Rocky Reach	73.9%	143,036	162,684	-12.1%
Wells	72.7%	140,760	153,637	-8.4%
Tumwater	6.0%	11,591	13,973	-17.0%
Ice Harbor	0.2%	278	392	-63.8%
Prosser	0.4%	870	456	+90.8%
Roza	0.4%	701	201	+248.7%

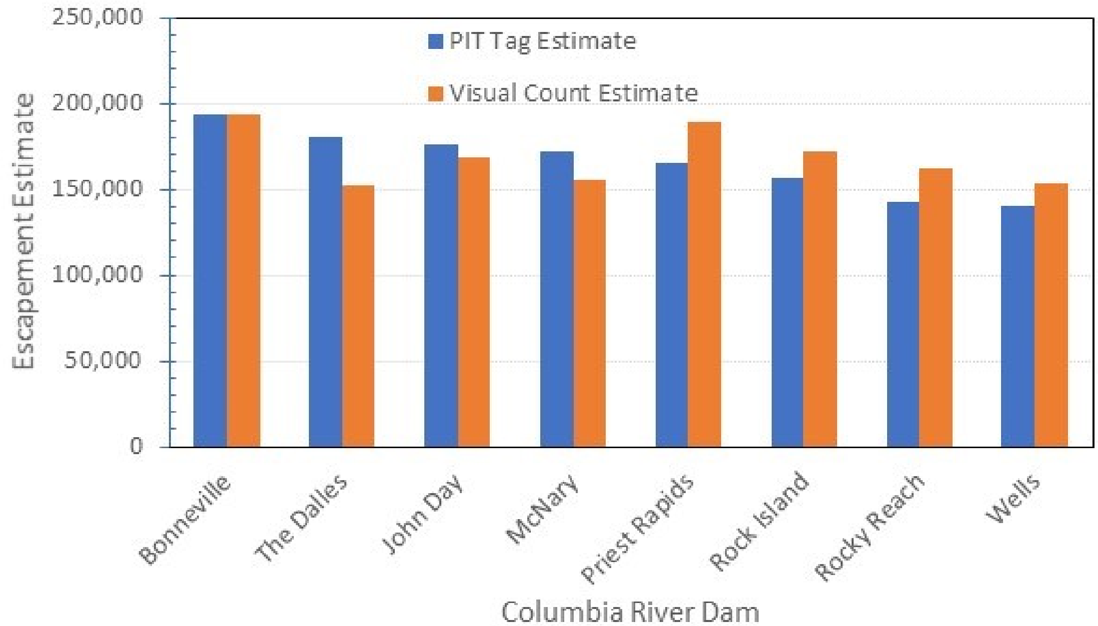

Figure 4. PIT tag and visual count estimates of escapement at Columbia River dams in 2018.

Sockeye Salmon tagged at Bonneville Dam show a significant linear decrease in survival over the period of the run to upstream dams in 2018 (Table 7, Figure 5). Sample sizes were low among Sockeye groups tagged as juveniles returning in 2018. Survival of the Rock Island-tagged group to Rock Island Dam (93.9%, n=33) was greater than that for the Bonneville-tagged group (80.7%) while that of the Okanagan-tagged group (69.5%, n=59) and the Wenatchee-tagged group (80.0%, n=5) was less (Table 8).

Table 7. Sockeye Salmon survival through selected reaches by statistical week as estimated by PIT tag detections in 2018 and the p-value for a linear regression between weekly reach survival and statistical week. No linear regressions were conducted for returning Sockeye tagged as juveniles due to the low number of returning adults.

Statistical Week at Bonneville Dam	Adults Tagged at Bonneville Dam				Sockeye Tagged as Juveniles BON-RIS		
	BON-TDA	BON-MCN	BON-PRD	BON-RIS	Wenatchee (n=5)	Okanagan (n=59)	Rock Island (n=33)
22-23	97.6%	97.6%	96.4%	95.2%	--	50.0%	100.0%
24	94.8%	92.1%	90.8%	89.5%	100.0%	42.9%	80.0%
25	94.3%	89.7%	86.9%	80.3%	66.7%	87.5%	100.0%
26	94.1%	91.6%	87.9%	82.0%	100.0%	82.4%	87.5%
27	91.2%	87.6%	84.0%	81.7%	--	--	100.0%
28	91.4%	79.2%	73.3%	71.0%	--	63.6%	100.0%
29	83.6%	67.3%	57.3%	51.8%	--	0.0%	--
30	83.1%	53.9%	41.6%	34.8%	--	0.0%	100.0%
Not Detected at Bonneville					--	66.7%	100.0%
Composite[8]	**93.3%**	**88.9%**	**85.4%**	**80.7%**	**80.0%**	**69.5%**	**93.9%**
p-value	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**--**	**--**	**--**

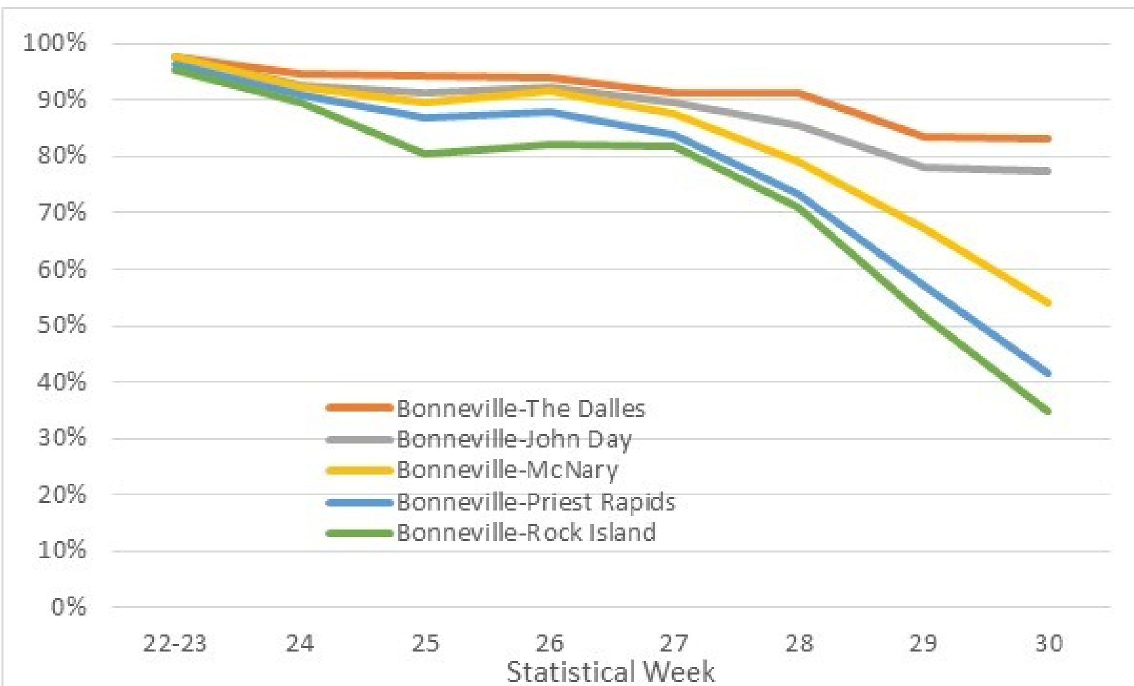

Figure 5. Survival of Sockeye Salmon PIT tagged at Bonneville Dam to The Dalles, McNary, Priest Rapids, and Rock Island dams by statistical week in 2018.

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

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 2018.

			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**	**Spawning Ground Conversion Rate (%)**
Okanagan	Juvenile	56	87.5	83.9	83.9	75.0	69.6	69.6	69.6	0.0	0.0	41.1
Wenatchee	Juvenile	6	100.0	100.0	100.0	100.0	80.0	0.0	0.0	80.0	0.0	83.3
Rock Island	Juvenile	32	100.0	100.0	100.0	100.0	93.8	65.6	62.5	25.0	0.0	52.5
Snake	Juvenile	8	87.5	75.0	75.0	12.5	12.5	12.5	12.5	0.0	62.5	12.5
Bonneville	Adult	1848	93.3	90.9	88.9	80.7	85.4	73.9	72.7	6.0	0.1	46.5

Among Sockeye tagged as juveniles, there were a total of eight returning Snake Basin juvenile-tagged Sockeye, five of which were detected at Ice Harbor and one (3D9.1C2E07D72C) strayed to Wells Dam. Among the five returning Wenatchee juvenile-tagged Sockeye, one was last detected at Priest Rapids Dam with the remaining four being detected at or above Tumwater Dam. Four were detected at Rock Island Dam and five were detected at Tumwater Dam. The returning Rock Island juvenile-tagged Sockeye had high upstream survival, with all 32 fish being detected at Priest Rapids Dam. Returning Okanagan juvenile-tagged Sockeye had a lower survival to all upstream dams than did Bonneville-tagged Sockeye from this study. Spawning ground conversion rates were highest for the six Wenatchee juvenile-tagged Sockeye (83.3%) and lowest for the Snake River Basin Sockeye (12.5%, Table 8).

Migration Rates and Passage Time

Adult Sockeye Salmon travel quickly upstream with a median migration rate between mainstem dams ranging between 33.0 and 59.8 km/day in 2018 for adults tagged at Bonneville. Among juvenile-tagged Sockeye returning as adults, migration rates between mainstem dams ranged from 31.5 to 61.0 km/d (Table 9).

Table 9. Median Sockeye Salmon migration rates and travel time between dams as estimated by PIT tag detections in 2018.

		Tagged at Bonneville Dam		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)
Bonneville-The Dalles	74	1.7	41.4	1.5	47.4
The Dalles-John Day	39	0.9	49.4	0.8	52.5
John Day-McNary	63	2.0	59.8	1.9	61.0
McNary-Priest Rapids	167	3.9	42.8	4.1	41.5
Priest Rapids-Rock Island	89	2.7	33.5	2.8	32.4
Rock Island-Rocky Reach	33	1.0	33.0	1.0	31.5
Rocky Reach-Wells	65	1.8	38.5	1.7	40.1
Rock Island-Tumwater	73	9.8	7.1	8.1	8.5
Bonneville-John Day	113	2.7	42.6	2.3	49.4
Bonneville-McNary	231	4.7	49.6	4.4	52.6
Bonneville-Priest Rapids	329	8.7	46.1	8.6	46.6
Bonneville-Rock Island	487	11.4	43.0	11.9	41.1
Bonneville-Tumwater	560	21.8	25.6	21.5	26.0
Bonneville-Wells	585	14.4	41.0	14.1	41.9

Sockeye Salmon tagged at Bonneville Dam later in the migration travel upstream faster than those tagged earlier in the migration (Table 10). This relationship was significant (α=0.05) for all dam pairings listed in Table 10 except for Bonneville-The Dalles, Bonneville-John Day, and Bonneville-Tumwater dams in 2018.

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 2018.

Statistical Week at Bonneville Dam	BON to TDA	BON to JDA	BON to MCN	BON to PRA	BON to RIA	BON to TUM	BON to RRH	BON to WEL	BON to ZSL	WEL to ZSL	RIA to TUM
22-23	1.8	2.8	5.2	10.9	14.7	29.4	15.9	18.2	NA	NA	21.5
24	1.9	2.8	5.0	9.1	12.1	23.7	13.0	15.2	NA	NA	17.6
25	1.9	2.8	4.8	9.0	12.0	21.7	13.1	15.0	64.3	44.9	11.0
26	1.7	2.7	4.6	8.2	11.2	19.1	12.1	13.9	56.5	41.5	9.2
27	1.7	2.6	4.5	8.1	10.9	18.0	11.8	13.4	48.5	34.6	7.5
28	1.4	2.3	4.5	8.0	10.7	20.2	11.7	13.4	40.5	27.1	6.8
29	1.3	2.1	4.1	8.0	10.2	18.1	11.7	13.8	32.5	18.2	10.8
30	1.8	2.7	4.8	8.7	11.4	32.0	12.5	14.4	26.5	11.1	7.3
p-value	**0.84**	**0.08**	**0.05**	**0.04**	**0.03**	**0.09**	**0.04**	**0.04**	**<0.01**	**<0.01**	**0.02**
Stock											
Okanagan	1.7	2.7	4.7	8.7	11.3	-	12.7	14.4	45.5	32.3	NA
Wenatchee	1.7	2.6	4.6	8.7	11.9	21.8	13.2	15.4	NA	NA	9.8
Age											
1.1	1.8	2.7	4.6	8.7	11.6	-	12.2	13.7	47.5	33.9	NA
1.2	1.9	2.9	4.9	9.0	11.9	21.8	13.1	15.0	45.1	30.7	9.8
1.3	2.1	3.1	5.0	9.3	12.3	27.1	12.7	15.4	28.5	8.3	14.8

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 2018 was 3.8 minutes compared to 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 compared to those tagged as adults at the AFF (Table 11).

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 2018.

	Adults Tagged at Bonneville Dam			Previously Tagged as Juveniles		
Dam	**N**	**Median Passage (Minutes)**	**%>12 Hours**	**N**	**Median Passage (Minutes)**	**%>12 Hours**
Bonneville	1772	9.2	0.1	75	7.6	0.0
The Dalles	1689	0.1	1.9	98	0.1	3.1
John Day	1607	0.1	3.4	91	0.1	4.4
McNary	1544	0.2	1.9	91	0.4	12.1
Priest Rapids	1512	5.0	1.6	85	6.4	2.4
Rock Island	1030	2.0	0.6	58	1.5	1.7
Rocky Reach	1316	6.0	1.7	65	6.5	1.5
Wells	1296	5.7	5.6	64	5.4	6.2
Zosel	370	37.2	10.2	11	0.2	0.0
Tumwater	98	7.4	0.0	13	27.7	0.0
Ice Harbor	4	0.2	0.0	5	2.0	0.0
Lower Monumental	1	0.1	0.0	5	3.9	20.0
Little Goose	1	224.6	0.0	5	0.1	0.0
Lower Granite	1	5.7	5.6	5	419.2	0.0
Weighted Mean (by detection number)	**12,241**	**3.8**	**2.1**	**671**	**6.7**	**4.0**

Night Passage

Okanagan Sockeye Salmon stock tagged at Bonneville Dam passed PIT tag antennas at night (2000-0400 hours) at a higher rate than Wenatchee Sockeye Salmon stock at seven out of eight dams where Sockeye from both stocks were detected (Table 12).

Table 12. Estimated Sockeye Salmon night passage (2000-0400) by stock at mainstem Columbia River dams in 2018.

Dam	Adults Tagged at Bonneville Dam			Sockeye Tagged as Juveniles
	All Adults	Okanagan	Wenatchee	
Bonneville	0.6%	0.7%	0.0%	2.7%
The Dalles	9.9%	9.8%	12.9%	7.1%
John Day	5.0%	5.1%	4.0%	2.2%
McNary	10.7%	10.8%	8.3%	13.2%
Priest Rapids	4.2%	4.4%	1.8%	5.9%
Rock Island	6.7%	7.2%	1.3%	3.4%
Rocky Reach	8.5%	8.6%	0.0%	7.7%
Wells	13.0%	13.0%	0.0%	10.9%
Tumwater	3.1%	NA	3.1%	7.7%
Zosel	51.1%	51.2%	NA	63.6%

Fallback

Estimated minimum fallback rates for adults tagged at Bonneville Dam in 2018 ranged from 0.1% at Bonneville Dam to 4.5% at John Day Dam for Columbia River dams (Table 13)[9]. Sockeye at Snake River dams had no fallback; however, sample sizes were very small with only four Sockeye detected at Ice Harbor and one at the other three Snake River dams with fish passage. Fallback rates of Sockeye tagged as juveniles were higher than those tagged as adults at five out of eight Columbia River dams, reaching a high of 4.9% at Priest Rapids Dam. Of the 201 Sockeye tagged as adults by this project in 2018 that were estimated to fall back over at least one dam, 20 fell back over two dams while one fell back over three dams (Table 14). Among Sockeye tagged as juveniles, the mean number of fallbacks events per Sockeye Salmon ranged from 0.00 for Sockeye tagged in the Wenatchee Basin (n=6) to 0.25 for the Snake Basin (n=12) compared to 0.16 for adult-tagged Sockeye in our Bonneville study (Table 14).

Table 13. Estimated minimum fallback rates for Sockeye Salmon at mainstem dams in 2018[10]. (NA indicates Sockeye were not detected at a dam outside the range of the particular stock.)

		Sockeye Tagged as Juveniles by Tagging Location				
Dam	**Adults Tagged at Bonneville**	**Okanagan Basin (n=56)**	**Rock Island Dam (n=32)**	**Snake Basin (n=8)**	**Wenatchee Basin (n=6)**	**Total (n=102)**
Bonneville	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
The Dalles	0.7%	0.0%	0.0%	0.0%	0.0%	4.3%
John Day	4.5%	2.1%	6.3%	16.7%	0.0%	4.7%
McNary	0.4%	4.3%	0.0%	0.0%	0.0%	2.2%
Priest Rapids	1.8%	9.5%	0.0%	NA	0.0%	4.9%
Rock Island	0.6%	0.0%	4.2%	NA	0.0%	1.3%
Rocky Reach	1.7%	2.6%	0.0%	NA	NA	1.6%
Wells	3.7%	0.0%	0.0%	NA	NA	0.0%
Tumwater	4.1%	NA	0.0%	NA	0.0%	0.0%
Ice Harbor	0.0%	NA	NA	20.0%	NA	16.8%
Lower Monumental	0.0%	NA	NA	20.0%	NA	12.4%
Little Goose	0.0%	NA	NA	0.0%	NA	7.9%
Lower Granite	0.0%	NA	NA	0.0%	NA	7.3%

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 2018.

	Sockeye Tagged as Juveniles by Tagging Location				
Fallback Events	**Okanagan Basin**	**Rock Island Dam**	**Snake Basin**	**Wenatchee Basin**	**Adults Tagged at Bonneville**
1	7	5	0	0	180
2	2	0	0	0	20
3	0	0	1	0	1
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
Number of Sockeye falling back at least once	**9**	**5**	**1**	**0**	**201**
% of Sockeye with at least one fallback event	**16.1%**	**15.6%**	**12.5%**	**0.0%**	**10.9%**
Total fallback events	**11**	**5**	**3**	**0**	**223**
Number of Sockeye in study	**56**	**32**	**12**	**6**	**1848**
Fallbacks events per Sockeye	**0.20**	**0.16**	**0.25**	**0.00**	**0.12**

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

2018 Stock Composition Estimates

In 2018, genetics stock identification (GSI) and Parental Based Tagging (PBT) were used to classify samples from 1,858 Sockeye Salmon collected at Bonneville Dam and the stock classification were compared by site to final PIT tag detection (Table 15). Of the 971 Sockeye that could be classified by stock by both GSI and PIT tags, there were only two disagreements. Both of these discrepancies were Sockeye last detected at Ice Harbor Dam and both were classified by GSI as being of Wenatchee stock. However, both of these fish were classified by PBT as having parents from the Yakima reintroduction program. We had another Sockeye, also classified by GSI as being of Wenatchee stock but by PBT as Yakima origin, which was detected passing Priest Rapids Dam before being detected at Prosser Dam in the Yakima River.

Table 15. Comparison of stock composition estimates for individual Sockeye Salmon sampled at Bonneville Dam in 2018. Green shading indicates agreement between the two methods, orange indicates the stock estimates differed.

Stock Estimated Using PIT Tags		Stock Estimated by Genetics (PBT or GSI)					
	Okanagan	Wenatchee	Snake	Deschutes	Yakima	Unknown[11]	Total
Okanagan	863	0	0	0	0	5	868
Wenatchee	0	103	0	0	0	0	103
Snake	0		2	0	2	0	4
Yakima	0	6	0	0	1	0	7
Unknown	801	53	2	3	3	4	866
No PIT tag	9	1	0	0	0	0	10
Total	**1673**	**164**	**4**	**3**	**6**	**9**	**1858**

When combining PIT and GSI stock determinations as described in the methods, this study estimated that the stock composition at Bonneville Dam in 2018 was 90.2% Okanagan, 9.0% Wenatchee, 0.6% Yakima, 0.2% Snake, and 0.0% Deschutes rivers (Table 16 and Figure 1). Using only PIT tag detections of Sockeye last detected in terminal areas resulted in a stock composition of 87.5% Okanagan, 11.3% Wenatchee, 0.4% Snake, 0.8% Yakima, and 0.0% Deschutes. Using visual fish counts at dams to estimate Okanagan stock abundance relative to the Wenatchee yielded a higher percentage of Okanagan (92.9% and 94.5%, Table 16) than did PIT and GSI estimates. There was a significant linear relationship between statistical week and the percentage of Okanagan Sockeye ($p=0.02$) at Bonneville Dam (estimated using PIT and GSI) but not for the percentage of the Wenatchee stock ($p=0.09$) (Table 16 and Figure 6).

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

Table 16. Weekly and composite Sockeye Salmon stock composition at Bonneville Dam as estimated by PIT tags and GSI in 2018 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	% Snake	% Yakima	% Deschutes
22-23	1.7	98.8	1.2	0.0	0.0	0.0
24	9.2	93.9	6.1	0.0	0.0	0.0
25	30.6	89.1	9.7	0.0	1.1	0.0
26	32.5	90.3	9.1	0.4	0.2	0.0
27	17.6	89.3	10.1	0.0	0.7	0.0
28	5.6	90.5	8.6	0.5	0.5	0.0
29	1.7	90.8	6.4	0.9	0.9	0.9
30	1.2	84.1	11.4	0.0	2.3	2.3
Combined PIT and GSI Estimate		**90.2**	**9.0**	**0.2**	**0.6**	**0.0**
PIT Tag Only Estimate		**87.5**	**11.3**	**0.4**	**0.8**	**0.0**
GSI Only Estimate		**90.4**	**9.4**	**0.2**	**NA**	**0.04**
Visual Fish Counts at dams (using difference between Rock Island and Rocky Reach counts to estimate proportion Wenatchee escapement; Rocky Reach to estimate Okanagan escapement)		94.5	5.5			
Visual Fish Counts at dams (Tumwater count to estimate the Wenatchee; Rocky Reach to estimate Okanagan)		92.9	7.1			

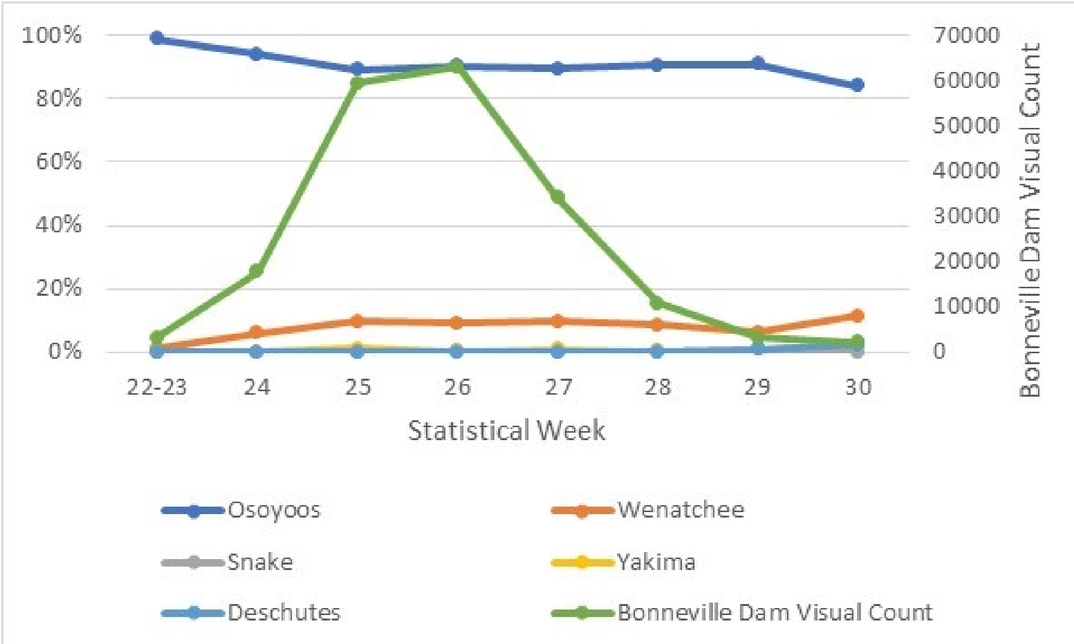

Figure 6. Percentage of the Sockeye run at Bonneville Dam estimated to be of Okanagan, Wenatchee, Snake, Yakima, and Deschutes origin by week in 2018.

Among the 103 Sockeye Salmon classified as Wenatchee stock that were last detected in the Wenatchee River, three (2.9%) were previously detected upriver from the mouth of the Wenatchee River at Rocky Reach Dam and one (1.0%) at Wells and Rocky Reach dams. One additional Sockeye Salmon classified as Wenatchee stock using GSI did not enter the Wenatchee River and was last detected at Rocky Reach Dam while a second was last detected at Wells Dam (Table 17).

Among the four Sockeye classified using GSI as Snake River origin and therefore listed under the Endangered Species Act, two were last detected exiting the Bonneville Dam Washington shore fish ladder (3DD.0077BA4D07 tagged June 27, 2018, and 3DD.0077BA9C60 tagged July 19, 2018). The other two Snake River Sockeye were last detected in the Snake River, 3DD.077BAA9FA on July 28, 2018, at Ice Harbor Dam and 3DD.0077BA4404 on July 7, 2018, at Lower Granite Dam.

Among the three Sockeye classified as Deschutes origin, two were last detected exiting the Bonneville Dam Washington shore fish ladder while one was last detected exiting The Dalles Dan north fish ladder.

Table 17. GSI classification of Sockeye Salmon by last detection area/site for Sockeye PIT tagged at Bonneville Dam in 2018.

Area (site) of Last Detection Non-Terminal Areas	Okanagan	Wenatchee	Snake	Deschutes	Yakima	Unknown[12]
Bonneville Dam (BO1, BO3, BO4)	112	23	2	2	1	2
Deschutes (DRM)	3	1	0	0	0	0
Eastbank H. (EBO)	1	0	0	0	0	0
Entiat (ENL)	1	0	0	0	0	0
Hood River (HRM)	1	0	0	0	0	0
John Day dam (JO1, JO2, JCJ)	56	4	0	0	0	0
McNary Dam (MC1, MC2, MCJ)	54	9	0	0	2	0
Methow River (MRC)	1	0	0	0	0	0
Priest Rapid Dam (PRA)	68	6	0	0	0	0
Prosser Dam (PRO)	0	1	0	0	0	0
Rock Island Dam (RIA)	14	2	0	0	0	1
Ringold Springs Hatchery (RSH)	2	0	0	0	0	0
Roza Dam (ROZ)	3	5	0	0	0	0
Rocky Reach (RRF,RRJ)	22	1	0	0	0	1
The Dalles Dam (TD1, TD2)	43	6	0	1	0	0
Wells Dam (WEA, WEJ)	408	1	0	0	0	0
Terminal Areas						
Wenatchee River (LWE, LWN, TUF, UWE, WTL)	0	103	0	0	0	0
Okanagan River (JOH, OKC, OKL, OKP, SKA, ZSL)	875	0	0	0	0	5
Snake River (ICH)	0	0	2	0	2	0
Yakima River (ROZ)	0	0	0	0	1	0

A total of seven Sockeye were detected at Prosser Dam with six of these subsequently detected at Roza Dam (Table 18). All seven were classified as Wenatchee origin by GSI, with PBT identifying one of these fish as having Yakima program parents.[13] Four other Sockeye that were not detected in the Snake River were classified by PBT as being of Yakima origin (two last detected at McNary Dam, one at Bonneville Dam, and one at Ice Harbor Dam). The Ice Harbor detection was classified by GSI as Wenatchee stock. A second Sockeye Salmon last detected at Ice Harbor Dam (3DD.007BA6919) was also classified as Wenatchee stock, raising the possibility that it is also a Yakima stray. Three other Sockeye, in addition to the six migrating upstream from Prosser, were detected at Roza Dam despite not being detected at Prosser Dam (Table 18). All three of these

[12] Either no genetics sample available or the sample did not classify to a particular stock.
[13] Limited genetics sampling of adult spawners means that it is only possible to estimate PBT of a small portion of the returning Sockeye Salmon. The overwhelming majority of adult spawners are transplanted Sockeye from Priest Rapids Dam, which classify, using GSI, as Okanagan and Wenatchee stock. Their offspring returning to the Yakima River would be expected to classify similarly.

were classified as Okanagan origin by GSI and were previously detected at Priest Rapids Dam Adult Fish Trap. It is presumed that these fish were trapped at Priest Rapids, transported to Cle Elum Lake, and then migrated downstream of Roza Dam only to be detected moving upstream through the Roza Dam fish ladder. There was a total of 34 Sockeye Salmon (in addition to the three detected at Roza Dam) tagged by this project at Bonneville Dam that were last detected at the Priest Rapids Dam Adult Fish Trap and were presumed transported to Cle Elum Lake[14].

Table 18. Sockeye Salmon PIT tagged at Bonneville Dam in 2018 last detected in the Yakima River or classified by PBT as Yakima origin.

	Genetics Classification			Date of First Detection				
PIT Tag	GSI	PBT	Tag Date	McNary	Prosser	Roza	Priest Rapids	Last Detection
3DD.0077BA558B	Wenatchee		6/20	6/27	7/6	7/15		
3DD.0077BA6487	Wenatchee	Yakima	6/20	6/25	7/5	7/14		
3DD.0077BAB5C2	Osoyoos	Yakima	6/21					Bonneville 6/22
3DD.0077BA54E6	Wenatchee		06/22	6/27	8/23			
3DD.0077BA649C	Wenatchee	Yakima	6/29	7/7				Ice Harbor 8/7
3DD.0077BA8F04	Wenatchee		7/02	7/7	8/31	9/19	7/22	
3DD.0077BA8D70	Wenatchee		7/6	7/13	8/29	9/9		
3DD.0077BAACF0	Wenatchee		7/6	7/10	8/29	9/17		
3DD.0077BA72AA	Wenatchee		7/19	7/23	8/24	9/20		
3DD.0077BA3E8E	Wenatchee	Yakima	7/23	7/28				McNary 7/28
3DD.0077BA83D2	Wenatchee	Yakima	7/23	7/28				McNary 7/28
Sockeye Salmon detected only at Roza Dam in the Yakima River								
3DD.0077BA814D	Osoyoos		06/27	7/2		7/21	7/6	
3DD.0077BA666F	Osoyoos		06/26	7/2		8/21	7/6	
3DD.0077BA5B19	Osoyoos		06/25	6/29		8/15	7/3	

A total of 13 Sockeye sampled by this project at Bonneville Dam were adipose or maxillary clipped, including all four of the Snake River Sockeye (Table 19). Juvenile Sockeye are adipose clipped in the Snake Basin and maxillary clipped in the Deschutes River, but it is unknown which project is adipose or maxillary clipping or visual implant tagging Okanagan or Wenatchee Sockeye Salmon.

[14] Sockeye transported from Priest Rapids Dam to Cle Elum Lake are not scanned for PIT tags.

Table 19. Type and number of fin clips and marks by stock for Sockeye Salmon sampled at Bonneville Dam in 2018.

	Clip or Mark Type				
Stock	**Adipose**	**Left Maxillary**	**Right Maxillary**	**Visual Implant**	**Total**
Okanagan	3	2	2	1	7
Wenatchee				1	1
Snake	4			0	3
Deschutes			3		2
Total	**6**	**2**	**5**	**2**	**16**

Stock Specific Upstream Survival

Upstream survival of Okanagan Sockeye Salmon to Rock Island Dam was higher than the Wenatchee stock (82.3% vs. 71.2%), however survival to the spawning grounds was lower (45.8% vs 56.1%, Table 20).

Table 20. Stock specific survival from Bonneville Dam weighted by weekly Bonneville Dam run size, as estimated by GSI and PIT tags in 2018.

	Estimated Survival from Bonneville Dam by Stock (%)							
	Okanagan (n=1660)		Wenatchee (n=157)			Snake River (n=4)		Okanagan, Wenatchee, Snake Combined (n=1821)
Statistical Week	**Rock Island Dam**	**Okanagan Spawning (OKC)**	**Rock Island Dam**	**Tumwater Dam**	**Wenatchee Spawning (LWE or WTL)**	**Snake River**	**Snake Spawning[15]**	**Snake, OKA, WEN Spawning**
22-23	95.2	77.1	100.0	100.0	100.0	NA	NA	77.4
24	90.2	64.0	78.6	78.6	78.6	NA	NA	64.9
25	82.0	53.7	73.5	73.5	61.8	NA	NA	54.5
26	83.8	41.7	68.3	61.0	53.7	50.0	0.0	42.8
27	83.2	34.4	74.2	67.7	54.8	NA	NA	36.5
28	71.7	30.8	78.9	63.2	36.8	100.0	0.0	31.3
29	53.5	26.3	42.9	28.6	14.3	0.0	0.0	25.5
30	40.5	27.0	10.0	10.0	10.0	NA	NA	25.0
Weighted[16]	**82.3**	**45.8**	**71.2**	**66.5**	**56.1**	**50.0**	**0.0**	**46.7**

Wells Dam Sampling Results

A total of 805 Sockeye Salmon were sampled at the Wells Dam east bank fish ladder in 2018 (Table 21), eight of which were previously PIT tagged (all by

[15] Detected in upper Salmon River upstream of Stanley, ID.
[16] Snake River estimates are unweighted due to low sample sizes (n=4 at Bonneville Dam, n=2 at Ice Harbor Dam)

this project at Bonneville Dam). The number of PIT tagged Sockeye Salmon that were detected and tracked subsequent to detection was 789.

Table 21. Number of Sockeye Salmon sampled, and PIT tagged at Wells Dam by date and statistical week in 2018.

Sampling Dates	Statistical Week	Sampled (n)	PIT Tagged	Previously Tagged	PIT Tagged Sockeye Released	Tracked
6/25-27	26	52	50	2	52	49
72,3,5	27	102	101	1	102	96
7/9-11-	28	276	275	1	276	275
7/16-18	29	242	238	4	242	240
7/23-24	30	108	108	0	108	106
7/30	31	25	25	0	25	23
Total		**805**	**797**	**8**	**805**	**789**

Among the Sockeye visually identified as males during sampling, 94.1% were Age 1.2 compared to 95.8% for those identified as females (Table 22).

Table 22. Age composition by week and sex for Sockeye Salmon sampled at Wells Dam in 2018. 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
26	6/25-27	11.1	52	51	0.0	92.2	0.0	0.0	7.8
27	7/2,3,5	28.7	102	101	0.0	92.1	2.0	3.0	3.0
28	7/9-11-	34.0	276	273	0.4	95.2	0.7	3.3	0.4
29	7/16-18	17.8	242	236	0.4	98.7	0.4	0.4	0.0
30	7/23-24	6.0	108	108	0.9	98.1	0.0	0.9	0.0
31	7/30	2.5	25	24	4.2	95.8	0.0	0.0	0.0
Composite			**805**	**793**	**0.4**	**94.8**	**0.9**	**2.1**	**1.8**
Males (visual ID)			440	358	0.2	94.1	0.2	3.2	2.2
Females (visual ID)			365	435	0.5	95.8	1.5	0.8	1.4

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

2018 age composition estimates for Sockeye sampled at Bonneville and Wells dams are presented in Table 23, as well as those estimated by stock from GSI of Sockeye sampled at Bonneville Dam. The GSI estimates show that Wenatchee Sockeye Salmon had a much higher percentage of older Age 1.3, and lower percentage of Age 1.2 Sockeye than Okanagan Sockeye Salmon.

Table 23. Age composition (%) of Columbia Basin Sockeye Salmon stocks as estimated by PIT tag detections as well as by sampling at Wells Dam in 2018.

Sampling Site	Stock	Ageable Sample Size	Brood Year and Age Class					
			2015	2014		2013		
			1.1	1.2	2.1	1.3	2.2	3.1
Bonneville Dam	Mixed	1842	0.4%	94.2%	2.0%	1.4%	1.3%	0.7%
Bonneville Dam	Wenatchee: Stock determined as described on page 25 of this report	478	0.0%	79.7%	0.0%	12.6%	7.7%	0.0%
Bonneville Dam	Okanagan Stock determined as described on pages 25 of this report	1642	0.4%	95.6%	0.4%	2.2%	0.6%	0.8%
Wells Dam	Okanagan	793	0.4%	94.8%	0.9%	2.1%	1.8%	0.0%

Mean fork lengths estimated by measuring Sockeye Salmon sampled at Wells Dam were greater than those estimated for the Okanagan stock, using data collected at Bonneville Dam, for the larger-sized fish age groups 1.2, 1.3, and 2.2 (Table 24). This is likely due to the 5.1 cm spacing of the bars on the weir diverting fish into the trap. This is sufficiently wide that smaller fish can slip through bars and avoid the weir diverting fish into the trap. Age 1.1 Sockeye sampled at Wells Dam were smaller than those collected at Bonneville Dam (39.0 vs. 40.9 cm), but sampled sizes were very small (n=2 for Wells Dam-sampled Sockeye compared to n=7 for Bonneville Dam-sampled Sockeye Salmon.).

Table 24. 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 dams in 2018.

Stock	Statistic	Brood Year and Age Class					
		2015	2014		2013		
		1.1	1.2	2.1	1.3	2.2	3.1
Bonneville Dam-Mixed Stock (Excluding weeks 28-29)	Mean Length	40.8	48.2	44.0	54.9	49.7	46.7
	St. Dev.	1.0	2.2	1.9	2.3	2.3	2.2
	N	8	1723	40	26	32	12
Okanagan-based on GSI of Sockeye tagged at Bonneville Dam	Mean Length	40.9	48.1	44.0	53.6	49.0	46.7
	St. Dev.	1.1	2.2	1.9	3.3	2.8	2.2
	N	7	1558	40	7	17	12
Okanagan-Wells Sampling	Mean Length	39.0	50.8		57.1	52.1	
	St. Dev.	2.8	2.7		2.1	1.0	
	N	2	682		89	8	
Snake River-based on GSI of Sockeye tagged at Bonneville Dam	Mean Length		52.9				
	St. Dev.		1.3				
	N		4				
Wenatchee based on GSI of Sockeye tagged at Bonneville Dam	Mean Length		49.3		55.3	50.7	
	St. Dev.		1.6		1.6	1.3	
	N		122		18	18	

Stock Composition at Wells Dam

In 2018 the project had insufficient funds to conduct GSI on all Sockeye sampled at Wells Dam. Therefore, GSI was only conducted on the 84 Sockeye Salmon tagged at Wells Dam that were last detected at locations other than Wells Dam or in the Okanagan River at, or downstream of, Zosel Dam. In previous years (as well as for Bonneville-tagged Sockeye in 2018), no Sockeye detected in the Okanagan River have been classified as anything other than Okanagan stock using GSI. This was the case for Wells-tagged Sockeye Salmon in 2018 last detected in the Okanagan Basin downstream of Zosel Dam as they were all classified by GSI as being of Okanagan stock (Table 25). Thus, all Wells-tagged Sockeye Salmon last detected at or above Zosel Dam in 2018 were classified as Okanagan stock while Sockeye Salmon last detected at Wells Dam were classified as unknown and omitted from Table 26.

Among the Sockeye PIT tagged at Wells Dam that moved downstream, all 13 detected in the Wenatchee Basin were classified as Wenatchee stock (Table 25). One out of seven Sockeye last detected in the Entiat River were classified as Okanagan stock with the remaining one classified as Wenatchee stock. Both Sockeye detected in the Methow River were classified as Wenatchee stock. No Sockeye Salmon that were detected in a Columbia River tributary upstream of Rock Island Dam were subsequently detected in the mainstem Columbia River or another tributary. All 14 of the Sockeye detected downstream, or moving downstream, in the mainstem Columbia downstream of Wells Dam, at Wells or Eastbank hatcheries, Wells Dam bypass, Rocky Reach or Rock Island dams were classified as Okanagan stock. There were two Sockeye for which GSI did not yield a stock classification, one last detected at Rocky Reach Dam and the other at OKL downstream of Zosel Dam.

The overall stock composition estimated from Wells Dam samples was 97.4% Okanogan and 2.6% Wenatchee, compared to 99.9% Okanagan and 0.1% Wenatchee for Sockeye tagged at Bonneville Dam that were detected at Wells Dam.

Table 25. Stock Classification of Sockeye Salmon passing Wells Dam. Eighty-four were classified using GSI, those last detected at or upstream of Zosel Dam were classified as Okanagan stock.

	Classification			
Last Detection	**Okanagan**	**Wenatchee**	**Unknown**	**Total**
Rock Island Dam	1	0	0	1
Wenatchee Basin	0	13	0	13
Rocky Reach Dam	7	0	1	8
Eastbank Hatchery	4	0	0	4
Entiat River	6	1	0	7
Wells Juvenile Bypass/Hatchery	2	0	0	2
Methow Basin	0	2	0	2
Okanagan downstream of Zosel Dam	30	0	1	31
Not Detected	15	1	0	16
No Stock ID, classified by last location				
Okanagan Basin at or upstream of ZSL	451	0	0	449
Wells Dam	0	0	300	303
Total	**514**	**17**	**303**	**834**

Table 26. Stock composition of Sockeye Salmon tagged at Wells Dam and Sockeye Salmon passing Wells Dam as estimated using GSI and PIT tags in 2018. (Wells Dam estimates are weighted by the weekly Wells Dam run size; Bonneville estimates are unweighted.) No sampling occurred at Wells Dam in weeks 25 and 32-34, however Bonneville-tagged Sockeye did pass Wells Dam during these weeks.

Week at	**Tagged at Bonneville Dam**			**Tagged at Wells dam**		
Wells Dam	**N**	**Okanagan**	**Wenatchee**	**N**	**Okanagan**	**Wenatchee**
25	19	100.0%	0.0%			
26	202	100.0%	0.0%	54	100.0%	0.0%
27	235	100.0%	0.0%	98	99.0%	1.0%
28	388	100.0%	0.0%	172	95.9%	4.1%
29	241	99.6%	0.4%	146	96.6%	3.4%
30	126	99.2%	0.8%	72	94.4%	5.6%
31	56	100.0%	0.0%	22	100.0%	0.0%
32	25	100.0%	0.0%			
33-34	4	100.0%	0.0%			
Total	**1289**	**99.9%**	**0.1%**	**564**	**97.4%**	**2.6%**

Migration into Natal Areas-Okanagan River

High flows in 2018 resulted in relatively low rates of detection at Zosel Dam fish ladder antennas as well as at PIT tag arrays in the Okanagan River, particularly early in the migration (Appendix A). Among Sockeye tagged at Wells Dam (Table 27), 100% of the Sockeye tagged in Week 26 detected upstream of Zosel Dam were not detected at Zosel Dam, with this decreasing to 96.5% for Sockeye tagged in Week 27 and 32.0% in Week 28. The same trend is observed for detection from Sockeye Salmon tagged at Bonneville Dam. No Sockeye Salmon tagged at

Bonneville Dam prior to Week 25 were detected at Zosel Dam[17]. The lack of detections of Sockeye early in the run makes it difficult to assess passage to Zosel. The early migrants were also generally more likely to miss detection at OKC (Tables 27 and 28).

Table 27. Number of Sockeye Salmon detected upstream of both Zosel and OKC that were detected at Zosel and OKC by week tagged Wells Dam in 2018.

Week Tagged at Wells Dam	Detected Upstream of Zosel	Percentage Not Detected at Zosel Dam	Detected Upstream of OKC	Percentage Not Detected at OKC
26	37	100.0	15	20.0
27	57	96.5	25	8.0
28	125	32.0	46	0.0
29	106	0.9	42	0.0
30	39	0.0	13	0.0
31	8	0.0	4	0.0
Total	**372**	**48.8**	**145**	**4.5**

Table 28. Number of Sockeye Salmon detected upstream of both Zosel and OKC that were detected at Zosel and OKC by week, tagged at Bonneville Dam in 2018.

Week Tagged at AFF	Detected Upstream of Zosel	Percentage Not Detected at Zosel Dam	Detected Upstream of OKC	Percentage Missing OKC
22	2	100.0	0	NA
23	62	100.0	23	4.3
24	139	100.0	51	19.6
25	168	92.3	50	12.0
26	173	43.4	46	2.2
27	94	3.2	27	0.0
28	61	0.0	21	0.0
29	26	0.0	8	0.0
30	20	0.0	8	0.0
Total	**745**	**58.5%**	**234**	**7.7%**

Sockeye tagged at Wells Dam in Week 26 had the highest conversion rate to the spawning grounds (OKC, SKA, OKP/OKS) at 75.5%, steadily declining to 34.8% for Sockeye tagged in Week 31 (Table 29, Figure 7). A similar trend was observed for Bonneville-tagged Sockeye Salmon with the rate dropping from 78.9% in Week 25 to 43.6% to 48.2% in weeks 29-31 before increasing in weeks 32 and 33 after sampling at Wells Dam had ceased for the year due to few Sockeye passing in those weeks (Table 29, Figure 7). The overall conversion rate from detection at Wells Dam to OKC for Wells-tagged Sockeye was 51.8% compared to 58.5% for Sockeye tagged at Bonneville that were detected at Wells Dam.

[17] Among Sockeye tagged at Bonneville Dam, none of the 319 Sockeye tagged prior to June 18 were detected at Zosel Dam.

Table 29. Number of Wells Dam sampled and tagged Sockeye released at the Wells Dam East Bank Fish ladder in 2018 with the estimated percentage last detected by site by week (weighted by the Wells weekly run size). Rates for adults tagged at Bonneville Dam and detected at Wells Dam are shown for comparison.

			Site of Last Detection (Downstream to Upstream)														Wells Tagged	BON Tagged
Week Tagged at Wells Dam	% of Total Sockeye Run Past Wells Dam	N	Rock Island	Wenatchee Basin	East Bank Hatchery	Rocky Reach Dam	Entiat River	Wells Dam	Wells Hatchery	Methow River	OKL Array	Okanagan Tributaries (US)	Zosel Dam (ZSL)	OKC Array	Skaha Dam (SKA)	OKP/OKS	Spawning Grounds (OKC, SKA, OKP, OKS)	
25	0.6																	78.9%
26	10.4	49	0.0%	0.0%	0.0%	2.0%	0.0%	10.2%	0.0%	0.0%	10.2%	0.0%	2.0%	44.9%	6.1%	24.5%	75.5%	77.2%
27	28.7	96	0.0%	1.0%	1.0%	0.0%	0.0%	22.9%	1.0%	0.0%	12.5%	0.0%	2.1%	33.3%	3.1%	22.9%	59.4%	74.0%
28	34.0	274	0.0%	2.2%	0.4%	0.7%	0.4%	41.6%	0.0%	0.0%	2.9%	0.7%	5.5%	28.8%	0.7%	16.1%	45.6%	50.0%
29	17.7	240	0.0%	1.7%	0.0%	1.3%	0.8%	43.8%	0.0%	0.4%	0.8%	0.0%	7.1%	26.7%	2.1%	15.4%	44.2%	43.6%
30	6.0	106	0.0%	1.9%	1.9%	1.9%	3.8%	43.4%	0.0%	0.9%	0.9%	0.0%	8.5%	24.5%	0.9%	11.3%	36.8%	43.7%
31	1.6	23	4.3%	0.0%	0.0%	0.0%	0.0%	39.1%	0.0%	0.0%	13.0%	0.0%	8.7%	17.4%	4.3%	13.0%	34.8%	48.2%
32	0.6																	68.0%
33	0.2																	100.0%
34	0.2																	0.0%
Weighted Total		**788**	**0.1%**	**1.5%**	**0.5%**	**0.8%**	**0.5%**	**33.2%**	**0.3%**	**0.1%**	**6.2%**	**0.2%**	**4.7%**	**31.0%**	**2.4%**	**18.5%**	**51.8%**	
Bonneville Tagged Sockeye Detected at Wells		**1296**	**0.0%**	**0.1%**	**0.0%**	**0.2%**	**0.0%**	**30.9%**	**0.0%**	**0.0%**	**6.1%**	**0.1%**	**3.9%**	**40.8%**	**2.9%**	**14.9%**		**58.5%**

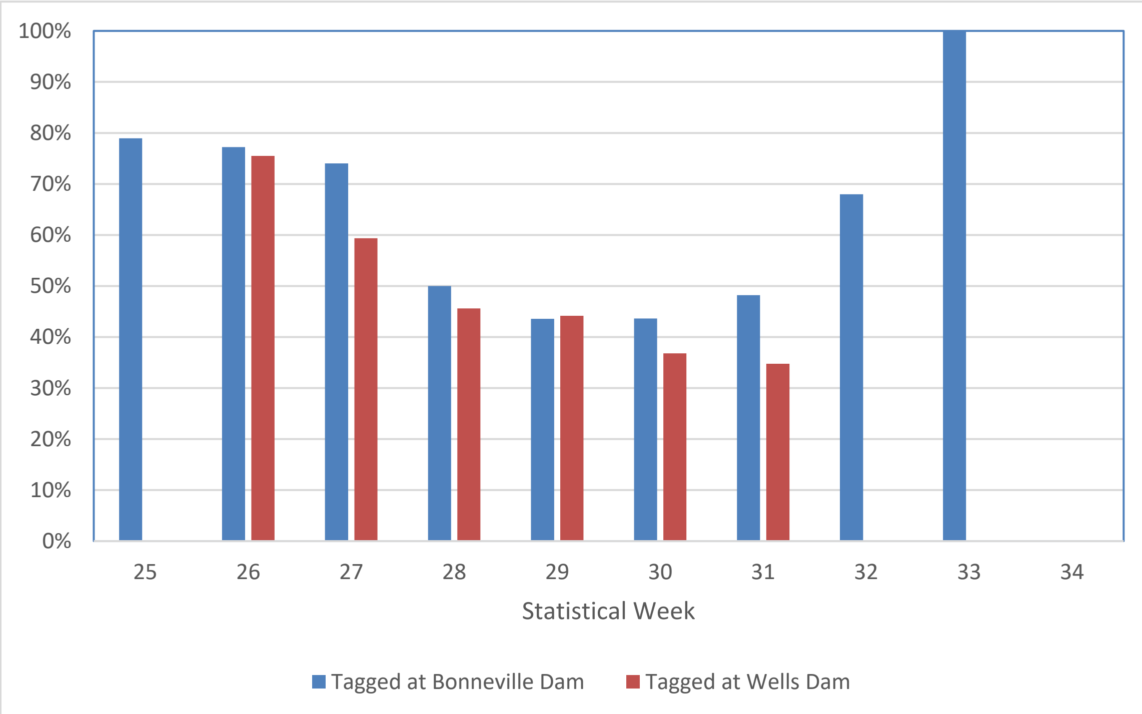

Figure 7. Percentage of Sockeye Salmon tagged at Bonneville and Wells dams last detected on Okanagan River spawning grounds (at or upstream of OKC) by week passing Wells Dam in 2018. (Note that although two Bonneville tagged Sockeye passed Wells Dam in Week 34, none were detected at or upstream of OKC.)

In 2018, most Sockeye Salmon entered the Okanagan River either prior to temperatures exceeding approximately 22°C or on temperature drops during periods after temperatures exceeded 22°C (Figure 8, Table 30). Sockeye Salmon detected at OKL were arbitrarily divided into five groups based on passage date at OKL separated by periods of little or no passage or a large change in numbers of Sockeye passing (Table 30). The groups with the highest conversion rate to OKC from OKL either passed at the very beginning of the run (76.6%) or end of the run (81.0%). The small group of Sockeye that attempted to migrate up the Okanagan River during the small dip in temperatures that occurred from 25.4°C on 8/1 to 23.3°C on 8/5 had the lowest conversion rate at 41.7%.

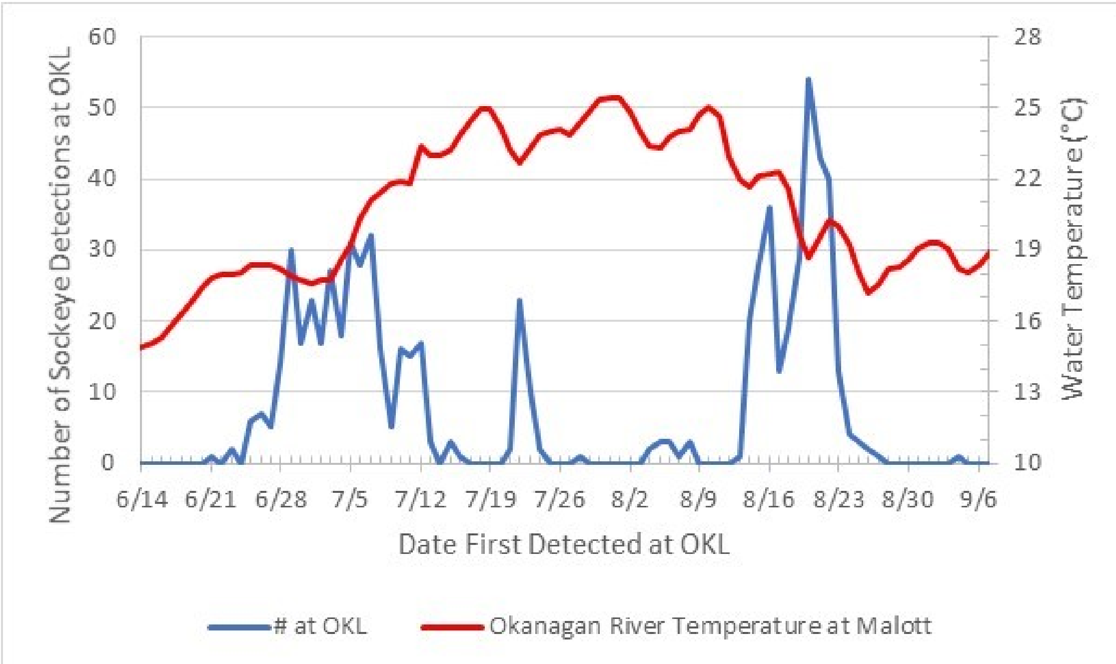

Figure 8. Number of PIT tagged adult Sockeye detected at OKL and Okanagan River water temperatures by date in 2018.

Table 30. Groups of PIT tagged Sockeye passing OKL and percent detected upstream at OKC by date at passing OKL in 2018.

Dates	N at OKL	% Detected at OKC	Description
6/21-7/4	167	76.6%	Early run, prior to temperatures exceeding 19C
7/5-7/16	167	70.5%	Period of rising temperatures from 19.2 to 23.9C
7/21-7/28	38	71.1%	Sockeye passing on a dip from 25.0 to 22.7C
8/4-8/8	12	41.7%	Sockeye passing on a dip from 24.0 to 23.3C
8/13-8/27	306	81.0%	End of run, temperatures drop from 22.1C
All	**724**	**76.9%**	

Migration into Natal Areas-Wenatchee River

In 2018, high flows resulted in the highest rate of missed PIT-tagged Sockeye Salmon at the lower Wenatchee PIT array (LWE, Figure 9) in the past five years (Table 2). Of the 98 Sockeye PIT tagged by this study and then detected upstream of LWE (all of which were detected at Tumwater Dam, TUF), only 31 were detected at LWE. Five fish detected at LWE were not detected at Tumwater Dam (Table 31) and are assumed to have died in the lower river, resulting in an estimated survival rate from LWE to Tumwater Dam of 86.1% 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). No Sockeye strayed into any of the Wenatchee River tributaries in 2018 (Figure 9).

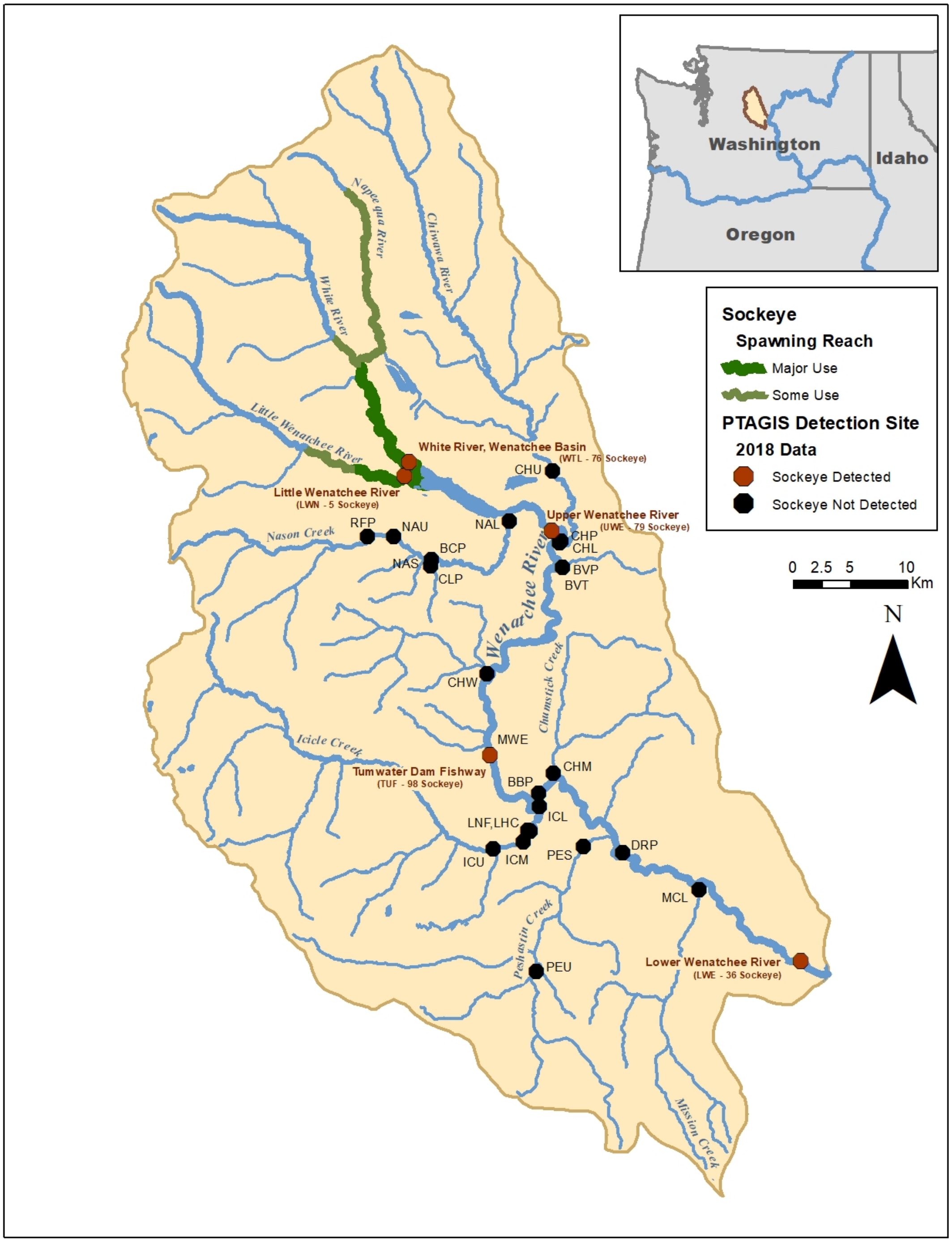

Figure 9. The Wenatchee Basin showing PIT tag interrogation sites and highlights the sites where Sockeye were detected in 2018. Also displayed is the spawning area of Sockeye. Appendix B, Table B1 has site information.

Table 31. 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 2018.

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	2	13.2	100.0	16.0	143.2
27	6	14.6	100.0	10.4	95.6
28	9	17.0	88.9	7.5	83.7
29	9	19.1	77.8	7.5	65.5
30	5	20.0	100.0	8.6	42.6
31	4	20.7	50.0	7.7	34.7
32	1	21.4	100.0	6.7	25.3
Unweighted Total	**36**[18]		**86.1**	**8.4**	

Of the Bonneville-tagged Sockeye tagged by this project detected at Tumwater Dam, 82.7% were detected by spawning ground PIT arrays at LWN and WTL (Table 32). Of these fish, 93.8% were last detected in the White River and 6.2% were last detected in the Little Wenatchee River. The preponderance of Sockeye on the White River compared to the Little Wenatchee River was similar for Sockeye tagged by WDFW as adults at Tumwater Dam as well as returning adults from Sockeye tagged as juveniles at Rock Island Dam and in the Wenatchee River (Table 33).

Table 32. Distribution of Sockeye Salmon tagged as adults at Bonneville and Tumwater dams as well as returning adults tagged as juveniles at Rock Island Dam and in the Wenatchee River detected at Tumwater Dam on the Wenatchee River Spawning grounds in 2018.

Tagging Location	Life Stage at Tagging	Number Detected or Tagged at Tumwater Dam	Percentage Detected on Spawning Grounds	Spawning Ground Distribution (Last Detection)	
				Little Wenatchee (LWN)	White River (WTL)
Bonneville AFF	Adult	98	82.7%	6.2%	93.8%
Tumwater Dam adult ladder	Adult	425	78.8%	7.8%	92.2%
Rock Island Juvenile Bypass	Juvenile	8	87.5%	14.3%	85.7%
Wenatchee River	Juvenile	4	100.0%	0.0%	100.0%

[18] An additional 67 Sockeye Salmon were not detected at LWE but detected upstream in 2018.

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

PIT Tag Location	Hatchery/ Wild	Life Stage at Tagging	Number at Tumwater Dam	Percent of Sockeye Detected at Tumwater Dam Detected Upstream: Little Wenatchee (LWN)	White River (WTL)	Total on Spawning Grounds (LWN and WTL)
Wenatchee River	Wild	Juvenile	4	0.0	100.0	100.0
Rock Island Dam	Mixed	Juvenile	8	12.5	75.0	87.5
Bonneville AFF (Wenatchee stock)	Mixed	Adult	98	5.1	77.6	82.7
Tumwater Dam	Mixed	Adult	429	6.7	72.1	78.1

2018 Okanagan Basin Juvenile PIT Tagging

In 2018, a total of 10,943 Sockeye smolts were captured, PIT tagged, and released between April 16 and May 9, 2018, at the Osoyoos Lake North Basin (OSOYOL), Osoyoos Lake Central Basin (OSOYHA), and Skaha Lake (SKAHAL) (Table 34). Sockeye captured and tagged at Skaha Lake were larger than those at Osoyoos Lake (Table 34, Figure 10).

Table 34. Summary of Okanagan Sockeye smolt PIT tagging effort in 2018.

	Number of PIT Tagged Sockeye Released (with Capture Method)			
	OSOYOL	OSOYHA	SKAHAL	
Date	Mid-Lake Trawl	Mid-Lake Trawl	Mid-Lake Trawl	Total
16-Apr-18	1236			1236
17-Apr-18	285			285
18-Apr-18		1358		1358
02-May-18		2204	225	2429
03-May-18			472	472
04-May-18			2606	2606
05-May-18			395	395
07-May-18			631	631
08-May-18			1349	1349
09-May-18			182	182
Total	**1521**	**3562**	**5860**	**10,943**
Mean Fork Length at Tagging (mm)	**85.2**	**87.6**	**96.6**	**92.1**

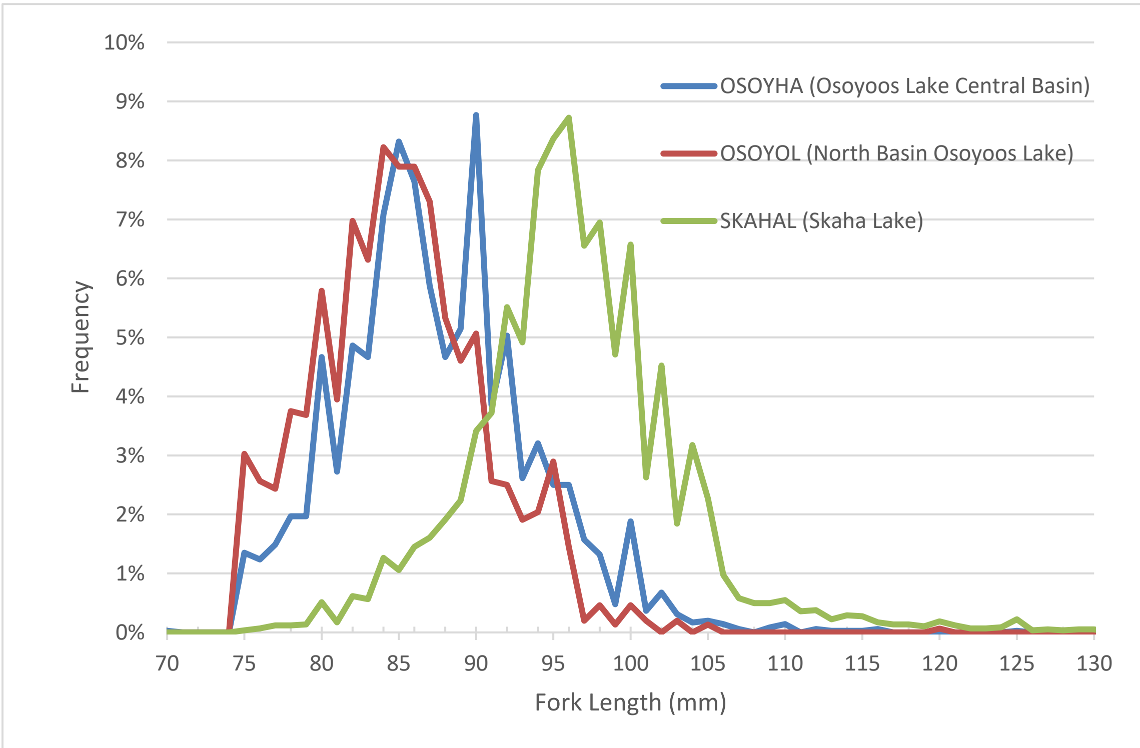

Figure 10. Length frequency for Sockeye PIT tagged as juveniles in Osoyoos and Skaha lakes in 2018.

Downstream survival estimates were calculated for all release groups. In 2018, 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 2018[19].

Release Site (individual or pooled)	Release (n)	Release-Rocky Reach		Rocky Reach-McNary		McNary-John Day		John Day-Bonneville		Release-Bonneville	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
OSOYOL	1,521	0.588	0.063	0.599	0.144	1.096	0.628	0.521	0.540	0.201	0.179
OSOYHA	3,562	0.691	0.039	0.887	0.140	0.921	0.352	1.329	1.020	0.750	0.511
SKAHAL	5,860	0.576	0.036	0.913	0.132	1.041	0.264	0.632	0.275	0.346	0.130
	Below are Summaries of the Data Above										
Osoyoos Lake (OSOYHA +OSOYOL)	5,183	0.659	0.033	0.801	0.105	0.962	0.306	1.101	0.687	0.559	0.308
Combined Okanagan	10,943	0.617	0.024	0.870	0.085	0.988	0.194	0.785	0.281	0.417	0.130

Survival to downstream points was also estimated for other groups of PIT tagged Columbia Basin Sockeye Salmon that out-migrated in 2018. These included a group of 1,063 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 50,000 juvenile Snake River Sockeye tagged at traps and hatcheries the Snake Basin. Survival of the Rock Island releases to McNary Dam was significantly higher than that of the combined Okanagan releases ($p=0.05$), (Table 36, Figure 11). Snake River releases had lower survival to McNary Dam than did those Sockeye tagged in the Okanagan, Wenatchee, and at Rock Island Dam, likely at least in part attributable to the longer migration route to McNary Dam. High standard errors make it difficult to assess differences in survival to points downstream of McNary Dam.

Table 36. Mean survival estimates for juvenile Sockeye released in the Okanagan and Wenatchee basins, the Snake Basin, and Rock Island Dam in 2018[20].

Capture Group	Release- McNary		McNary-John Day		John Day-Bonneville		Release-Bonneville	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Osoyoos Lake	0.528	0.065	0.962	0.306	1.101	0.687	0.559	0.308
Skaha Lake	0.526	0.069	1.041	0.264	0.632	0.275	0.346	0.130
Combined Okanagan	0.537	0.048	0.988	0.194	0.782	0.281	0.417	0.130
Wenatchee	0.638	0.055	0.630	0.102	0.771	0.274	0.310	0.102
Rock Island	0.921	0.116	0.958	0.246	0.402	0.170	0.355	0.128
Snake	0.300	0.036	1.007	0.117	1.848	0.307	0.559	0.082

[19] Estimates were compiled September 3, 2019 using www.cbr.washington.edu/dart/query/pit_sum_tagfiles.
[20] Estimates were compiled September 3, 2019 using www.cbr.washington.edu/dart/query/pit_sum_tagfiles.

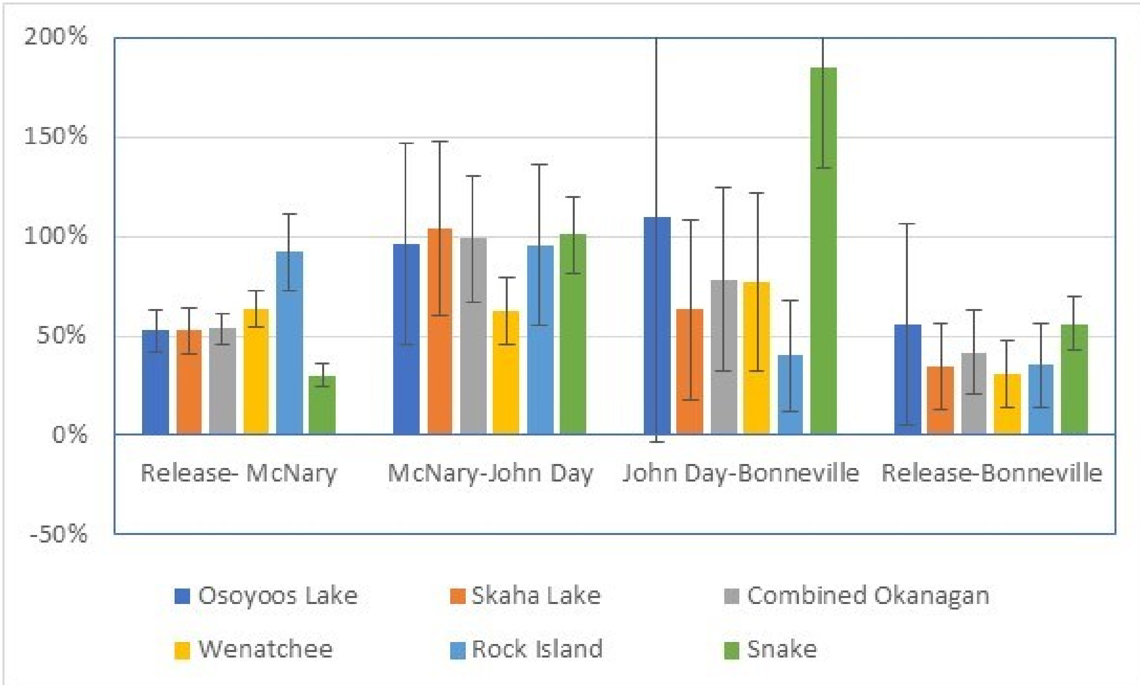

Figure 11. Survival of juvenile Sockeye PIT tagged in the Okanagan, Wenatchee, and Snake basins as well as at Rock Island Dam to McNary, John Day, and Bonneville dams with 90% confidence intervals in 2018.

Travel times to downstream detection locations were also compiled for 2018 smolts (Table 37). Sockeye tagged at Osoyoos Lake (OSOYOL and OSOYHA) had slower migration times downstream through John Day, but similar travel times to Bonneville Dam when compared to Skaha Lake releases. The combined Okanagan group took the longest time to McNary Dam, on average 7.8 days more than Wenatchee-tagged Sockeye Salmon, 1.8 days greater than Snake River-tagged Sockeye, and 12.7 days greater than Rock Island tagged juvenile Sockeye Salmon (Table 37).

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 2018 can be found in Appendix D.

Table 37. Mean travel time from release to downstream sites for Sockeye tagged in the Okanagan, Wenatchee, and Snake basins as well as at Rock Island Dam in 2018. (Estimated using http://www.cbr.washington.edu/dart/query/pit_sum_tagfiles on October 28, 2019.)

Release Site	Statistic	Mean Travel Time from Release to:					
		Zosel	Rocky Reach	McNary	John Day	Bonneville	Estuary Trawl
OSOYOL	Mean	22.4	21.3	25.7	26.7	29.3	33.0
	SE	3.3	0.3	0.6	0.8	0.7	1.8
OSOYHA	Mean	15.3	19.1	22.7	24.8	26.4	29.2
	SE	1.8	0.2	0.2	0.5	0.4	1.0
Combined Osoyoos Lake	Mean	15.3	19.1	22.8	24.8	26.0	29.2
	SE	1.8	0.2	0.2	0.5	0.4	1.0
Skaha Lake (SKAHAL)	Mean	10.9	12.5	14.0	16.9	25.6	25.0
	SE	0.7	1.1	0.2	1.9	3.3	7.9
Combined Okanagan	Mean	12.9	16.4	19.0	19.6	26.0	26.9
	SE	0.9	0.5	0.2	1.3	1.8	4.3
Wenatchee	Mean			12.2	18.8	21.1	24.7
	SE			0.2	0.3	0.4	0.8
Rock Island	Mean			6.3	10.0	9.0	11.0
	SE			0.2	0.4	0.4	1.1
Snake	Mean			17.2	18.3	16.8	15.2
	SE			0.2	0.2	0.1	0.2

Side-scan Sonar

A side-scan acoustic survey was conducted at Okanagan Lake in October 2018. An ultra-high resolution EdgeTech 4125 side-scan sonar was tested along the eastern shore of Okanagan Lake to assess its potential use for locating aggregations of kokanee (and future referencing for reintroduced Sockeye spawners). Methods and results are found in Appendix E.

Lake Wenatchee Acoustic Trawl and Limnology Surveys

Two multi-year reports funded in part by this project are included as Appendices F (Lake Wenatchee and Osoyoos Lake Juvenile Sockeye Salmon and Limnology Comparison Brood Years 2009-2016) and G (Lake Wenatchee juvenile Sockeye Salmon and limnology status report Brood Years 2009-2017 (in-lake 2010-2018)).

DISCUSSION

This report covers 2018, which was the 10th year of this Accords study and the 13th year we have been PIT tagging Sockeye Salmon at Bonneville Dam.

After the abnormally high temperature year of 2015, which resulted in high mortality (Fryer et al. 2017), temperatures and survival have returned to more typical levels in recent years (Table 4, Figure 12). Survival to Priest Rapids Dam estimated by this study was 85.4% in 2018 compared to 85.3% in 2016, 74.6% in 2017, and 44.9% in 2015 with a mean of 77.8% for 2006-2018[21]. River temperatures were generally at, to slightly above, the 2005-2014 baseline (Figure 12), though well under 2015 levels until late July.

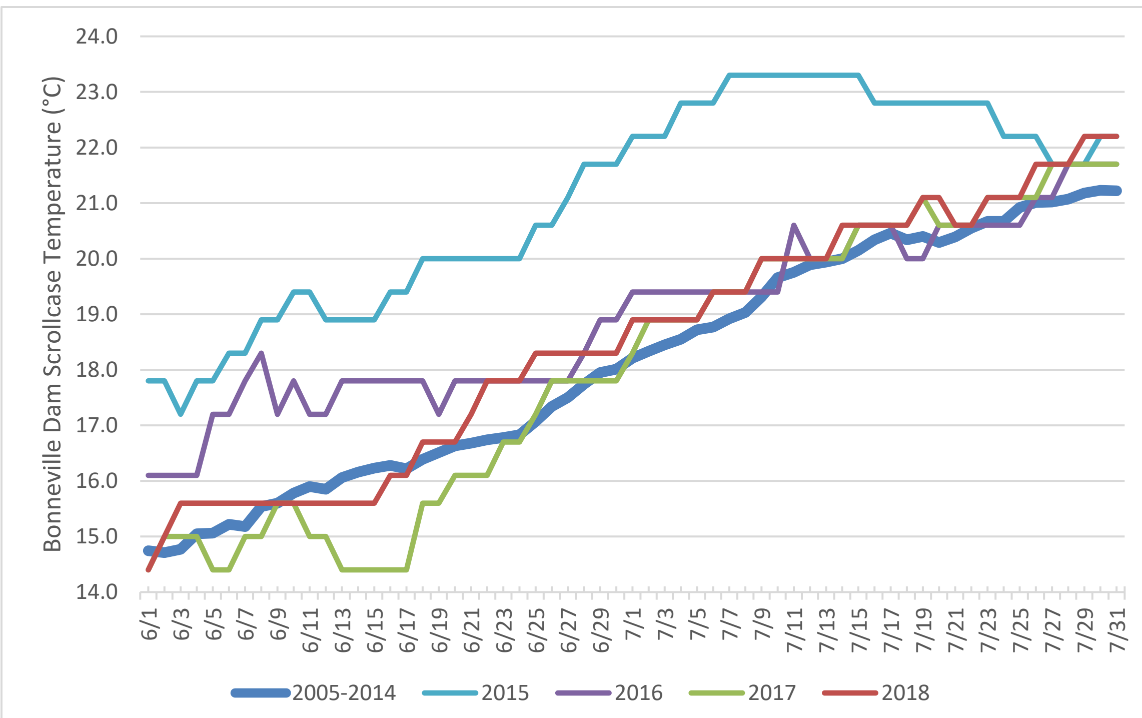

Figure 12. Mean daily water temperature at Bonneville Dam during the months of June and July in the years 2015-2018 with the mean 2005-2014 temperature.

Columbia River flows encountered by Sockeye migrating in 2018 were the fourth lowest over the years 2006-2018 during which we have been PIT tagging Sockeye Salmon at Bonneville Dam (as measured by the mean flow between June 16 and July 15 at Bonneville Dam) (Figure 13). The mean travel time of 4.8 days

[21] Sockeye were tagged at Bonneville Dam in 2006-2008 as part of a Pacific Salmon Commission-funded project.

from Bonneville to McNary Dam was the second shortest in the 13 years we have been 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 14). Similarly, the mean time from McNary to Priest Rapids of 4.1 days was the fourth shortest and the time from Priest Rapids to Rock Island of 2.9 days was the 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 ($p<0.01$, Figure 15).

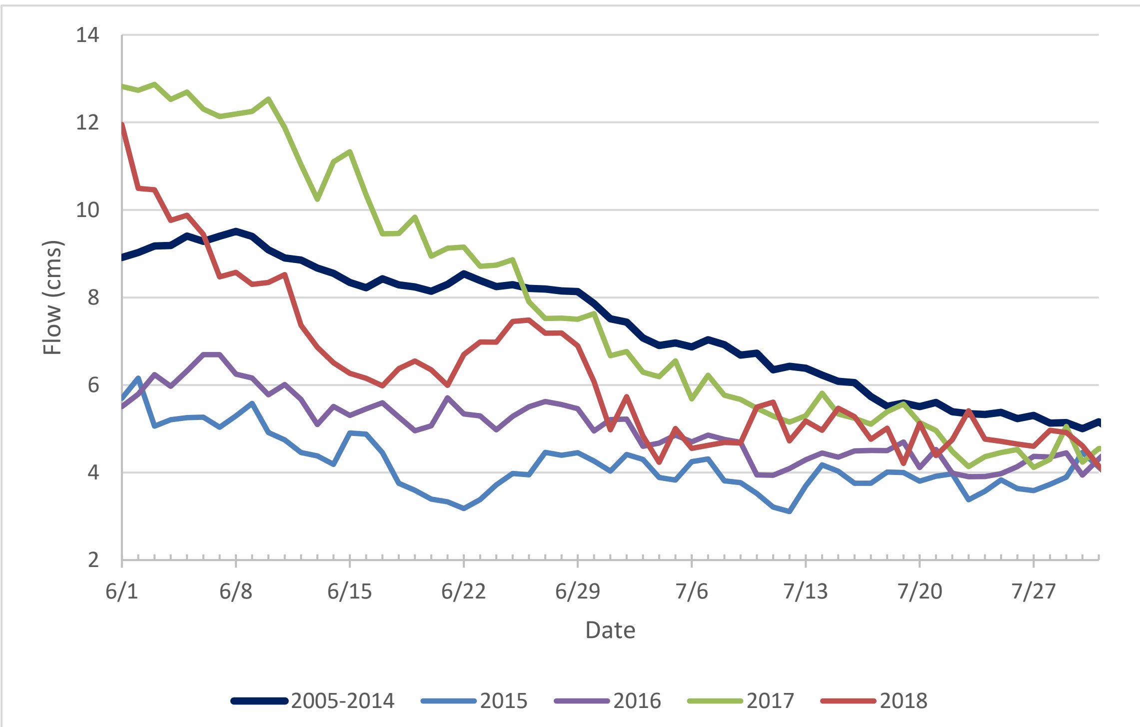

Figure 13. Mean daily flow at Bonneville Dam during the months of June-August in the years 2015-2018 with the mean 2005-2014 flow for comparison.

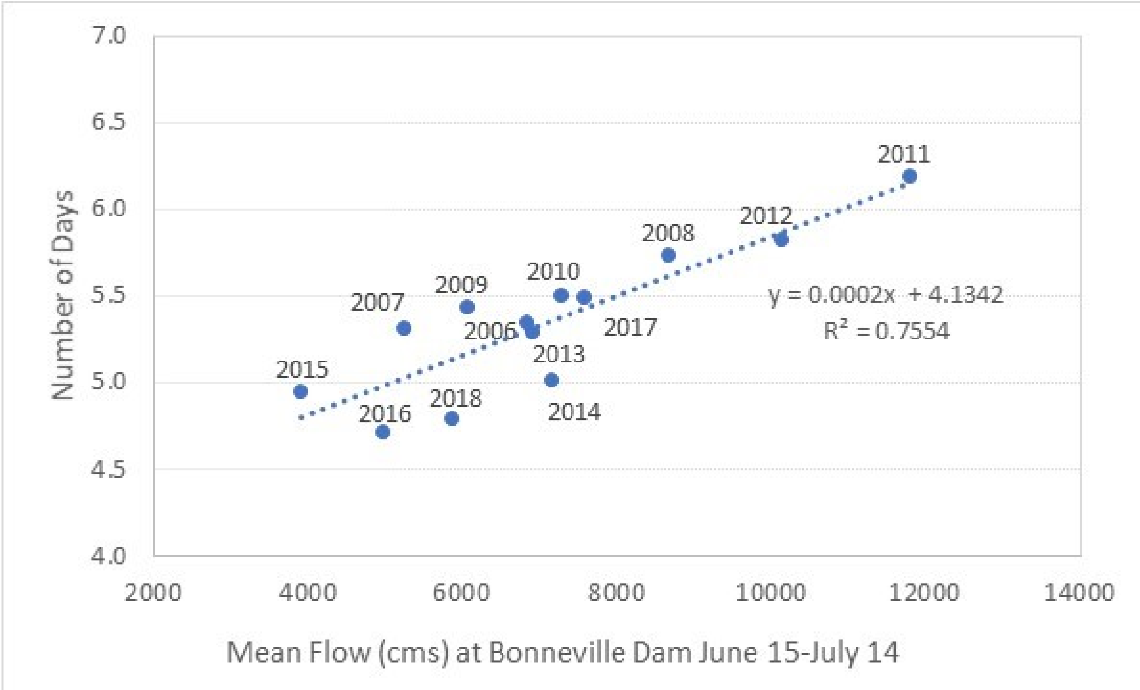

Figure 15. Relationship between mean annual Sockeye Salmon travel time for Sockeye PIT tagged at Bonneville Dam from Bonneville to McNary Dam and mean annual June 15-July 14 flow at Bonneville Dam for migration years 2006-2018.

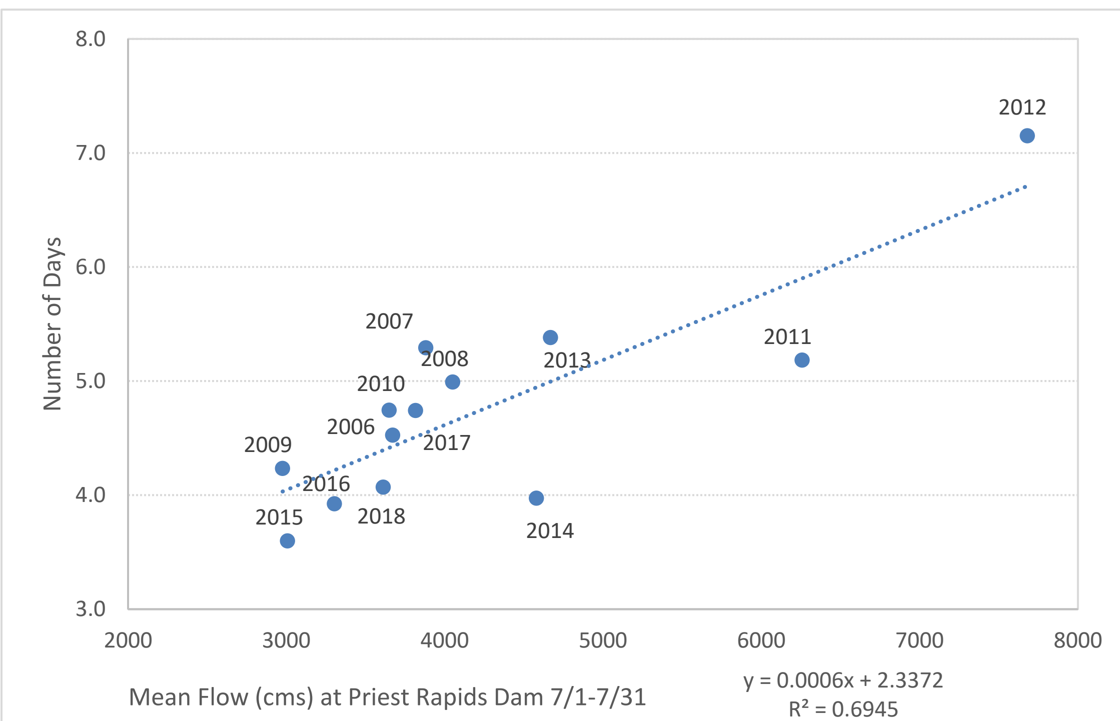

Figure 14. Relationship between mean annual Sockeye Salmon travel time for Sockeye PIT tagged at Bonneville Dam from McNary to Priest Rapids Dam and mean annual July flow at Priest Rapids Dam for migration years 2006-2018.

In 2018, there were 103 Wenatchee stock Sockeye (as identified by GSI) tagged by this project last detected in the Wenatchee Basin with two (2.0%) overshooting the Wenatchee River, one of which was last detected at Rocky Reach Dam and the other at Wells Dam. Of the 103 Wenatchee stock Sockeye last detected in the Wenatchee Basin, there were three that also overshot the Wenatchee River and passed Rocky Reach Dam, with one also passing Wells Dam. These three Sockeye then migrated back downstream in the Columbia River, entering the Wenatchee River and being detected at Tumwater Dam. No Okanagan stock Sockeye Salmon were detected in the Wenatchee River in 2018. The total number of Wenatchee Sockeye detected at Wells Dam was two, compared to 1,289 Okanagan stock Sockeye detected at Wells Dam, or 0.16%. In contrast, of the 805 Sockeye this project sampled and tagged at Wells Dam, 17 (or 2.1%) were Wenatchee stock Sockeye Salmon. We have noted a higher percentage of Wenatchee Sockeye Salmon in our Wells sample than in those Bonneville-tagged Sockeye passing Wells Dam in other years as well. For example, Bonneville-tagged Sockeye detected at Wells Dam were 1.8% Wenatchee stock in 2016, while Sockeye trapped at Wells Dam were estimated to be 10.3% Wenatchee stock (Fryer et al. 2018). On the other hand, in 2017, Bonneville tagged Sockeye passing Wells Dam were 1.2% Wenatchee stock, which was the same as those trapped at Wells Dam. The reason for the increased percentage of Wenatchee Sockeye in our sample collected at Wells Dam compared with Bonneville-tagged Sockeye passing Wells Dam is unknown.

This project has been funding, in collaboration with Grant and Chelan Public Utility Districts, 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 for tagging by this method in 2018 (Table 38). 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. However, this does not appear to be the case as the percentage of juveniles detected migrating downstream the year after tagging has not exceeded 1.1%, while the

percentage not migrating downstream at all and being detected upstream has not exceeded 0.4% since this project began in 2013 (Table 39).

Table 38. Number and percentage of Sockeye Salmon captured in the Okanagan Basin by gear type 2013-2018.

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	75.7	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
Total	**12,778**	**10,217**	**16,978**	**8,198**	**26.5**	**21.2**	**52.3**

Table 39. 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 detected upstream (kokanee) for release years 2013-2018.

Release Year	Same Year Downstream Detections	Following year Downstream Detections		Only Upstream Detections (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	8	0.3		0.0	2,924
Total	**13,572**	**55**	**0.4**	**25**	**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 at Zosel Dam, which detected 31 out-migrating smolt (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. If this had happened, we would have lost the antennas. High flows in 2017 resulted in the decision not to deploy the antennas. In 2018, despite the forecast high flows, we deployed one antenna on April 25 with a new mounting system designed by Biomark (Figure 16). Since the installation occurred after the tagging and release of 2,879 juvenile Sockeye (26.3% of the total releases, Table 34) it would be expected that these fish could have already passed downstream and

were undetected. Of the 32 juvenile Sockeye detected at Zosel Dam in 2018, 14 were detected by the floating antenna with the remaining 18 detected in the ladders. The system was challenged by high flows (Figure 18) as Osoyoos Lake water levels reached an elevation of 916.4 feet on May 12, far above the 912-foot maximum elevation for which the lake is managed. As the water level increased, flow through the dam came to a virtual stop as water backed up from the Similkameen, which joins the Okanagan a short distance downstream. The antenna rigging forced the antenna underwater where it would have been highly vulnerable to debris, thus it was raised out of the water from May 18 through June 7 (Figure 17). However, two juvenile Sockeye were detected despite the antenna being out of the water.

Figure 16. Floating PIT tag antenna at Zosel Dam spillway with old rigging (left) installed in 2015 and the replacement new rigging (right), installed in 2018.

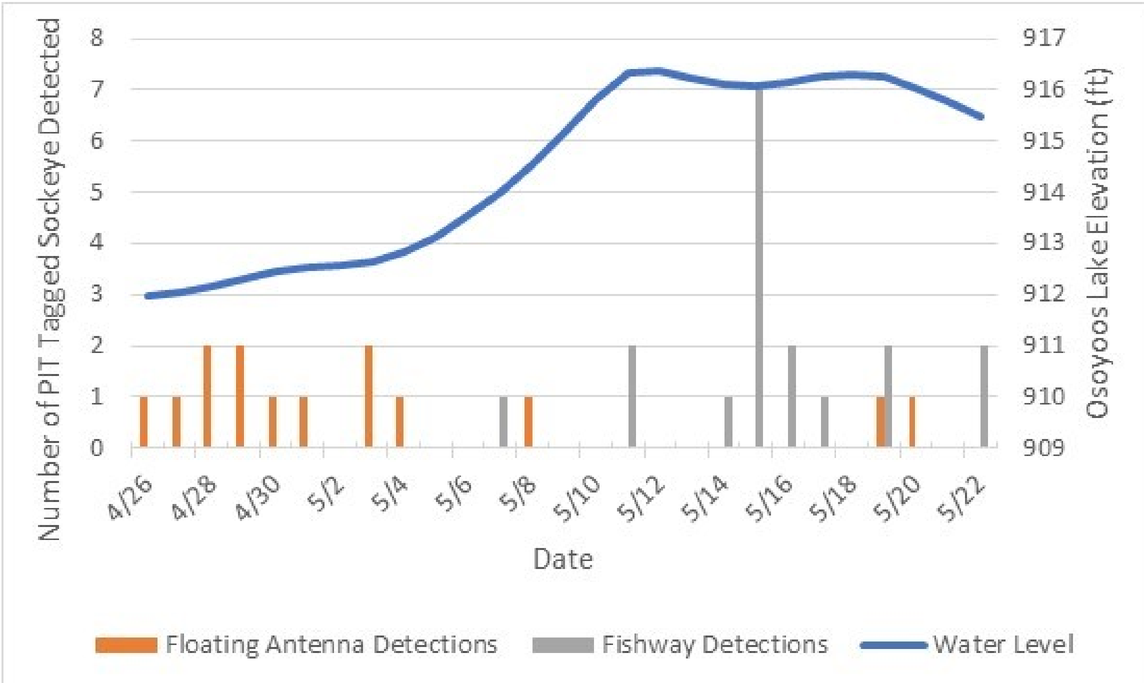

Figure 18. Relationship between Zosel detections by date of juvenile Sockeye PIT tagged in Osoyoos and Skaha lakes in 2018 and Osoyoos Lake water level. The floating antenna was installed April 25, 2018, but raised out of the water May 18 through June 7.

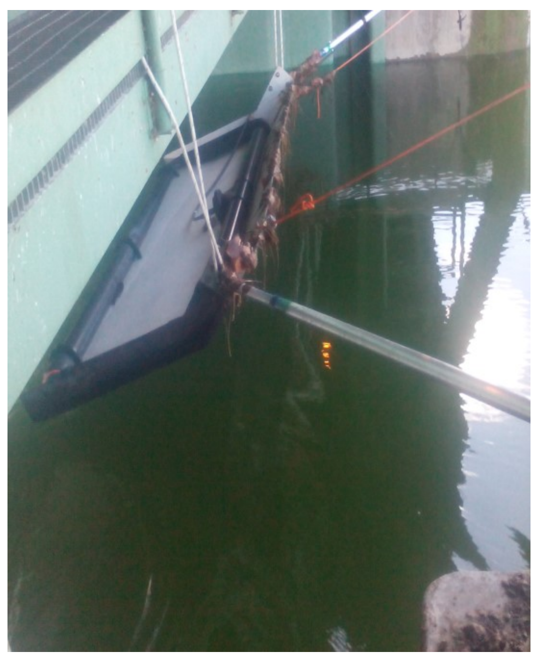

Figure 17. Submerged antenna at Zosel Dam on May 28, 2018 (left) and the antenna after it was lifted out of the water (right).

As reported in our 2017 report, the OKC site had a second array added on March 16, 2017, but performance has been hampered by a “ghost tag” from 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 the new antenna on May 11, 2017, and started generating near-constant detections, which significantly degraded the performance of Antenna 2 in the new array. High flows made it difficult to try to remove the tag in 2018 until the fall[22]. 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.

Based on upstream detections at our Skaha Dam fish ladder site, the detection efficiency of OKC for Sockeye in 2018 was 94.0% (Appendix A, Table A5). Detection efficiency of the older downstream array was 91.0%, while detection efficiency of the newer upstream array (but the array with the ghost tag) was 54.2%. Detection efficiency at SKA in 2018 was 96.2% (Appendix A, Table A5).

Unlike previous years, no PIT tags from adults tagged by this study at Bonneville Dam in 2018 were found on avian colonies. The PIT tags from 24 juvenile Sockeye tagged at Skaha and Osoyoos lakes in 2018 were detected at two different colonies compared to 61 detections in 2017 and 106 detections in 2016 (Figure 19). Three adult Sockeye PIT tagged by this study at Bonneville Dam were recovered in tribal fisheries between Bonneville and John Day dams in 2018 (Figure 1).

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

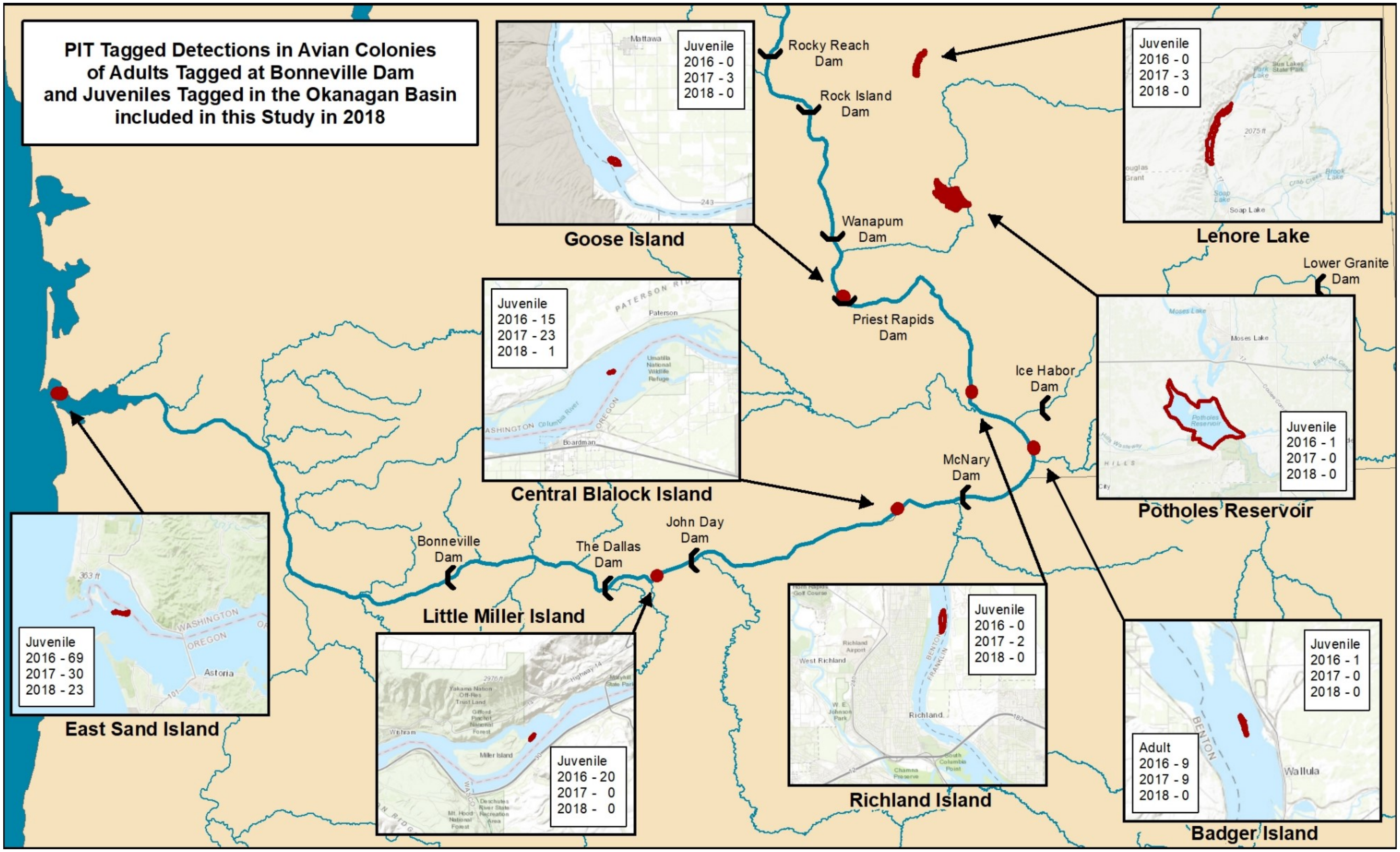

Figure 19. Detections at avian colonies in of Sockeye Salmon PIT tagged by this project in 2016-2018.

The percentage of Sockeye sampled at Bonneville Dam missing PIT tag detection at mainstem dams was 1.0% or less for all dams except Rock Island (28.3%), McNary (2.9%), John Day (2.8%), and Bonneville (1.1%) dams (Table 2). At Bonneville, John Day, and McNary dams (in addition to The Dalles and the Snake River dams), it is possible that Sockeye are using the navigation locks. Rock Island Dam is known for having lower rates of detection than other mainstem dams due to electrical interference (Fryer et al. 2011A) at the antennas.

Minimum fallback rates at Columbia River mainstem dams (Table 13) in 2018 of adult Sockeye sampled at Bonneville Dam as part of this study ranged from 0.1% at Bonneville Dam to 4.5% at John Day Dam. For Sockeye tagged as juveniles, the Snake Basin tagged fish had the highest fallback rates at John Day (16.7%) and 20% at Ice Harbor and Lower Monumental compared to other juveniles tagged at other locations, though sample sizes were small for this 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. We had good PIT tag detection at Zosel Dam in 2016, but in 2017 and 2018 over 50% of the run passed through the spillways at Zosel Dam. Of the Bonneville-tagged Sockeye Salmon passing Wells Dam in 2017 and 2018, only 45.2% were detected at OKC in 2017 and 58.5% in 2018. It is unknown what portion of this mortality may have been associated with migration conditions downstream of Zosel Dam or in Osoyoos Lake. We would like to improve PIT tag detection at, or near, Zosel Dam to improve our understanding of adult survival to this point at high flows when Sockeye Salmon do not use the fish ladders.

We have had two focal areas for improved PIT tag detection. The first is Zosel Dam. In 2019 and 2020 we continue to work on upgrading the detection system at Zosel by upgrading floating antennas and the electronics. Both should increase the detection range of the floating antennas, possibly resulting in detection of adults moving through the spillways. We will also continue

opportunities to collaborate with WDFW and the Confederated Colville Tribes on in-stream arrays in the area.

A second site for improved PIT tag detection is the Highway 3 Bridge in Osoyoos between the north and central basins of Osoyoos Lake. The north basin is deep enough to provide a cold-water refuge for Sockeye Salmon and most Sockeye hold here prior to moving upstream to spawn in late September and early October. We did some testing of the use of a Dual Frequency IDentification SONar, or DIDSON, in 2017 and 2018 in this area, with a memo describing results in Appendix H. We hope to use information from these trials to determine where Sockeye migrate relative to the lake bottom and bridge abutments with the goal of using this data to design an antenna system for this site. Another option for this area, which is expected to be tested for smolt outmigration in 2020, is a PIT tag barge (Rundio et al. 2017).

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 during 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 may help answer this question.

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 project’s success. With passage into Okanagan Lake likely in 2020, we hope to continue to work with the ONA and DFO 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.., 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., 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.

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.

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

2018 Performance of Okanagan Basin PIT Tag Detection Infrastructure Funded by this Project

This project has funded installation of PIT tag antennas at five sites in the Okanagan Basin: fish ladders at Zosel Dam (ZSL, 2010) and Skaha Dam (SKA, 205), a spillway at McIntyre (OKM, 2015), and Skaha (SKA, 2015) dams and in-river arrays spanning the Okanagan River at Oliver, BC (OKC, 2009 with a second array in 2017) and Penticton (OKP, 2017) (Figure A1).

Zosel Dam

PIT Tag antennas were installed at both Zosel Dam fish ladders 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.

At Zosel Dam, PIT tags from 695 Sockeye, 19 steelhead, four Chinook, two Coho, and one White Sturgeon were detected between January 1, 2018, and December 31, 2018 (Table A1 and Figure A2). Among the Sockeye detections were 32 juveniles detected between April 26, 2018, and May 22, 2018, 18 of which were detected in Zosel fish ladders (16 east and two west) with the remaining 14 detected at a floating PIT tag antenna installed on April 25, 2018, immediately upstream of the east-most spillway (Figure A3). High flows resulted in the floating antenna being pulled partially out of the water from May 18 through June 7, although there were still two detections at the floating antenna during this period.

Sockeye Salmon tagged by CRITFC adult tagging projects at Bonneville and Wells dams comprised 2,664 or 91.5% of the Sockeye Salmon detected at Zosel Dam in 2018. Of these, 988 PIT tagged Sockeye were detected upstream of Zosel Dam, with only 414 (41.9%) also detected at Zosel Dam.

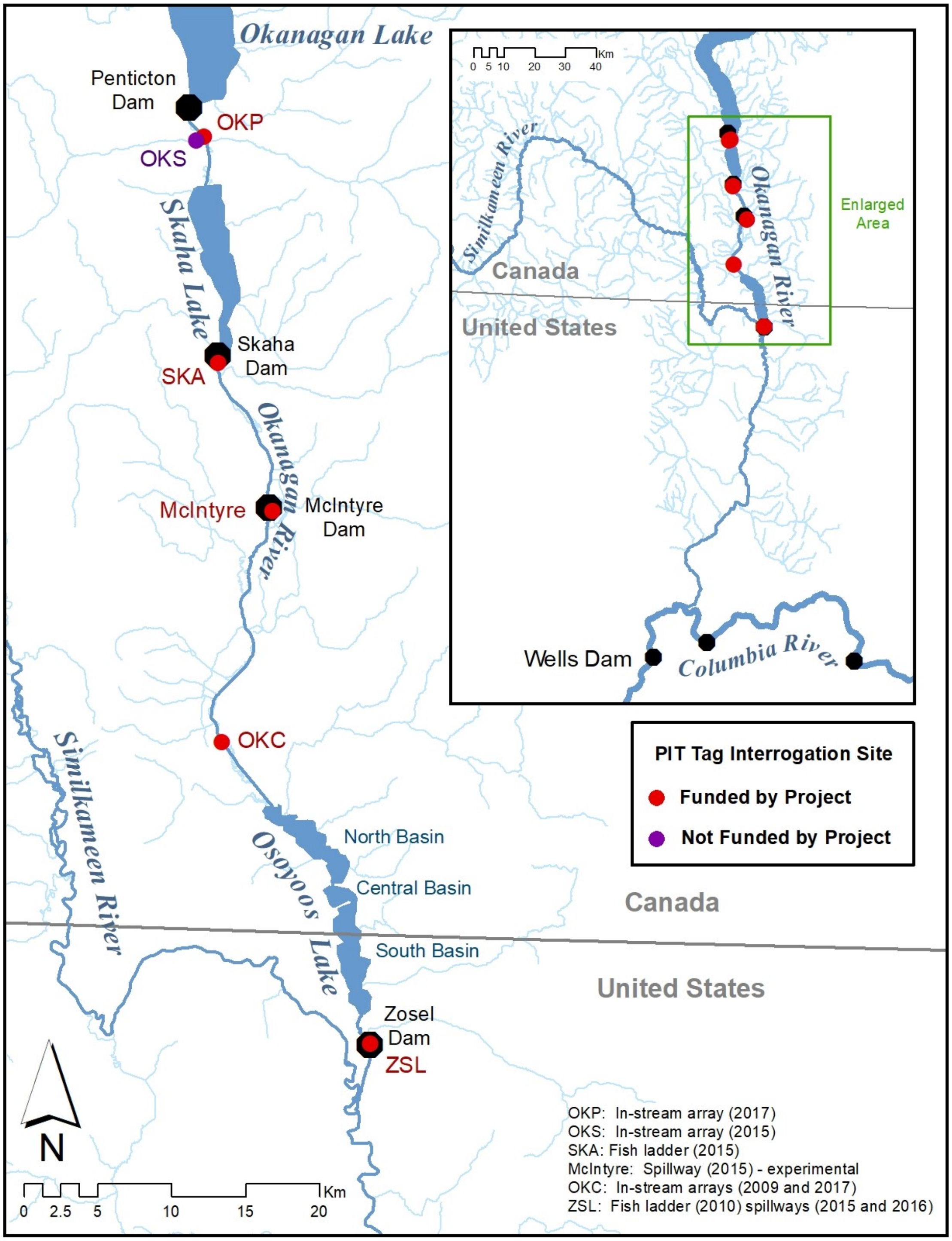

Figure A1. Map of the Okanagan River showing locations of PIT tag antennas funded by this project since its inception. Zosel, Skaha, and McIntyre dams, an in-river array immediately downstream of spawning areas at OKC and an in-river array immediately downstream of Penticton Channel spawning areas at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

Table A1. Number of PIT tagged Chinook, steelhead, and Sockeye detected at Zosel Dam ladders between January 1, 2018, and December 31, 2018, by release site and life stage at time of tagging.

Release Site	Life Stage at Release	Chinook	Coho	Sockeye Returning Adults	Sockeye Downstream Juveniles	Steelhead	White Sturgeon	Total
Bonneville Dam	Adult	1	0	370	0	1	0	372
Priest Rapids Dam	Adult	0	0	0	0	8	0	8
Wells Dam	Adult	1	0	283	0	1	0	285
Rock Island Dam	Juvenile	1	0	5	0	0	0	6
Wells Pool	Juvenile	0	0	0	0	0	1	1
Methow	Juvenile	0	2	0	0	0	0	2
Chief Joseph Hatchery	Juvenile	1	0	0	0	0	0	1
US Okanagan	Juvenile	0	0	0	0	9	0	9
Canadian Okanagan	Juvenile	0	0	5	32	0	0	37
Grand Total		4	2	663	32	19	1	721

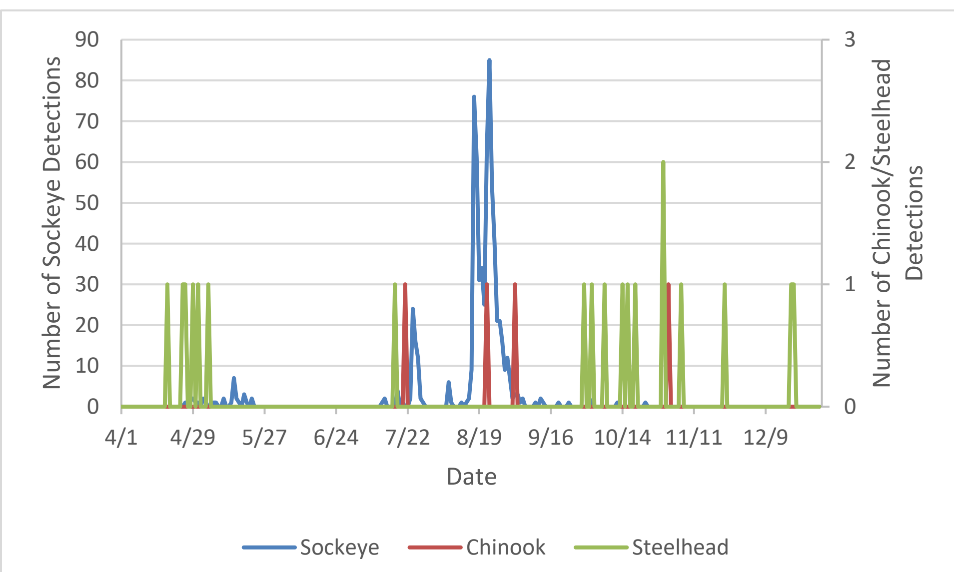

Figure A2. Number of PIT tagged Chinook, Steelhead, and Sockeye detected by date at Zosel Dam in 2018.

Figure A3. Zosel Dam showing a floating PIT tag array (top) and the number of Sockeye detected at each floating array and ladder in 2018 (bottom).

Okanagan Channel (OKC)

A total of 1,153 Sockeye Salmon, 33 Chinook Salmon and nine steelhead were detected at OKC in 2018 (Table A2). Of these fish, 13 Sockeye and five 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 2018. Of the adult Sockeye detected

at OKC, 17.3% passed in July, 17.8% in August, and the remainder in September and October, primarily after the water temperature dropped below 15°C (Figure A4). Sockeye passing OKC in July and August were primarily 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, 2018, and December 31, 2018, by release site and life stage at time of tagging.

Release Site	Life Stage at Release	Chinook	Sockeye Returning Adults	Sockeye Downstream Juveniles	Steelhead	Total
Bonneville Dam	Adult	3	730			733
Priest Rapids Dam	Adult				5	5
Rock Island Dam	Juvenile		12		1	13
Wells Dam	Adult	25	369		2	396
Methow	Juvenile	2				2
US Okanagan	Juvenile	2				2
Canadian Okanagan	Juvenile	1	42	13	1	57
Grand Total		**33**	**1153**	**13**	**9**	**1208**

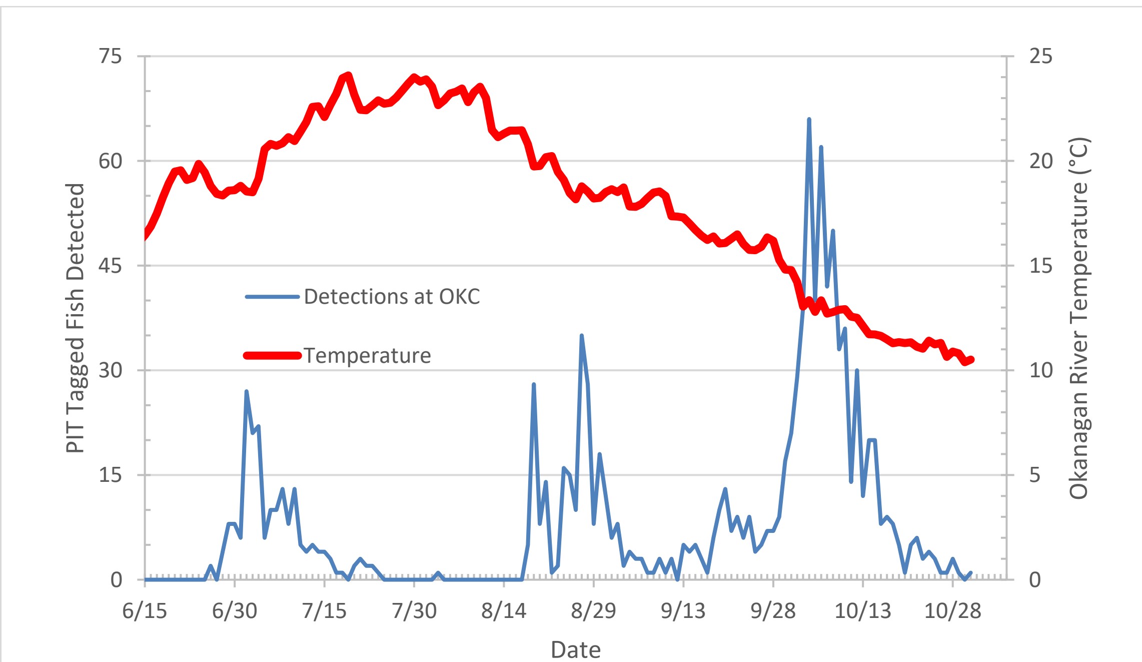

Figure A4. Number of PIT tagged Sockeye Salmon detected by date at OKC and mean daily Okanagan River water temperature at OKC between June 15 and October 31, 2018.

Skaha Dam (SKA)

Of the 398 salmon and steelhead detected at Skaha Dam[23] (SKA), 365 were Sockeye Salmon tagged at Wells or Bonneville dams by this study and an additional four were tagged as adults by the ONA (Table A3). A total of 22 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 20°C in late August through October (Figure A5).

Table A3. Number of PIT tagged Chinook, steelhead, and Sockeye detected at SKA between January 1, 2018, and December 31, 2018, by release site and life stage at time of tagging.

Release Site	Life Stage at Release	Chinook	Sockeye Returning Adults	Sockeye Downstream Juveniles	Steelhead	Total
Bonneville Dam	Adult	1	225			226
Rock Island Dam	Juvenile		9			9
Wells Dam	Adult	3	140		1	144
Canadian Okanagan	Juvenile		13		2	15
Canadian Okanagan-	Adult		4			4
Grand Total		**4**	**391**	**0**	**3**	**398**

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

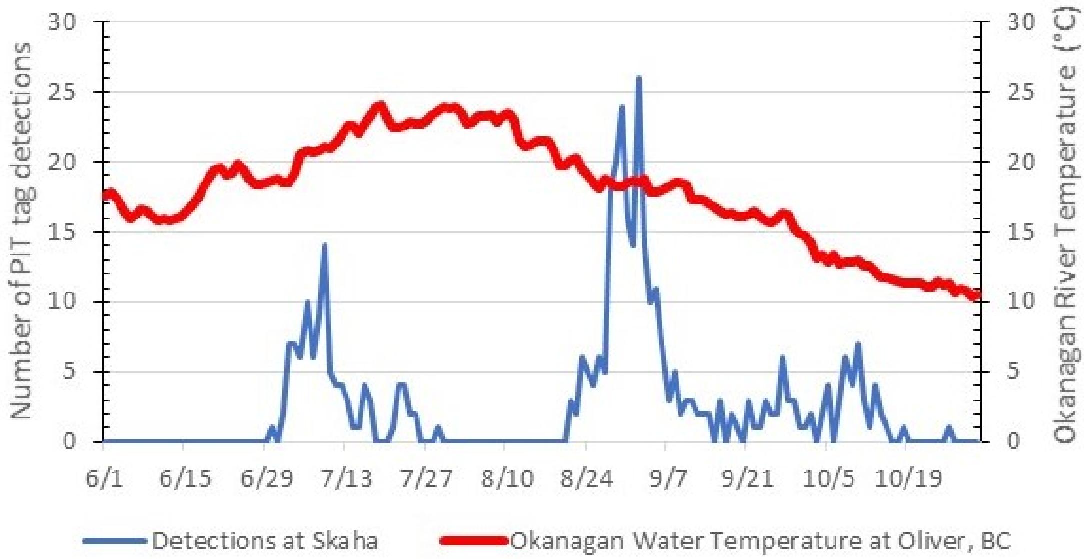

Figure A5. Number of PIT tagged Sockeye Salmon detected by date at Skaha Dam (SKA) and mean daily Okanagan River water temperature at Oliver, BC, between June 1 and October 31, 2018. Four Sockeye tagged as adults at Skaha Dam were removed from this figure as not being representative of upstream migrating Sockeye Salmon.

Penticton Channel (OKP)

Of the 424 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 A4). 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 September 1, 2018, with 3.9% detected in September and 96.1% in October (Figure A6).

Table A4. Number of PIT tagged Chinook, steelhead, and Sockeye detected at OKP between January 1, 2018, and December 31, 2018, by release site and life stage at time of tagging.

Release Site	Life Stage at Release	Sockeye Returning Adults	Sockeye Downstream Juveniles	Steelhead	Total
Bonneville Dam	Adult	190			190
Rock Island Dam	Juvenile	9			9
Wells Dam	Adult	129			129
Canadian Okanagan	Juvenile	15		2	17
Canadian Okanagan-Adults	Adult	81			81
Grand Total		**424**	**0**	**2**	**426**

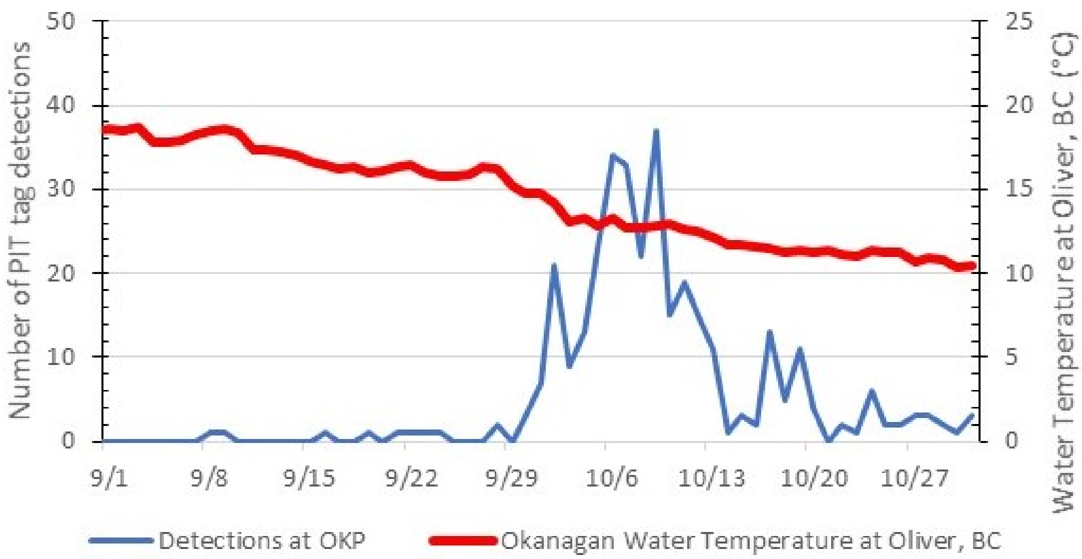

Figure A6. Number of PIT tagged Sockeye Salmon detected by date at Skaha Dam (OKP) and mean daily Okanagan River water temperature at Oliver, BC, between June 1 and October 31, 2018. Eighty-one Sockeye tagged as adults at Skaha Dam were omitted from this figure as not representative of upstream migrating Sockeye Salmon.

Detection Efficiency at Okanagan River PIT Tag Arrays

High flows resulted in a relatively low detection rate for early migrating Sockeye Salmon in the Okanagan River (Table A5). This was particularly apparent at Zosel Dam where high flows meant early migrating Sockeye Salmon could swim through the spillways, thus avoiding PIT tag arrays located in the ladders. The same likely occurred at Skaha Dam, though fewer of the early migrating Sockeye would have made it to Skaha Dam until much later in the year when the spillway gates were closed. The Lower Okanagan River PIT tag array (OKL) had a high

rate of missed Sockeye throughout the summer migration. A combination of high flows and a tree that knocked out the upstream row of antennas from July 1 to August 1 (12/19/2019 e-mail from Randy Johnson, Colville Tribes) was likely a major contributor, though the percentage missed was still high after August 1 (which occurred in Statistical Week 31) even with much lower flows and the restoration of the upstream antennas at OKL.

Table A5. Percentage of adult PIT tagged Sockeye passing upstream that were detected at Okanagan River PIT Tag arrays by week passing Wells Dam in 2018.

Week Detected at Wells Dam	Percentage of PIT tagged Sockeye passing upstream that were 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)
25	37.5	0.0	100.0	83.3	212.0	70.3
26	44.8	0.0	81.6	90.6	184.1	66.2
27	51.6	2.8	89.8	93.6	140.2	58.6
28	43.0	56.8	99.0	99.0	119.2	57.7
29	46.9	99.1	100.0	98.5	91.7	49.9
30	53.8	100.0	100.0	100.0	65.2	31.4
31	40.0	100.0	100.0	100.0	45.4	19.0
32	40.9	100.0	100.0	100.0	33.6	11.4
33	33.3	100.0	NA	NA	27.4	8.9
All Weeks	**46.5**	**48.2**	**94.0**	**96.2**		

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 (2006-18).

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.
CHL	Lower Chiwawa River	Chiwawa River rkm 1, located between the Chiwawa smolt trap and the Chiwawa Acclimation Ponds.
CHU	Upper Chiwawa River	Chiwawa River rkm 12, located above the Forest Road 62 bridge and below Alder Creek.
CHW	Chiwaukum Creek	Located at rkm 0.4 on Chiwaukum Creek, a tributary of Wenatchee River, near Tumwater Campground.
CRW	Chewuch River above Winthrop	Chewuch River at river km 1, above Winthrop, WA.
DRM	Deschutes River mouth	Mouth of the Deschutes River in the west channel at Moody Island (rkm 0.46).
EBO	East Bank Hatchery Outfall	Located in the East Bank Hatchery outfall channel.
ENA	Upper Entiat River at rkm 17.1	The site is located approximately 400 meters above the mouth of the Mad River near the township of Ardenvoir at river kilometer 17.1.
ENL	Lower Entiat River	Entiat River rkm 2, located immediately upstream of Entiat, WA.
ENM	Middle Entiat River	Entiat River rkm 26, below the McKenzie Diversion Dam.
ENS	Upper Entiat River at rkm 35.7	The site is located approximately 4.3 km above Stormy Creek at river kilometer 35.7 and near the entrance of the Riverwood subdivision.
GOA	Little Goose Fish Ladder	Adult Fishway at Little Goose Dam.
GOJ	Little Goose Dam Juvenile	Little Goose Dam Juvenile Fish Bypass/Transportation Facility.
GRA	Lower Granite Dam Adult	Lower Granite Dam Adult Fishway and Fish Trap.
GRJ	Lower Granite Dam Juvenile	Lower Granite Dam Juvenile Fish Bypass/Transportation Facility.
HRM	Hood River Mouth	Located at the mouth of the Hood River against the west side jetty just inside the bar where the Hood River meets the Columbia River.
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.
IR1	Lower Imnaha River ISA at km 7	Lower Imnaha River at river km 7 (N 45.761162, W -116.750658).
IR2	Lower Imnaha River ISA at km 10	Lower Imnaha River at river km 10 (N 45.742839 W -116.764563).
IR3	Upper Imnaha River ISA at km 41	Upper Imnaha River at river km 41 (N 45.49004 W 116.80393).
IR4	Imnaha Weir Downstream Array	Located downstream of the Oregon Dept. of Fish and Wildlife (ODFW) fish weir on the Imnaha River.
IR5	Imnaha Weir Upstream Array	Located upstream of the Oregon Dept. of Fish and Wildlife (ODFW) fish weir on the Imnaha River.
JDJ	John Day Dam Juvenile	John Day Dam Juvenile Fish Bypass and Sampling Facility.
JO1	John Day South Fish Ladder	The interrogation site at the John Day Dam south fish ladder.
JO2	Joseph Creek ISA at km 3	Joseph Creek, Grande Ronde basin at river km 3 (N 46.030016, W -117.016042).
JOH	Johnson Creek	The site is located approximately 0.2 km upstream from the confluence of the Okanogan River.
LMA	Lower Monumental Adult Ladders	This interrogation site is in both ladders at Lower Monumental Dam.
LMJ	Lower Monumental Dam Juvenile	Lower Monumental Dam Juvenile Fish Bypass/Transportation Facility.
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.
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.
MRW	Methow River at Winthrop	Methow River. During 2009 and early 2010, the array was located at river km 81, above Winthrop, WA near Winthrop National Fish Hatchery. In Sept. 2010 it was moved upstream to its new location below Wolf Creek on the mainstem Methow River, at river km 85.
MWE	Middle Wenatchee River	This is an in-stream interrogation system at Wenatchee River rkm 50 above Tumwater Dam.
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.
OKP	Penticton Channel PIT Array	Penticton Channel, is the portion of the Okanagan River connecting Okanagan Lake with OKPha Lake, within the city of Penticton BC. This represents the upstream most accessible portion of mainstem river for Columbia River anadromous fish.
PES	Peshastin Creek	Instream interrogation system at rkm 3 on the Peshastin River (Wenatchee River Basin), located just below the bridge at Smithson's property.
PRA	Priest Rapids Adult	Priest Rapids Dam Adult Fishways (both).
PRH	Priest Rapids Hatchery Outfall	Priest Rapids Hatchery outfall channel. The site is located just upstream of the typical point of inundation in the channel.
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.
RSH	Ringold Springs Hatch. Outfall	PIT tag detection system located in the Ringold Springs Hatchery outfall channel.
SHK	Shitike Creek PIT Array	he array is located across the tailout of a pool created by a bridge (known as the Scale Bridge) that is used by logging truck to deliver lumber to the Warm Springs Mill.
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.
STL	Sawtooth Hatchery Adult Trap	Ladder of the Sawtooth Hatchery adult fish trap.
SUN	Sunnyside Instream Array	Located 600 M below Sunnyside Dam on the Yakima River.
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.
TWR	Lwr Twisp Rvr near MSRF Ponds	Lower Twisp River adjacent to the Methow Salmon Recovery Foundation Ponds.
USE	Upper Salmon River at rkm 437	Located in the Salmon River at river km 522.303.437 (N45.028939 W-113.915892).
USI	Upper Salmon River at rkm 460	Located in the mainstem Salmon River at river km 522.303.460 (N44.890380 W-113.962575).
UWE	Upper Wenatchee River	Located at rkm 81.2 on the Wenatchee River, near Plain, WA.
VC2	Valley Creek, Downstream Site	Located on Valley Creek below Stanley, ID., in the Upper Salmon River.
WEA	Wells Dam, DCPUD Adult Ladders	Wells Dam Adult Fishways (both).
WEJ	Wells Dam Bypass Bay Sample	The system is located in Bypass Bay 2 on the right (west) side of Wells dam on the Columbia River, Washington.
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.

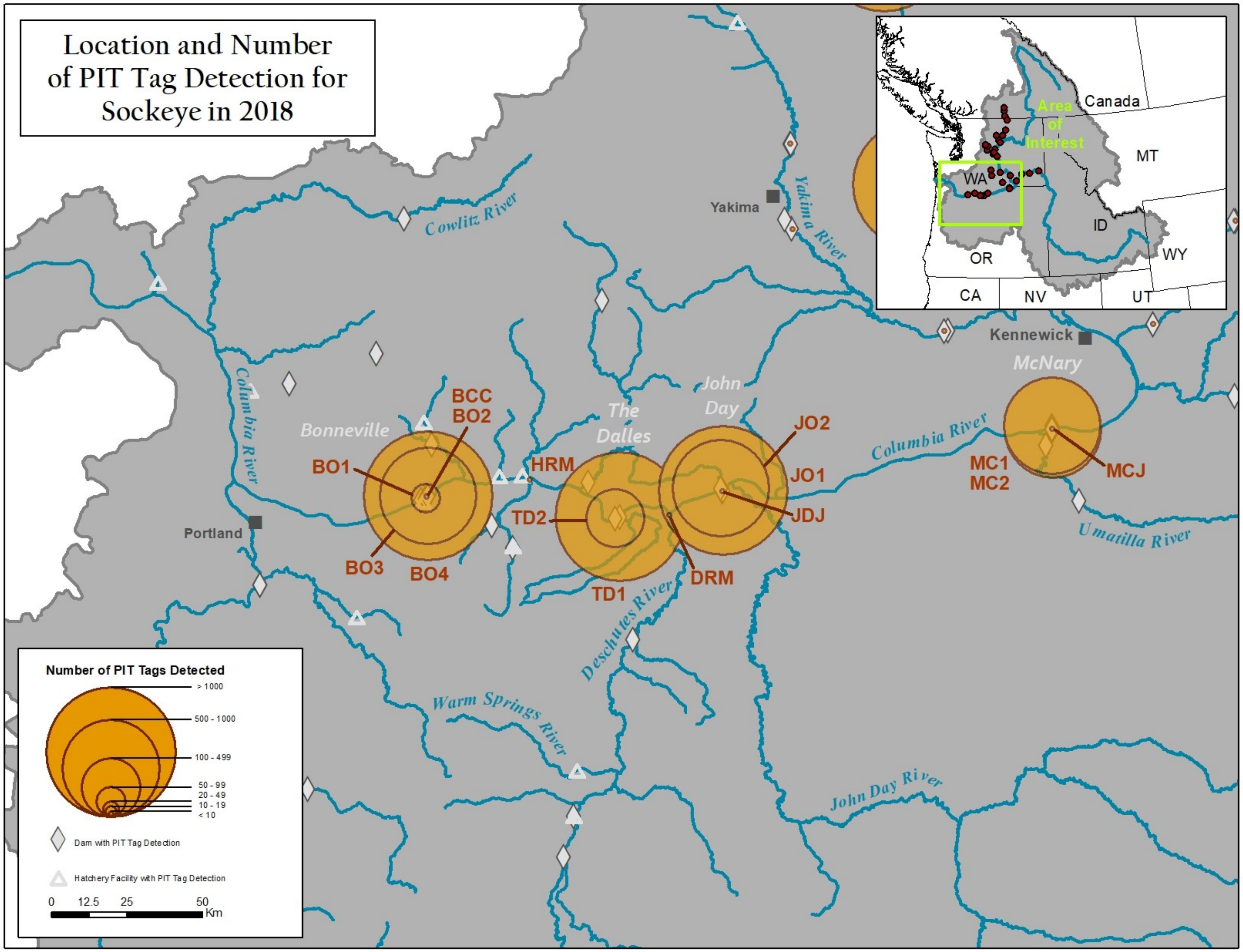

Figure B1. Map of Lower Columbia River detection sites (below Snake River) and number of Sockeye Salmon detected in 2018. Table B1 in the Appendix lists the PTAGIS sites' full name and the three-letter codes on this map.

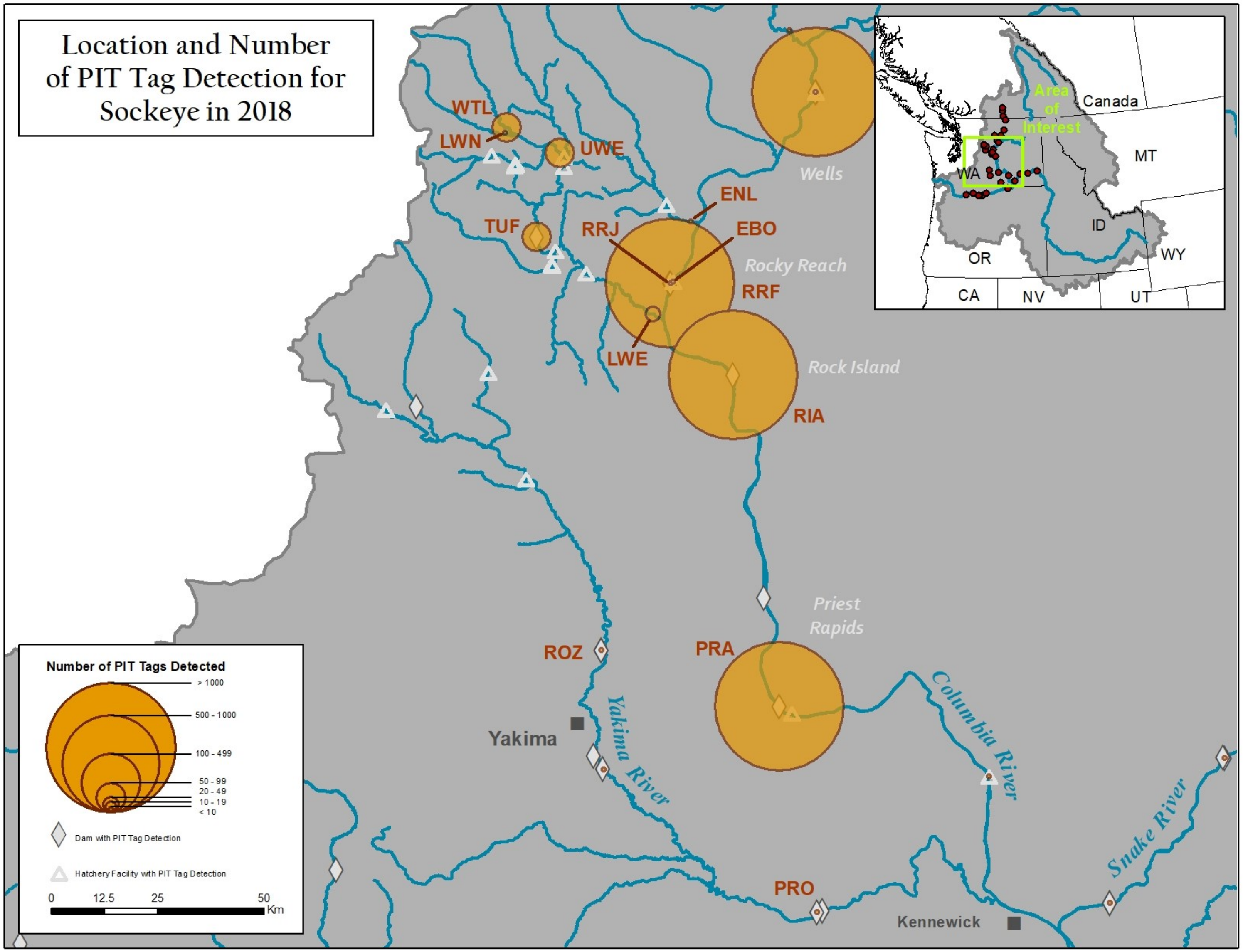

Figure B2. Map of Upper Middle Columbia River (between the Snake River and Wells Dam) detection sites and number of Sockeye Salmon detected in 2018. Table B1 in the Appendix lists the PTAGIS sites' full name and the three-letter codes on this map.

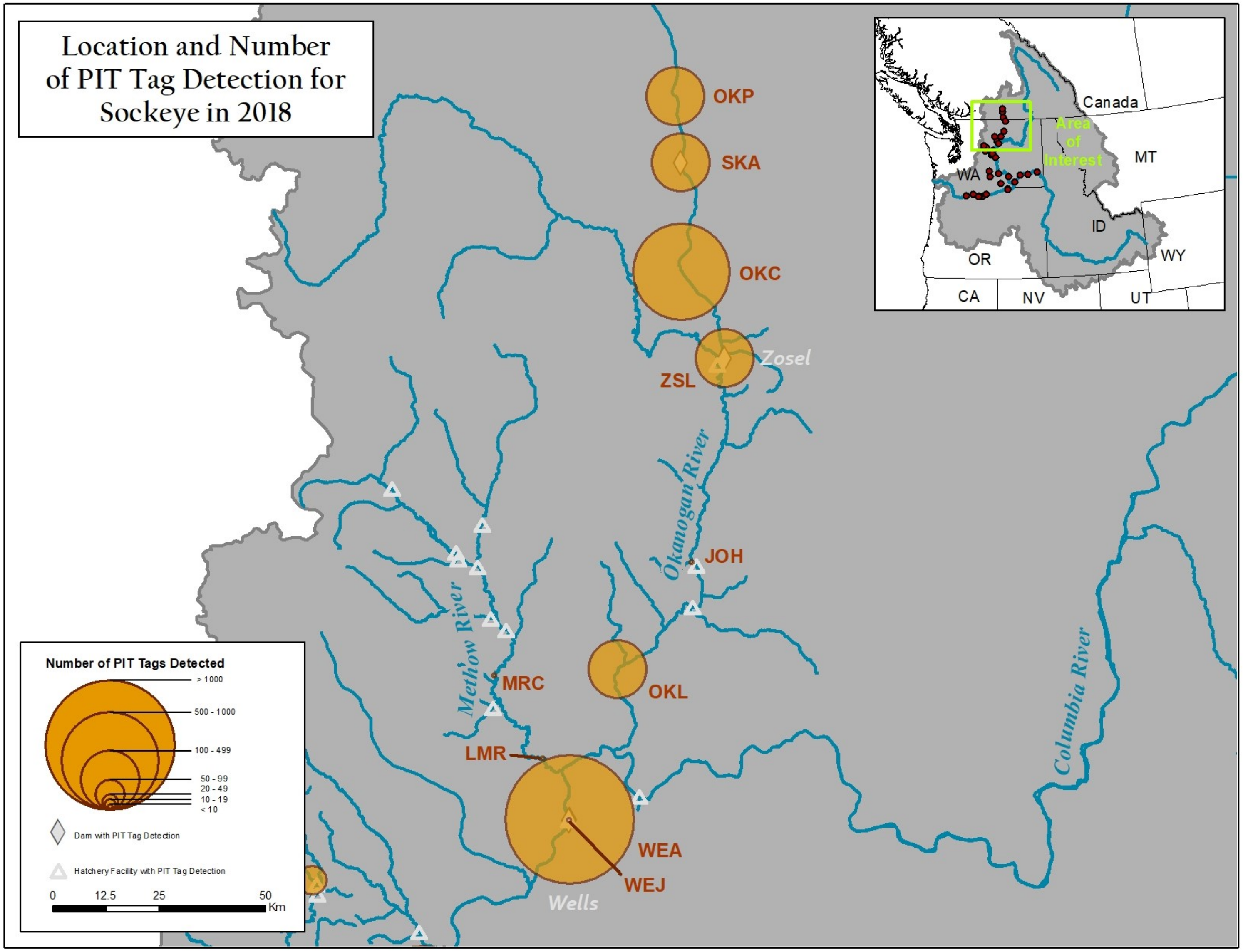

Figure B3. Map of Upper Columbia River (Wells Dam and above) detection sites and number of Sockeye Salmon detected 2018. Table B1 in the Appendix lists the PTAGIS sites' full name and the three-letter codes on this map.

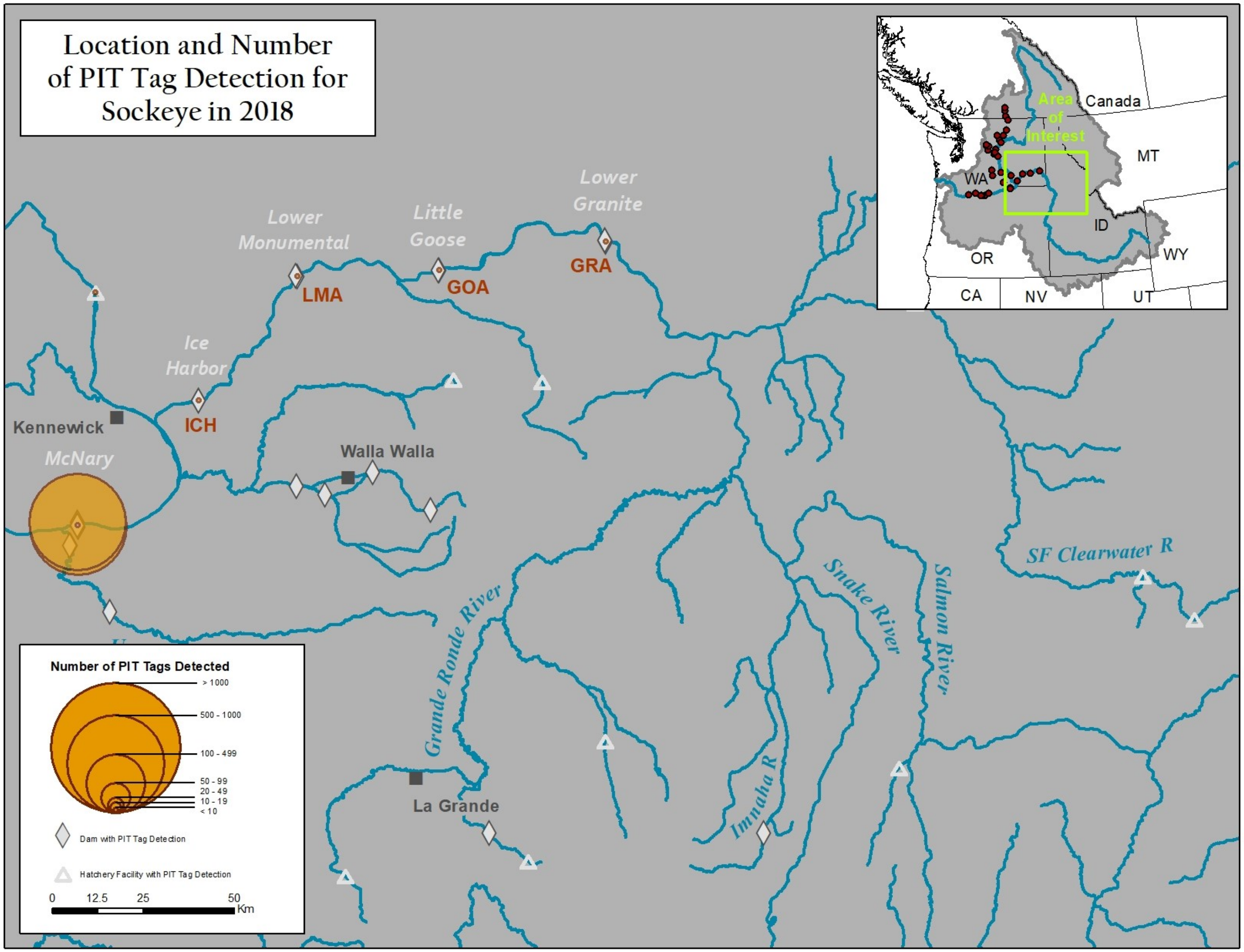

Figure B4. Map of Lower Snake River detection sites (Salmon River not included) and number of Sockeye Salmon detected in 2018. Table B1 in the Appendix lists the PTAGIS sites' full name and the three-letter codes on this map.

APPENDIX C

Q̓AWST'IKʷ [Okanagan River] Sockeye Smolt out of Basin Survival: Purse Seining & PIT Tagging BY 2016

q̓awsitkʷ (Okanagan River) Sockeye Smolt Out of Basin Survival:
Purse Seining & PIT Tagging BY 2016

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

December 2018

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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 (ONA) 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, ONA conducted a pilot study to evaluate Passive Integrated Transponder (PIT) technology to test the methodology, effectiveness, and survival and travel time of smolts as the migrate out of the Okanagan River basin.

In 2018 (Brood Year 2016), 10,943 smolts were tagged and released during ten tagging sessions between 16 April and 9 May. A total of 5083 smolts were successfully tagged at suwiw̓s at two sites: OSOYOL, in the north basin of suwiw̓s, and OSOYHA, at Haynes Point Provincial Park in the central basin, downstream of the Osoyoos Narrows. The Osoyoos sessions lasted three days, from 16 April to 18 April. Survival probability for suwiw̓s combined release groups to Rocky Reach Dam was 0.66 (SE=0.033). Survival from release to Bonneville Dam was 0.56 (SE=0.31). Travel time from release to Rocky Reach Dam was approximately 18.0 days. The overall travel time (release to Bonneville) for all Osoyoos smolts was 25.6 days.

An additional 5860 smolts were tagged at SKAHAL, at the southern end of q̓awst'ik'ʷt between 2 May and 9 May. Survival probability for q̓awst'ik'ʷt smolts to Rocky Reach Dam was slightly lower than suwiw̓s smolts at 0.59 (SE=0.037). Survival from release to Bonneville Dam was also lower at 0.33 (SE=0.12). Travel time from release to Rocky Reach Dam was approximately 9.2 days. The overall travel time (release to Bonneville) for all Skaha smolts was 16.6 days.

The aggregate population of smolts had a survival probability to Rocky Reach Dam of 0.62 (SE=0.025) and a survival probability to Bonneville Dam of 0.41 (SE=0.127). Travel time for the aggregate population averaged 13.0 days to Rocky Reach and 19.7 days to Bonneville.

Recommendations from the 2018 sampling year include the following:

- 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 should be a back-up capture method, only if the purse seine vessel is unavailable.
- McNary and John Day dam PIT detection data should be remove 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.
- Continue to monitor the hatchery smolt component to test the 10% proportion assumption in suwiw̓s.

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

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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

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 nx̌ʷəntkʷitkʷ (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. 2018). 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 4018 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; and 11,588 in 2017 (Folks et al. 2017).

In 2016, OAE piloted purse seining in both lakes as a method of capturing smolts (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. Contrary to methodology in 2017, 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.

In this report, we summarize the capture and tagging program for the 2018 season (2016 Broodyear). Tagging targets of >10,000 (5,000 from each lake) were set to refine 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, 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 the Osoyoos Lake Narrows, a part of the lake that connects the Central and North Basin of the lake. From suwiw̓s the q'awsitkʷ flows south through the Okanogan County, past the towns of Okanogan and Omak. q'awsitkʷ enters nxˇʷəntkʷitkʷ 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.

For the 2016 brood year, 4,493,577 hatchery-reared fry were released into q'awst'ik'ʷt (Stefanovic et al. 2018). This is the highest amount of fry released since the start of the program in 2003. In addition, an estimated 4,000 natural Sockeye spawned in Penticton Channel in 2016 (Yaniw and Benson 2018). Therefore, smolts outmigrating from q'awst'ik'ʷt in 2018 were of mixed natural and hatchery origin.

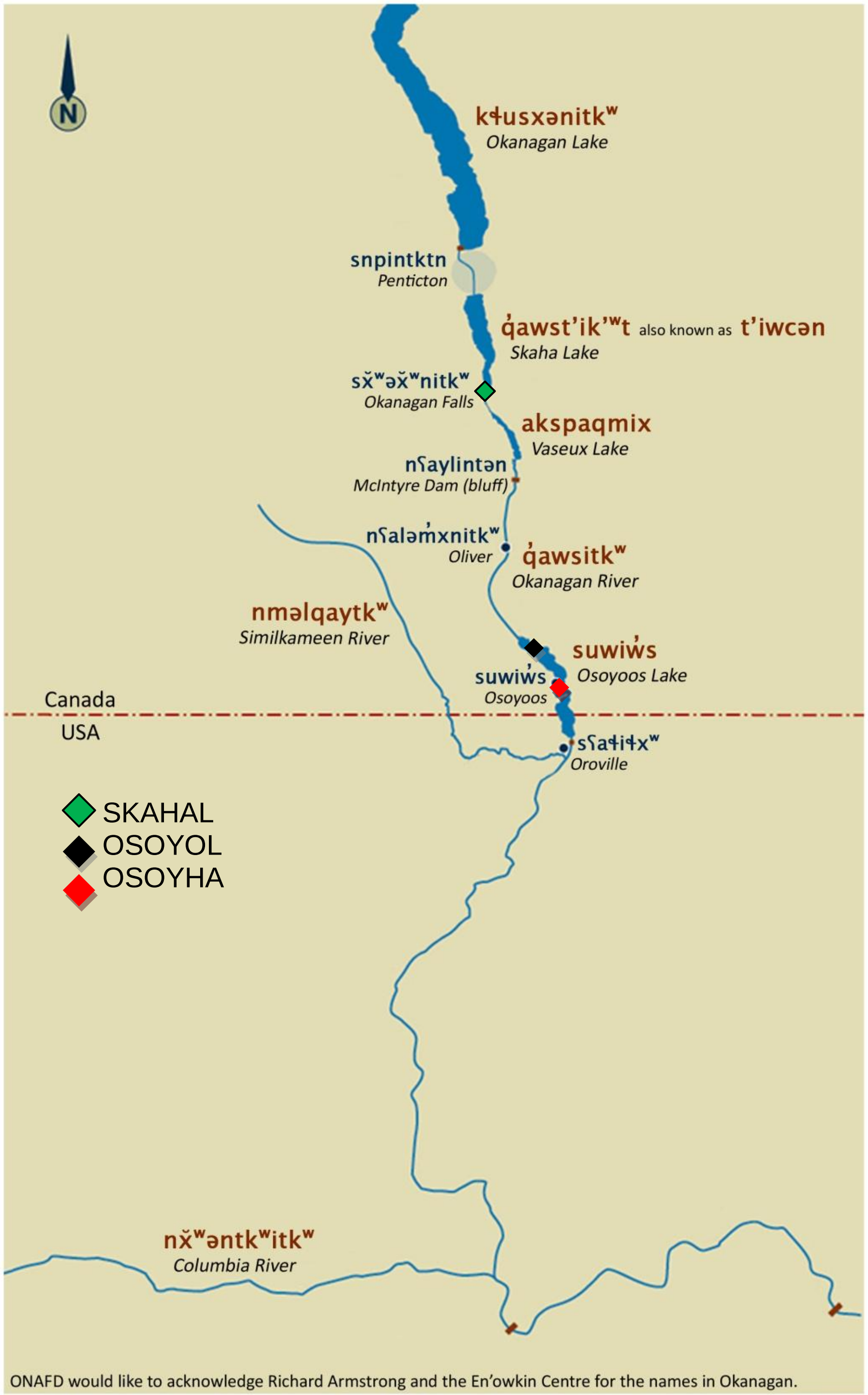

Figure 1. q'awsitkw juvenile PIT tagging locations in 2018.

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, at a minimum.

2. Continue to refine smolt capture techniques using 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

We 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 of suwiw̓s where the majority of Sockeye smolts were congregating. In addition, water turbidity was very high in the north basin due to extremely high flows in Inkaneep Creek, which deposited large amounts of sediment in the Lake. Seining in q̓awst'ik'ʷt was concentrated in the southern area where smolts were congregating.

Due to the success of the purse seine operation in 2017, the fyke net was not deployed in Osoyoos Narrows as had 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 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 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 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 suwiw̓s. In q̓awst'ik'ʷt, smolts were released, just offshore from the tagging site, upstream of Skaha Dam. All post-tagged smolt mortalities were removed and bio-sampled. PIT tag numbers from fish mortalities were removed from the database 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 2018, we captured 53.5% (n=5860) of smolts in q̓awst'ik'ʷt and 46.5% (n= 5083) in suwiw̓s. All suwiw̓s smolts were captured in the Central Basin; all Skaha smolts were captured in the southern end of the Lake, just upstream of Skaha Dam. The majority of smolts were captured in the evening, held overnight in net pens just offshore, and tagged the next day.

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 selected for biosampling. In total, 623 smolts were biosampled (Skaha, n = 321; Osoyoos, n = 302). Skaha smolts had a mean fork length of 9.5 cm and mean weight of 8.6 g. Osoyoos smolts were smaller, with a mean fork length of 8.2 cm and mean weight of 5.4 g. To determine origin, thermal marks from otoliths were checked from all smolts sampled. Amongst suwiw̓s smolts, 99.7% (n=301) were natural origin. The rate of natural origin was much lower for q̓awst'ik'ʷt smolts, at 28.0% (n= 90).

Tagging mortalities from suwiw̓s were also biosampled. A total of 250 mortalities were biosampled, all of which were natural origin. Mean fork length for suwiw̓s mortalities was 7.6 cm, mean weight was 4.7 g. To test for the potential size bias, we conducted a two sample Kolmogorov-Smirnov test. The test was conducted for random live vs. mortalities. For large sample sizes ($n > 100$) the critical D-value (α 0.05) is 0.116. Results of the KS-test indicate a significant difference ($D = 0.48$, $P > 0.05$). This indicates the samples (random and mortality) came from different populations and tagging stress and mortality differentially affected smaller smolts.

3.2 PIT Tagging Results

10,943 smolts were successfully tagged and released during 10 tagging days, between 16 April and 9 May 2018 at three sites: OSOYOL (Baptiste property, north end of suwiw̓s), OSOYHA (Haynes Point Provincial Park, central basin of suwiw̓s), and SKAHAL (South End of q̓awst'ik'ʷt). Tagging effort has been summarized (Table 1).

Table 1. Summary of Okanagan Sockeye smolt PIT tagging effort, 2018.

Date	OSOYOL	OSOYHA	SKAHAL
16-Apr-18	1236		
17-Apr-18	285	1358	
18-Apr-18		2204	
02-May-18			225
03-May-18			472
04-May-18			2606
05-May-18			395
07-May-18			631
08-May-18			1349
09-May-18			182
TOTAL	**1521**	**3562**	**5860**

3.2.1 Survival

Estimates of survival from release to Rocky Reach Dam were calculated for both release groups, and combined as one population. Survival from release to Rocky Reach Dam was 0.621 (SE = 0.0246) (Table 2). After Rocky Reach, error associated with survival estimates typically increases, namely Rocky Reach to McNary, McNary to John Day, and John Day to Bonneville (Figure 2, Table 3).

Table 2. Survival for PIT tagged q'awsitk^{w} (Okanagan River) Sockeye smolts, 2018.

Period	Survival Combined OSOYOL and OSOYHA	SE	Survival SKAHAL	SE	Survival combined SKAHAL, OSOYOL, OSOYHA	SE
Release to Rocky Reach	0.6588	0.0327	0.5851	0.0374	0.6206	0.0246
Rocky Reach to McNary	0.7995	0.1050	0.8692	0.1255	0.8506	0.0828
McNary to John Day	0.9642	0.3071	1.1105	0.2881	1.0276	0.2053
John Day to Bonneville	1.1008	0.6872	0.5873	0.2569	0.7511	0.2699
Release to Bonneville	0.5590	0.3079	0.3317	0.1246	0.4074	0.1271

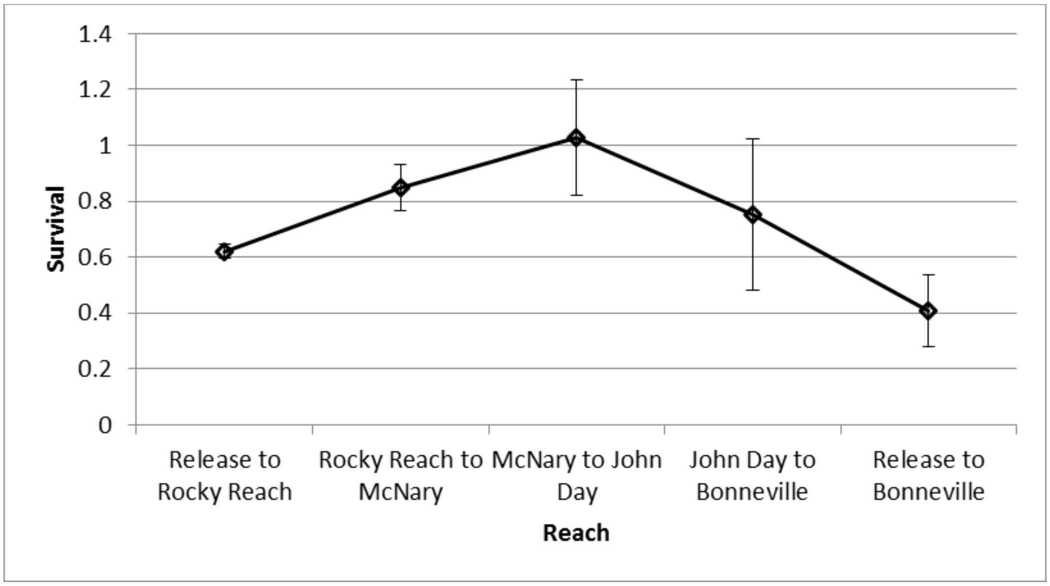

Figure 2. Survival for PIT tagged q'awsitkw (Okanagan River) Sockeye smolts (OSOYOL, OSOYHA, and SKAHAL), 2018.

Table 3. Comparison of annual survival for PIT tagged q'awsitkw (Okanagan River) Sockeye smolts, 2013-2018. Standard Errors of mean presented in brackets.

Period	2013	2014	2015	2016	2017	2018
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)
Rocky Reach to McNary	1.14 (0.26)	0.68 (0.44)	0.80 (0.13)	0.79 (0.07)	0.94 (.11)	0.85 (0.08)
McNary to John Day	1.25 (0.66)	2.80 (0.65)	0.72 (0.18)	0.97 (0.19)	0.88 (0.15)	1.03 (0.21)
John Day to Bonneville	0.70 (0.58)	0.26 (0.24)	1.79 (0.66)	0.49 (0.14)	0.63 (0.21)	0.75 (0.27)
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)

* 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 13.0 days (Figure 3, Table 4). Overall aggregate travel time from release to Bonneville Dam was approximately 19.7 days. Travel time to Rocky Reach was approximately 18.0 days for Osoyoos smolts and 9.2 days for Skaha smolts. Travel time to Bonneville was approximately for 25.6 days for Osoyoos smolts, and 16.6 days for Skaha smolts. This faster travel time for Skaha smolts is likely due to fish being larger than Osoyoos smolts and had better swimming performance

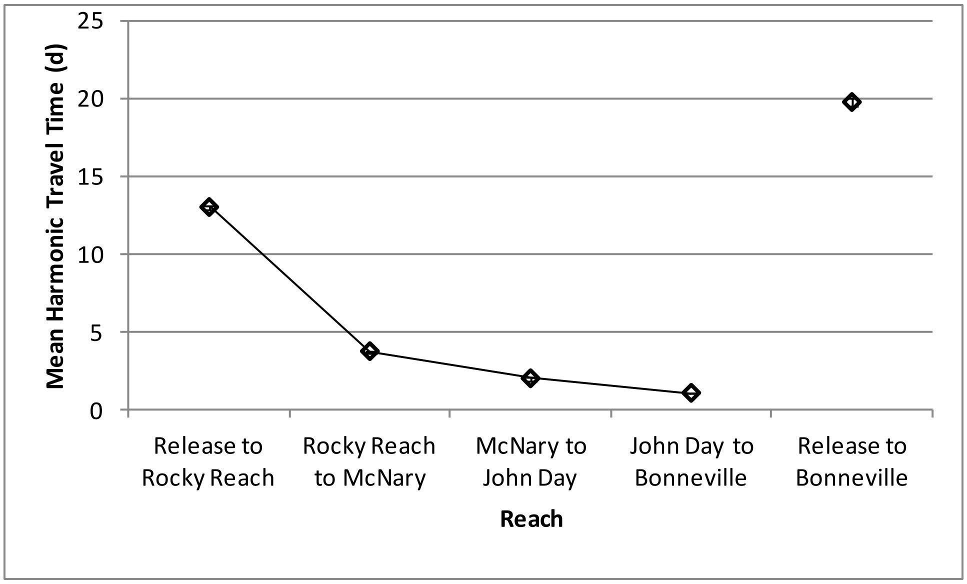

Figure 3. Mean harmonic travel time for PIT tagged q'awsitk^{w} (Okanagan River) Sockeye smolts (Osoyoos and Skaha), 2018.

Table 4. Mean Harmonic Travel Time for PIT tagged q'awsitk^{w} (Okanagan River) Sockeye smolts, 2018.

Period	OSOYOL and OSOYHA Combined Travel Time (d)	SE	SKAHAL Travel Time (d)	SE	All Sites Combined Travel Time (d)	SE
Release to Rocky Reach	17.96	0.13	9.23	0.09	13.00	0.13
Rocky Reach to McNary	4.15	0.08	3.12	0.09	3.74	0.07
McNary to John Day	2.42	0.20	1.73	0.11	2.00	0.12
John Day to Bonneville	1.21	0.06	0.99	0.04	1.06	0.04
Release to Bonneville	25.56	0.30	16.58	0.22	19.74	0.27

Table 5. Comparison of Harmonic mean travel time for PIT tagged q'awsitkw (Okanagan River) Sockeye smolts, 2013-2018. Standard Errors of mean presented in brackets.

Period	2013	2014	2015	2016	2017	2018
Release to Rocky Reach	19.3 (0.25)	15.9 (0.19)	16.2 (0.14)	14.2 (0.13)	10.2 (0.078)	13.00 (0.13)
Rocky Reach to McNary	4.41 (0.14)	3.90 (0.07)	5.79 (0.14)	4.89 (0.07)	3.9 (0.073)	3.74 (0.07)
McNary to John Day	2.32 (0.22)	2.35 (0.11)	2.71 (0.28)	2.58 (0.17)	2.19 (0.08)	2.00 (0.12)
John Day to Bonneville	1.53 (0.15)	1.40 (0.16)	1.66 (0.05)	1.41 (0.04)	1.28 (0.03)	1.06 (0.04)
Release to Bonneville	29.0 (0.74)	23.2 (0.56)	26.6 (0.27)	23.4 (0.29)	17.67 (0.19)	19.74 (0.266)

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

4.0 Discussion and Recommendations

In 2018, 5083 smolts were tagged from suwiẁs, and 5860 from q̓awst'ik'ʷt. Therefore, it was possible to determine survival and travel time for the combined population (>10,000) as far as Bonneville. Overall survival to Bonneville was the higher that in 2016 and 2017 (Folks et al. 2016a). Travel time (both from release to Rocky Reach and release to Bonneville) was greater than 2017 but lower than every other year since 2013 (Table 5). A likely explanation for elevated survival and rapid migration was the higher than average spring flow in q̓awsitkʷ.

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 (Table 3). 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). For future years, we recommend removing McNary and John Day dam PIT detections from the survival and travel time analyses.

In 2017, we captured solely within suwiẁs, to test the assumption q'awst'ik'ʷt and suwiẁs 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. 2017). In order to capture trends for q'awst'ik'ʷt, in 2018, we targeted smolts from both lakes equally.

The majority of suwiẁs smolts (99.7%) were natural origin. This does not support the 10% hatchery proportion assumption. Future smolt monitoring efforts should continue to monitor this proportion.

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 should be a back-up capture method, only if the purse seine vessel is unavailable.

- McNary and John Day dam PIT detection data should be remove 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.

- Continue to monitor the hatchery smolt component to test the 10% proportion assumption in suwiẁs.

5.0 References

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.

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., C. Fuller, R. Benson and L. Wiens. 2018. Collection and Rearing of Okanagan Sockeye Salmon for the Skaha Re-introduction Program: Brood Year 2016 Annual Report. Prepared as part of the Skaha Lake Sockeye Salmon Re-Introduction Monitoring and Evaluation Program: Brood Year 2016. 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. q̓awst'ik'ʷt (Skaha Lake) Nerkid Spawner Enumeration and Biological Sampling 2016. Prepared as part of the Skaha Lake Sockeye Salmon Re-Introduction Monitoring and Evaluation Program: Brood Year 2016. Okanagan Nation Alliance Aquatic Enterprises Ltd., Westbank, BC.

APPENDIX D

Fish Passage Center Memoranda regarding 2018 Okanagan Sockeye Smolt Survival

FISH PASSAGE CENTER

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MEMORANDUM

To: Jeff Fryer, CRITFC

From: Michele DeHart

Date: September 20, 2018

Re: Okanogan River sockeye passage timing, travel times, juvenile survival, and smolt-to-adult returns, migration years 2013-2018 (Revised).

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 2018 PIT-tagged sockeye smolts. In addition, we provide updated estimates of overall SARs from migration years 2013-2016, with adults detected at Bonneville Dam through September 15, 2018. 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 (2013-2018). Juvenile survival for Release-RRH in 2018 was 0.62 (95% CI: 0.57-0.67).

- 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 2018, which was 0.54 (95% CI: 0.36–0.72).
- A total of 32 and 13 PIT-tagged Okanogan River sockeye juveniles were detected at Zosel Dam and/or at the Okanogan Channel in 2018, respectively. However, detection probabilities at these two sites were sufficiently low that we were unable to estimate survival from release to these sites.
- The 2018 Draft CSS Annual Report provides estimates of smolt-to-adult return (SAR) rates for Rocky Reach-to-Bonneville (RRE-to-BOA) for migration years 2013-2016 and McNary-to-Bonneville (MCN-to-BOA) for migration years 2014-2016. The RRE-to-BOA SARs for 2013-2016 have ranged from 1.30% (95% CI: 1.05-1.56%) to 8.13% (95% CI: 6.96-9.45%). The MCN-to-BOA SARs for 2014-2016 ranged from 1.58 (95% CI: 1.06-2.21%) to 2.99 (95% CI: 2.25-3.71%).

Methods

Timing and Travel Time

Juvenile passage timing and fish travel times were estimated for 2013-2018 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 and 2018, 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.

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 2013-2015 out-migrations and the nearly complete return from the 2016 out-migration, we were able to estimate Smolt-to-Adult Returns (SARs). Given the juvenile detection capabilities at RRE, we estimated SARs for two different reaches: 1) juveniles at RRE to adult returns at BON (RRE-to-BOA) and 2) juveniles at MCN to adult returns at BON (MCN-to-BOA). The methodology for estimating SARs is discussed in Chapter 4 of the CSS Annual Report (McCann et al., 2018). Estimates of SARs that are provided in McCann et al. (2018) included adults detected at BOA through July 21, 2018. For this request, we investigated whether any additional Okanogan sockeye adults were detected at BOA through September 15, 2018. However, there were no additional detections of Okanogan sockeye adults at BOA between July 21st and September 15th.

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 2013-2018.

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 2013-2018.

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

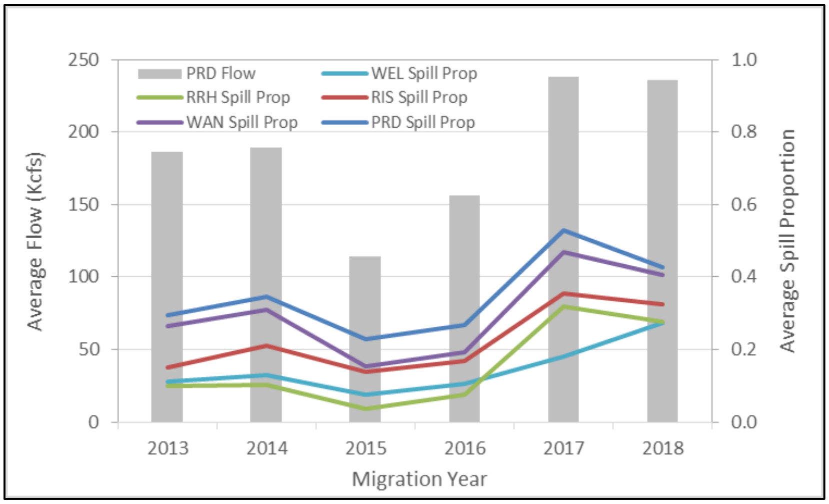

Figure 1. Average spring (April 15–June 30) flow at Priest Rapids Dam (PRD) and average spill proportion at Wells (WEL), Rocky Reach (RRH), Rock Island (RIS), Wanapum (WAN), and PRD in 2013-2018.

Travel Time and Timing

Over the last five years, 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 2013-2018.

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

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 and 2018, travel times to ZSL are also provided for these two years. It is important to note that the detection system at ZSL was not installed until April 25th in 2018, 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 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, based on 13 PIT-tag detections. These travel time estimates are based on the fish tagged and released at Skaha Lake only, as this 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 2018. PIT-tag detection sites include: Okanogan Channel (OKC), Zosel (ZSL), Rock Reach (RRE), McNary (MCN), John Day (JDA), and Bonneville (BON) dams.

Migration Year	Project	Release to Project Travel Time (days)			95% Confidence Limits	
		Min	Med	Max	Lower	Upper
2013	RRE	5.6	19.4	56.3	18.7	19.9
	MCN	10.0	23.7	63.7	22.1	24.7
	JDA	12.0	25.5	62.3	24.0	27.2
	BON	16.3	28.2	57.3	26.6	29.0
2014	RRE	4.4	16.7	40.6	16.4	17.4
	MCN	8.1	19.4	54.8	18.8	20.0
	JDA	13.0	23.0	67.5	22.1	24.0
	BON	11.8	22.7	59.0	20.8	24.6
2015	ZSL	4.7	14.2	31.0	12.0	16.0
	RRE	5.9	15.7	39.4	15.4	16.1
	MCN	14.0	23.2	43.0	21.6	24.0
	JDA	17.0	24.5	49.5	23.0	25.7
	BON	16.9	25.9	48.2	24.9	26.4
2016	RRE	3.8	16.7	49.5	16.4	17.4
	MCN	8.0	21.4	51.5	20.6	22.3
	JDA	11.2	22.0	71.1	21.0	23.0
	BON	12.4	23.7	58.9	23.3	24.6
2017	RRE	4.5	10.5	61.4	10.4	10.6
	MCN	8.1	15.0	31.5	14.2	15.4
	JDA	9.9	15.9	40.1	15.2	16.0
	BON	10.8	17.8	46.4	17.5	18.4
2018	OKC	0.9	3.1	7.7	1.8	3.7
	ZSL	7.1	11.2	33.1	10.3	12.3
	RRE	4.8	14.9	54.3	14.6	15.7
	MCN	7.8	19.1	43.6	18.4	19.7
	JDA	10.1	17.1	42.5	15.7	18.3
	BON	11.0	21.4	46.0	20.8	21.9

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.

As requested, we estimated juvenile timing to OKC in 2018. As with the estimates of travel time to OKC, these timing estimates are based on fish tagged and released from Skaha Lake only, as this detection site is upstream from Osoyoos Lake. Tagging efforts on Skaha Lake occurred between May 2nd and May 9th in 2018. 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 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 2018.

		Estimated Passage Date		
Migration Year	**Project**	**10%**	**50%**	**90%**
2013	RRE	8-May	13-May	18-May
	MCN	11-May	17-May	25-May
	JDA	14-May	21-May	27-May
	BON	15-May	24-May	2-Jun
2014	RRE	10-May	14-May	22-May
	MCN	12-May	19-May	24-May
	JDA	16-May	22-May	28-May
	BON	16-May	21-May	28-May
2015	ZSL	30-Apr	4-May	9-May
	RRE	6-May	12-May	19-May
	MCN	13-May	18-May	26-May
	JDA	16-May	20-May	25-May
	BON	17-May	21-May	27-May
2016	RRE	24-Apr	5-May	10-May
	MCN	27-Apr	10-May	18-May
	JDA	29-Apr	10-May	20-May
	BON	1-May	12-May	20-May
2017	RRE	8-May	11-May	20-May
	MCN	12-May	14-May	23-May
	JDA	13-May	16-May	24-May
	BON	14-May	18-May	26-May
2018	OKC*	7-May	9-May	12-May
	ZSL	28-Apr	14-May	19-May
	RRE	2-May	12-May	20-May
	MCN	7-May	14-May	23-May
	JDA	10-May	17-May	24-May
	BON	11-May	18-May	27-May

* 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 2nd through May 9th in 2018. Timing at the other sites includes all fish tagged in 2018.

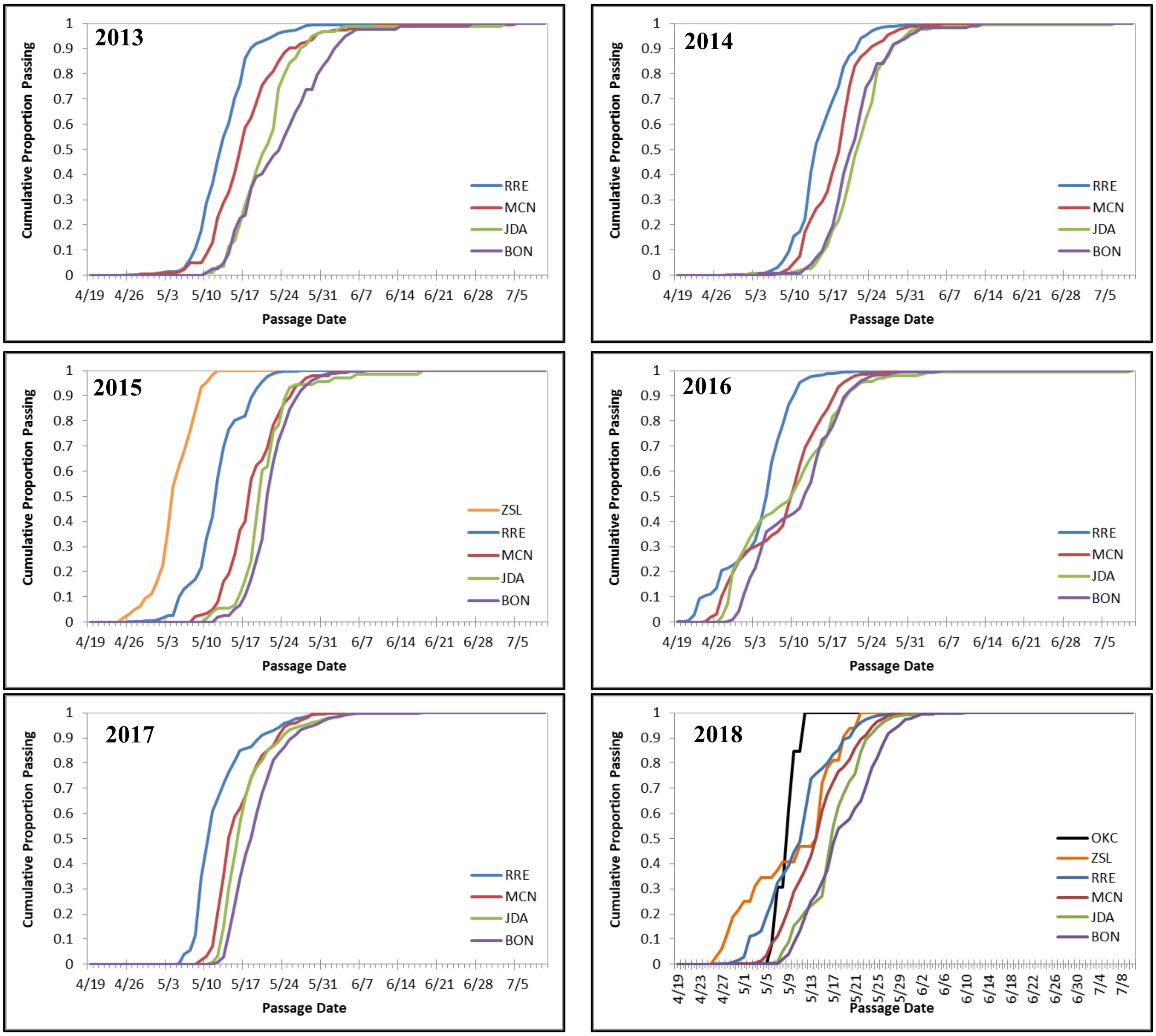

Figure 2. Cumulative passage timing of PIT-tagged wild Okanogan River basin sockeye smolts at Rocky Reach (RRE), McNary (MCN), John Day (JDA), and Bonneville (BON) dams in migration years 2013-2018. Cumulative passage timing to Zosel Dam (ZSL) is provided for MY 2015 and 2018 and the Okanogan Channel for MY 2018. 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 2nd through May 9th in 2018. Timing to the other sites includes all fish tagged in 2018.

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 2014-2018 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 2013-2018.

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)

Survival by Release Site

Of the 4,018 total wild sockeye that were tagged and released in 2013, 1,178 were tagged and released from Skaha Dam or just below (SKA or SKATAL), 2,783 were tagged and released from Osoyoos Lake Narrows Bridge (OSOYBR), and 57 were tagged and released from Osoyoos Lake (OSOYOL). Too few tags were released from OSOYOL to estimate survivals for this release location. For the SKA-SKATAL and OSOYBR release sites, we were only able to obtain reliable estimates of survival for the Release-RRE reach, which were 0.46 (95% CI: 0.36-0.57) for fish released at SKA-SKATAL and 0.50 (95% CI 0.41-0.58) for fish released at OSOYBR (Table 6). Estimates of survival for the RRE-MCN reach were unreliable for both release sites and, therefore, are not reported in Table 6.

In 2014, a total of 5,055 PIT-tagged sockeye were released in the Okanogan Basin. Of these, 1,348 were tagged and released from Skaha Dam or just below (SKA or SKATAL) and 3,707 were tagged and released from Osoyoos Lake Narrows Bridge (OSOYBR). For 2014, we were able to generate estimates of both individual reach survival (Release-RRE and RRE-MCN) and combined reach survival (Release-MCN) for each of the two release sites (Table 6). Fish tagged and released from SKA-SKATAL had a Release-MCN survival of 0.25 (95% CI: 0.13-

0.36) whereas those from OSOYBR had a Release-MCN survival of 0.44 (95% CI: 0.34-0.54) (Table 6).

In 2015, 7,176 total sockeye smolts were PIT-tagged and released into the Okanogan River Basin. Of these, 5,435 were tagged and released just below Skaha Dam (SKATAL) and 1,741 were tagged and released from Osoyoos Lake Narrows Bridge (OSOYBR). We were able generate estimates of Release-RRE for both release sites (Table 6). However, we were only able to generate a reliable estimate of RRE-MCN survival for the SKATAL release site, which was 0.70 (95% CI: 0.46-0.95) (Table 6). The estimate of RRE-MCN survival for the OSOYBR release site was greater than 1.0 and, therefore, deemed unreliable. Similar to 2013, this was due to the lower release total for this group and the low number of detections at and below MCN. Of the 35 OSOYBR fish that were detected at MCN in 2015, only five were subsequently detected downstream of MCN. Because the RRE-MCN survival estimate was unreliable for the OSOYBR release site, we could not estimate survival from Release-MCN for this group. However, we were able to estimate Release-MCN survival for the SKATAL release site, which was 0.28 (95% CI: 0.19-0.38) (Table 6).

In 2016, 10,238 total sockeye smolts were PIT-tagged and released from four different release sites in the Okanogan River Basin. Of these, 2,338 were tagged and released at Skaha Lake (SKAHAL), 3,102 were tagged and released just below Skaha Dam (SKATAL), 1,754 were tagged and released from Osoyoos Lake Narrows Bridge (OSOYBR), and 3,044 were tagged and released from Osoyoos Lake (OSOYOL). We were able generate estimates of individual reach survival (i.e., Release-RRE and RRE-MCN) for all four release sites (Table 6). In addition, we were able to estimate Release-MCN survival for all four release sites. These Release-MCN survivals were: 0.38 (95% CI: 0.23-0.53) for the SKAHAL release site, 0.39 (95% CI: 0.19-0.59) for the SKATAL release site, 0.53 (95% CI: 0.31-0.75) for the OSOYBR release site, and 0.51 (95% CI: 0.31-0.75) for the OSOYOL release site. Although the point estimates of Release-MCN survival appear to be lower for the two Skaha release sites (SKAHAL and SKATAL) compared to the two Osoyoos release sites (OSOYBR and OSOYOL), the confidence intervals for all four of these release sites overlap. This indicates that these differences in survival are likely not significant.

A total of 11,588 sockeye smolts were PIT-tagged and released from two different release sites in 2017. Of these, 2,794 were tagged and released from Osoyoos Lake Narrows Bridge (OSOYBR) and 8,794 were tagged and released from Osoyoos Lake (OSOYOL). We were able generate estimates of Release-RRE survival for both release sites (Table 6). However, we were only able to estimate RRE-MCN survival for the OSOYOL release site, as the estimate for the OSOYBR release site was unreliable. Therefore, we were only able to estimate Release-MCN survival for the OSOYOL release site. The 2017 Release-MCN survival for the OSOYOL release site was 0.60 (95% CI: 0.46-0.73).

In 2018, 10,943 total sockeye smolts were PIT-tagged and released from three different release sites. Of these, 1,521 were tagged and released from Osoyoos Lake (OSOYOL), 3,562 were released from Osoyos Lake at Haynes Point Campground (OSOYHA), and 5,860 were released from Skaha Lake (SKAHAL). We were able generate estimates of Release-RRE and RRE-MCN survival estimates for all three release sites (Table 6). In addition, we were able to

estimate Release-MCN survival for each release site separately. The 2018 Release-MCN survivals for the OSOYOL, OSOYHA, and SKAHAL release sites were 0.36 (95% CI: -0.01-0.73), 0.62 (95% CI: 0.44-0.80), and 0.52 (95% CI: 0.39-0.66), respectively (Table 6). Finally, there were a total of 32 detections of PIT-tagged Okanogan River sockeye at ZSL and 13 detections at OKC in 2018. While we were able to estimate travel time and/or timing to these two sites, we were unable to get reliable estimates of survival from release to ZSL or release to OKC, as the estimated detection probabilities at the two sites were extremely low (~0.001).

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, of the 2,794 total sockeye smolts that were tagged and released at this site, only 152 were captured using the fyke net method. With so few tags being released from the fyke net capture method, we were unable to generate reliable estimates of reach survivals for this capture method. Therefore, we were unable to compare the two capture methods.

Table 6. Survival of PIT-tagged sockeye juveniles, by release site, tagged and released into the Okanogan River in 2013-2018.

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)

Capture Methods: ST = Screw Trap, FN = Fyke Net, and PS = Purse Seine

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 2013-2016. These estimates of SARs are based on all release sites combined and are summarized below (Table 7, Figure 3). Due to an unreliable estimate of

juvenile survival for the RRH-MCN reach in 2013 (Table 5), the MCN-to-BOA SAR for 2013 is not provided.

Table 7. Overall McNary-to-Bonneville (MCN-to-BOA) and Rocky Reach-to-Bonneville (RRE-to-BOA) SARs for Okanogan River wild sockeye, 2013-2016.

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[C,D]	--	--	--	--	1,993	8.13	6.96	9.45
2014[C]	2,110	2.99	2.25	3.71	2,937	2.15	1.70	2.66
2015	2,538	1.58	1.06	2.21	3,064	1.31	0.98	1.67
2016[C,E]	4,522	1.68	1.30	2.07	5,777	1.30	1.05	1.56

[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.
[B] CJS estimation of S1 uses both the detector and recaptures at Rocky Reach Dam, as well as PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[C] PIT-tagged sockeye were coded as "unknown" rearing type. Some PIT-tagged smolts may have been hatchery sockeye released into Skaha Lake as fry.
[D] Juvenile survival estimate for RRE-MCN reach was greater than 100%, resulting in an overestimate of the juvenile population at MCN. Therefore, $SAR_{MCN\text{-}to\text{-}BOA}$ was not estimated for this year.
[E] Incomplete, 2-salt returns through Sept. 15, 2018.

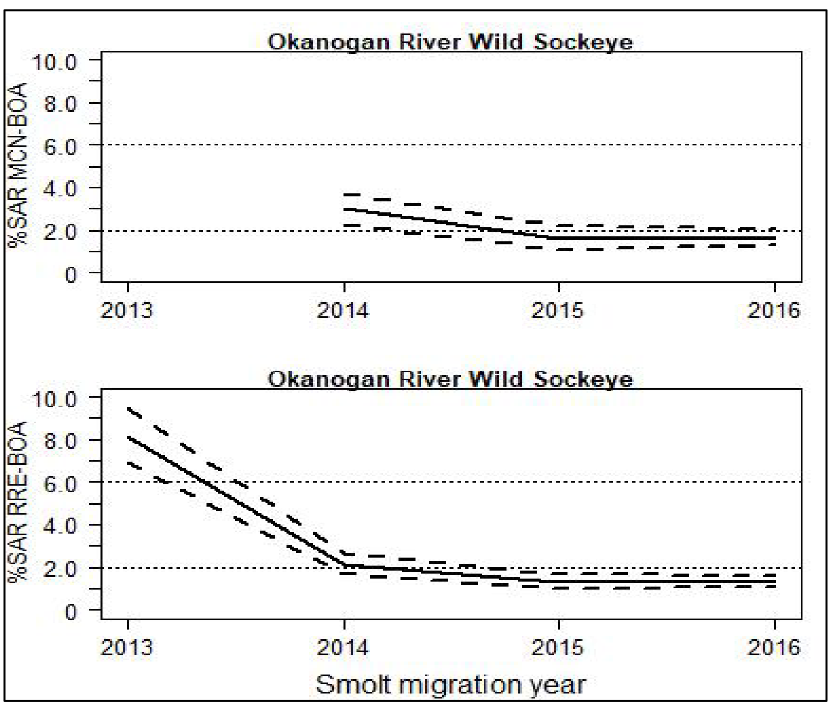

Figure 3. Bootstrapped SAR (MCN-to-BOA and RRE-to-BOA) and upper and lower CI for Okanogan River sockeye, 2013-2016 migration years. The NPCC (2014) 2%-6% SAR objective for listed wild populations is shown for reference. Figure adapted from Figure 4.20 of McCann et al. (2018)

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 both the RRE-to-BOA and MCN-to-BOA reaches. The CSS Oversight Committee hopes 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, C. Petrosky, T. Copeland, E. Tinus, A. Storch, and D. Rawding. 2018. Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye: DRAFT 2018 Annual Report. BPA Contract #19960200.

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

Side-scan Sonar Foreshore Survey for Lacustrine Spawning Salmonines at Okanagan Lake, BC, October 2018

SIDE-SCAN SONAR FORESHORE SURVEY FOR LACUSTRINE SPAWNING SALMONINES AT OKANAGAN LAKE, BC, OCTOBER 2018.

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Disclaimer: Okanagan Nation Alliance Fisheries Department reports frequently contain preliminary data, and conclusions based on these may be subject to change. Reports may be cited in publications but their manuscript status (MS) must be noted. Please obtain the individual author's permission before citing their work.

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ABBREVIATIONS

ONA - Okanagan Nation Alliance
als – above sea level
ppm – parts per million
ppb - parts per billion
ug/L – micrograms per liter
m – meter
ha – hectares
#/cm2 – number per square centimeter
Anon. – anonymous
KHz - kilohertz
GB – Gigabyte
GPS – global positioning system
Nerka –referencing *Oncorhynchus nerka*, either Sockeye and/or Kokanee aggregate

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ABSTRACT

A side-scan acoustic survey was conducted at Okanagan Lake in October 2018. An ultra-high resolution EdgeTech 4125 side-scan sonar was tested, along the eastern shore of Okanagan Lake to assess its potential use for locating aggregations of kokanee (and future referencing for reintroduced sockeye spawners). Data was collected simultaneously with two frequencies: 1600 KHz (25 m range) and 600 kHz (50 m range). Georeferenced data covering approximately 9.5 km of shoreline was processed and analyzed in SonarWiz Version 7.02.05 64-bit Edition.

The side-scan sonar data provided excellent imagery of the bottom structure and substrate. The identification of fish, however, proved to be more challenging. In the data analyzed we found two examples indicating the presence of > 10 fish and five smaller groups. Our analysis of this test dataset indicates that, while side-scan sonar is not suitable as a stand-alone tool for the quantitative detection of kokanee in Okanagan Lake, it may be able to help locate aggregations of kokanee, especially if used in conjunction with other sampling tools (e.g. split-beam sonar aimed sideways or at an oblique angle), and/or associate aggregations with habitat. Side-scan sonar's biggest contribution is excellent qualitative information, especially where habitat type and structure provide valuable context. As is true of most other gear types, side-scan sonar should be augmented with independent information for further corroboration.

Based on the surveys completed in 2018, we recommend the following for the purpose of supporting the ONAs broader interests in improved management of resident and anadromous fish stocks in the Okanagan watershed, and specifically the Okanagan kokanee (and future sockeye) beach spawning ecotypes:

1. Use side-scan sonar in conjunction with other sampling tools (e.g. split-beam sonar aimed sideways or at an oblique angle) to help locate aggregations of kokanee and/or associate aggregations with habitat. Develop a step wise approach to designing large lake monitoring programs for beach spawning populations using these passive acoustic gears to locate aggregations, and supplement with active acoustic telemetry (Vemco, ATS, Lotek) to refine abundance estimates for fisheries management decisions;
2. Improvements to *Foreshore Sensitive Habitat and Inventory Methods* should consider integrating side-scan sonar techniques. Confirm side-scan substrate characterization for habitat inventory and impact assessments in terms of foreshore lake development with complementary underwater videography and/or standard sediment collection methods, along with repeat surveys using sides can sonar every five years.

INTRODUCTION

In 2014, following the direction of Grand Chief Phillip and ONA Chief Executive Council, a process was established by ONA fisheries for the reintroduction of Anadromous Salmon to Okanagan Lake. The study findings from this report may inform a collaborative process to implement further studies and/or develop management recommendations. The 2018 feasibility study using acoustic technologies for monitoring adult beach spawning sockeye comprises one facet of the broader Syilx (Okanagan) Salmon Reintroduction Program. The overall goal of this fall survey is to:

a) test novel methods for assessing population abundance, distribution, and behaviour of beach spawning salmon(ines) in Okanagan Lake, and
b) test novel methods for monitoring foreshore development and habitat impacts to salmonids within large lakes, including the Okanagan.

This report documents the results from the feasibility testing at Okanagan Lake in 2018. The purpose of this report is largely to document sampling methods and recommend methods to calibrate and improve sockeye production estimates for the Okanagan basin.

Lake Characteristics

The Okanagan Lake Nerkid Lake Rearing System (Wood, Kalamalka, Okanagan, Skaha, and Osoyoos Lakes; Table 1) is the northernmost migration destination for sockeye salmon (*Oncorhynchus nerka*) in the Okanagan River watershed (Stockner and Northcote, 1974). The system currently contains one sockeye run of stream type spawners: with fish arriving at spawning grounds in late September (Hyatt and Rankin, 1999). Traditional ecological knowledge recognizes and early (May) and late (September) sockeye run in the Okanagan River, as well as beach spawning populations (Dr. Jeanette Armstrong, *pers. comm.*).

Table 1. Limnological and biological characteristics of Okanagan Lake. Sources: Stockner and Northcote. 1974; Canada-British Columbia Consultative Board 1974.

	Wood	**Kalamalka**	**Okanagan**	**Skaha**	**Osoyoos**
Volume (10^6 m^3)	200	1,520	26,200	558	397
Surface Area (10^6 m2)	9.3	25.9	348.0	20.1	23.0
Mean Depth (m)	22	59	76	26	14
Perimeter	16.7	42.4	270.0	29.5	47.9

(km)					
Water Residence Time (Yrs.)	19.8	71.3	59.7	1.2	.7
Growing Season					
Mean Total Phosphorus (ppm)	0.083	0.04	0.02	0.015	0.015
Mean Total Nitrogen (ppm)	0.026	0.023	0.020	0.010	0.016
Mean Chl a (ug/l)	50.0	2.5	5.0	31.0	23.0
Secchi Depth (m) (Apr-Oct)	2.5	9.0	8.0	4.5	3.3
Zooplankton Avg. Density (#/cm^2)	139	136	101	233	76
Salmonids biomass (%)	12	49	49	33	40

<u>Physical Characteristics</u>

Okanagan Lake is the larger of the nerkid rearing lakes chain, with a surface area of 350 square kilometres, length of 110 km, and mean depth of 75 m (Figure 1, Anon, 2006). Stockner and Northcote describe the Okanagan Lake basins in detail (Stockner and Northcote, 1974). Okanagan Lake has an elevation of at 342 m elevation a.s.l. . Water residence time is > 60 years (Anon. 2006).

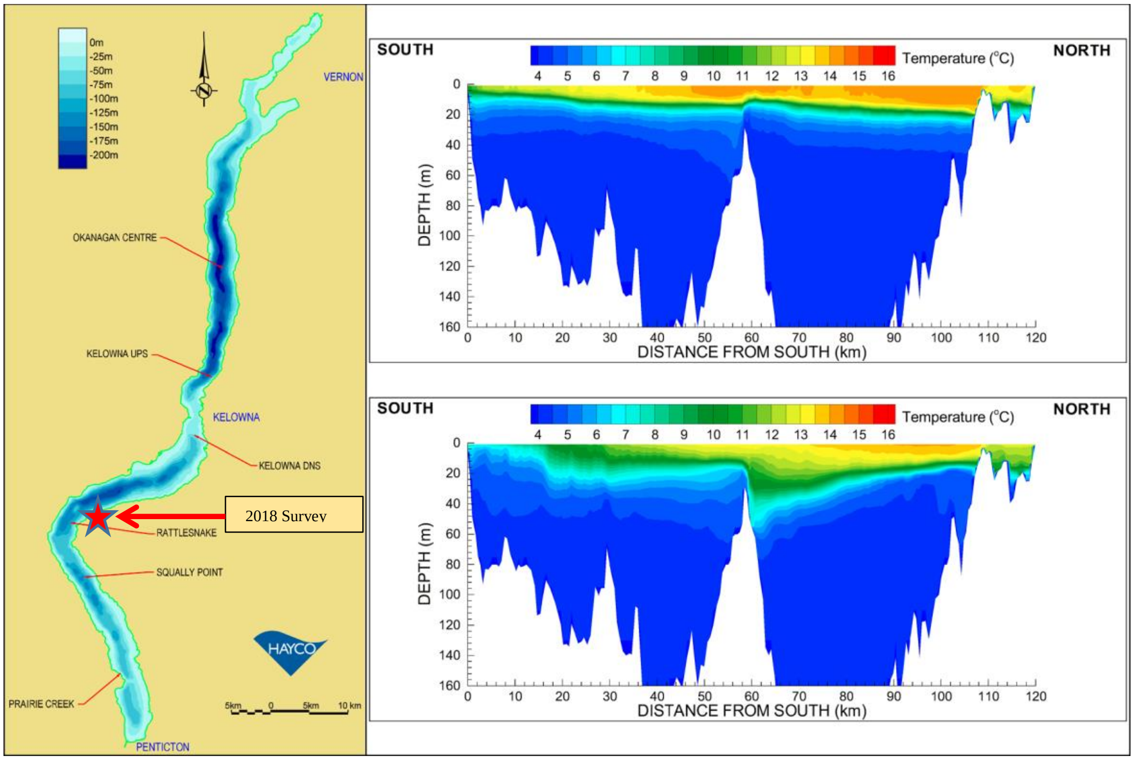


Figure 1. Bathymetry and longitudinal profile of Okanagan Lake, Prepared by EBA Consultants for Okanagan Basin Water Board, June 10, 2010 Presentation by Jim Stonach. Note: Location of 2018 Survey.

Water Chemistry

Anon (2006) described Okanagan Lake having a constant temperature of 4° C from surface to bottom during the winter, mixing of water results in contact oxygen levels in winter, with N:P ratios of 12:1. Mean epilimnetic phosphorus levels in winter were 4 ppb and nitrate levels were 48 ppb (Anon, 2006).

Fish Species

Okanagan Lake supports populations of Kokanee, Sockeye Salmon, Rainbow Trout (*Oncorhynchus mykiss*), Rocky Mountain Whitefish *(Prospium williamsoni)*, and Lake Whitefish (*Coregonus clupeaformis*). Other resident indigenous fish species observed in the watershed are sculpin (*Cottus spp.*), sucker (*Catostomus spp.*), Lake shiner (*Richardsonius balteatus*), Peamouth Chub (*Mylocheilus caurinus*), Longnose Dace (*Rhinichthys cataractae*), silver grey minnow (*Apocope falcata*), Burbot (*Lota lota*), and Northern Pike Minnow (*Ptychocheilus oregonensis*). Prior to dam construction, Chinook (*Onchorrhynchus tschawytscha*), sockeye (*O. nerka*), coho (*O. kisutch*), and Steelhead (*O.mykiss*) (Clemens, 1935).

In addition, exotic species were introduced to the lake including: Black Bullhead

(*Ameiurus melas*), Common Carp (*Cyprinus carpio*), Pumpkinseed (*Lepomis gibbosus*), Smallmouth Bass (*Micropterus dolomieu*), and Yellow Perch (*Perca flavescens*).

METHODS

Field Reconnaissance & Training

Feasibility testing sidescan technologies and data collection protocols occurred between 17 September and 19 September 2018. An ultra-high resolution EdgeTech 4125 side-scan sonar was tested in Okanagan lake along the east shore to characterize "known" kokanee beach spawning habitat. Higher than normal flows in the Penticton Channel and vessel-crew safety concerns precluded testing the unit in a riverine environment.

A lower cost commercial 1197c hummingbird side scan sonar was tested in the Penticton Channel on 23 October, 2018. A total of two hours data was collected from the outlet of Okanagan Lake to Shingle Creek. Resolution of recorded files was poor to low, and no additional processing was completed.

Foreshore Side-Scan Survey and Visual Observations

A single segment was used for side-scan mapping at Okanagan Lake (Figure 3) in a northerly direction. The start and end points for the completed survey (22 October) was N 49°43'26", W 119°43'21", and N 49°46'41", W 119°37'29", respectively, using a Garmin ETrex 20 ® global positioning system. The segment was located in areas of maximum depth ranging from 2 m to 20 m, and covering approximately 12 km of lake within four hours at a vessel speed of 3 km/hr.

Acoustic data was collected using an EdgeTech 4125 side-scan sonar. The sonar towfish was towed approximately 0.5 m below the water surface, sampling a total swath of 100 m with 600 kHz and 50 m with 1600 kHz. Data for the two frequencies are recorded simultaneously.

Acoustic processing

Most of the data recorded on October 22nd, 2018 (18:01 – 20:25 or 6.1 GB out of total of 8.3 GB) were processed and analyzed in SonarWiz Version 7.02.05 64-bit Edition. The remaining 2.2 GB, recorded after 20:25, could not be analyzed in SonarWiz because it was missing GPS information. These data could instead only be reviewed in replay mode in EdgeTech Discover 4125 software.

The georeferenced data analyzed in SonarWiz covered approximately 9.5 km of shoreline. A subset spanning approximately 3 km was cross-examined with data collected over the same area on September 18th, 2018, 17:25 – 17:58. Side scan data processing in SonarWiz involved bottom tracking, gain normalization (SonarWiz EGN function) to compensate for range dependent variation in image brightness, and marking potential fish sightings or other observations of interest. The georeferenced marks were imported into ArcGIS to be mapped over satellite imagery.

SIDESCAN SURVEY RESULTS & DISCUSSION

The georeferenced data analyzed in SonarWiz covered approximately 9.5 km of shoreline (Figure 2).

Figure 2. A segment of the easterly shoreline of Okanagan Lake (in proximity to Rattlesnake Island) surveyed using an EdgeTtech side-scan sonar and analyzed in SonarWiz software for habitat complexing and fish aggregations, 22 October, 2018.

The side-scan sonar data provided excellent imagery of the bottom structure and substrate. The identification of fish, however, proved to be more challenging. Side-scan sonar has been successfully used to identify very large fish (e.g. > 1m sturgeon) over a uniform background. The detection of smaller fish is less reliable. Over uniform fine-grained sediment smaller fish may still be detected, especially aggregations of fish or when they cast conspicuous shadows that are clearly not associated with rocks. However, over coarser gravel or cobble, their images or shadows blend into the speckled background, to an extent that makes the interpretation (rock or fish) too ambiguous. Under these circumstances, reasonably reliable detection of fish is limited to the dark "water column" portion of the side scan image in "waterfall view" (i.e., data displayed in range over time). The "water column" portion of the image refers to the dark center between the nearest bottom echoes received on the port and starboard side. It is important to note that, over the swath sampled, not all fish that are physically in the water column will appear in the "water column" portion of the side scan image (Figure 3). The closer to the bottom the fish are in the real world, the narrower the cross-track distance over which they will be seen in the "water column" portion of the side scan image. At a farther distance from the track center line fish may still be in the sampled volume and therefore produce echoes, but they will be superimposed on echoes generated by the bottom, where they may or may not be detected.

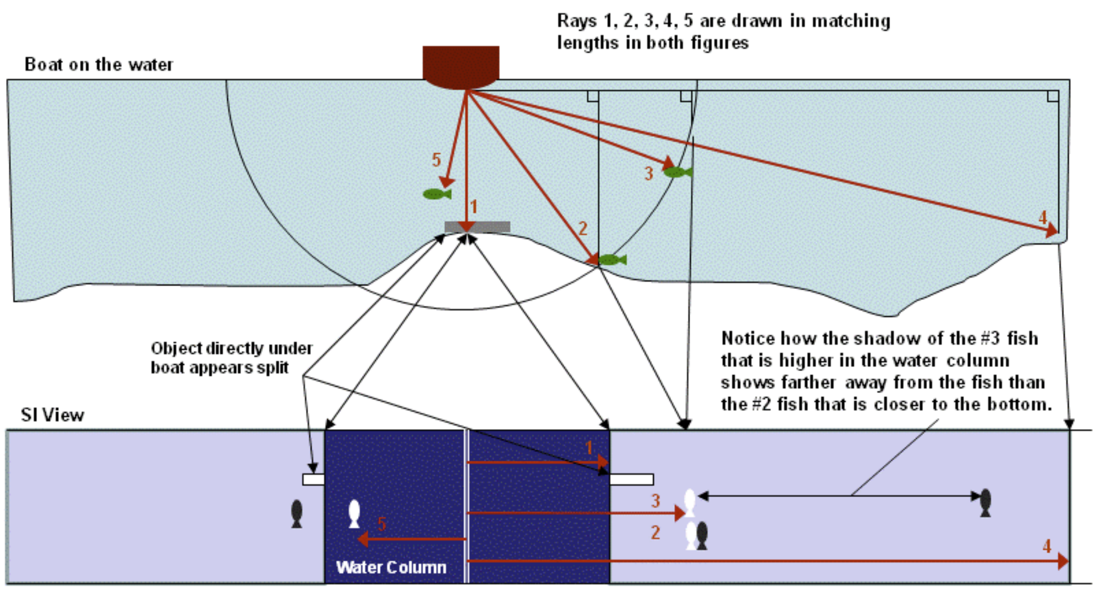


Figure 3. Diagram by Tom Vickers (from:forums.sideimagingsoft.com/index.php?topic=946.0) showing the relationship between the real-world geometry of objects (upper part of the diagram) and how they and their shadows appear on a sides can image in "waterfall view" without slant range correction (lower part of the diagram). Note how fish 5 (ray 5) is seen at a shorter range than the nearest bottom return

(ray 1) and therefore appears in the dark “water column” part of the image. Fish 3 (ray 3) is also well above the bottom but, because it is seen at a farther range than the nearest bottom it superimposes over the brighter part of the image, which represents returns from the bottom over the range illuminated. Depending on the size of the fish and the brightness and texture of the background, fish 2 and 3 may blend into the background and not be detected.

In the data analyzed in SonarWiz we found two examples indicating the presence of > 10 fish (see map in Figure 2 and images in Figures 4 and 5) and five smaller groups (see map in Figure 2 and image in Figure 6). When there is no clear separation between the bright objects that could potentially be fish and the bottom return, there can be some ambiguity. Based on its zoom view, we believe the example shown in Figure 7 are rocks.

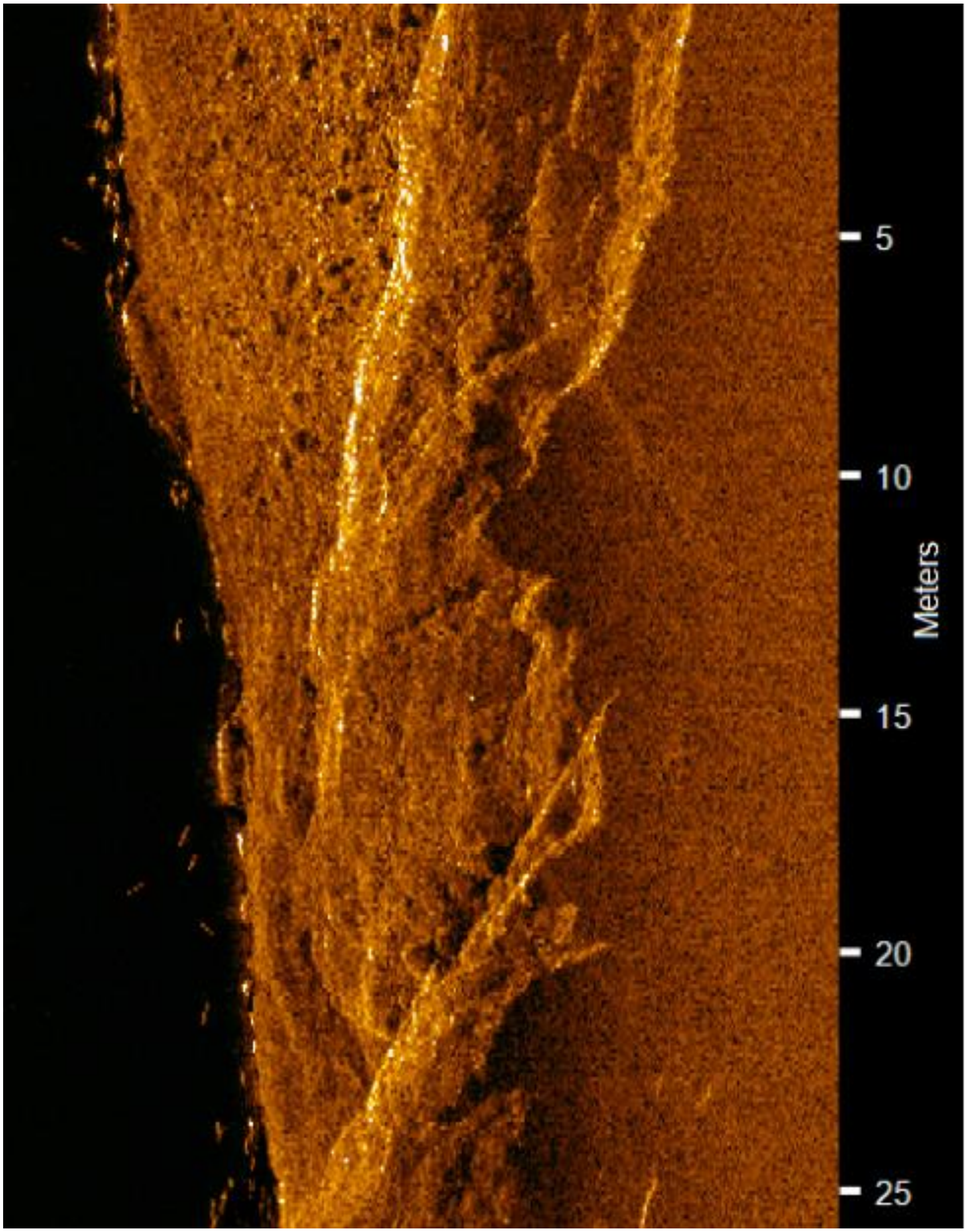


Figure 4. Aggregation of > 10 fish (approximate length: 30 – 50 cm) seen in the "water column" portion of the image. Water depth: 8 – 11 m. Shown is the starboard side of the waterfall view of 1600 kHz data collected 2018-10-22 19:51:33.

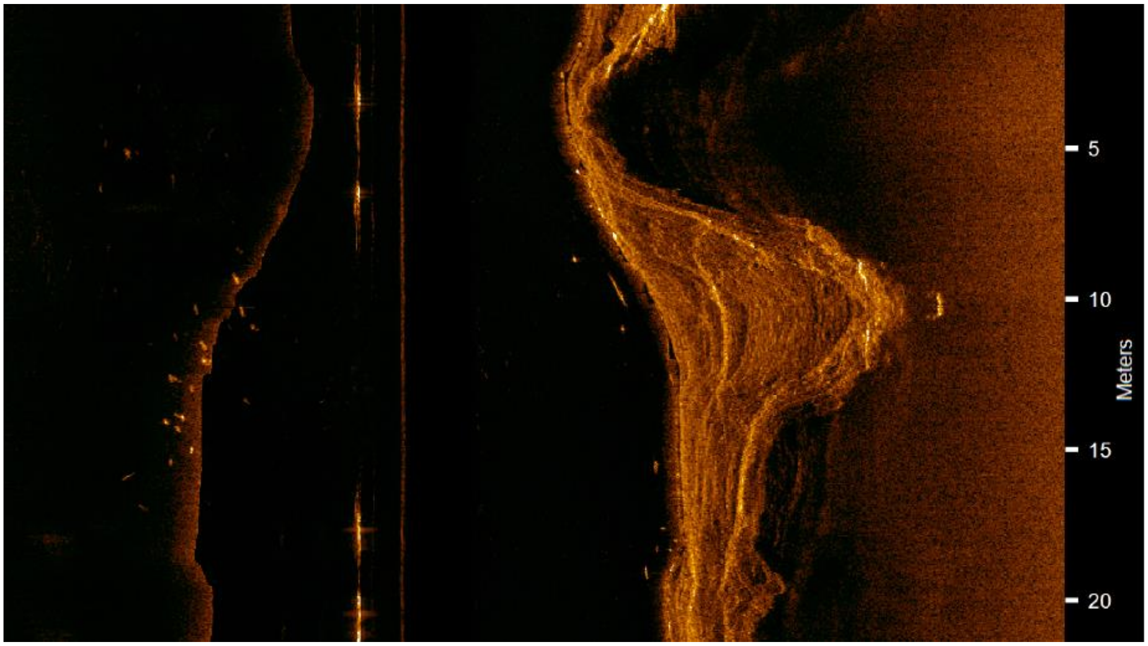


Figure 5. Aggregation of > 10 fish (approximate length: 30 – 50 cm). Water depth: 6 – 8 m. Shown is the waterfall view of 1600 kHz data collected 2018-10-22 18:19:09. Note the interpretation of the left side of the image is confounded by the portside beam being partially blocked by the hull of the boat (possibly in a way that shadowed the bottom while still illuminating objects, like fish, that are physically above the bottom).

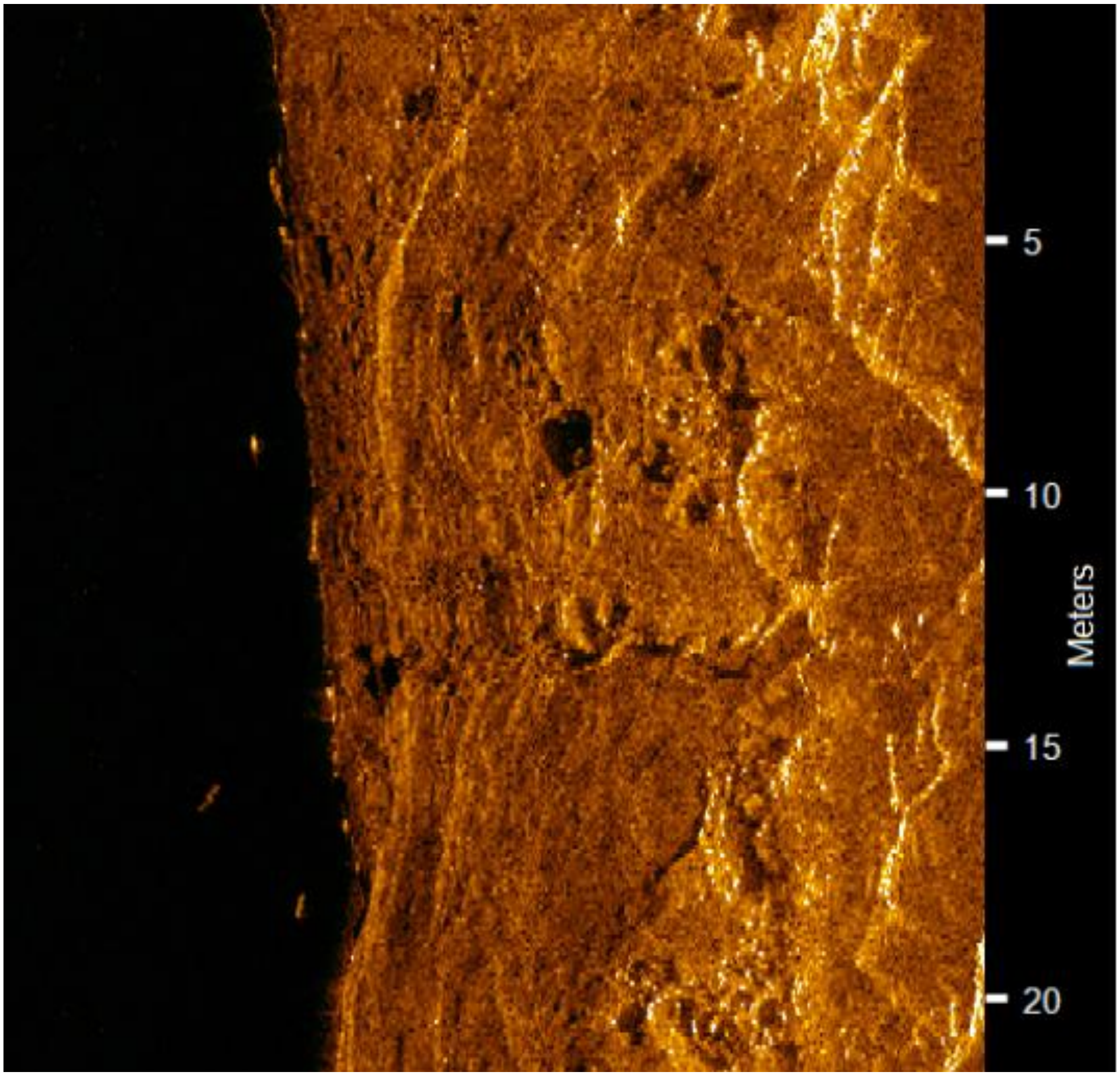


Figure 6. Aggregation of < 10 fish (approximate length: 30 – 50 cm). Water depth: 9 – 10 m. Shown is the starboard side of the waterfall view of 1600 kHz data collected 2018-10-22

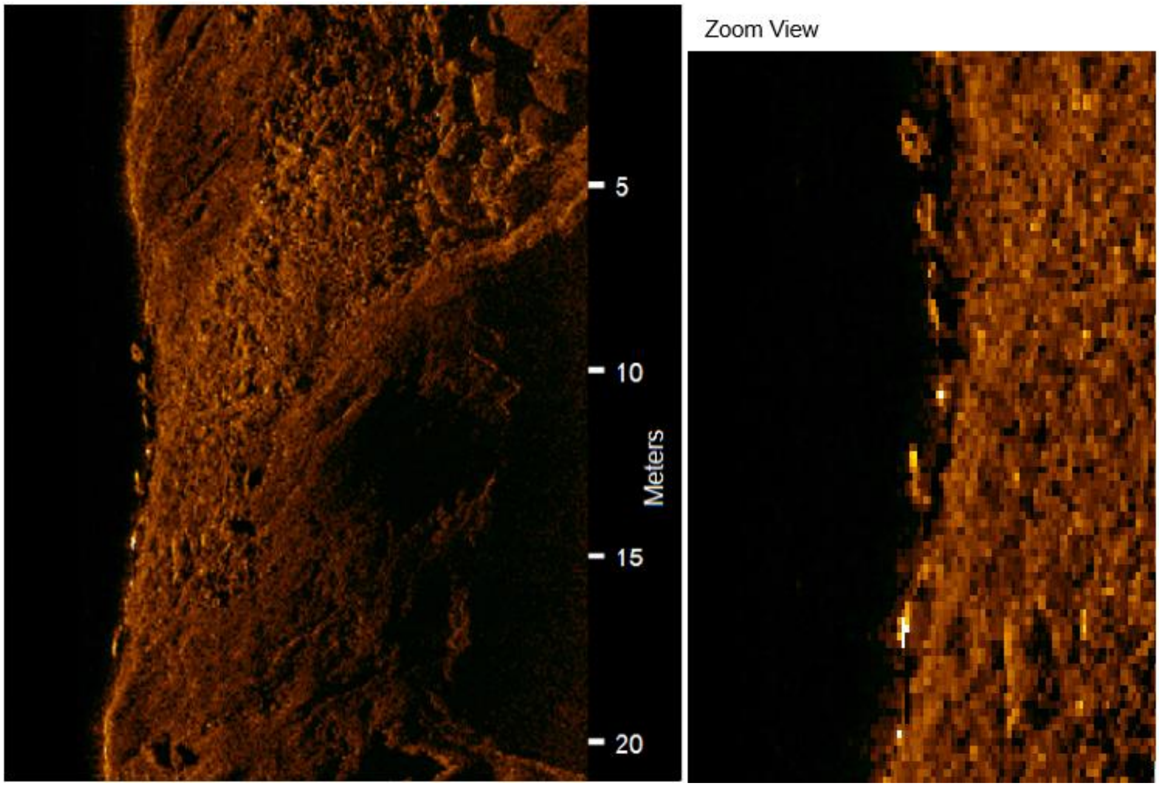


Figure 7. Objects interpreted as bright leading edges of rocks along the bottom. Shown is the starboard side of the waterfall view of 1600 kHz data collected 2018-10-22 19:14:37. Note the potential ambiguity and confusion with fish at lower zoom level.

Looking for fish shadows, we found one group of > 10 fish shadows (see map in Figure 2 and image in Figure 8). The interpretation that these are fish shadows is supported by the fact that side scan imagery collected a month earlier in the same location shows the same background without this particular group of shadows (Figure 9). This example demonstrates how the comparison of georeferenced imagery collected in the same area at different times can provide valuable clues that help distinguish stationary objects like rocks from moving fish. While it may not be practical to duplicate an entire survey, it may be well worth resampling selected areas with potential fish sightings at a later time, at least initially, to increase the confidence, with which the images can be interpreted.

The caveats discussed in our results mean that the effective sampling volume where aggregations of fish could be detected depends on depth (deeper water provides a larger "water column" portion of the image where fish can be clearly seen against a black background) and substrate (groups of fish or their shadows can be detected over a uniform background like sand but not necessarily over the speckled background of e.g. gravel or cobble). Given the relatively small effective sampling volume of the "water column" portion of the image, boat avoidance may also play a role, biasing detection towards fish in deeper water. All the fish observations made in this test set occurred in areas where water depth ranged from 4 – 10 m

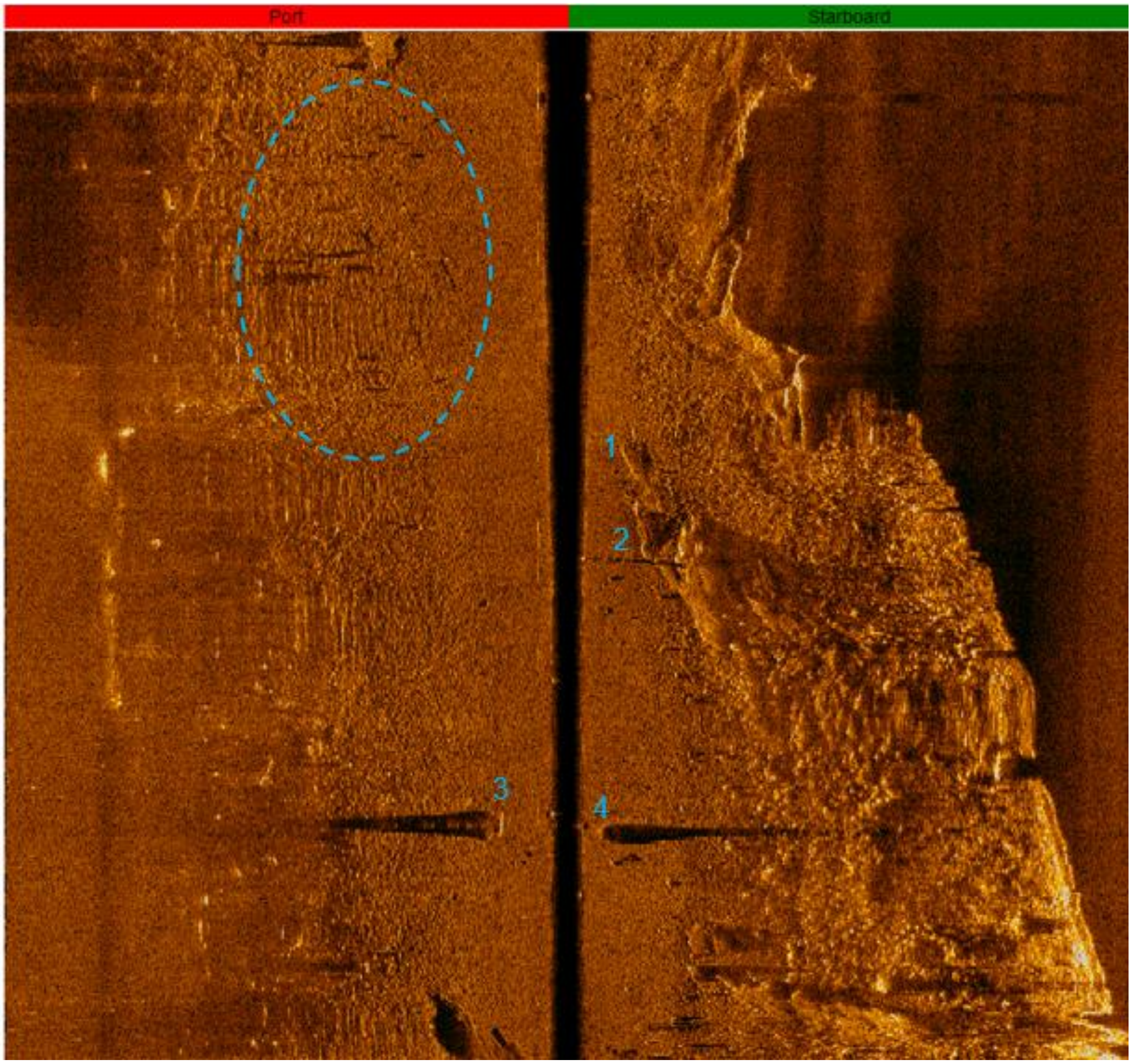


Figure 8. Shadows (within the dashed blue circle) of > 10 fish, over relatively uniform bottom. Shown are the port and starboard side of the waterfall view (covering approximately 70 m along track) of 600 kHz data collected 2018-10-22 19:00:0. Compare with the image collected in an earlier survey (Figure 1), in particular, the area where the shadows are cast and the relative geometry between the 4 stationary objects that are marked with numbers.

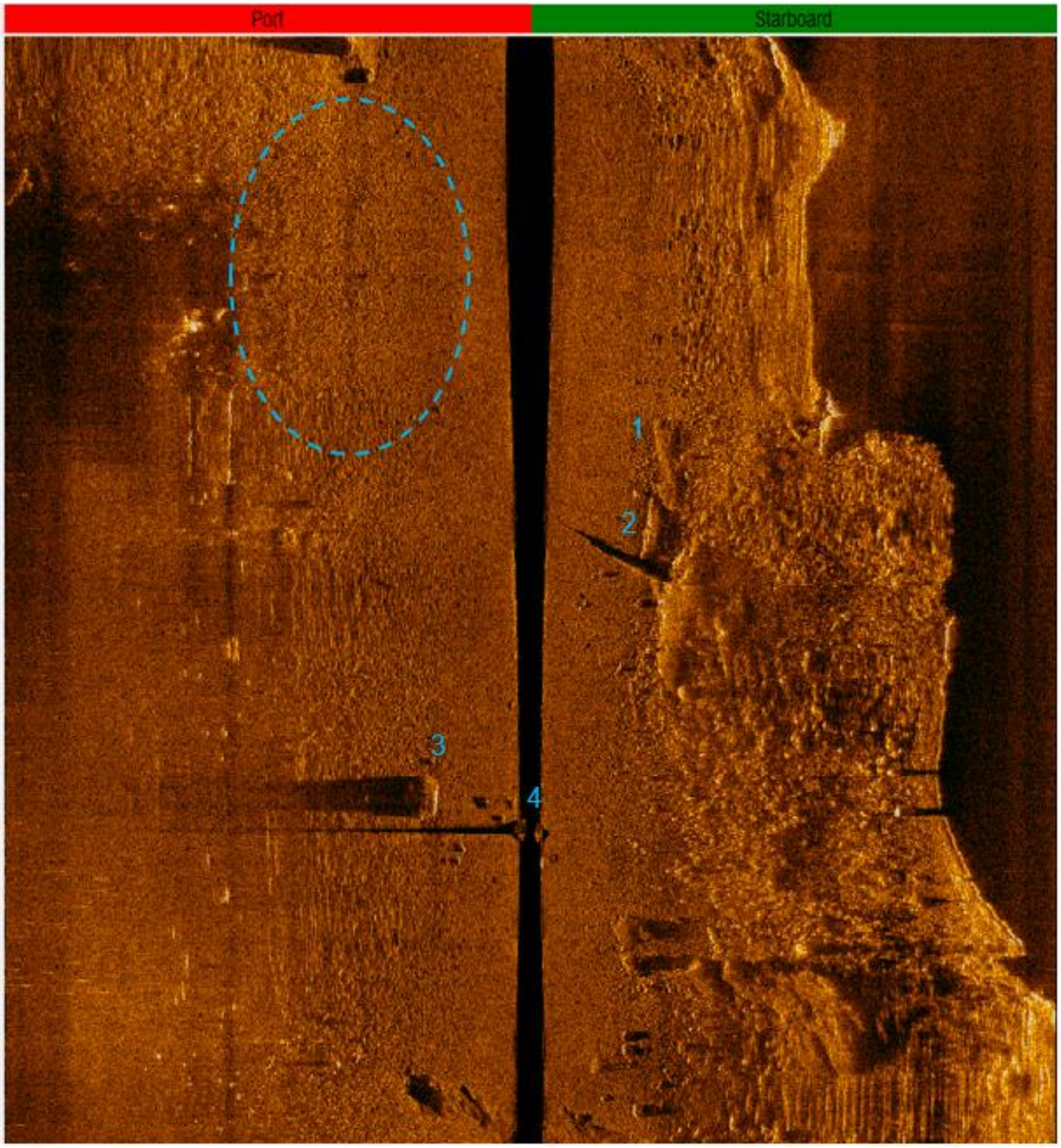


Figure 9. Side scan image of the same area shown in the previous example, as it appeared in an earlier survey. Shown are the port and starboard side of the waterfall view (covering approximately 70 m along track) of 600 kHz data collected 2018-09-18 17:33:50.

In our review of the last third of the data collected on October 22nd, 2018, (which had to be done in EdgeTech Discover replay because of the missing GPS information), we found one more example of an aggregation of > 10 fish in the "water column" and two more examples of < 10 fish.

Other interesting features encountered in our review include the large tree shown in Figure 10 (mapped in Figure 2) and an especially conspicuous patch of aquatic vegetation, shown in Figure 11 (from data collected towards the end of the survey, after GPS had been lost).

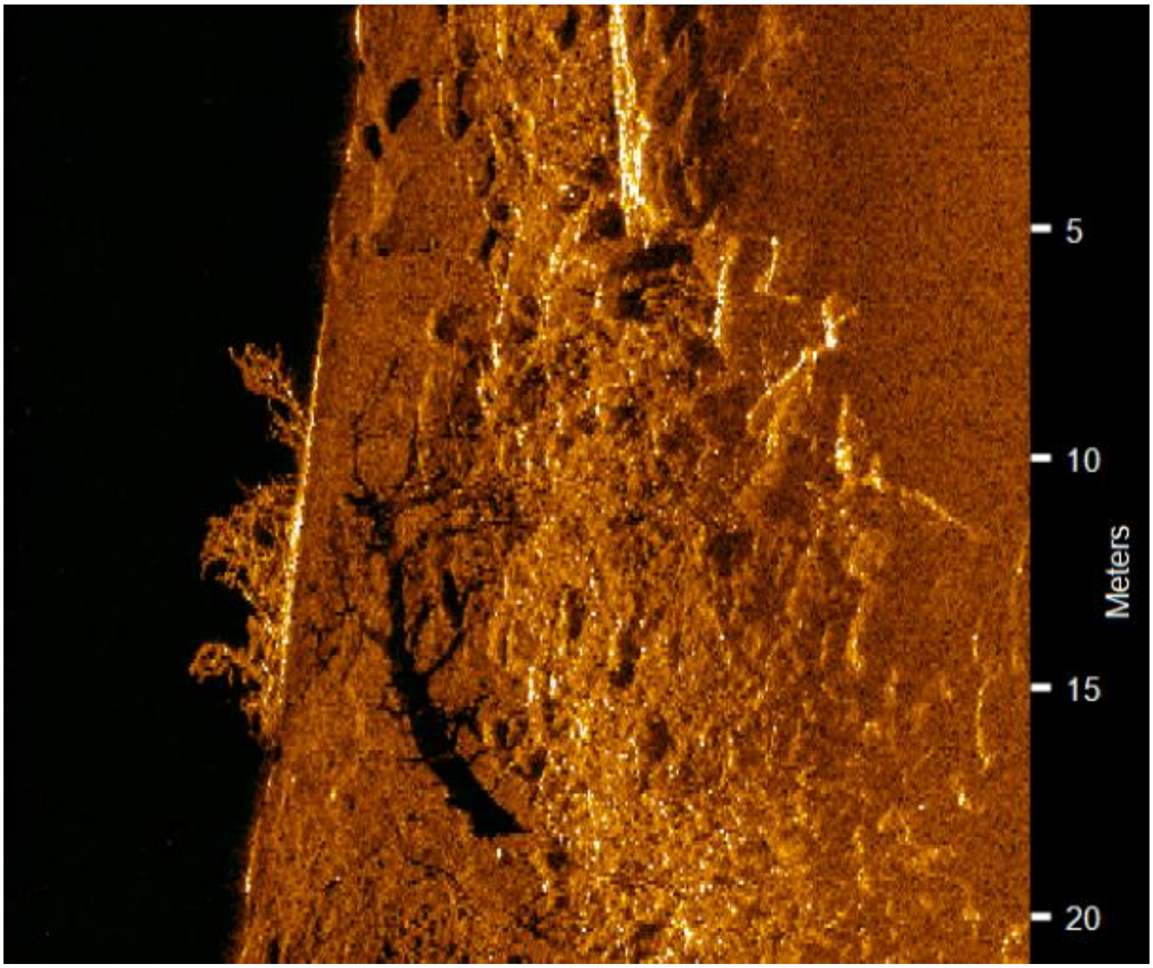


Figure 10. Submerged tree. Shown is the starboard side of the waterfall view of data collected 2018-10-22 18:43:21. Note the conspicuous shadow of the trunk and branches, and direct reflections from the branches extending into the "water column" part of the image.

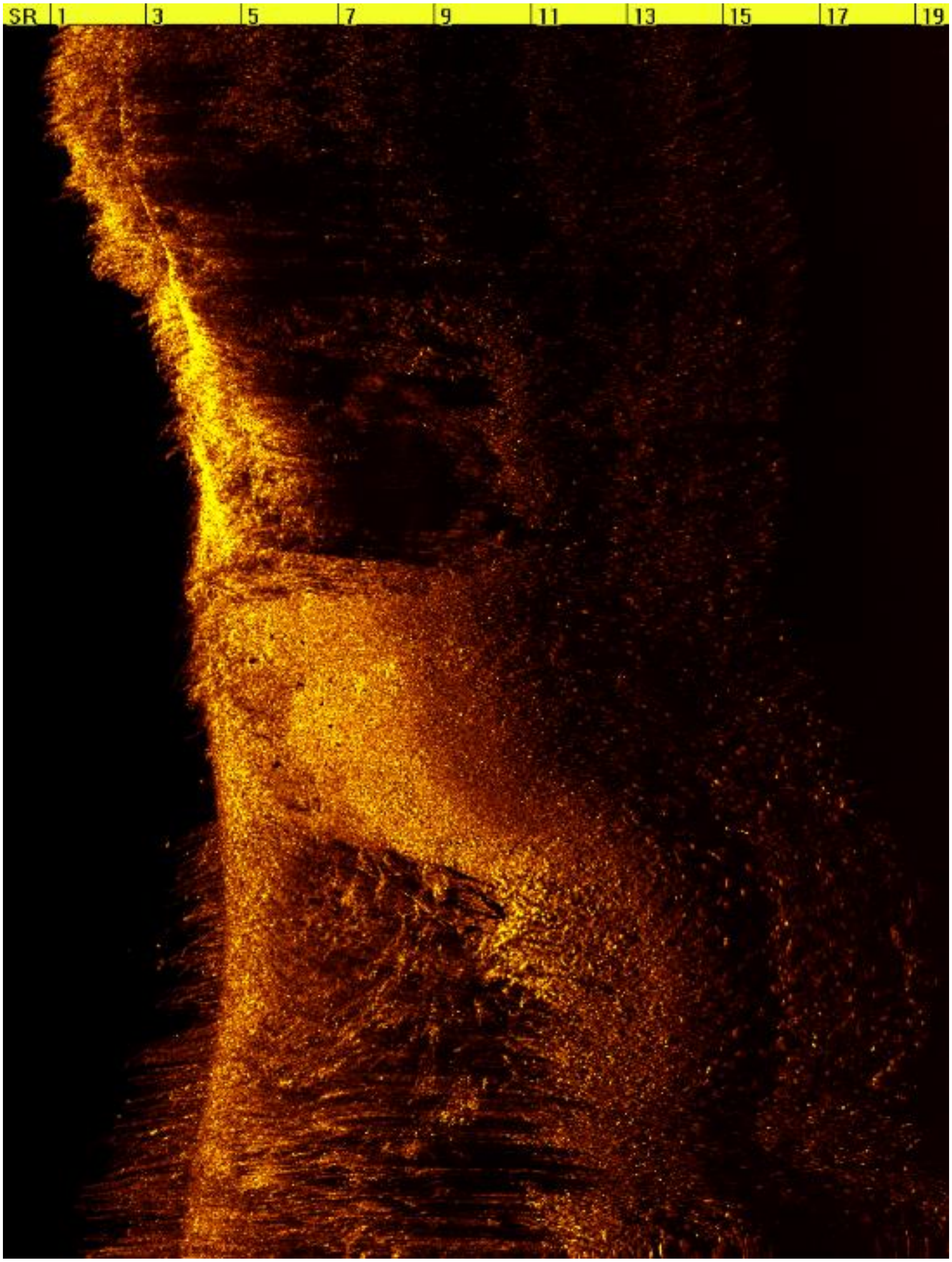


Figure 11. Patch of aquatic vegetation. Shown is the starboard side of the waterfall view (EdgeTech Discover software) of data collected 2018-10-22 21:02:30.

DISCUSSION & RECOMMENDATIONS

Evaluating aquatic habitats is an important component of ecological studies and resource assessments. Conventional fisheries surveys are time and labour intensive and do not provide continuous data. Robust methods in large riverine and lake environments using side-scan sonar to quantify suitable fish spawning habitat and monitor artificial reef enhancements have been outlined, as follows for: Lake Trout (Edsall et al. 1989), sturgeon (Walker et al. 2016), walleye (Graham et al. 2017); and general reef restoration for lakes (McLean et al. 2015). To our knowledge, this is the first report to test methods for sockeye beach spawning using side-scan sonar. With future climate uncertainties and plastic reproductive strategies of sockeye and kokanee demonstrating fluvial and lacustrine spawning and recovery goals for biodiversity, one should not discount the concept of assessing measures for compensation and mitigation of this species as related to the creation, rehabilitation and restoration of spawning habitat in the lakes (e.g. all spawning habitat enhancement has focussed on riverine projects to date in the Okanagan River basin.). Moving sockeye recovery forward, we assume the highest gains in productivity will remain from the stream spawning types (e.g., H_o> 95% of the population), but recommend with facing climate uncertainties and salmon recovery potential in the middle Columbia Basin (Okanagan) and future upriver reintroduction programs, that prescriptions for beach spawning habitat protection, enhancement, and restoration be considered, as a component for adaptive management strategies (i.e. sustaining life histories for kokanee re-anadromization and sockeye residualization).

Based on the surveys completed in 2018, we recommend the following for the purpose of supporting the ONAs broader interests in improved management of resident and anadromous fish stocks in the Okanagan watershed, and specifically the Okanagan kokanee (and future sockeye) beach spawning ecotypes, using Fall side-scan surveys:

- Use side-scan sonar in conjunction with other sampling tools (e.g. split-beam sonar aimed sideways or at an oblique angle) to help locate aggregations of kokanee and/or associate aggregations with habitat. Side-scan sonar’s biggest contribution is excellent qualitative information, especially where habitat type and structure provide valuable context.
- If funds (> 250,000) are available, mark recapture abundance estimators using active acoustic technologies (e.g. Vemco, or Combined Radio Acoustic Technologies (LOTEK-CaRT)), could be considered to validate stream versus lake spawning abundance of kokanee and future sockeye stocking.
- Confirm side-scan substrate characterization for habitat inventory and impact assessments in terms of foreshore lake development with complementary underwater videography and/or standard sediment collection methods, along with repeat surveys using sides can sonar every five years.

REFERENCES

Anon. 2006. Ten year summary of the Okanagan Lake Action Plan (1996-2005). Min. Environment, January 2006. p36.

Clemens, W.A., D.S. Rawson, and J.C. McHugh. 1935. A biological survey of Okanagan Lake, British Columbia. Bull. Fish. Res. Bd. Can. LVI.

Edsall, T.A., T.P. Poe, R.T. Nester, and C.L. Brown. 1989. Side scan sonar mapping of Lake trout spawning habitat in Northern Lake Michigan. N. Am. J. Fish. Mgmt. 9:269-279.

Graham, J.D., A.W. Hafs, and A.J. Kennedy. 2017. Quantification of walleye spawning substrate in a Northern Minnesota River using side scan sonar. N. Am. J. Fish. Mgmt. 37:420-428.

Hyatt, K.D. and D.P. Rankin. 1999. A habitat based evaluation of Okanagan Sockeye Salmon Escapement Objectives. CSAS Research Document 99/191, p 59.

McLean, M, E. Roseman, J. Pritt, G. Kennedy, and B. Manny. 2015. Artificial reefs and reef restoration in the Laurentian Great Lakes. J. Great Lakes Research. 41 (1):1-8.

Stockner, J.G. and T.G. Northcote. 1974. Recent limnological studies of Okanagan Basin lakes and their contribution to comprehensive water resource planning. J. Fish. Res. Board Can. 31: 955-976.

Walker, D.J., and J.B. Abford. 2016. Mapping Lake Sturgeon spawning habitat in the upper Tennessee River using side scan sonar. N. Am. J. Fish. Mgmt. 36:1097-1105.

APPENDIX F

Lake Wenatchee and Osoyoos Lake Juvenile Sockeye Salmon and Limnology Comparison Brood Years 2009-2016 (in-lake 2010-2018)

FINAL Wenatchee Osoyoos Comparison 2019.11.27c

LAKE WENATCHEE AND OSOYOOS LAKE JUVENILE SOCKEYE SALMON AND LIMNOLOGY COMPARISON BROOD YEARS 2009-2016 (IN-LAKE 2010-2017)

November 2019

SUMMARY

The most important result: Growth rates and rates of survival for age-0 Sockeye Salmon in Lake Wenatchee and Osoyoos Lake are very similar. Lake Wenatchee has a substantial additional capacity to support production of more than the average density (i.e. 2200 ha^{-1}) of juvenile Sockeye recorded during 2010-17.

Physical conditions: Both lakes have similar surface areas (Lake Wenatchee = 1011 ha and Osoyoos Lake = 933 ha) but Lake Wenatchee is slightly deeper and has a much greater water volume (Lake Wenatchee = 444,052,800, m^3 and Osoyoos Lake 276,540,800 m^3.

Lake Wenatchee river discharge rates were about twice as high as they were for Osoyoos Lake (Lake Wenatchee = 103 m^3 sec^{-1} and Osoyoos Lake = 54 m^3 sec^{-1}). However, because Lake Wenatchee has a larger lake volume than Osoyoos Lake, these high rates of water flow were associated with lake-turnover times that were about the same in both lakes (50-140 days). In Lake Wenatchee, water temperature is negatively associated with rates of river discharge.

Because of its elevation, spring to summer water temperatures in the epilimnion of Lake Wenatchee (average 11-15^{O}C) were much lower than in Osoyoos Lake (15-17 ^{O}C). It is likely that this influenced Sockeye growth rates. Lake Wenatchee had a highly oxygenated hypolimnion. Hypolimnetic oxygen in Osoyoos Lake was substantially lower.

Chemical conditions: Lake Wenatchee is oligotrophic (epilimnetic TP average 5.5 $\mu g\ L^{-1}$). Osoyoos Lake is mesotrophic (epilimnetic TP average 9.2 $\mu g\ L^{-1}$). Calcium concentrations in Osoyoos Lake (20-30 mg L^{-1}) are relatively high. Calcium concentrations in Lake Wenatchee (1.5-2.7 mg L^{-1}) are near the lower limit for successful growth and reproduction of *Daphnia*.

Phytoplankton: Phytoplankton biovolume in Osoyoos Lake was **3 times** higher than in Lake Wenatchee, but the high percent edibility for Lake Wenatchee phytoplankton taxa resulted in edible phytoplankton biovolumes that were only **1.5 times** higher in Osoyoos Lake than in Lake Wenatchee (Osoyoos average = 275 mm^3 m^{-3}, Wenatchee = 176 mm^3 m^{-3}).

Zooplankton: Osoyoos Lake had higher species diversity and biomasses of zooplankton than Lake Wenatchee (Wenatchee June-August average zooplankton biomass = 25 $\mu g\ L^{-1}$, Osoyoos Lake = 67 $\mu g\ L^{-1}$). The Lake Wenatchee zooplankton community was dominated by *Hesperodiaptomus* a very large copepod species (>30 µg dry weight) that provides excellent food for age-0 Sockeye. The Osoyoos Lake zooplankton community comprised smaller species and also included *Mysis* an important consumer of zooplankton and a competitor for age-0 Sockeye.

Sockeye fry: Year 2010-17 average Sockeye fry densities in Lake Wenatchee were less than half of the average densities maintained in Osoyoos Lake (Wenatchee = 2201 $ha^{-1,}$ Osoyoos = 5042 ha^{-1}). Sockeye biomasses in Lake Wenatchee were much lower than in Osoyoos Lake (Osoyoos = 23,828 g ha^{-1}, Wenatchee = 5914 g ha^{-1}). This was principally due to the large number of age-1 Sockeye fry in Osoyoos Lake,

Average age-0 Sockeye lengths and weights recorded in September of each year were almost the same (lengths for Wenatchee = 58 mm and Osoyoos = 61 mm) (weights for Wenatchee = 2.0 g and Osoyoos = 2.4 g mm). During the four years when data were available (2014-17) age-0 Sockeye September to winter mortality was similar (Wenatchee = 25% and Osoyoos = 30%). Spring to summer mortality observations were unavailable for Lake Wenatchee.

The average temperature at depths occupied by Lake Wenatchee Sockeye were colder (9.8^{O}C) than in Osoyoos Lake (11.0 ^{O}C) and the spring-to-summer epilimnetic temperatures in Lake Wenatchee were also colder (17 ^{O}C vs 21-22 ^{O}C). This suggested that age-0 Sockeye would need to consume more prey in Lake Wenatchee than in Osoyoos Lake in order to achieve the same growth rates. Bioenergetics calculations which estimate ration size with respect to temperature mediated rates of digestion and assimilation showed that this was the case. Sockeye fry in Lake Wenatchee consumed 11.5% of their body weight per day and Sockeye fry in Osoyoos Lake consumed only 7.5% of their body weight per day.

Hesperodiaptomus: In Lake Wenatchee, *Hesperodiaptomus* were the primary prey consumed by juvenile Sockeye. At the moment we do not have enough data to estimate the total production potential for this species, but we do know that *Hesperodiaptomus* may reproduce only once (summer) or perhaps twice (spring and summer) per year. Therefore if the age-0 summer-fall Sockeye population is large enough to consume most of the available copepodids and adults, this important food supply will not be replaced and Sockeye fry growth and survival rates may be negatively affected. The same applies to the spring population of age-1 Sockeye prior to their emigration from the lake when they could conceivably consume substantial portions of the *Hesperodiaptomus* population early in the season before the age-0s enter the lake to begin feeding. Additional spring and fall samples (March-November) will be needed to clarify details of life history and associated production of *Hesperodiaptomus*.

PREFACE

Lake Wenatchee and Osoyoos Lake are the two most important Sockeye Salmon nursery lakes in the Columbia River watershed.

This report compares Lake Wenatchee and Osoyoos Lake Sockeye Salmon fry densities, lengths, weights and production for brood years 2009-16 (in-lake 2010-2017). The report also summarizes comparative data for in-lake, limnological conditions for 2012-17. These comparisons include rates of river discharge and lake-turnover, water chemistry, phytoplankton and zooplankton abundance. All of the detailed data used for limnological and fish comparisons are included in two reports. (1**) Lake Wenatchee** juvenile sockeye salmon and limnology status report brood years 2011-2016 (in-lake 2012-2017); 46 pp. and (2) **Osoyoos Lake:** 2005-17 assessments of Sockeye Salmon, kokanee, *Mysis* and zooplankton; 51 pp. Both reports were 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).

The objective of this comparative analysis is to assess the growth and production potential for juvenile Sockeye Salmon in oligotrophic Lake Wenatchee and mesotrophic Osoyoos Lake. The data sets for the two lakes are unequal. Intensive limnological and fisheries work in Osoyoos Lake began in 2005 and continued through to 2017. In-lake Sockeye Salmon studies in Lake Wenatchee began in 2010 and intensified gradually through to 2016-17. Due to the restricted nature of the Lake Wenatchee data we have limited our limnological comparisons between these lakes to in-lake years 2012-17. Also because in-lake sampling for Sockeye fry in Lake Wenatchee was limited through to 2016, our focus for Sockeye lengths, weights and densities has been on samples collected in September for both lakes from 2010-17. Although this treatment is limited by data availability, the results provide surprising insights and may provide quite useful guidance for management and future enhancement of the Lake Wenatchee Sockeye Salmon population.

The reader will find methodological detail in the Lake Wenatchee and Osoyoos Lake reports noted above. Here we need only point out that the same research teams using the same methods sampled both lakes. Phytoplankton samples from both lakes were collected from the top 10 m of each lake and were "counted" by the same person. Zooplankton were collected from the top 30m of each lake using identical, metered, vertical haul nets and "counted" by the same people. Juvenile sockeye salmon in both lakes were enumerated using the same equipment, i.e. Biosonics DT-X echosounder (200 kHz sounder, pulse width at 0.4 ms and a 6.6° transducer), and juvenile Sockeye biosamples were collected using the same equipment, i.e. 3m x 7m mid-water trawl and were processed using the same procedures.

RESULTS and DISCUSSION

1. Lake Wenatchee and Osoyoos Lake physical conditions:

Both lakes have similar surface areas. Lake Wenatchee = 1011 ha and Osoyoos Lake = 933 ha. However Lake Wenatchee is slightly deeper than Osoyoos Lake (Figures 1, 2) and has a much greater water volume (Lake Wenatchee = 444,052,800, m^3 and Osoyoos Lake 276,540,800 m^3). As we shall see, this physical difference has significant effects on rates of lake-turnover and water temperatures.

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.

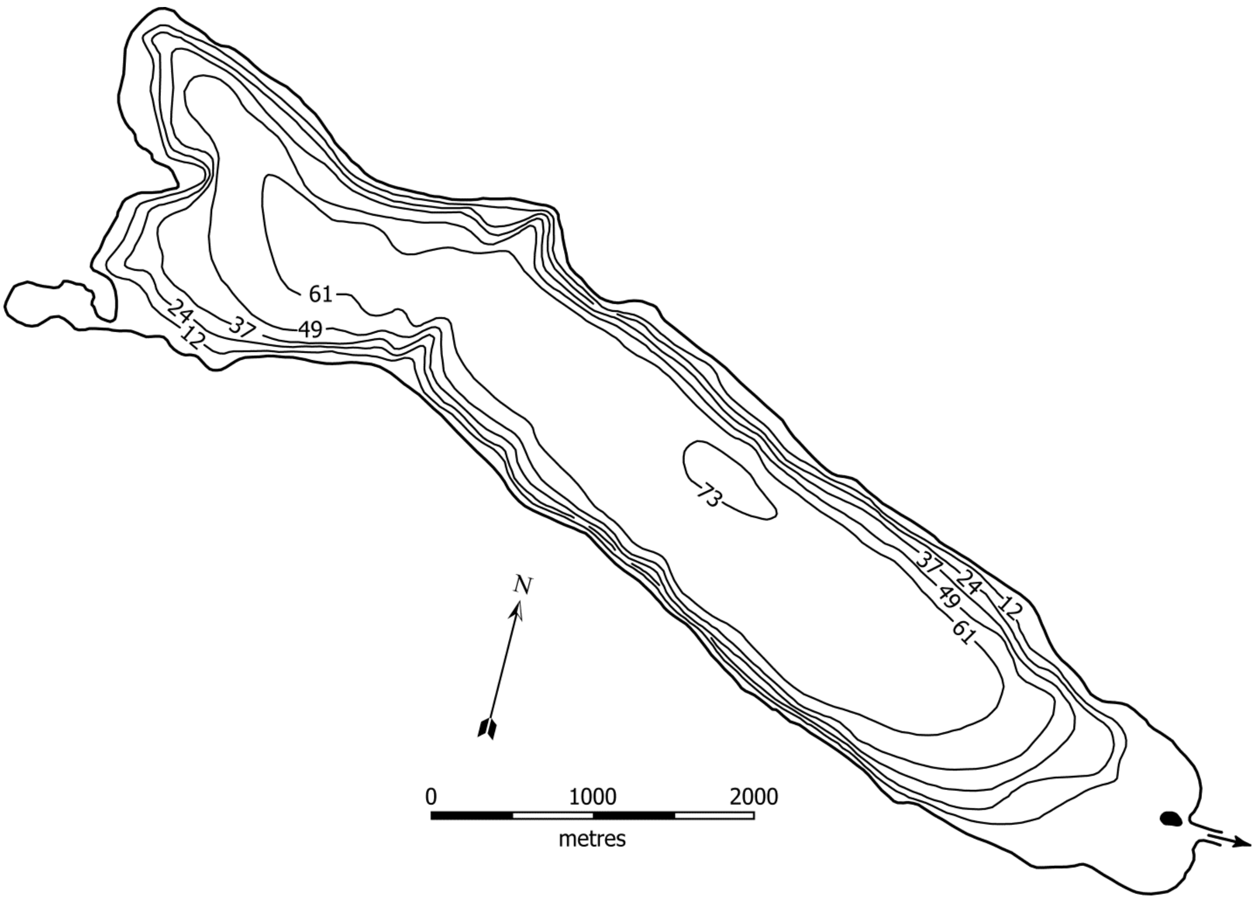
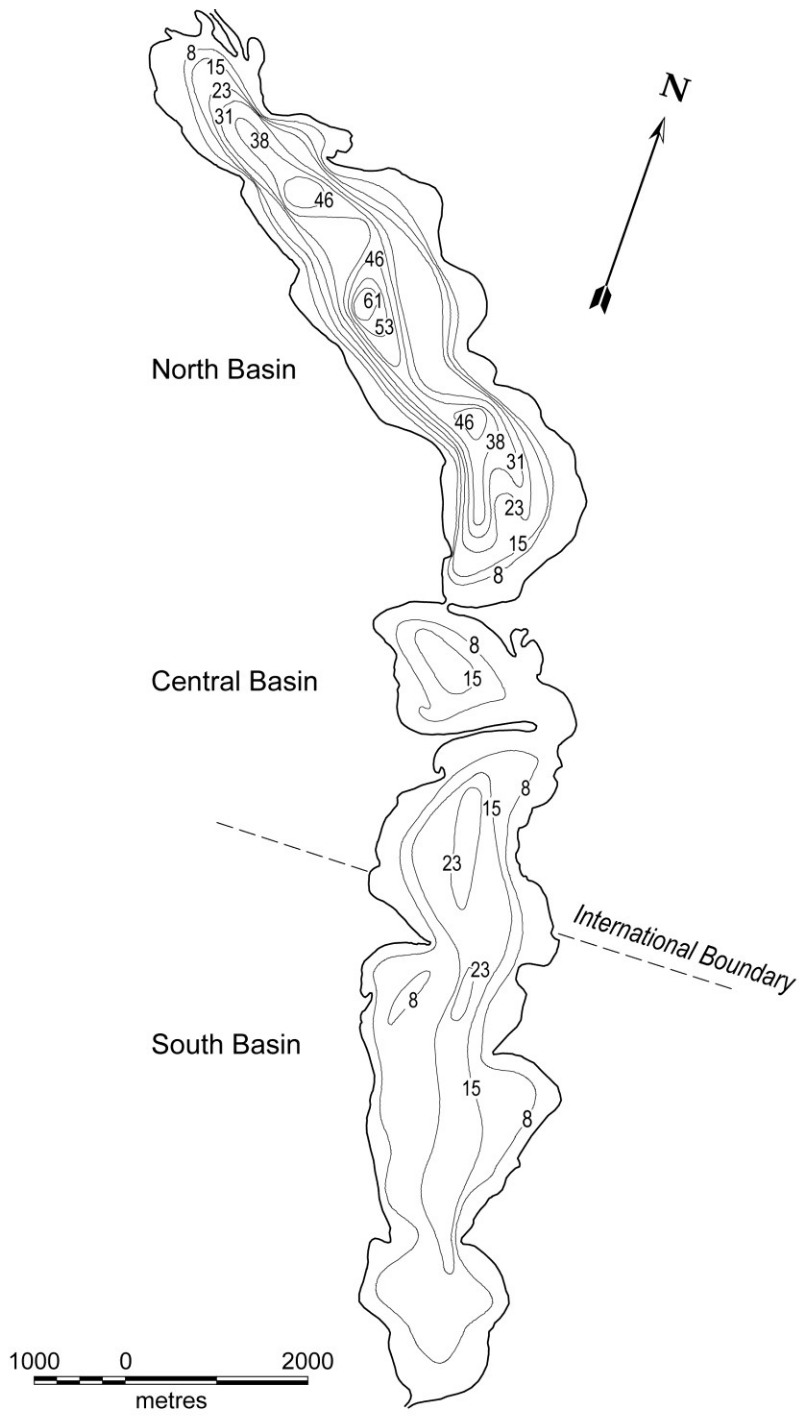


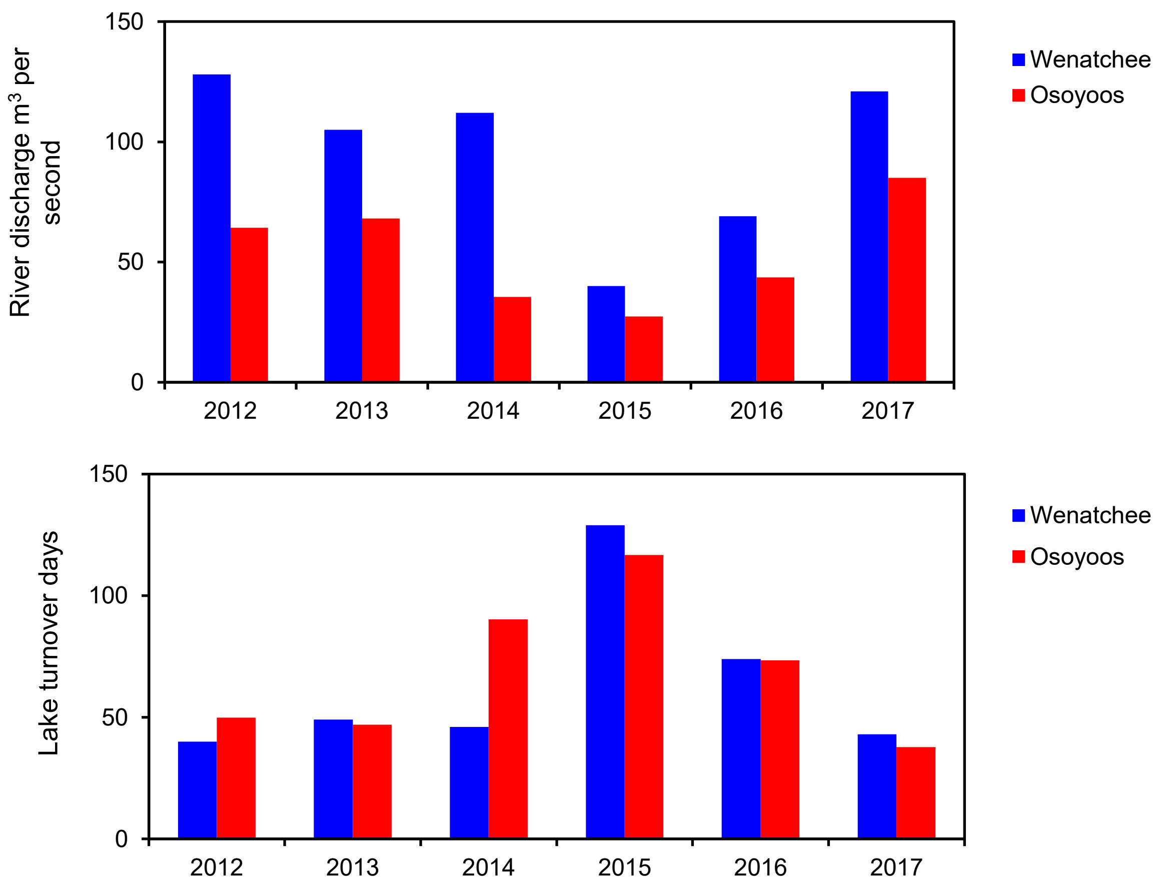
Figure 2: Osoyoos Lake bathymetric map. Depth contours in m. Only the North Basin provided nursery habitat for Sockeye fry and all of the data in this report are from the North Basin.



For many years we have noted that Osoyoos Lake has surprisingly high rates of lake-turnover caused by high rates of river discharge from the Okanagan River. We have also observed that rates of discharge in the early years of our study were significantly lower than during the later years. May-October cumulative river discharge during 2005-10 averaged 0.28 km^{-3}, but during 2011-13, the discharge from Okanagan Lake and the Okanagan River into Osoyoos Lake ranged between 0.62-0.68 km^3. These river flows created May-October average annual turnover rates of 2.2 epilimnetic volumes in 2005-10, and 4.4 epilimnetic volumes during 2011-17. Annual May-October turnover rates for the entire north basin of Osoyoos Lake averaged 1.0 in 2005-10 and 2.1 in 2011-17. In Osoyoos Lake, there were significant negative correlations between river flow rates and the biomasses of both algae and zooplankton (Hyatt et al. 2018).

Based on this experience at Osoyoos Lake, we tested the hypothesis that river discharge rates into Lake Wenatchee could influence zooplankton and phytoplankton biomasses. We used US Geological Survey data to estimate May-August rates of Wenatchee River discharge measured at Plain WA, which is located downriver from Lake Wenatchee. In addition we knew that the Plain WA estimates included contributions from the Chiwawa River which flows into the Wenatchee River between Lake Wenatchee and Plain WA. To account for this extra contribution, we subtracted the Chiwawa flow from the flow recorded at Plain WA (Figure 3).

Figure 3: Upper panel – Average (m^3 per second) May-August rates of river flow out of Lake Wenatchee (blue) and Okanagan River flow into Osoyoos Lake (red). Bottom panel – Average May-August rates of lake-turnover rates in Lake Wenatchee (blue) and Osoyoos Lake (red).



We found that Lake Wenatchee river discharge rates were about twice as high as they were for Osoyoos Lake (Figure 3 top panel) i.e. Lake Wenatchee = 96 m^3 sec^{-1} and Osoyoos Lake = 54 m^3 sec^{-1}. However, because Lake Wenatchee has a larger lake volume than Osoyoos Lake, these high rates of water flow were associated with lake-turnover rates that were about the same in both lakes (Figure 3 – bottom panel).

Although Osoyoos Lake showed negative relationships for both zooplankton and phytoplankton biomass with respect to rates of river flow recorded during 2005-17, we did not find the same relationships for the more restricted data sets ranging from 2012-17 (Figures 4, 5). This difference results from the fact that rates of river discharge into Osoyoos Lake during 2005-10 were only half as high as they were in 2012-17 i.e. 2005-10 = 18 m^3 sec^{-1} and 2012-17 = 36 m^3 sec^{-1}.

Figure 4: Years 2012-17 average (May-August) Lake Wenatchee (blue) and Osoyoos Lake (red) zooplankton biomass with respect to rates of river discharge from the Wenatchee River and the Okanagan River.

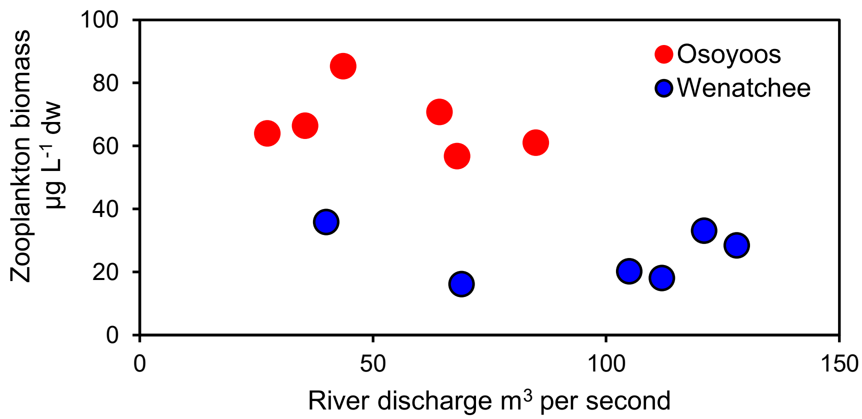
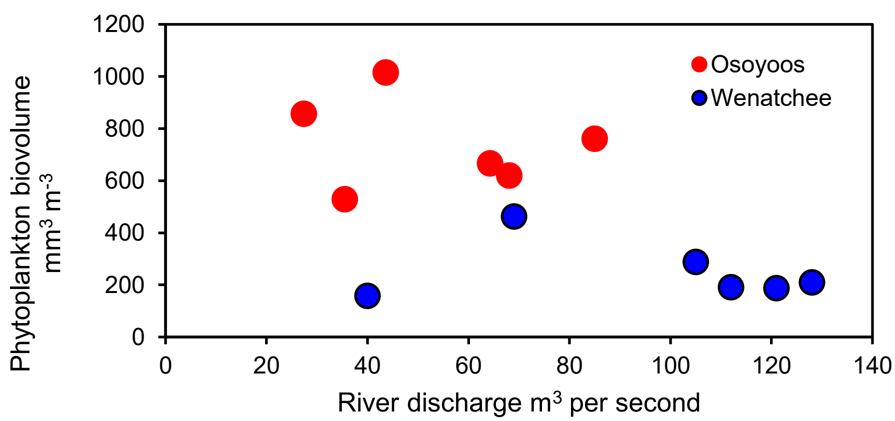


Figure 5: Years 2012-17 average (May-August) Lake Wenatchee (blue) and Osoyoos Lake (red) phytoplankton biovolume with respect to rates of river discharge from the Wenatchee River and the Okanagan River.



From Figures 4 and 5, we see that for both Lake Wenatchee and Osoyoos Lake, there were no relationships between average (May-August, 2012-17) rates of river discharge and both zooplankton biomass and phytoplankton biovolume. We also see that zooplankton biomasses (Figure 4) and phytoplankton

biovolumes (Figure 5) were much lower in Lake Wenatchee than they were in Osoyoos Lake. This will be the focus of sections 5 and 6 of this report.

2. Lake Wenatchee and Osoyoos Lake water temperature:

In all but one year, average (0-20m, June-August) Lake Wenatchee water temperature was cooler than in Osoyoos Lake (Figure 6). The 2012-17 average for Lake Wenatchee = 14.5^{O}, and for Osoyoos Lake = 16.5^{O}. The single exceptional year was 2015 when average discharge rate for Lake Wenatchee was in the range of the discharge rates recorded for Osoyoos Lake (Figure 7). During that year, water residence time in Lake Wenatchee was greater than normal.

In Lake Wenatchee there was a negative relationship between epilimnetic water temperature and the rate of river discharge from high elevation snow-melt. In Osoyoos Lake, there was no relationship between epilimnetic water temperature and discharge from the Okanagan River which is fed from surface water originating from upstream Okanagan valley lakes (Figure 7).

Figure 6: Years 2012-17 average (May-August, 0-20m) water temperatures in Lake Wenatchee (blue) and Osoyoos Lake (red).

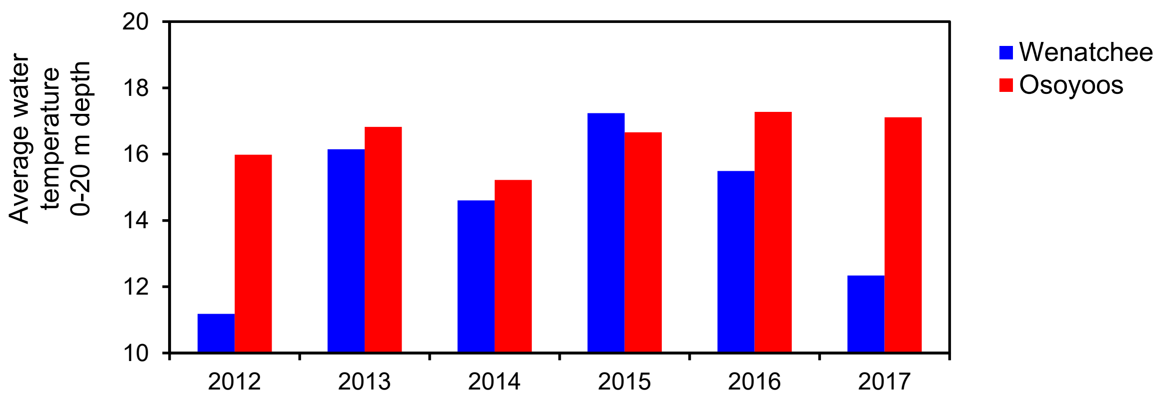
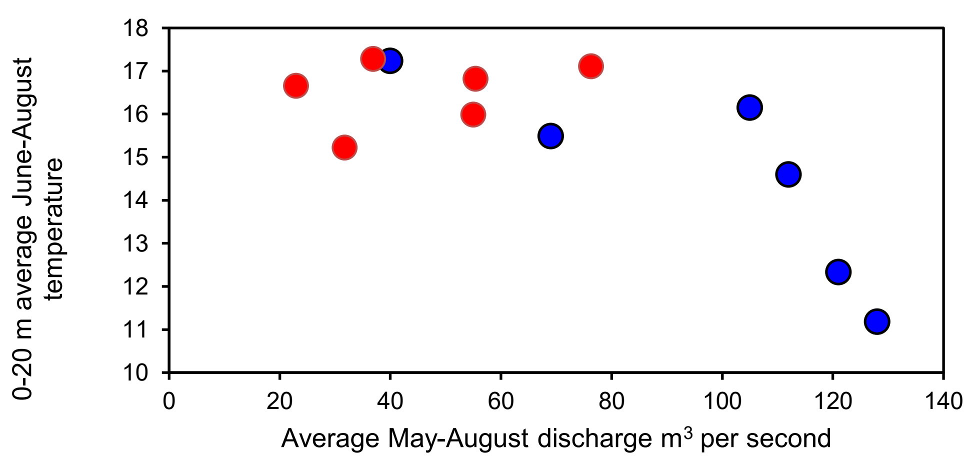


Figure 7: Years 2012-17 average (June-August, 0-20m) water temperatures in Lake Wenatchee (blue) and Osoyoos Lake (red) with respect to average (May-August) rates of river discharge.



At Lake Wenatchee during 2015, low flow rates were associated with earlier stratification of the epilimnion (Figure 8) which may have excluded juvenile Sockeye Salmon known to avoid waters warmer than 17^{O} C. At Osoyoos Lake during all years, flow rates were lower and Sockeye exclusion areas were observed from spring to fall (Figure 9). These data suggest that in most years, Lake Wenatchee Sockeye fry had greater access to zooplankton than they did in Osoyoos Lake.

Figure 8: Years 2012-17 water temperatures in Lake Wenatchee. The grey areas are water depths avoided by juvenile Sockeye Salmon.

Water depth (m)	04-Jun-12	05-Jul-12	09-Aug-12	06-Oct-12	25-Jun-13	30-Jul-13	26-Aug-13	23-Sep-13	05-Jun-14	23-Jun-14	14-Jul-14	11-Aug-14	04-Sep-14	08-Oct-14	01-Jun-15	25-Jun-15	14-Jul-15	05-Aug-15	28-Aug-15	16-Sep-15	08-Jun-16	29-Jun-16	20-Jul-16	10-Aug-16	31-Aug-16	29-Sep-16	28-Jun-17	21-Aug-17	15-Sep-17
1	8	11	14	14	11	18	19	16	9	12	15	19	18	16	13	17	19	19	18	17	12	13	16	17	19	16	9	18	17
2	8	10	14	14	11	18	18	16	9	12	15	19	18	15	13	17	19	19	18	16	12	13	16	17	19	15	9	18	17
3	8	10	14	14	10	17	18	16	9	11	15	18	17	15	13	17	19	19	18	16	12	13	16	17	18	15	9	18	17
4	7	9	14	14	10	17	18	16	9	11	15	18	17	15	13	16	19	19	18	16	11	13	16	17	18	15	9	18	17
5	7	9	14	14	10	17	18	16	9	11	15	18	17	15	12	16	19	18	18	16	11	13	16	17	18	15	9	18	17
6	7	9	14	14	10	17	18	16	9	11	14	17	17	15	12	16	19	18	18	16	11	13	15	17	18	15	9	17	17
7	7	9	14	14	10	17	18	16	9	11	14	17	17	15	11	15	19	18	18	16	11	13	15	17	18	15	9	17	17
8	7	9	14	14	10	16	18	16	9	11	14	17	17	15	11	15	19	18	18	16	11	13	15	17	18	15	9	17	17
9	7	9	14	14	10	16	18	16	9	11	14	16	17	15	11	15	18	18	18	16	10	13	15	17	18	15	8	17	17
10	7	9	14	14	10	16	18	16	9	10	14	16	17	15	11	15	18	18	18	16	10	13	15	17	18	15	8	17	17
11	7	9	14	14	10	16	18	16	9	10	14	16	17	15	10	14	18	18	18	16	10	13	15	17	18	15	8	17	17
12	7	9	13	14	10	16	18	16	9	10	13	16	16	15	10	14	17	18	18	16	10	12	14	17	18	15	8	16	17
13	7	8	13	14	9	16	17	16	9	10	13	16	16	15	10	14	16	18	18	16	10	12	14	17	18	15	8	16	16
14	7	8	13	14	9	15	17	16	9	10	12	15	16	15	10	14	15	18	18	16	10	12	14	17	18	15	8	16	16
15	7	8	13	14	9	15	17	16	8	10	12	15	16	15	10	13	14	18	18	16	9	12	14	16	17	15	8	15	16
16	7	8	13	14	9	13	16	15	8	9	12	15	15	15	10	13	14	18	18	16	9	12	14	16	17	15	8	15	16
17	7	8	13	14	9	13	16	15	8	9	12	14	14	15	10	13	13	18	18	16	9	12	13	16	17	15	8	14	16
18	7	8	13	14	9	11	15	15	8	9	11	13	14	15	10	12	12	18	18	16	9	12	13	16	16	15	8	14	15
19	7	8	13	14	9	11	14	14	8	9	11	12	13	14	9	12	12	16	18	16	9	12	13	16	16	15	8	13	13
20	7	8	12	13	9	11	13	13	8	9	11	12	13	14	9	12	12	15	17	16	9	12	13	16	15	15	8	13	12
24	7	7	10	13	8	10	11	11	8	9	10	11	12	13	9	11	10	11	13	15	9	11	11	13	13	14	8	11	10
28	6	7	10	11	8	10	10	10	8	9	10	10	11	11	9	10	10	10	10	10	8	10	10	12	11	11	8	9	9
32	6	7	9	9	8	9	9	9	8	8	9	9	10	10	8	9	9	9	9	9	8	9	9	10	10	10	8	9	8
36	6	7	8	8	8	8	9	8	8	8	9	9	9	9	8	8	8	8	8	8	8	8	9	9	9	9	8	8	8
40	6	7	8	8	8	8	8	8	7	8	9	8	9	9	7	8	8	8	8	8	8	8	8	9	8	8	8	8	8
44	6	7	8	7	7	8	8	8	7	8	8	8	8	8	7	7	7	8	8	7	7	8	8	8	8	8	8	8	8
48	6	7	7	7	7	7	8	8	7	8	8	8	8	8	7	7	7	7	7	7	7	8	8	8	8	8	8	8	7
52	6	7	7	7	7	7	7	7	7	7	8	8	8	8	6	7	7	7	7	7	7	8	7	8	8	8	7	7	7

Figure 9: Years 2012-17 water temperatures in Osoyoos Lake. The grey areas are water depths avoided by juvenile Sockeye Salmon.

Water depth (m)	11-Jun-12	16-Jul-12	07-Aug-12	11-Oct-12	24-Jun-13	30-Jul-13	26-Aug-13	23-Sep-13
1	15	23	24	16	19	23	22	20
2	15	22	24	16	19	23	22	20
3	15	22	23	15	19	23	22	19
4	14	22	23	15	19	23	22	19
5	14	22	22	15	19	23	22	19
6	14	22	22	15	18	23	22	19
7	14	20	22	15	18	22	22	19
8	13	19	22	15	18	22	22	19
9	13	18	21	15	17	22	22	19
10	13	17	20	15	17	22	22	19
11	13	16	19	15	17	22	22	19
12	12	15	18	15	16	20	22	19
13	11	14	15	15	16	19	18	19
14	11	13	13	15	15	17	16	19
15	9	11	13	15	14	15	15	19
16	9	10	12	14	13	14	13	16
17	8	9	10	13	12	13	12	13
18	8	9	9	11	11	11	11	11
19	8	8	9	10	10	11	11	10
20	8	8	8	9	10	10	10	10
24	7	8	8	9	9	9	10	10
28	7	8	8	9	9	9	9	9
32	7	8	8	8	9	9	9	9
36	7	8	8	8	9	9	9	9
40	7	7	8	8	8	9	9	9
44	7	7	8	8	8	9	9	9
48	7	7	8	8	8	8	9	9
52	7	7	8	8	8	8	8	9

Water depth (m)	02-Jun-14	23-Jun-14	16-Jul-14	12-Aug-14	09-Sep-14	14-Oct-14	02-Jun-15	22-Jun-15	15-Jul-15	10-Aug-15	31-Aug-15	08-Sep-15
1	16	21	26	23	18	16	19	20	23	23	20	18
2	16	21	25	23	19	16	19	20	23	23	20	18
3	16	20	24	23	19	16	19	20	23	23	20	18
4	16	19	24	23	19	16	19	20	23	23	20	18
5	16	19	23	23	19	16	19	20	23	23	20	18
6	16	18	23	23	19	16	19	20	23	23	20	18
7	16	18	21	23	19	16	19	20	23	23	20	18
8	15	18	20	22	19	16	18	20	23	23	20	18
9	15	17	19	22	19	16	17	19	21	22	20	18
10	15	17	17	21	19	16	16	18	18	21	20	18
11	15	16	15	18	19	16	13	16	16	20	20	18
12	14	15	14	16	19	16	13	14	14	18	19	18
13	12	13	13	14	16	16	12	12	12	16	18	18
14	11	12	10	13	15	16	11	11	11	14	17	16
15	10	11	9	12	14	15	10	11	11	13	13	15
16	9	9	9	11	12	14	10	10	10	12	12	12
17	8	8	8	10	10	13	10	10	10	11	11	11
18	8	8	8	10	10	11	9	9	10	10	10	10
19	8	8	8	9	10	9	9	9	9	10	10	10
20	7	8	8	9	9	9	9	9	9	10	10	10
24	7	7	8	8	9	9	9	9	9	9	9	9
28	7	7	7	8	8	8	9	9	9	9	9	9
32	7	7	7	8	8	8	9	9	9	9	9	9
36	7	7	7	8	8	8	9	9	9	9	9	9
40	7	7	7	8	8	8	8	9	9	9	9	9
44	7	7	7	8	8	8	8	9	9	9	9	9
48	7	7	7	8	8	8	8	9	9	9	9	9
52	7	7	7	8	8	8	8	9	9	9	9	9

Water depth (m)	06-Jul-16	12-Jul-16	06-Aug-16	19-Jun-17	15-Aug-17	12-Sep-17
1	21	21	24	17	22	21
2	21	21	23	17	22	21
3	20	21	23	17	22	21
4	20	20	23	17	22	21
5	20	20	22	16	22	21
6	20	20	22	16	22	21
7	20	20	22	16	22	21
8	20	20	22	16	22	21
9	20	20	21	16	22	21
10	19	19	21	16	22	21
11	18	19	20	16	22	21
12	17	18	19	16	21	21
13	16	16	18	15	20	20
14	15	14	16	15	14	19
15	13	13	15	14	13	17
16	12	12	14	13	11	16
17	11	12	12	12	10	14
18	10	11	11	11	9	12
19	10	10	10	10	9	11
20	9	10	10	9	9	10
24	9	9	9	8	9	9
28	9	9	9	8	8	9
32	8	8	9	8	8	9
36	8	8	9	8	8	9
40	8	8	9	8	8	9
44	8	8	9	7	8	8
48	8	8	9	7	8	8
52	8	8	9	7	8	8

3. Lake Wenatchee and Osoyoos Lake oxygen concentration:

In Lake Wenatchee oxygen concentrations were always well above 4 mg L^{-1} which is the lower limit of the concentration range normally occupied by juvenile Sockeye Salmon (Figure 10). In Osoyoos Lake, during the late summer fall, oxygen concentrations in the deep hypolimnion, were often < 4 mg L^{-1} (Figure 11).

Figure 10: Years 2012 oxygen concentrations in Lake Wenatchee. Bold numbers on the left are water depths (m). Lake Wenatchee oxygen concentrations were always greater than 4 mg L^{-1}.

Water depth (m)	04-Jun-12	05-Jul-12	09-Aug-12	06-Oct-12	25-Jun-13	30-Jul-13	26-Aug-13	23-Sep-13	05-Jun-14	23-Jun-14	14-Jul-14	11-Aug-14	04-Sep-14	08-Oct-14	01-Jun-15	25-Jun-15	14-Jul-15	05-Aug-15	28-Aug-15	16-Sep-15	08-Jun-16	29-Jun-16	20-Jul-16	10-Aug-16	31-Aug-16	29-Sep-16	12-Apr-17	28-Jun-17	21-Aug-17	15-Sep-17
1	10	13	10	10	11	9	9	9	11	10	10	9	9	9	10	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
2	10	13	10	10	11	9	9	9	11	10	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
3	10	13	10	10	11	9	9	9	11	10	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
4	10	13	10	10	11	9	9	9	11	11	10	9	9	9	11	10	9	9	10	9	11	10	10	9	9	9	11	11	9	9
5	10	13	10	10	11	9	9	9	11	11	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
6	10	13	10	10	11	9	9	9	11	11	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
7	10	13	10	10	11	9	9	9	11	11	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
8	10	13	10	10	11	9	9	9	11	11	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
9	10	13	10	10	11	9	9	9	11	11	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
10	10	14	10	10	11	9	9	9	11	11	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
11	10	14	10	10	11	9	9	9	11	10	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
12	10	14	10	10	11	9	9	9	11	10	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
13	9	14	10	10	11	9	9	9	11	10	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
14	10	13	10	10	11	9	9	9	11	10	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	10	9
15	10	14	10	10	11	9	9	9	11	10	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
16	10	14	10	10	11	9	9	9	11	10	10	9	9	9	11	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
17	10	14	10	10	11	9	9	9	11	10	10	9	9	9	10	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
18	10	14	10	10	11	10	9	9	11	10	10	9	9	9	10	10	9	9	9	9	11	10	10	9	9	9	11	11	9	9
19	10	14	10	10	11	10	9	8	11	10	10	9	9	9	10	10	9	9	9	9	11	10	10	9	8	9	11	11	9	9
20	10	14	10	9	11	10	9	9	11	10	10	9	9	9	10	10	9	9	9	9	11	10	10	9	8	9	11	11	10	9
24	6	14	10	9	11	10	9	9	11	10	10	9	9	9	10	10	9	9	8	9	11	10	10	9	8	9	11	11	9	9
28	7	14	10	10	11	10	9	9	11	10	10	9	9	8	10	10	9	9	8	8	11	10	10	9	9	8	11	11	9	9
32	7	14	10	10	11	10	9	9	11	10	10	9	9	8	10	10	9	9	9	8	11	10	10	9	9	8	11	11	9	9
36	7	14	10	10	11	10	9	9	11	10	10	9	9	9	10	10	10	9	9	8	10	10	10	9	9	8	11	11	10	9
40	7	14	10	10	11	9	9	9	10	10	10	9	9	9	10	10	10	9	9	8	10	10	10	9	9	9	11	11	9	9
44	7	14	10	10	10	9	9	9	10	10	10	9	9	9	10	10	10	9	9	8	10	10	10	9	9	8	10	11	9	10
48	7	14	10	10	10	9	9	9	10	10	10	9	9	9	10	10	10	9	9	8	10	10	9	9	9	8	10	11	9	10
52	7	14	10	10	10	9	9	9	10	10	10	9	9	9	10	10	10	9	9	8	10	10	9	9	9	8	10	10	9	10

Figure 11: Years 2012-late summer and fall oxygen concentrations in Osoyoos Lake. The grey areas are water depths avoided by juvenile Sockeye Salmon (i.e less than 4 mg L^{-1}). Bold numbers on the left are water depths (m). During the spring and summer (not shown here), Osoyoos Lake oxygen concentrations were always greater than 4 mg L^{-1}, but never as high as they were in Lake Wenatchee.

Depth	04-Sep-12	11-Sep-12	17-Sep-12	24-Sep-12	30-Sep-12	11-Oct-12	29-Oct-12
1	9	9	9	10	10	10	10
2	9	9	9	10	10	10	10
3	9	9	9	10	10	10	10
4	9	9	9	10	10	10	10
5	9	9	9	10	10	10	10
6	9	9	9	10	9	10	10
7	8	9	9	10	9	10	10
8	8	9	9	9	9	10	10
9	8	9	9	9	9	10	10
10	8	9	9	9	9	10	10
11	8	8	9	9	9	9	9
12	8	8	9	8	9	9	10
13	8	8	8	8	9	9	10
14	6	5	7	8	8	9	10
15	5	5	6	7	8	9	10
16	5	5	5	7	7	9	10
17	5	5	4	5	5	8	10
18	5	4	4	4	4	7	10
19	5	4	4	4	4	5	10
20	5	4	4	4	4	4	10
24	5	4	4	4	3	4	8
28	5	4	4	4	3	3	5
32	5	4	4	4	3	3	4
36	4	4	4	4	4	3	2
40	4	4	4	4	3	3	2
44	4	4	4	4	3	3	2
48	4	4	4	4	3	3	2
52	4	4	4	4	3	3	2

Depth	05-Sep-13	16-Sep-13	23-Sep-13	10-Oct-13	16-Oct-13	23-Oct-13
1	7	8	8	9	10	10
2	7	8	8	9	10	10
3	6	8	8	9	10	10
4	6	8	8	9	9	10
5	6	8	8	9	9	10
6	7	8	8	9	9	10
7	6	8	8	9	9	10
8	6	8	8	9	9	10
9	7	8	8	9	9	10
10	6	8	8	9	9	10
11	6	8	8	9	9	10
12	6	8	8	9	9	10
13	5	8	8	9	9	10
14	5	6	8	9	9	10
15	3	5	7	9	9	10
16	3	3	6	9	9	10
17	3	3	6	8	9	10
18	3	3	4	8	9	10
19	3	3	4	8	8	10
20	3	3	3	7	7	9
24	3	3	4	6	5	9
28	3	3	3	4	3	5
32	3	3	3	3	2	4
36	3	3	4	2	2	3
40	3	3	3	2	2	2
44	3	3	3	2	2	2
48	3	3	3	2	1	1
52	3	3	3	2	1	1

Depth	09-Sep-14	15-Sep-14	14-Oct-14	20-Oct-14	10-Nov-14
1	9	9	9	10	10
2	9	9	9	10	9
3	9	9	9	10	9
4	9	9	9	10	9
5	9	9	9	10	9
6	8	9	9	9	9
7	8	9	9	9	9
8	8	9	9	9	9
9	8	9	9	9	9
10	8	9	9	9	9
11	8	9	9	9	9
12	8	9	9	9	9
13	6	9	9	9	9
14	6	8	9	9	9
15	4	6	9	9	9
16	4	5	8	9	8
17	4	4	6	7	8
18	4	4	5	7	8
19	4	4	4	5	8
20	4	4	4	4	8
24	4	4	3	4	6
28	4	4	3	3	4
32	4	4	3	3	3
36	4	4	3	3	3
40	4	4	3	3	3
44	4	4	3	3	3
48	4	4	3	3	2
52	4	4	3	3	2

Depth	23-Aug-15	31-Aug-15	08-Sep-15	28-Sep-15	13-Oct-15	15-Nov-15
1	8	8	9	10	10	10
2	8	8	9	10	10	9
3	8	8	9	9	10	9
4	8	8	9	9	10	9
5	8	8	9	9	10	9
6	8	8	9	9	9	9
7	8	8	9	9	9	9
8	8	8	9	9	9	9
9	8	8	9	9	9	9
10	8	8	9	9	9	9
11	8	7	9	9	9	9
12	5	7	9	9	9	9
13	4	6	9	9	9	9
14	4	6	7	9	9	9
15	4	4	5	8	9	9
16	4	4	4	8	9	9
17	4	4	4	6	9	9
18	4	4	4	5	8	9
19	4	4	4	4	7	9
20	4	4	4	4	5	9
24	4	4	4	3	4	9
28	4	4	4	3	3	9
32	4	3	3	3	3	9
36	4	4	4	3	2	9
40	4	3	3	3	2	8
44	4	3	3	3	2	5
48	4	3	3	3	2	1
52	4	3	3	2	2	1

Depth	06-Aug-16	06-Oct-16	25-Oct-16
1	8	10	10
2	8	9	10
3	8	9	10
4	8	9	10
5	8	9	10
6	8	9	10
7	8	9	10
8	8	9	10
9	7	9	10
10	7	9	10
11	7	9	10
12	6	9	9
13	5	9	9
14	4	9	9
15	4	9	9
16	4	9	9
17	4	9	9
18	4	7	9
19	4	5	9
20	4	4	9
24	4	3	7
28	4	2	2
32	4	2	1
36	4	2	2
40	4	2	1
44	4	1	1
48	4	2	1
52	4	1	1

Depth	12-Sep-17	10-Oct-17	16-Nov-17
1	9	10	10
2	9	10	10
3	9	10	10
4	9	10	10
5	9	10	10
6	9	10	10
7	9	10	10
8	9	9	9
9	9	10	10
10	9	10	10
11	8	10	10
12	8	10	10
13	8	10	10
14	6	10	10
15	5	10	10
16	4	10	10
17	4	10	10
18	4	10	10
19	4	10	10
20	4	9	9
24	4	8	8
28	4	7	7
32	4	6	6
36	4	5	5
40	4	5	5
44	4	5	5
48	4	5	5
52	4	4	4

4. Lake Wenatchee and Osoyoos Lake water chemistry:

Lake Wenatchee water chemistry samples were taken during 2012, 2013 and 2017. During 2012 nutrient chemistry was recorded on two dates and calcium concentrations were recorded on one date. During 2013, alkalinity and calcium concentrations were recorded on one date. During 2012, 2013 and 2017 total phosphorus and nitrogen samples were taken on 2 dates. In Osoyoos Lake, water chemistry samples were taken every month in all years.

In the 2012-16 version of the Lake Wenatchee annual report we noted that low alkalinity and low concentrations of calcium (range 1-3 mg Ca L^{-1}) have been shown to limit some *Daphnia* species, and we suggested that this could be an issue for Lake Wenatchee. 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. For *Daphnia galeata* the threshold for survival lies between 0 - 2.0 mg Ca L^{-1}. 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. For *Daphnia pulex x Daphnia pulicaria* hybrid, survival and reproduction decreased at Ca concentrations < 1.0 mg/L. Lake Wenatchee calcium concentrations measured in 2012, 2013 and 2017show that calcium varied from 1.5-2.7 mg L^{-1}, which is very low compared with Osoyoos Lake, but still high enough to support *Daphnia.* Osoyoos Lake calcium concentrations are in the range of
20-30 mg L^{-1}.

Comparisons of total phosphorus and nitrogen concentrations (Table 1) show that both are much higher in Osoyoos Lake than in Lake Wenatchee. Lake Wenatchee is oligotrophic and Osoyoos Lake is mesotrophic.

Table 1: Lake Wenatchee and Osoyoos Lake water chemistry compared on all dates for which comparable samples were taken.

Wenatchee total phosphorus µg L^{-1}				Osoyoos total phosphorus µg L^{-1}		
	Epilimnion	Hypolimnion			Epilimnion	Hypolimnion
12-Jun-12	6.5	7.4		11-Jun-12	13.5	12.7
18-Sep-12	5.2	7.5		24-Sep-12	8.8	20.7
23-Aug-17	5.0	5.0		15-Aug-17	8.8	23.5
21-Sep-17	5.3	5.3		12-Sep-17	5.7	29.5
Average	**5.5**	**6.3**			**9.2**	**21.6**

Wenatchee total nitrogen µg L^{-1}				Osoyoos total nitrogen µg L^{-1}		
	Epilimnion	Hypolimnion			Epilimnion	Hypolimnion
23-Aug-17	70.0	68.0		15-Aug-17	223.0	254.0
21-Sep-17	53.5	69.0		12-Sep-17	280.0	311.0
Average	**61.8**	**68.5**			**251.5**	**282.5**

4. Lake Wenatchee and Osoyoos Lake phytoplankton:

Phytoplankton biovolumes were recorded from both lakes in all years. During all years, total biovolumes were much greater in Osoyoos Lake than in Lake Wenatchee. (i.e. total phytoplankton biovolumes in Osoyoos averaged 741mm^3 m^{-3} and in Wenatchee averaged 249 mm^3 m^{-3} (Figure 12 top panel).

However, the phytoplankton species found in Lake Wenatchee were much more "edible" than the phytoplankton species found in Osoyoos Lake (Figure 13). The Osoyoos Lake species tended to be larger and had more gelatinous sheaths making them less available as food to zooplankton.

Although total phytobiomass in Osoyoos Lake was **3 times** higher than in Lake Wenatchee, high percent edibility for Lake Wenatchee phytoplankton taxa resulted in edible phytoplankton biovolumes that were only **1.5 times** higher (Osoyoos average = 275 mm^3 m^{-3}, Wenatchee = 176 mm^3 m^{-3}) (Figure 12 – bottom panel).

Figure 12: Years 2012-17 average (May-October) phytoplankton biovolume for Lake Wenatchee (blue) and Osoyoos Lake (red). Top panel = total and bottom panel = nontoxic, "edible" phytoplankton that do not have a gelatinous sheath and can be consumed by zooplankton.

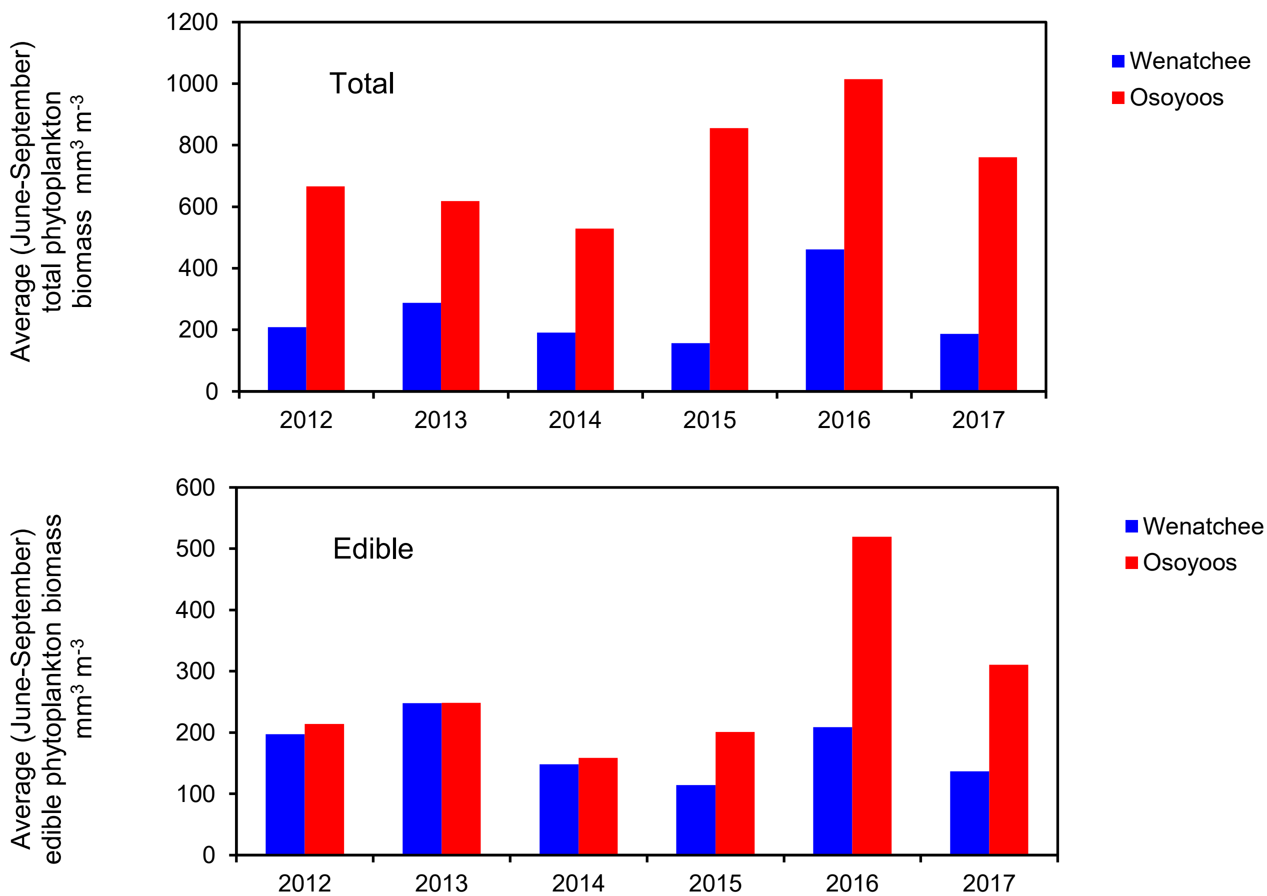
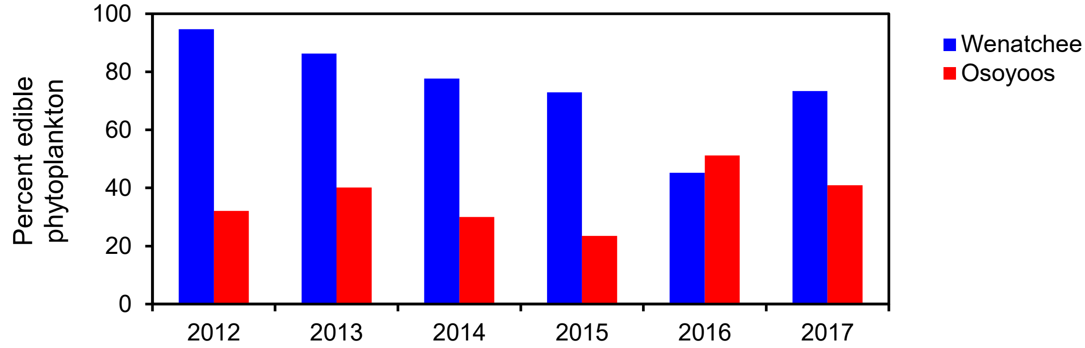


Figure 13: Percent edibility for Lake Wenatchee (blue) and Osoyoos Lake (red) phytoplankton.



5. Lake Wenatchee and Osoyoos Lake zooplankton:

The zooplankton communities found in Lake Wenatchee and Osoyoos Lake were very different (Figures 14, 15). In Lake Wenatchee there are four dominant species including two cladocerans (*Daphnia schodleri*. and *Bosmina longirostris*) and two copepods (*Diacyclops bicuspidatus* and *Hesperodiaptomus kenai*). In Osoyoos Lake there are seven dominant species. There are four common cladocerans (*Daphnia thorata, Bosmina longirostris, Leptodora kindtii, Diaphanosoma leuchtenbergianum*) and three copepods (*Diacyclops bicuspidatus*, *Epischura nevadensis* and *Leptodiaptomus ashlandi*). Osoyoos Lake has a number of minor species which are listed in the 2017 Osoyoos data report.

The species substitution of *Hesperodiaptomus* for *Leptodiaptomus* represents a major difference in the availability of zooplankton for fish. On average, the *Leptodiaptomus* copepodids and adults found in Osoyoos Lake weigh 2.5 µg dry weight and measure less than 1 mm in body length. The average weight for Lake Wenatchee *Hesperodiaptomus* is >30 µg dry weight and the average body length is about 2 mm. This makes *Hesperodiaptomus* an important target for consumption by juvenile sockeye. In general, lower Lake Wenatchee total zooplankton biomasses (Wenatchee May-August average zooplankton biomass = 25 µg L^{-1}, Osoyoos Lake = 67 µg L^{-1}) suggest that, all other things being equal, Lake Wenatchee sockeye should have grown more slowly than Osoyoos Lake Sockeye.

Figure 14: Year 2012-17, Lake Wenatchee zooplankton biomass.

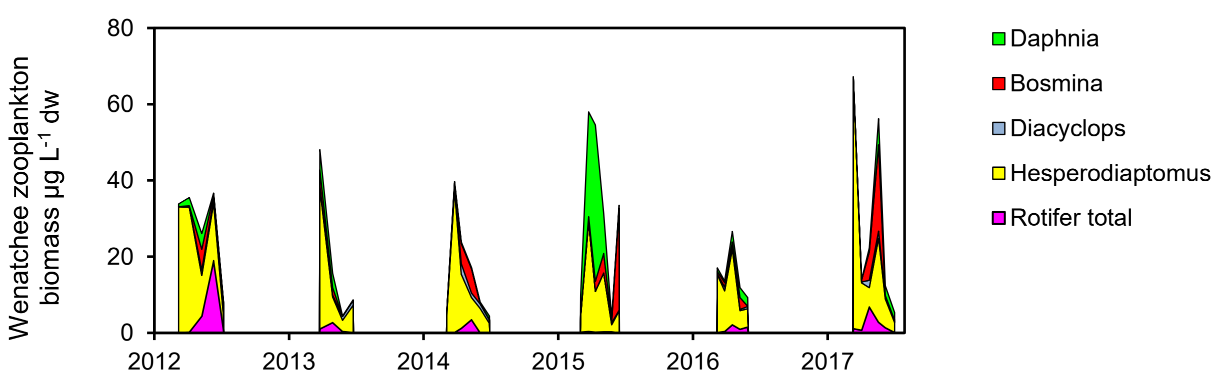
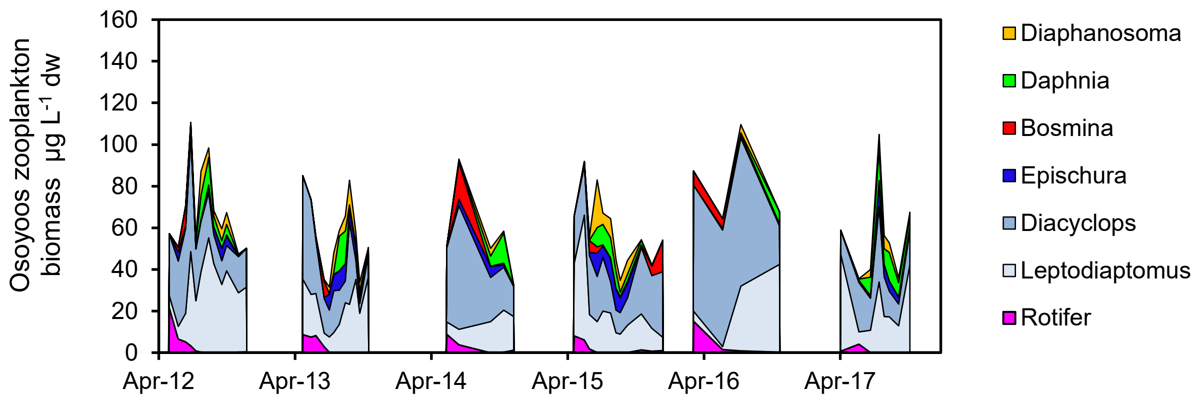


Figure 15: Year 2012-17, Osoyoos Lake zooplankton biomass. *Mysis* are common in Osoyoos Lake but are absent from Lake Wenatchee. To facilitate comparisons, *Mysis* biomasses are not included in these plots of microzooplankton.



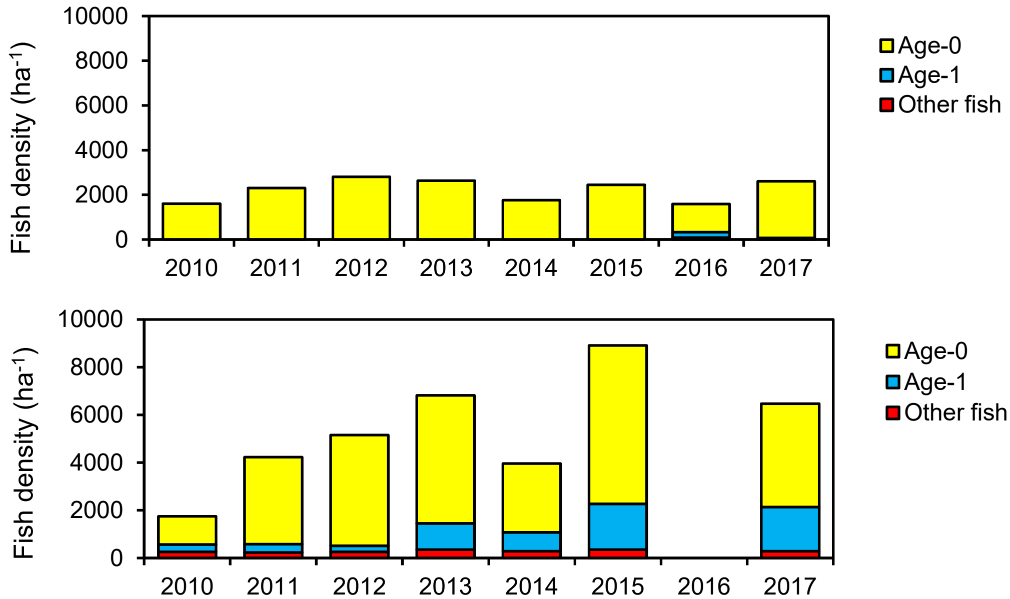
6. Lake Wenatchee and Osoyoos Lake fish including Sockeye Salmon:

Species composition: The fish populations in Lake Wenatchee and Osoyoos Lake are quite different. The Wenatchee community comprises juvenile Sockeye Salmon (*O. nerka*), Chinook (*Oncorhynchus tshawytscha*) adults that pass through the lake, and some spring Chinook juveniles that rear in the lake, Bull Trout (*Salvelinus confluentus*), Pikeminnow (*Ptychocheilus oregonensis*), suckers (*Catostomos* sp.), some Steelhead (*Oncorhynchus mykiss*), and sculpin (*Cottus asper*) in the nearshore areas (Polivka et al., 2013).

The Osoyoos Lake fish community is more diverse. In the early 1970's, there were about 20 species. By 2004, the total had increased to approximately 28 species including several species of bass (*Micropterus* spp.), bullheads (*Ictalurus* spp.), suckers (*Catostomus* spp.), chub (*Mylocheilus* sp.), perch (*Perca* sp.), dace (*Rhinichthys* spp.), sculpins (*Cottus* spp.), and carp (*Cyprinus* sp.). Anadromous salmonids include Chinook (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*), and Sockeye (*O. nerka*). Wild-origin, Sockeye are orders of magnitude more common than the other salmon species and occupy limnetic waters along with small numbers (< 1% of the total) of kokanee (*O. nerka*) that complete their entire life cycle in freshwater (Hyatt et al., 2018).

Sockeye salmon density: Lake Wenatchee sampling frequency for Sockeye Salmon density, length and weight gradually increased from 2010 through to 2017 (i.e. 2010 n=1, 2011-15 n=2, 2016 n=3, 2017 n=5). Osoyoos Lake was sampled 5-6 times every year except 2016 when frequency of trawl samples to identify fish composition was so low that it was impossible to derive useful data. Although the assessment in the two lakes was very different, September samples were always collected from both Lake Wenatchee and Osoyoos Lake. Those are the samples that we have used for the between-lake comparisons that follow (Figure 16).

Figure 16: Lake Wenatchee (top panel) and Osoyoos Lake (bottom panel) fish densities recorded during September in 2010-17. Fish are categorized as age-0 Sockeye, age-1 Sockeye and "other fish" >15 cm in the echograms. Osoyoos 2016 Sockeye samples did not permit density estimates.



During 2010-17, Sockeye Salmon density in Osoyoos Lake was more than twice the density recorded from Lake Wenatchee (Figure 16, Table 2). Because the two lakes have almost identical surface areas, numbers per lake were also more than twice as high in Osoyoos Lake (Table 2).

Table 2: Lake Wenatchee and Osoyoos Lake surface area and Sockeye Salmon fry density.

Wenatchee surface area	1004	ha
Osoyoos surface area	933	ha
Wenatchee Sockeye density	2201	per ha
Osoyoos Sockeye density	5042	per ha
Wenatchee sockeye density	2,209,804	per lake
Osoyoos sockeye density	4,704,186	per lake

It is important to note that age-1 sockeye were common in Osoyoos Lake in September surveys in all years, especially during 2015 and 2017. These fish comprise age-1 wild Sockeye originating in Osoyoos Lake, age-1 smolts migrating down the Okanagan River from Skaha Lake and age-1 kokanee originating in Osoyoos Lake. In Lake Wenatchee, age-1s were identified only in 2016 and 2017 and during those years they accounted for 16% and 1% of the September density estimates recorded in 2016 and 2017 respectively.

"Other fish" were identified in the echograms as fish > 15 cm in length. In Osoyoos Lake they are primarily ages 2, 3 kokanee and Lake Whitefish. In Wenatchee Lake they could be any

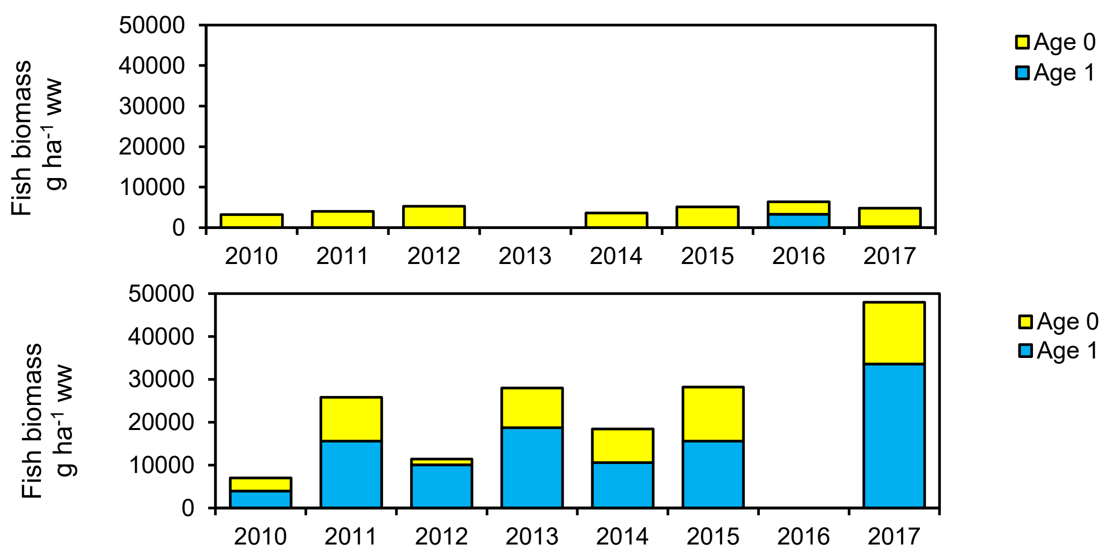
of the species listed in the preceding section except for suckers and sculpins which as benthic species are not encountered in our acoustic-and-trawl surveys.

Sockeye salmon biomass: Although age-0, plus age-1 densities in Osoyoos Lake were only **twice** as high as they were in Lake Wenatchee (Figure 16, Table 2), Sockeye (age-0 plus age-1) biomasses were almost **five times** as high in Osoyoos Lake (Figure 17, Table 3). This is because age-1 sockeye were more numerous in Osoyoos Lake (Figure 16) and contributed significantly to total Sockeye density (Figure 17). Note that "other fish" have not been included in our biomass estimates. That is because other fish lengths and weights were not recorded in Lake Wenatchee, and although they were recorded on Osoyoos Lake, the sample sizes were very small and the data are not as reliable as the density, length and weight data for age-0 and age-1 sockeye.

Table 3: Lake Wenatchee and Osoyoos age-0 plus age-1 Sockeye salmon biomass.

Wenatchee area	1004	ha
Osoyoos area	933	ha
Wenatchee age-0&1 biomass g per ha ww	5914	g per ha
Osoyoos age-0&1 biomass g per ha ww	23828	g per ha
Wenatchee sockeye biomass per lake	5,938	kg per lake
Osoyoos sockeye biomass per lake	22,232	kg per lake

Figure 17: Lake Wenatchee (top panel) and Osoyoos Lake (bottom panel) fish biomasses recorded during September in 2010-17. Fish are categorized as age-0 Sockeye and age-1 Sockeye.



Sockeye salmon lengths and weights: September lengths for Lake Wenatchee age-0 Sockeye fry were almost the same as they were in Osoyoos Lake (Figure 18). (Wenatchee = 58 mm and Osoyoos = 61 mm). September weights for Lake Wenatchee age-0 Sockeye fry were slightly smaller (Wenatchee = 2.0 g and Osoyoos = 2.4 g mm) (Figure 19). It seems likely that

the age-0 Sockeye weight differences were related to zooplankton density and perhaps water temperatures. June-August microzooplankton biomass averaged 25 µg L^{-1} in Lake Wenatchee and 67 µg L^{-1} in Osoyoos Lake, suggesting that Lake Wenatchee sockeye should have grown at about half the rate of Osoyoos Lake juvenile sockeye. However, presence of *Hesperodiaptomus* in Lake Wenatchee changed everything.

Figure 18: Lake Wenatchee and Osoyoos Lake age-0 Sockeye average lengths recorded in September.

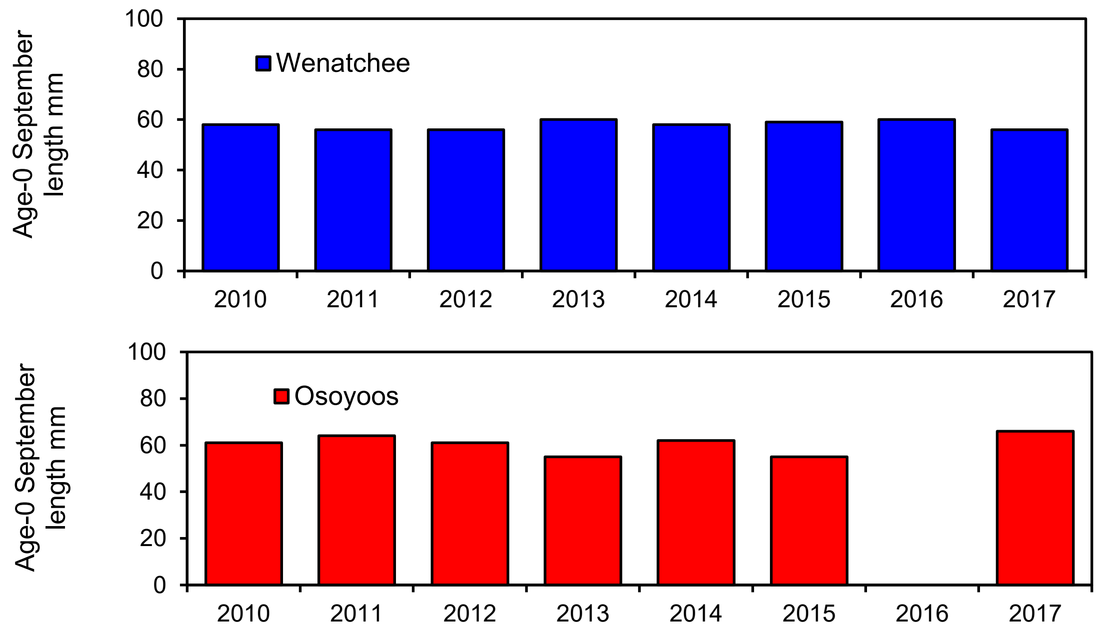
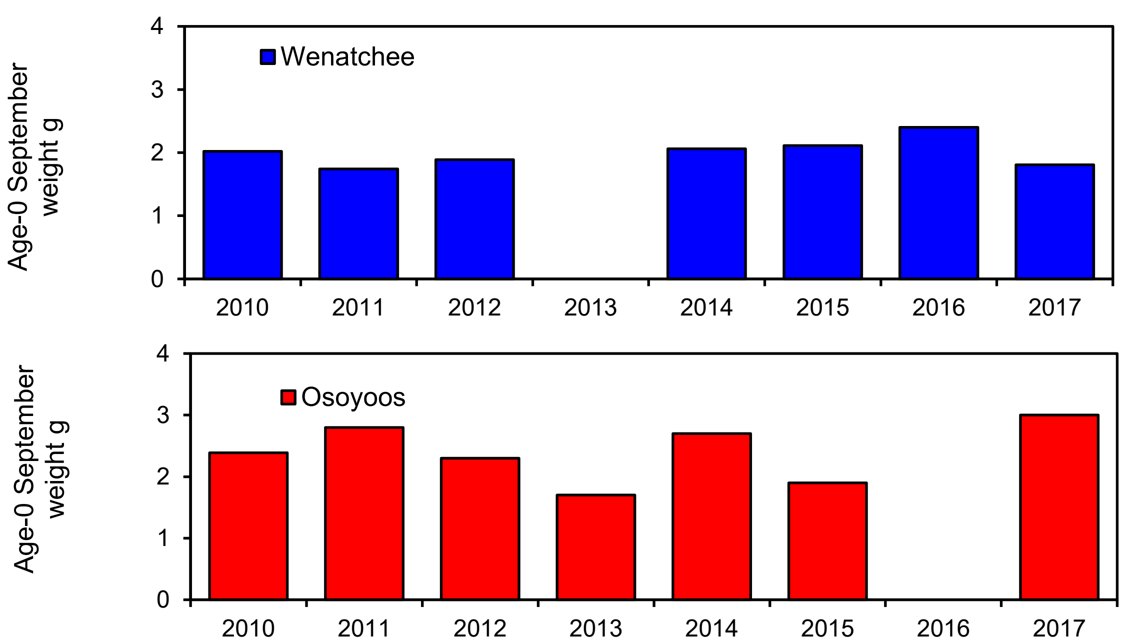


Figure 19: Lake Wenatchee and Osoyoos Lake age-0 Sockeye average weights recorded in September.

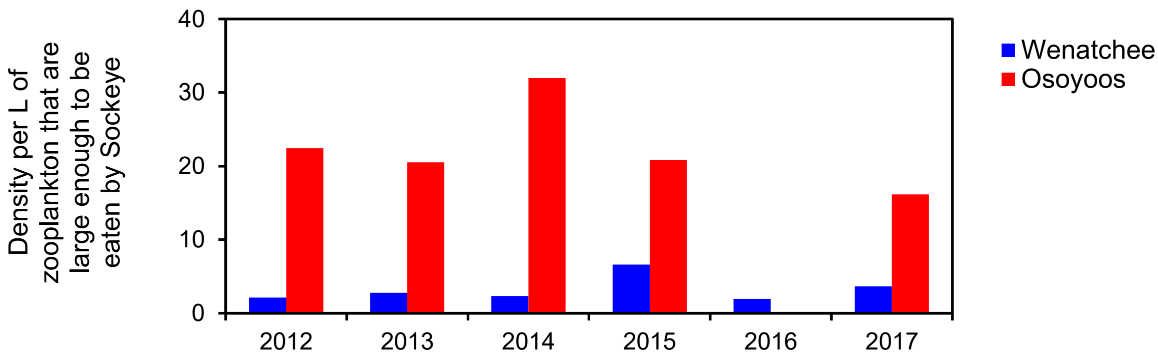


In all years at least half of the zooplankton biomass recorded in Lake Wenatchee was *Hesperodiaptomus*, a very large copepod (30 average µg dw) weighing 5-15 times as much as any of the other zooplankton consumed by age-0 Osoyoos Sockeye. Their presence likely allowed Lake Wenatchee sockeye to forage with greater efficiency (energy return per feeding strike was higher), resulting in a smaller than expected differences in sockeye growth rates (Figure 18, 19). On the other hand, in Lake Wenatchee, the density of zooplankton large enough to be consumed by age-0 Sockeye was very low (Figure 20) (i.e. Lake Wenatchee large zooplankton density = 3.2 L^{-1}, Osoyoos Lake large zooplankton density = 22.4 L^{-1}).

When hunting, a Lake Wenatchee Sockeye fry encountered about 14% as many microzooplanktonic targets as Osoyoos Lake Sockeye fry, but when they captured *Hesperodiaptomus* the energy return was much greater. The interplay between zooplankton density and average individual biomass likely accounts for the small difference in Sockeye fry September weighs (i.e. Lake Wenatchee = 2.0 g and Osoyoos = 2.4 g mm).

A possible caveat to the above is that Osoyoos Lake Sockeye are known to consume *Mysis* which are absent from Lake Wenatchee.

Figure 20: Density (per L) of zooplankton that were large enough to be consumed by age-0 Sockeye. The Lake Wenatchee list includes *Diacyclops*, *Daphnia*, *Bosmina* and *Hesperodiaptomus*. The Osoyoos Lake list includes the first three plus *Diaphanosoma*, *Epischura*, *Leptodiaptomus*, and *Leptodora*.



Sockeye salmon survival: For Lake Wenatchee, both fall to winter age-0 density data were available only during 2014-17. When compared to similar data for Osoyoos Lake, between-year variability was very high but the four year averages were similar.

Table 4: Lake Wenatchee and Osoyoos age-0 plus Sockeye salmon fall-winter percent mortality.

	Percent fall to winter mortality	
	Wenatchee	Osoyoos
2014	14	46
2015	13	8
2016	53	56
2017	25	11
Average	**26**	**30**

Sockeye salmon bioenergetics: For Lake Wenatchee, bioenergetics-based, production-and-consumption estimates were available for **2017**. For Osoyoos Lake, comparable estimates were available for **2015** (Figure 21, 22). Lake Wenatchee diet data were available for 3 dates (Table 5). To facilitate diet comparisons, the larger Osoyoos Lake data set was reduced to include similar dates and the diets were restricted only to include data for age-0 Sockeye.

Prey types consumed by age-0 Sockeye in each lake were different. Important prey items in Lake Wenatchee include *Hesperodiaptomus*, *Daphnia* and *Bosmina*. Important prey items in Osoyoos Lake include *Diacyclops*, *Daphnia* and *Epischura.* It should be noted that in the restricted 2015 data set from Osoyoos Lake, *Mysis* did not appear in the fish stomachs, but in all of the other years (2005-15) *Mysis* were found in the fish diets and accounted for 17% of the total prey consumed by all age classes of Sockeye and kokanee together. In many cases *Mysis* were targeted by age 2-3 kokanee and in most cases *Mysis* were consumed in the fall.

For age-0 Sockeye, the average number of prey per stomach from Lake Wenatchee was greater than in Osoyoos Lake and the average dry weight of prey per age-0 Sockeye stomach from Lake Wenatchee was much greater than in Osoyoos Lake (Table 5). This is reflected in the bioenergetics estimates which show that the average (June to September) rate of consumption for Lake Wenatchee age-0 Sockeye was 11.5% of body weight per day and average consumption for Osoyoos Lake age-0 Sockeye was 7.5% of body weight per day.

Table 5: Lake Wenatchee and Osoyoos Lake average number of prey per age-0 Sockeye fry stomach. The calanoid in Lake Wenatchee was *Hesperodiaptomus* and the calanoid in Osoyoos Lake was *Leptodiaptomus*. The average weight for *Hesperodiaptomus* is about 30 µg dry weight. The average weight for *Leptodiaptomus* is about 3.2 µg dry weight. The average biomass of each type of prey per stomach, equals (prey species number *average prey species weight) and is measured in µg dw.

Lake Wenatchee 2017													
	Age	Sample size	Cyclops	Calanoid	Daphnia	Bosmina				Chironomid larvae	Adult fly	**Sum**	Prey biomass consumed per fish
29-Jun-17	0	40	0.4	97.2	3.6	0.0				0.1	0.1	**101**	2272
31-Aug-17	0	30	9.3	19.8	22.2	144.7				0.0	0.8	**197**	1835
16-Sep-17	0	30	0.9	11.9	7.9	0.0				0.0	0.0	**21**	226

Osoyoos Lake 2015													
	Age	Sample size	Cyclops	Calanoid	Epischura	Daphnia	Bosmina	Diaphanosoma	Mysis	Chironomid larvae	Adult fly	**Sum**	Prey biomass consumed per fish
18-Jun-15	0	30	60.1	0.0	11.3	10.8	12.5	2.3	0.0	0.0	0.0	**97**	497
15-Aug-15	0	30	18.3	10.0	7.7	1.0	0.8	0.0	0.0	0.0	0.0	**38**	182
09-Sep-15	0	30	26.8	17.7	9.8	3.3	1.6	14.5	0.0	0.1	0.0	**74**	472

Figure 21: Lake Wenatchee 2017 zooplankton biomass (top), zooplankton production (middle) and consumption by age-0 and age-1 Sockeye (bottom).

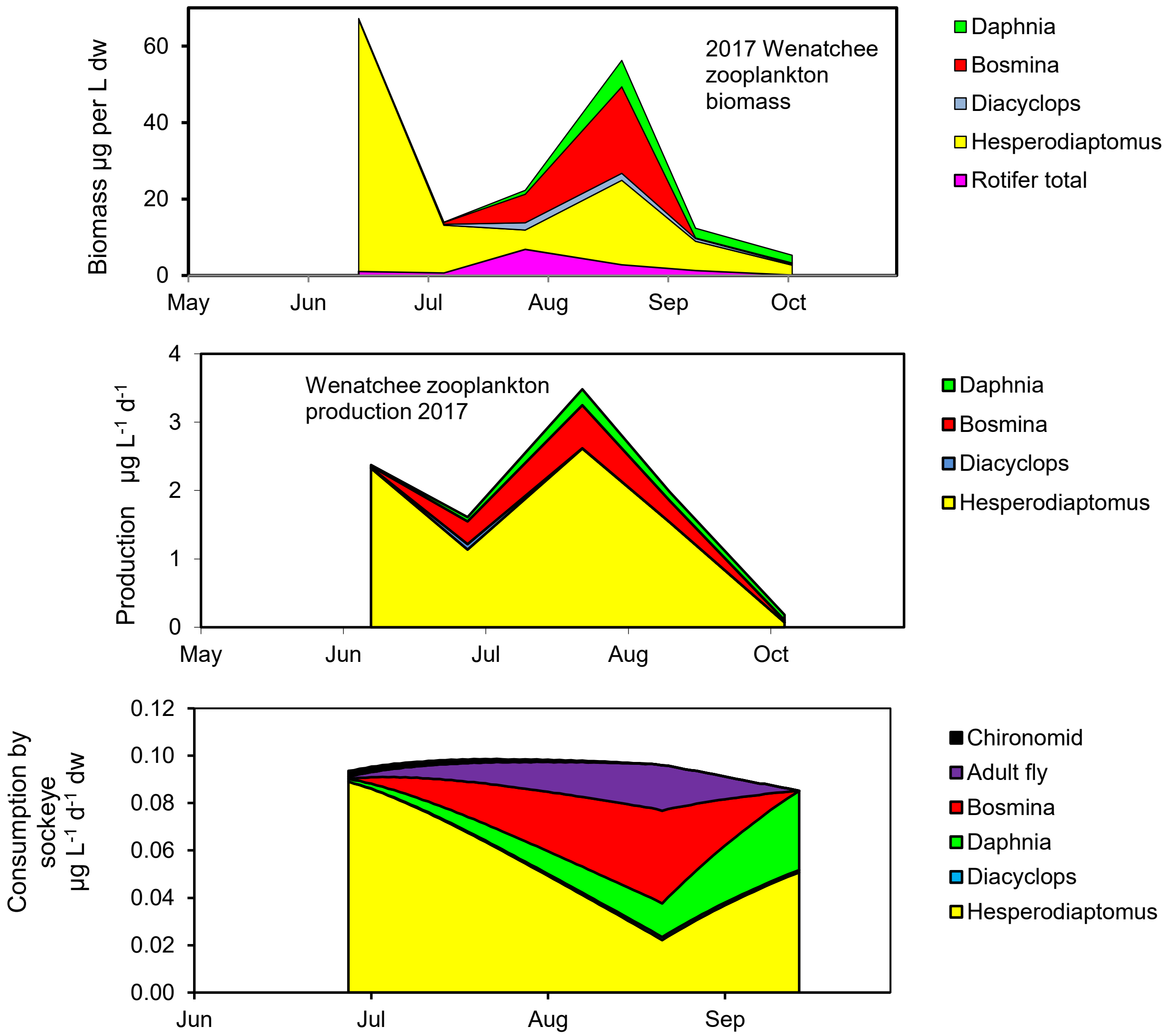
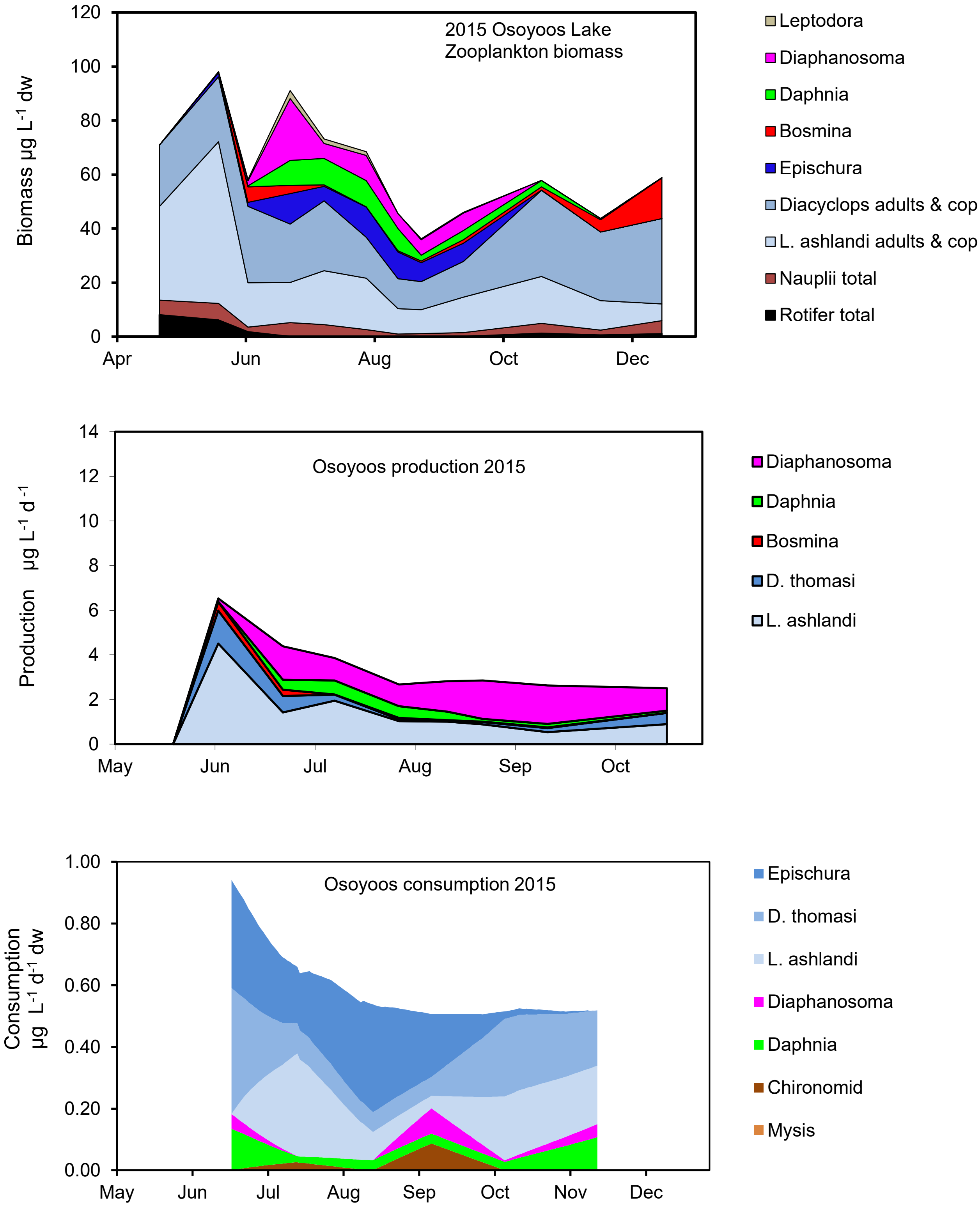


Figure 22: Osoyoos Lake 2015 zooplankton biomass (top), zooplankton production (middle) and consumption by age-0 and age-1 Sockeye (bottom).



Comparisons of bioenergetics data from 2017 Lake Wenatchee (Figure 21) and 2015 Osoyoos Lake (Figure 22), show that during the time period when production and biomass were estimated (i.e. late-June to mid-September), (1) zooplankton biomasses in Osoyoos Lake were more than twice as high as in Lake Wenatchee (Osoyoos = 61 µg L^{-1}, Wenatchee = 33 µg L^{-1} dw) (Tables 6, 7). (2) Zooplankton production in Osoyoos Lake was about 50% higher (Tables 6, 7). (3) Osoyoos Lake Sockeye fry population consumed almost 6 times as much zooplankton biomass as Lake Wenatchee Sockeye fry population and their daily impact on zooplankton standing stock and production was 3 times as high. That is; during 2015, Osoyoos Lake Sockeye alone consumed about 1.0% of the zooplankton standing stock and 17.2% of zooplankton production per day. During 2017, the Lake Wenatchee Sockeye population consumed about 0.3% of the zooplankton standing stock and 5% of zooplankton production per day (Tables 6, 7). Note also that 10% of the prey consumed by age-0 Sockeye comprised chironomids and adult flies. These were not included in our calculation of zooplankton production. Therefore the percentages of production and biomass consumed by Lake Wenatchee Sockeye fry were about 10% smaller than the figures shown in Table 6.

None of this is surprising. The 2015 Osoyoos Lake Sockeye density was about 4 times higher than the 2017 Lake Wenatchee Sockeye density (Tables 6, 7) and about ¼ of the Sockeye in Osoyoos Lake were age-1s which were larger and consumed more prey than age-0 Sockeye. .

This is also the more general result that we would expect from the two lakes. During 2012-17, Sockeye density in Osoyoos Lake was about twice as high as the Sockeye density in Lake Wenatchee and because Osoyoos Lake age-1 Sockeye densities were higher; total Sockeye biomass in Osoyoos Lake was about 3 times higher (Tables 2,3).

During 2015 in Osoyoos Lake, consumption of zooplankton by all Sockeye, plus kokanee, plus Lake Whitefish, plus *Mysis diluviana* averaged 42% of zooplankton production per day, and even at that high level, there was no obvious impact on age-0 Sockeye growth or survival. During 2017 in Lake Wenatchee, consumption by age-0 and age-1 Sockeye averaged only 5% of zooplankton production per day. We conclude that Lake Wenatchee has substantial unused capacity for additional Sockeye production.

Table 6: Summary of Lake Wenatchee 2017 bioenergetics model input and output data. All consumption estimates refer to age-0 and age-1 Sockeye alone. Consumption by other fish is not included.

Average fall density age-0	2317	per ha
Average density age-1	25	per ha
Average zooplankton biomass	33	µg per L dw
Average zooplankton production	1.9	µg per L per day dw
Average consumption by fish	0.099	µg per L per day dw
% biomass consumed per day	0.3	%
% production consumed per day	5	%

Table 7: Summary of Osoyoos Lake 2015 bioenergetics model input and output data. All consumption estimates refer to age-0 and age-1 Sockeye alone. Consumption by other fish is not included.

Average fall density age-0	6641	per ha
Average density age-1	1923	per ha
Average zooplankton biomass	61	µg per L dw
Average zooplankton production	3.4	µg per L per day dw
Average consumption by fish	0.586	µg per L per day dw
% biomass consumed per day	1.0	%
% production consumed per day	17.2	%

But note. In Lake Wenatchee *Hesperodiaptomus* were the primary prey consumed by juvenile Sockeye. At the moment we do not have enough data to estimate the total production potential for this species, but we do know that *Hesperodiaptomus* may reproduce only once (summer) or perhaps twice (spring) per year. Therefore if the Sockeye population is large enough to consume most of the available copepodids and adults, this important food supply will not be replaced and growth and survival rates may be negatively affected. The same applies to the spring population of age-1 Sockeye which could conceivably consume substantial portions of the *Hesperodiaptomus* population early in the season before the age-0s enter the lake to begin feeding. At the moment, we sample zooplankton from June to October. Additional spring and fall samples (March-November) will be needed to clarify details of life history and associated production of *Hesperodiaptomus*.

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APPENDIX G

Lake Wenatchee Juvenile Sockeye Salmon and Limnology Status Report Brood Years 2009-2017 (in-lake 2010-2018)

LAKE WENATCHEE
JUVENILE SOCKEYE SALMON AND LIMNOLOGY STATUS REPORT
BROOD YEARS 2009-2017
(IN-LAKE 2010-2018)

November 2019

Editorial note: Sockeye Salmon from Brood Years BY2009-17 were sampled in-lake during 2010-18. Because these and associated limnological data were recorded during the summer following egg deposition (for example BY2017 is followed by inlake 2018) this document reports data in terms of in-lake years.

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ABSTRACT

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. Then 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 2018, survey intensity has increased in each year with the 2017 and 2018 programs being especially exemplary.

In aggregate, the data collected during 2012-18 suggest that Lake Wenatchee provides excellent habitat for Sockeye fry. Although Lake Wenatchee is oligotrophic and Sockeye fry growth is expected to be limited, the unique mix of physical and biological conditions found in the lake, permit 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 2010-18, the fall population density for Lake Wenatchee Sockeye fry averaged 2115 ha^{-1}. Over the years there was a slight increase to 2532 ha^{-1} recorded in 2017, but this was followed by a decrease to 1387 ha^{-1} recorded in 2018, (ii) based on the limited data available to date, total mortality of Sockeye fry from June to the following winter in Wenatchee Lake has averaged about 50%, (iii) also based on limited data, age-1 holdovers comprised about 4%, 10%, 1% and 5% of the total Sockeye fry population in 2015, 2016, 2017 and 2018 respectively, (iv) fry growth rates in all years were about equal and were higher than expected when compared to similar data from Osoyoos Lake. (v) Finally, bioenergetics-based production and consumption analysis from (2012, 2013, 2017 and 2018) produced remarkably similar results. The percentage total prey biomass consumed per day by Sockeye fry was 0.5% in three of the years and 0.3% in one year; and the percentage of prey production consumed ranged from 2.1% to 11.9% per day. In no case was there any indication that age-0 and age-1 fry were capable of limiting prey availability.

From this we conclude that Lake Wenatchee has unused capacity to support additional Sockeye fry. However, this conclusion is based on limited data. (1) To date there has been only one year (2017) when echosounding and trawl data sets have included at least 5 samples spanning most of the temporal interval (June-following winter) when fry are in the lake. This limits the application of our life history and bioenergetics-based estimates of potential carrying capacity to the summer-fall seasonal interval (i.e. excludes winter to early spring). (2) Stomach content samples and bioenergetics analysis demonstrate that *Hesperodiaptomus* account for the largest portion of the Sockeye fry diets. However, our zooplankton samples have been restricted to include samples from June to October. These data suggest that *Hesperodiaptomus* reproduce in the spring, are heavily impacted by fish in the summer and then decline precipitously in the fall. The unanswered question is how much predation can this keystone species withstand? That will be the focus of our work in future years.

METHODS AND SITE DESCRIPTION

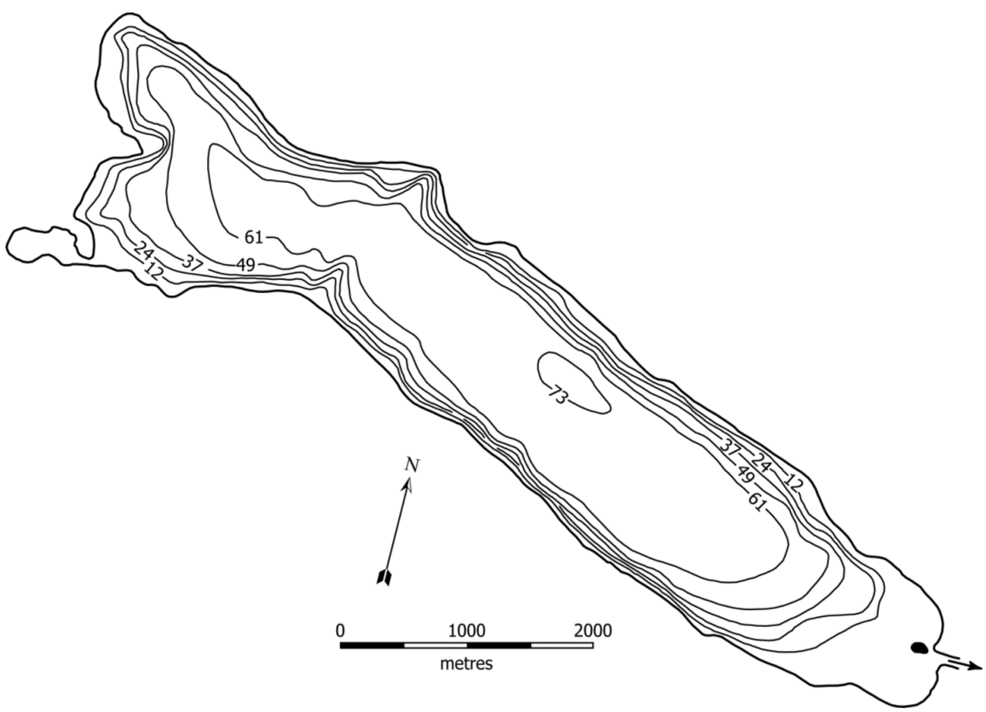
Site Description

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 3.

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

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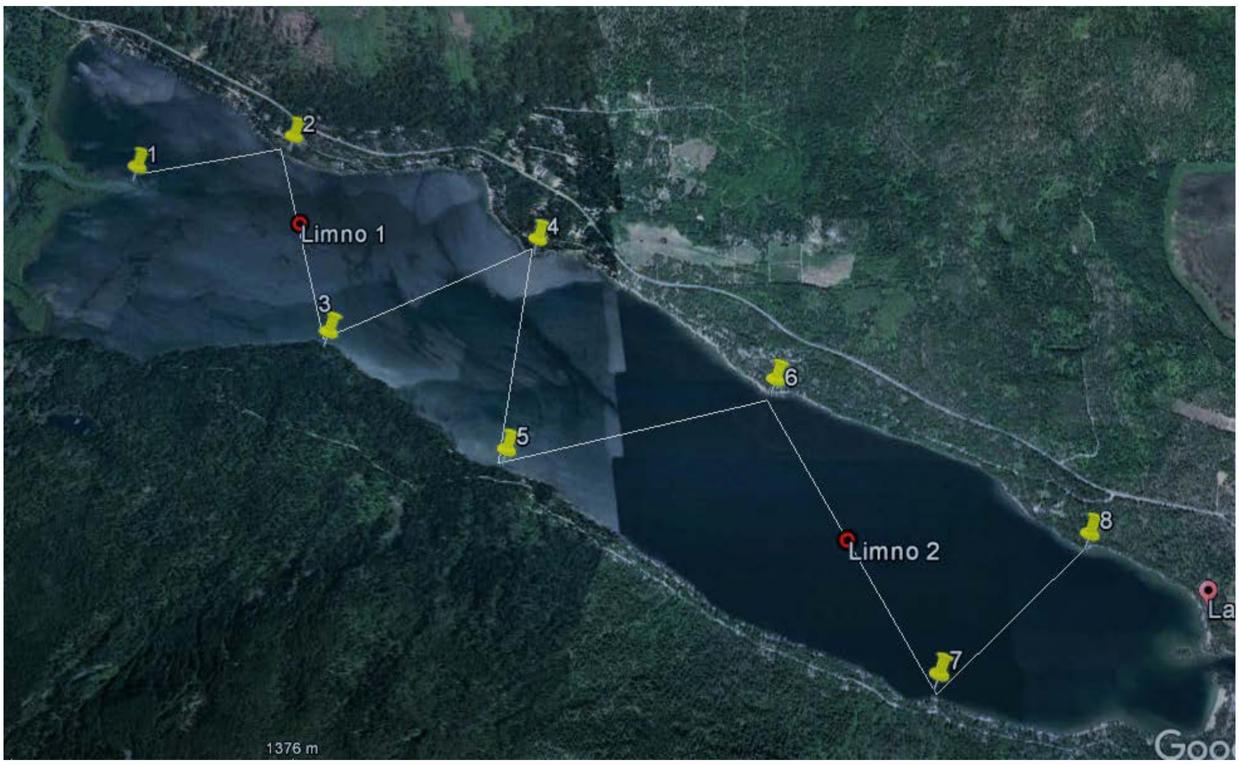


Oxygen and temperature were recorded at both Limno 1 and Limno 2. Sampling depths were at 1 meter intervals (1-20 m) and at 4 meter intervals (24-52 m) thereafter.

All 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 3. 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.

During 2012-18, phytoplankton biomasses were sampled at two stations (Limno 1 and 2). At each station, water was combined from depths of 1, 5, and 10m. 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, samples were analyzed by Biologica Environmental Services, Ltd. using the protocol developed by Ms. Carney.

During 2012-18, 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 weeks (see sample schedule Table 3). 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, Cladocera 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 Cyclopoida, 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 2010-18, juvenile Sockeye Salmon (*Oncorhynchus nerka*) densities were assessed 1-5 times per year (depending on the lake-year; see sample schedules in Table 3) 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 2012-18, 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) and two dates in 2018 (14 August, age-0 n=30; age-1, n=30 and 07 November age-0, n=30). Prey identified included *Diacyclops*, *Hesperodiaptomus*, *Daphnia*, Chironomid larvae and pupae, 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 and 2018 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 and 2018. 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 and 2018, 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, chironomids 2000 J/g, adult dipternas 1500 J/g and *Mysis* 3400 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 3. The most complete sample sets were collected in 2017 and 2018.

Table 3: Samples collected at Lake Wenatchee during 2012-18. 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

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). From this we conclude that spring-summer rates of lake-turnover were also variable (Table 3).

Figure 3: Rates of Wenatchee River discharge recorded at Plain Washington during May-September 2012-2018. (Reference gauge USGS 12457000 Wenatchee River at Plain, WA).

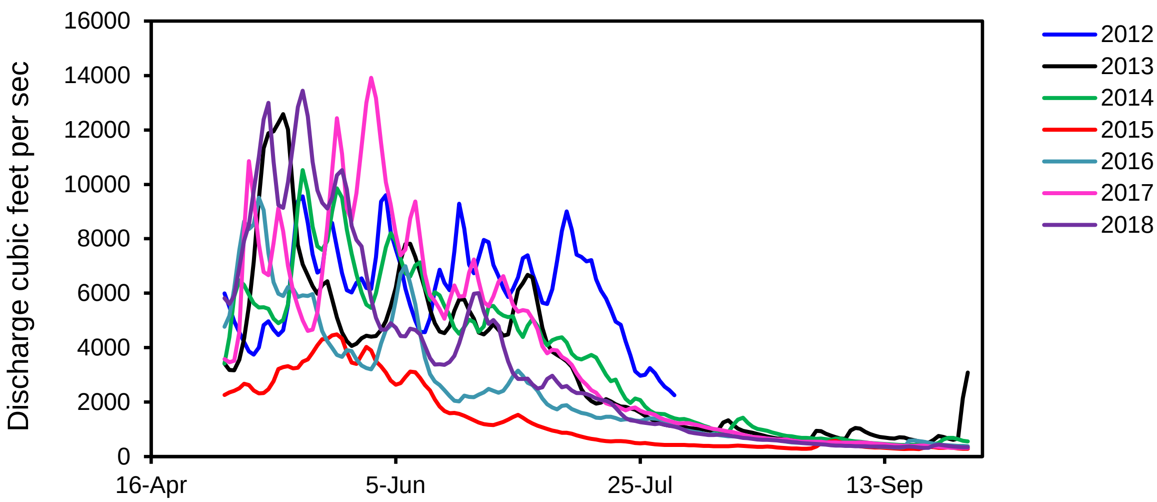


Table 3: Rates of Wenatchee River discharge and estimates of Wenatchee Lake-turnover based on Wenatchee River flow rates recorded at Plain Washington during May-September 2012-2018.

Year	Discharge ft^2 per Second	Discharge m^3 per Second	Lake-turnover days
2012	6,141	174	30
2012	4,972	141	37
2012	5,244	149	35
2012	2,014	57	90
2012	3,580	101	51
2012	5,846	166	31
2012	5,245	149	35
Average	**4,720**	**134**	**44**

The Plain WA estimates (Table 4) 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 4).

Table 4: 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 (May-July) Wenatchee River at Plain Washington cubic feet per second	Flow (May-July) Chiwawa River cubic feet per second	Net flow cubic feet per second (Plain - 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
Average	**4,720**	**1,277**	**3,443**	**97**	**8,425,162**	**61**

It should be noted that the net discharge estimates (Table 4) 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 flow rates recorded in Table 4 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) , and 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 2012-18, this optimal mix of temperature and oxygen conditions was available to Sockeye fry at all times (Tables 5, 6). 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 5: Lake Wenatchee 2012-18 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 0-20	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 0-20	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 0-20	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 0-20	11	15	16	18	18	16

Table 5 continued: Lake Wenatchee 2012-18 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	12-Apr-17	28-Jun-17	21-Aug-17	15-Sep-17	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	11.8	13.4	16.4	16.6	18.8	15.5	4.1	8.7	18.3	17.1	4.1	9.8	10.5	14.7	17.6	18.9	18.7	16.2	14.2	13.4	10.7
2	11.8	13.3	16.2	16.5	18.6	15.5	4.1	8.7	18.1	17.2	4.1	9.8	10.4	14.6	17.6	18.6	18.7	16.2	14.2	13.5	10.7
3	11.6	13.2	16.1	16.5	18.4	15.4	4.0	8.7	17.7	17.1	4.0	9.8	10.3	14.5	17.6	18.5	18.7	16.2	14.3	13.6	10.7
4	11.4	13.0	15.9	16.5	18.3	15.4	4.0	8.6	17.6	17.1	4.0	9.8	10.3	14.3	17.5	18.4	18.7	16.2	14.4	13.6	10.8
5	11.1	12.8	15.7	16.5	18.2	15.4	4.0	8.6	17.5	17.1	3.9	9.8	10.2	14.0	17.5	18.2	18.7	16.2	14.4	13.6	10.8
6	10.8	12.8	15.4	16.5	18.1	15.4	3.9	8.5	17.4	17.0	3.8	9.8	10.2	13.5	17.3	17.9	18.5	16.2	14.4	13.6	10.8
7	10.7	12.8	15.2	16.5	18.1	15.3	3.9	8.5	17.2	17.0	3.5	9.7	10.1	13.1	17.2	17.5	18.1	16.2	14.4	13.7	10.8
8	10.6	12.7	15.1	16.5	18.1	15.3	3.9	8.5	17.0	16.9	3.4	9.7	10.0	12.8	17.1	17.1	17.7	16.3	14.4	13.7	10.8
9	10.5	12.7	14.9	16.5	18.0	15.3	3.9	8.5	16.9	16.8	3.4	9.6	9.8	12.7	17.0	17.0	17.3	16.3	14.4	13.7	10.8
10	10.3	12.6	14.8	16.5	18.0	15.3	3.9	8.5	16.7	16.7	3.3	9.5	9.5	12.6	16.8	16.7	17.2	16.3	14.4	13.7	10.8
11	10.2	12.6	14.6	16.5	17.8	15.3	3.9	8.5	16.6	16.7	3.3	9.5	9.4	12.5	16.8	16.5	16.9	16.3	14.4	13.7	10.8
12	10.0	12.5	14.4	16.5	17.7	15.3	3.9	8.5	16.5	16.6	3.3	9.4	9.3	12.4	16.5	16.3	16.4	16.3	14.4	13.7	10.8
13	9.8	12.4	14.2	16.5	17.6	15.3	3.9	8.5	16.2	16.5	3.3	9.3	9.3	12.3	15.9	16.2	16.7	16.3	14.4	13.7	10.8
14	9.6	12.3	14.0	16.5	17.5	15.3	3.9	8.5	15.9	16.3	3.3	9.3	9.3	12.2	14.6	16.1	16.6	16.2	14.4	13.7	10.8
15	9.3	12.2	13.7	16.5	17.5	15.2	3.9	8.5	15.4	16.3	3.3	9.3	9.2	11.9	14.3	15.6	16.4	16.2	14.4	13.7	10.8
16	9.2	12.2	13.5	16.5	17.3	15.2	3.9	8.5	15.1	16.2	3.2	9.3	9.1	11.8	14.1	14.8	16.1	16.2	14.4	13.7	10.8
17	9.1	12.1	13.3	16.4	16.7	15.1	3.9	8.5	14.4	16.0	3.2	9.3	9.1	11.7	13.6	14.3	15.5	16.1	14.4	13.7	10.8
18	9.0	12.1	13.2	15.9	16.4	15.1	3.9	8.5	13.8	15.0	3.2	9.3	9.0	11.5	13.3	13.5	14.4	16.0	14.4	13.7	10.7
19	8.9	12.0	13.1	15.8	15.5	15.0	3.9	8.5	12.9	13.5	3.2	9.2	9.0	11.4	12.7	12.8	14.0	15.5	14.3	13.6	10.7
20	8.8	11.7	13.0	15.8	14.7	14.9	3.9	8.5	12.6	12.4	3.2	9.2	9.0	11.3	12.2	12.3	13.3	15.0	14.3	13.6	10.7
24	8.7	10.7	11.2	13.3	13.0	14.0	3.9	8.4	10.9	10.1	3.2	8.7	9.0	10.8	10.6	11.1	11.6	11.6	12.8	12.6	10.2
28	8.4	9.6	10.4	11.8	11.0	11.4	3.9	8.4	9.4	9.0	3.2	8.4	8.7	9.9	10.1	10.2	10.8	10.4	10.4	10.3	9.9
32	8.2	9.0	9.5	10.2	9.6	9.6	3.9	8.1	8.9	8.4	3.2	8.1	8.5	9.3	9.4	9.5	10.0	9.7	9.7	9.4	9.7
36	7.9	8.4	8.6	9.1	8.9	8.8	3.9	7.9	8.4	8.0	3.2	7.9	8.3	9.0	8.9	8.9	9.3	9.2	9.1	8.8	9.4
40	7.6	8.0	8.1	8.6	8.5	8.3	3.9	7.7	8.0	7.7	3.2	7.6	8.3	8.6	8.5	8.5	8.7	8.8	8.7	8.4	8.9
44	7.4	7.7	7.8	8.2	8.2	8.0	3.9	7.6	7.8	7.5	3.2	7.5	8.0	8.4	8.3	8.1	8.3	8.4	8.4	8.1	8.3
48	7.3	7.5	7.6	7.9	7.8	7.8	3.9	7.5	7.6	7.3	3.2	7.3	7.9	8.0	8.0	7.9	8.1	8.2	8.2	7.9	8.0
52	7.2	7.5	7.5	7.7	7.6	7.6	3.9	7.0	7.5	7.2	3.2	7.2	7.8	7.7	7.9	7.7	7.9	7.9	8.0	7.7	7.7
Average 0-20	10	13	15	16	18	15	4	9	16	16	3	10	10	13	16	16	17	16	14	14	11

Table 6: Lake Wenatchee 2012-18 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

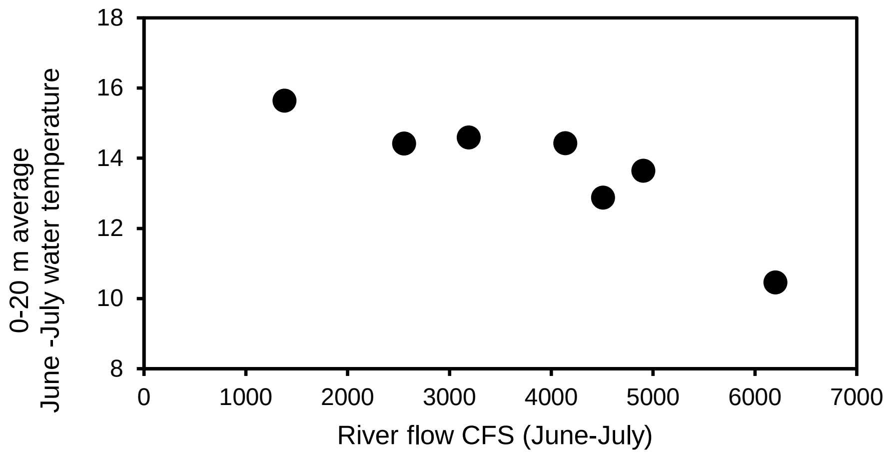
Water depth (m)	01-Jun-15	25-Jun-15	14-Jul-15	05-Aug-15	28-Aug-15	16-Sep-15
1	10.5	9.7	8.8	9.2	9.1	9.1
2	10.5	9.7	8.8	9.2	9.1	9.2
3	10.5	9.7	8.8	9.2	9.0	9.2
4	10.5	9.8	8.8	9.1	9.5	9.2
5	10.5	9.7	8.8	9.1	9.5	9.2
6	10.6	9.7	8.8	9.1	9.5	9.2
7	10.7	9.8	8.8	9.1	9.0	9.1
8	10.6	9.8	8.8	9.1	8.9	9.1
9	10.7	9.8	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 6 continued: Lake Wenatchee 2012-18 oxygen concentrations (ppm)

Water depth (m)	08-Jun-16	29-Jun-16	20-Jul-16	10-Aug-16	31-Aug-16	29-Sep-16	12-Apr-17	28-Jun-17	21-Aug-17	15-Sep-17	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	10.7	10.4	9.5	9.2	8.8	9.4	10.9	10.5	9.1	9.5	12.5	10.8	10.1	9.2	9.2	9.3	9.7	9.7	10.1	17.4
2	10.7	10.5	9.7	9.2	8.9	9.4	10.9	10.6	9.1	9.4	12.5	11.0	10.1	9.1	9.2	9.3	9.8	9.7	9.9	17.0
3	10.7	10.4	9.7	9.2	8.9	9.4	10.9	10.6	9.1	9.4	12.6	11.0	10.1	9.1	9.2	9.3	9.8	9.6	9.8	16.9
4	10.7	10.4	9.7	9.2	8.9	9.4	10.9	10.7	9.1	9.4	12.6	11.0	10.2	9.1	9.2	9.3	9.8	9.6	9.8	16.7
5	10.7	10.5	9.8	9.2	8.9	9.4	10.8	10.7	9.1	9.4	12.6	11.0	10.1	9.1	9.2	9.3	9.8	9.5	9.7	16.6
6	10.7	10.5	9.8	9.1	8.9	9.4	10.8	10.7	9.1	9.4	12.7	11.0	10.2	9.1	9.2	9.2	9.8	9.5	9.7	16.6
7	10.8	10.4	9.8	9.1	8.9	9.3	10.8	10.7	9.1	9.4	12.8	11.0	10.2	9.1	9.2	9.2	9.8	9.5	9.7	16.5
8	10.8	10.4	9.8	9.1	8.9	9.3	10.8	10.7	9.1	9.4	12.8	11.0	10.2	9.1	9.1	9.2	9.8	9.4	9.7	16.5
9	10.8	10.4	9.8	9.1	8.9	9.3	10.8	10.7	9.1	9.3	12.8	10.9	10.2	9.1	9.1	9.2	9.8	9.4	9.7	16.4
10	10.8	10.4	9.8	9.1	8.9	9.3	10.9	10.7	9.1	9.3	12.9	11.0	10.2	9.1	9.1	9.2	9.8	9.4	9.6	16.4
11	10.7	10.4	9.8	9.1	8.8	9.3	10.9	10.7	9.1	9.3	12.8	11.0	10.1	9.1	9.0	9.1	9.9	9.4	9.6	16.4
12	10.7	10.4	9.7	9.1	8.8	9.2	10.9	10.7	9.0	9.3	12.8	11.0	10.1	9.1	9.0	9.1	9.8	9.3	9.6	16.4
13	10.7	10.4	9.7	9.1	8.8	9.2	10.8	10.7	9.0	9.2	12.8	11.0	10.1	9.2	8.9	9.1	9.8	9.3	9.6	16.4
14	10.7	10.4	9.7	9.0	8.8	9.2	10.8	10.7	9.5	9.2	12.8	11.0	10.1	9.2	8.9	9.1	9.8	9.3	9.6	16.4
15	10.7	10.4	9.7	9.0	8.8	9.2	10.8	10.7	9.0	9.1	12.8	10.9	10.1	9.3	8.8	9.1	9.7	9.3	9.6	16.3
16	10.7	10.4	9.7	9.0	8.7	9.1	10.8	10.7	9.0	9.1	12.8	10.9	10.1	9.3	8.8	9.1	9.7	9.2	9.5	16.3
17	10.7	10.4	9.7	9.0	8.7	9.1	10.7	10.7	9.1	9.0	12.8	10.9	10.0	9.3	8.8	9.0	9.7	9.2	9.5	16.2
18	10.7	10.4	9.6	9.0	8.6	9.0	10.7	10.7	9.0	8.9	12.8	10.9	10.0	9.3	8.8	9.0	9.7	9.2	9.5	16.2
19	10.7	10.3	9.6	8.9	8.4	9.0	10.7	10.6	9.0	8.8	12.8	10.9	10.0	9.3	8.8	8.9	9.8	9.2	9.5	16.1
20	10.7	10.3	9.6	8.9	8.4	9.0	10.7	10.6	9.6	8.8	12.8	10.9	10.0	9.3	8.8	8.8	9.8	9.1	9.4	16.1
24	10.6	10.2	9.7	8.9	8.5	8.7	10.7	10.6	9.3	9.0	12.8	10.8	9.9	9.4	8.9	8.7	9.9	8.8	9.4	15.9
28	10.6	10.1	9.6	8.9	8.5	8.4	10.6	10.6	9.5	9.2	12.8	10.8	9.9	9.4	9.0	8.8	9.9	8.7	9.0	15.9
32	10.5	10.1	9.6	9.0	8.7	8.4	10.6	10.5	9.5	9.3	12.8	10.7	9.8	9.5	9.0	8.9	10.0	8.6	8.9	15.9
36	10.4	10.0	9.6	9.1	8.8	8.5	10.6	10.5	9.5	9.4	12.8	10.7	9.8	9.5	9.0	8.9	10.0	8.6	8.8	15.8
40	10.4	10.0	9.6	9.1	8.8	8.5	10.5	10.6	9.5	9.5	12.7	10.6	9.7	9.5	9.1	8.9	10.0	8.6	8.9	15.3
44	10.3	9.9	9.5	9.1	8.8	8.5	10.5	10.6	9.4	9.5	12.7	10.5	9.7	9.4	9.0	8.8	10.1	8.6	8.9	14.6
48	10.3	9.9	9.4	9.1	8.9	8.4	10.5	10.5	9.4	9.6	12.7	10.5	9.6	9.2	9.0	8.7	10.0	8.5	8.8	14.2
52	10.2	9.9	9.3	9.1	8.7	8.2	10.4	10.4	9.5	9.6	12.7	10.4	9.6	9.1	8.9	8.6	10.0	8.4	8.8	13.7

There was a strong (R^2=0.79, p=0.007, n=7) (Figure 7) correlation between average June-July discharge rate from Lake Wenatchee and June-July 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 7: Average Lake Wenatchee 0-20 m water temperatures recorded during June and July 2012-18, with respect to average rates of river flow (cubic feet per second) recorded at Plain WA during June and July 2012-18.



Lake Wenatchee 2012-18 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, samples were taken at night and Secchi depths were recorded on only one and four dates respectively (Table 8).

Table 8: 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		

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 9) 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 9: Lake Wenatchee 2012, 2013 and 2017 water chemistry. Water chemistry data were not collected during 2018.

Lake Wenatchee 2012		Station 1		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 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 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 2012-17 phytoplankton

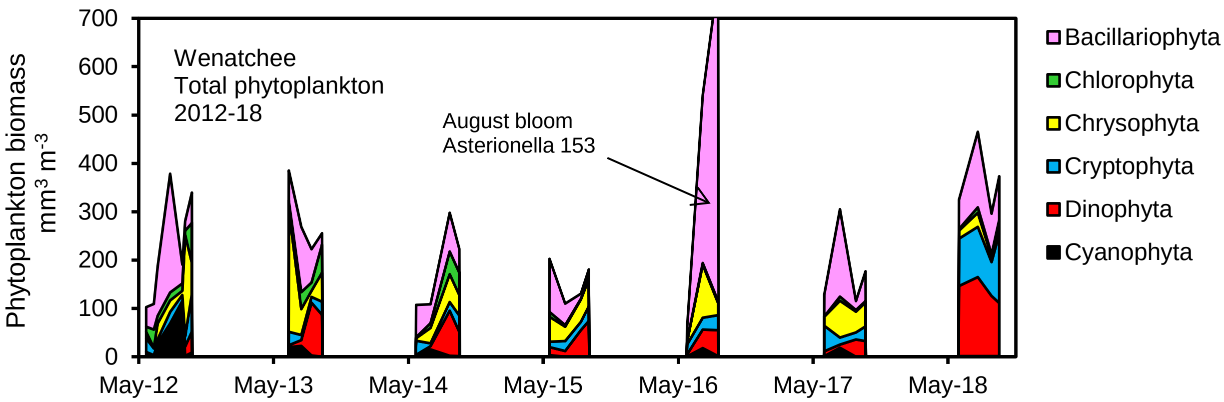
Phytoplankton were collected on seven dates during 2012, four dates during 2013-15, three dates during 2016 and on 4 dates during 2017-18 (Figure 8, Tables 9,10). Samples taken at 1,5,10 m were combined. Densities, cell sizes, cell shapes and biovolumes were recorded. One of the objectives of the phytoplankton 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 257 $mm^3\ m^{-3}$ and the edible biovolume averaged 190 $mm^3\ m^{-3}$. 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 74%, Osoyoos 28%). Detailed count data are provided in Tables 9, 10. 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 2012-18 (Figure 8, Tables 9, 10) 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 9) that is too large for consumption by zooplankton.

During 2015, phytoplankton biovolumes, especially edible phytoplankton biovolumes, were lower than in the other 4 years. 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 (2) higher rates of predation by the 2015 zooplankton population. From Table 4 we see that 2015 rates of river flow were the lowest recorded suggesting that 2015 phytoplankton washout should have been minimal. From Figures 10, 11; Table 12, we see that during 2015, zooplankton biomasses were the highest recorded and that *Daphnia* biomasses were exceptionally high suggesting that 2015 grazing rates may have been higher than normal accounting for lower than normal 2015 phytoplankton biomasses. This is discussed in more detail in the section on zooplankton which follows.

Figure 8: Lake Wenatchee 2012-18, total and edible phytoplankton biovolume as mm^3 m^{-3} which approximates µg•L^{-1} wet weight.



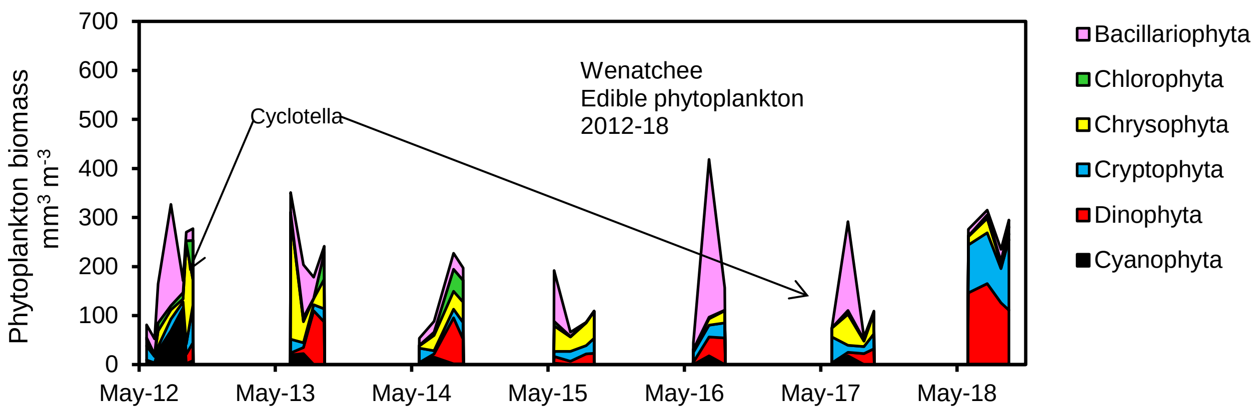


Figure 9: Asterionella measuring 153 x 102 x 3 µm.

Table 10: Lake Wenatchee 2012-18, 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**

Table 11: Lake Wenatchee 2012-18, <u>edible</u> phytoplankton biovolume as $mm^3\ m^{-3}$ which approximates $\mu g\ L^{-1}$ 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**

Lake Wenatchee 2012-18 zooplankton

The Lake Wenatchee zooplankton community comprises a very small number of species. There are two dominant copepods (*Diacyclops thomasi*, *Hesperodiaptomus kenai*), and two bosminids (*Bosmina longirostris*, *Eubosmina coregoni*) which were counted separately but grouped together in this report (Figure 10, Table 12). The remaining cladocerans are *Daphnia schodleri* and *Leptodora kindtii.* Most of these 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 2012-18, there was considerable variation in zooplankton biomass (Figure 10). 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 10, Table 12). 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 12). 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 in 2012. In all years, *Hesperodiaptomus* accounted for the largest portion of zooplankton biomass.

Figure 10: Year 2012-18 zooplankton biomass (µg L^{-1} dry weight).

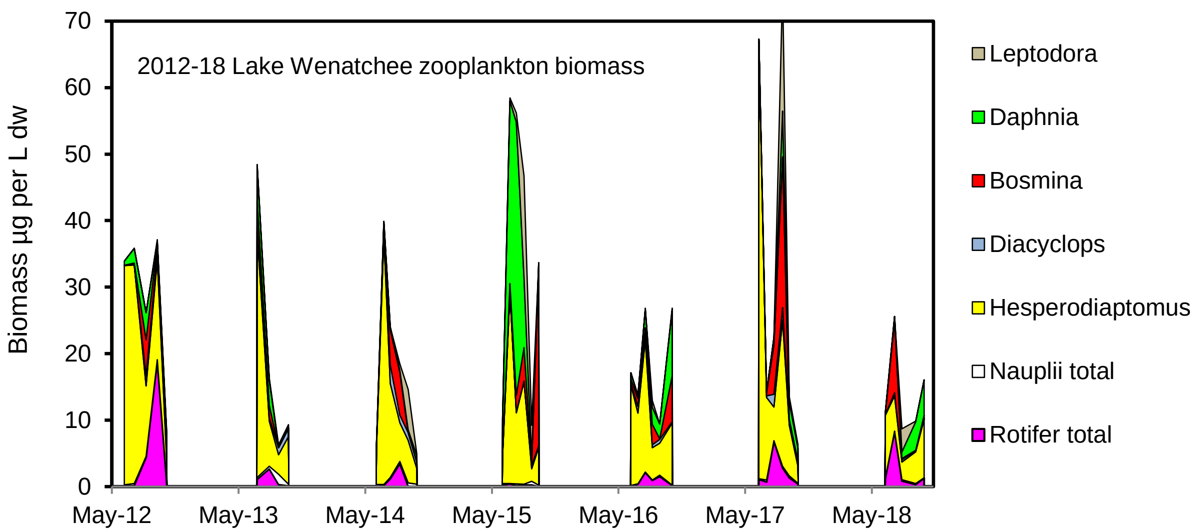


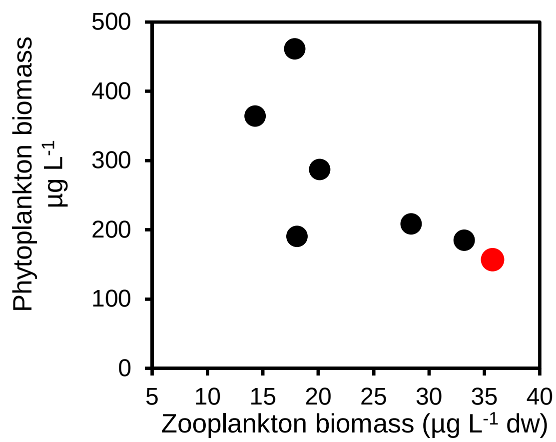
Table 12: 2012-18 Lake Wenatchee zooplankton biomasses (µg L^{-1} dry weight)

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**

Explanations for the between-year differences in zooplankton biomass: Here we investigate three possible hypotheses for the between-year differences in zooplankton biomasses shown in Figure 10 and Table 12.

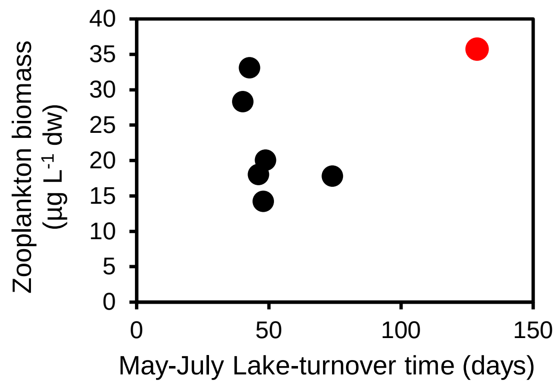
Working Hypothesis 1 – There is a negative correlation between phytoplankton and zooplankton biomass. A comparison of Figure 8 (phytoplankton biomass) and Figure 10 (zooplankton biomass) suggests that when zooplankton biomasses were highest (2015 and 2017), phytoplankton biomasses were lowest and conversely, 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 2012-18 data set is plotted (Figure 11) there appears to be a negative, but not significant (R^2=0.52, p=0.07), relationship between zooplankton and phytoplankton biomass. From this we conclude that during some years, Lake Wenatchee zooplankton populations may be capable of regulating phytoplankton biomass. We also conclude that year to year changes in phytoplankton biomass do no limit zooplankton biomass.

Figure 11: Year 2012-18 June-September phytoplankton biomass with respect to zooplankton biomass. Year 2015 is shown in red.



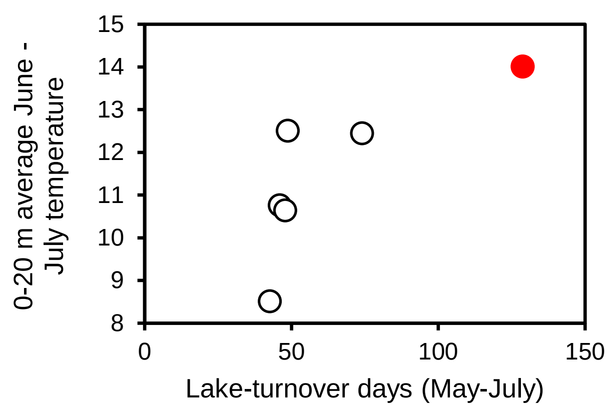
Working Hypothesis 2- There is an inverse relationship between the volume of water flowing through Lake Wenatchee and zooplankton biomass. This hypothesis is based on observations in the Okanagan valley where there were strong negative relationships between discharge in the Okanagan River and mean summer zooplankton biomasses in Osoyoos (p=.004) and Skaha (p=.008) lakes. However in Lake Wenatchee (Figure 12), there is no obvious relationship between rates of lake-turnover (converse of river flow) and average summer zooplankton biomass.

Figure 12: Year 2012-18 Average spring-summer (June-September) zooplankton biomass with respect to average (May-July) rate of lake-turnover. Red data point = year 2015.



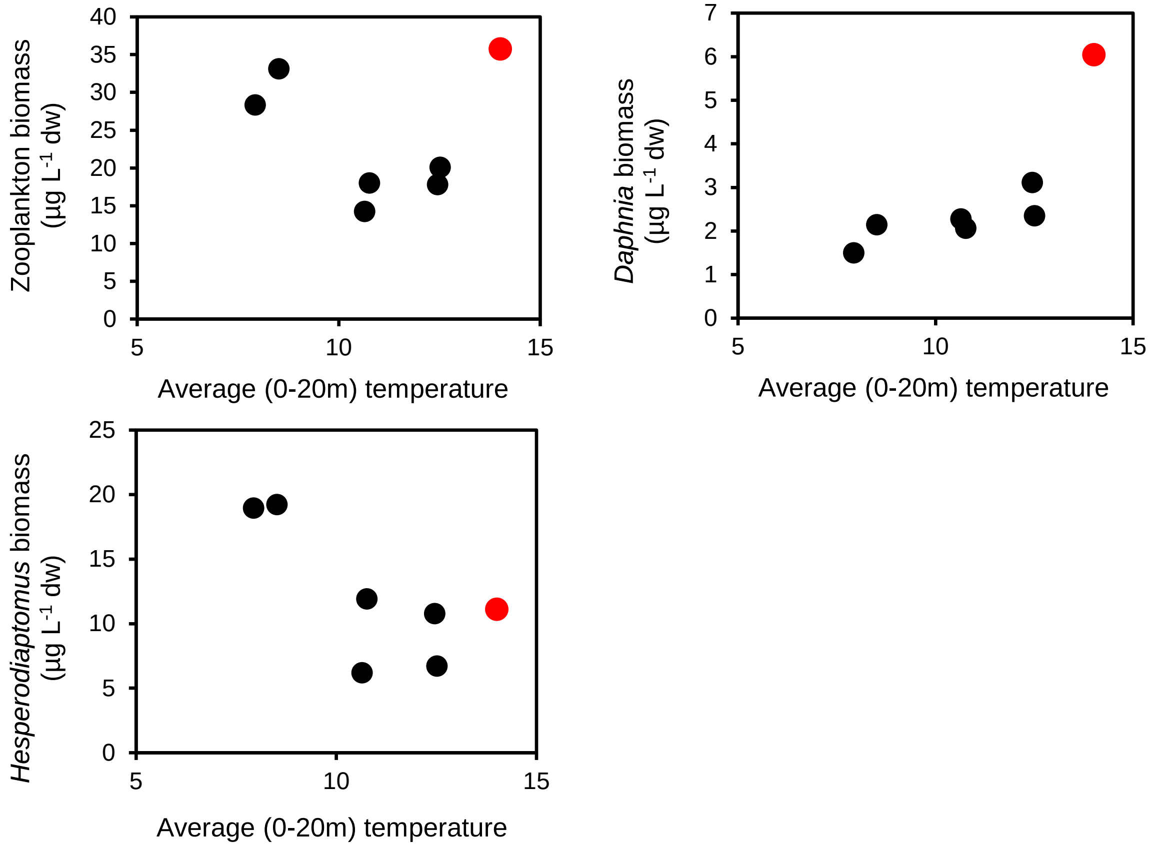
Working Hypothesis 3- There is a relationship between lake temperature and zooplankton biomass. As we saw from Figure 7, there was a strong negative (R^2=0.79, p=0.007) correlation between discharge rate from Lake Wenatchee and average (0-20m) water temperature. There was also a significant (R^2=0.58, p=0.045) relationship between lake-turnover and water temperature (Figure 13). 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 13: Year 2012-18 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.



We have seen that there is no relationship between zooplankton biomass and lake-turnover (Figure 12), but there is a positive relationship between lake temperature and lake-turnover (Figure 13). So is there a relationship between zooplankton biomass and water temperature? The answer is both yes and no (Figure 14).

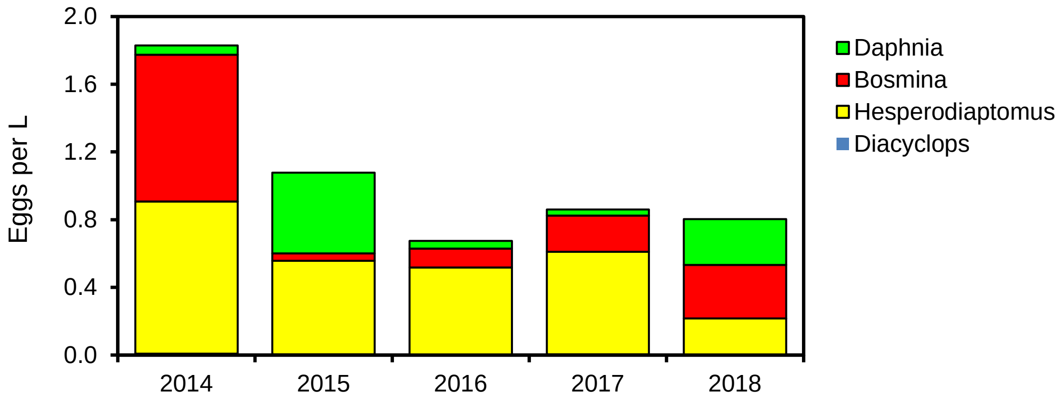
Figure 14: Year 2012-18 total zooplankton, *Daphnia* and *Hesperodiaptomus* biomass with respect to average (0-20 m) water temperature.



From Figure 14 we see that *Daphnia* biomass is positively (R^2=0.59, p=0.04) associated with water temperature and *Hesperodiaptomus* biomass is negatively (R2=0.51, p=0.07) associated with water temperature. It appears that the two relationships cancel each other so that total zooplankton biomass is not correlated with water temperature.

The data summarized in Figures 12, 13, and 14, are all strongly influenced by results from year 2015, when river flow was low, lake-turnover time was high and *Daphnia schodleri* biomasses were especially high. During the summer of 2015, egg counts for *Daphnia* were the highest recorded (Figure 15). During late-June and early-July 2015, the epilimnion warmed to >17^{O}C and these warm conditions persisted through to late August - early September. 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. These trends in zooplankton biomass suggest that during 2015, high grazing rates by *Daphnia* may have reduced the abundance of phytoplankton (Figure 8). We conclude that during 2015, food web dynamics were strongly influenced by climate.

Figure 15: Year 2014-18 average (June-September) zooplankton eggs counts per L of lake water.



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 >30 µg dry weight and the average body length is about 2 mm. This makes *Hesperodiaptomus* an important target as prey for juvenile sockeye.

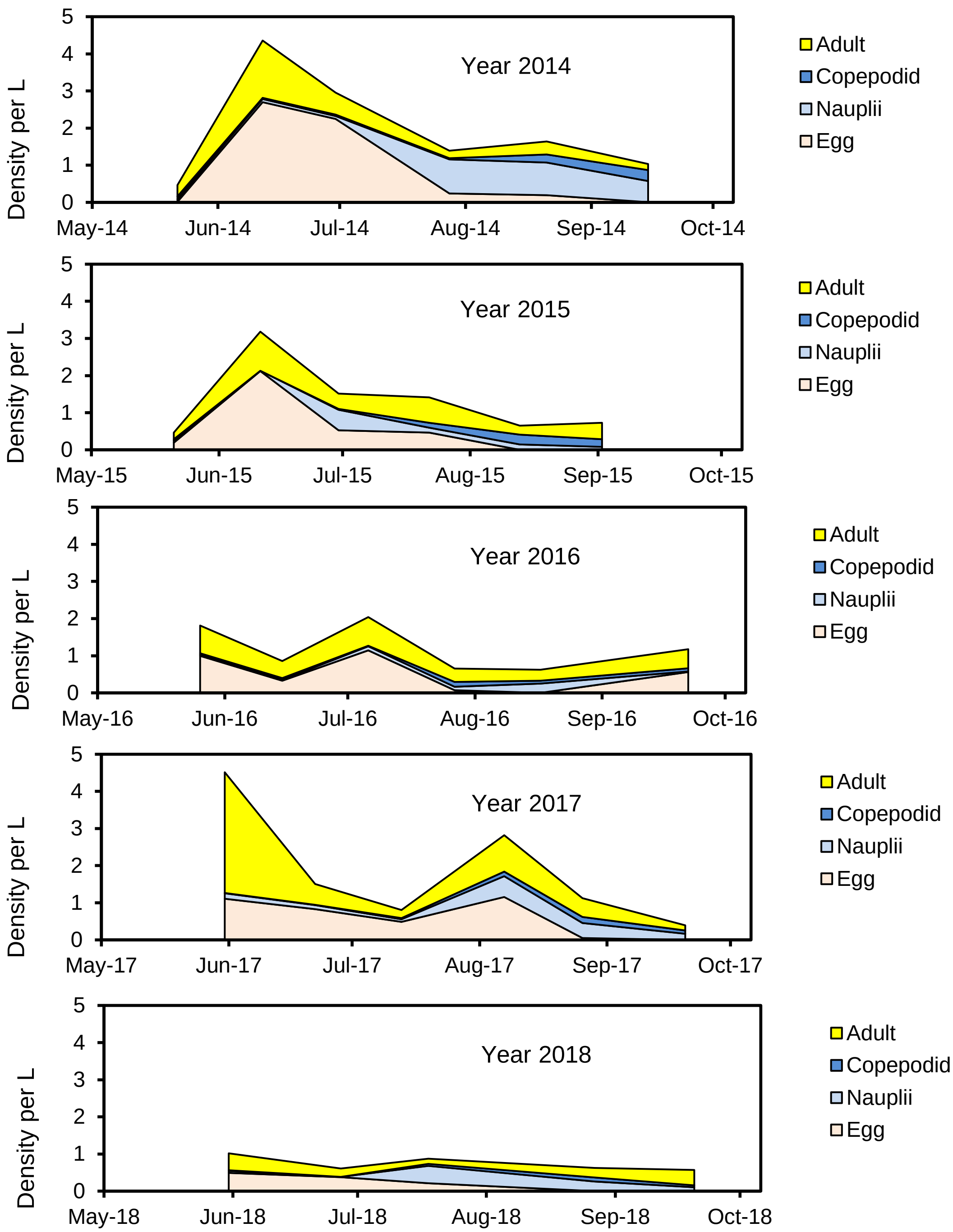
In general, lower Lake Wenatchee total zooplankton biomasses suggest that Lake Wenatchee sockeye should have grown at about half the rate of Osoyoos Lake juvenile sockeye. However, the presence of *Hesperodiaptomus* likely allowed Lake Wenatchee sockeye to hunt with greater efficiency (energy return 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 13).

Table 13: 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 16), suggest that there is a period of reproduction in the spring and early summer. 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 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 will begin earlier and end later in the season during 2019.

Figure 16: *Hesperodiaptomus kenai* egg, nauplius, copepodid and adult density



Lake Wenatchee 2012-18 Juvenile Sockeye Salmon

Table 14: Year 2010-18 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)

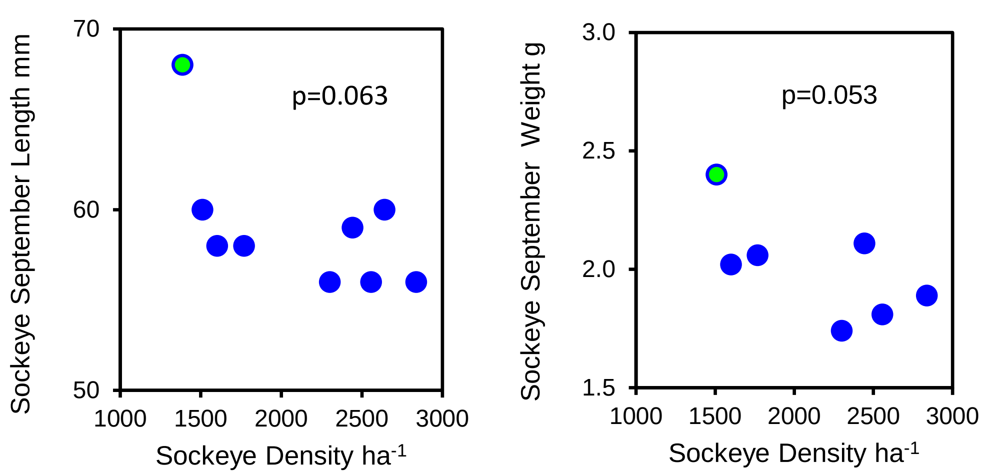
Table 14 Continued…..

	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
Wenatchee	2017	2018	0	13-Jun-18	1,638,528	1632	3.03	0.24	487	96%	ONA echosound (length, weight ONA)
Wenatchee	2017	2018	0	13-Aug-18	1,244,960	1240	5.38	1.60	112	94%	ONA echosound (length, weight ONA)
Wenatchee	2017	2018	0	09-Oct-18	1,290,140	1285	6.75	3.09	148	93%	ONA echosound (length, weight ONA)
Wenatchee	2017	2018	0	06-Nov-18	1,031,108	1027	6.84	3.31	56	94%	ONA echosound (length, weight ONA)
Wenatchee	2016	2018	1	13-Jun-18	69,276	69	7.16	3.70	14	4%	ONA echosound (length, weight ONA)
Wenatchee	2016	2018	1	13-Aug-18	74,296	74	10.39	12.42	38	6%	ONA echosound (length, weight ONA)
Wenatchee	2016	2018	1	09-Oct-18	102,408	102	10.88	13.83	5	7%	ONA echosound (length, weight ONA)
Wenatchee	2016	2018	1	06-Nov-18	63,252	63	-	-	0	6%	ONA echosound (length, weight ONA)

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 negative relationship between age-0 sockeye density (x variable) and zooplankton biomass (y variable), and (iii) a positive relationship between zooplankton biomass (x variable) and age-0 sockeye growth rate (y variable). We found only one of these predicted results.

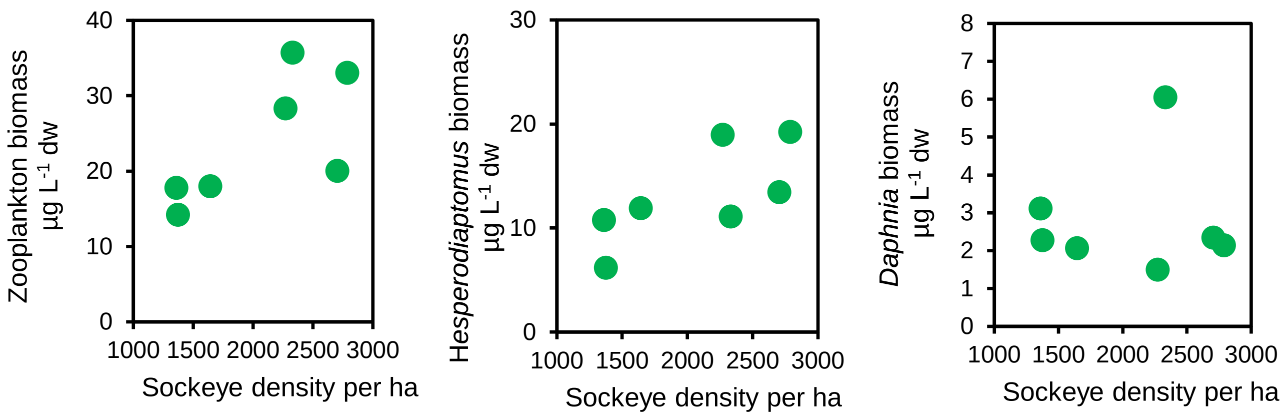
(i) There are negative but not statistically significant relationships between age-0 sockeye density (x variable) and age-specific juvenile sockeye length and weight (i.e. growth rate) (Figure 17). This suggests that food-based density dependence is possible. The potential for food-based density dependence is discussed in Appendix 1.

Figure 17: Sockeye fry September-October length (left figure) and weight (right figure) with respect to September fry density. Green data point = 2018



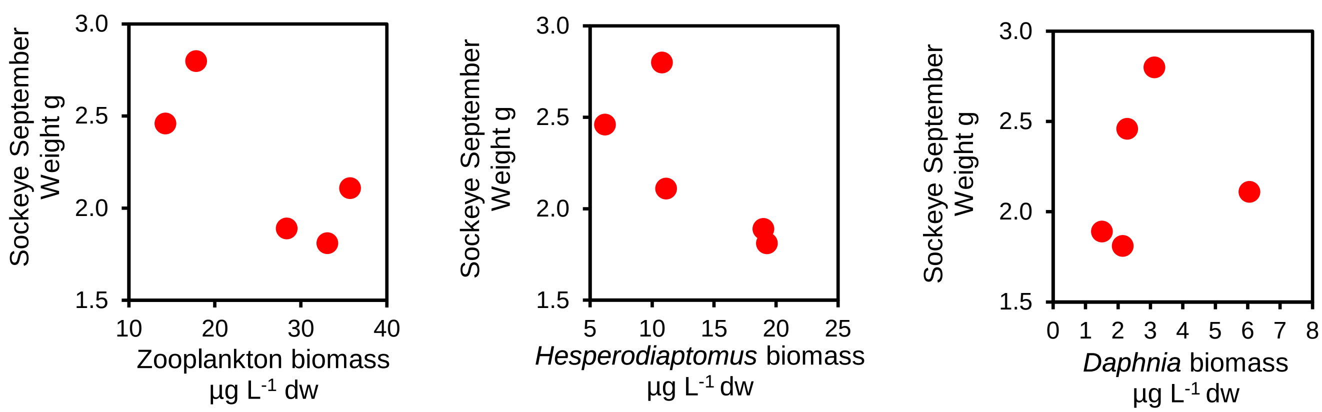
(ii) The relationships between age-0 sockeye density (x variable) and total zooplankton biomass (y variable) is positive rather that negative (Figure 18). *Hesperodiaptomus* biomass is also positively associated with juvenile Sockeye density. There is no relationship for *Daphnia* biomass and juvenile Sockeye biomass. This suggests that resource-based density dependence is unlikely.

Figure 18: <u>Left panel</u> - average June-September zooplankton biomass with respect to average spring-summer fry density; <u>middle panel</u> - average June-September *Hesperodiaptomus* biomass with respect to spring-summer fry density; <u>right panel</u> - average June-September *Daphnia* biomass with respect to spring-summer fry density.



(iii) Under the food-based density-dependent hypothesis we expect positive relationships between zooplankton biomass (x variable) and age-0 sockeye growth rate (y variable). This relationship was not observed for Sockeye weight with respect to total zooplankton biomass, *Hesperodiaptomus* biomass or *Daphnia* biomass (Figure 19). This again suggests that resource-based density dependence is unlikely.

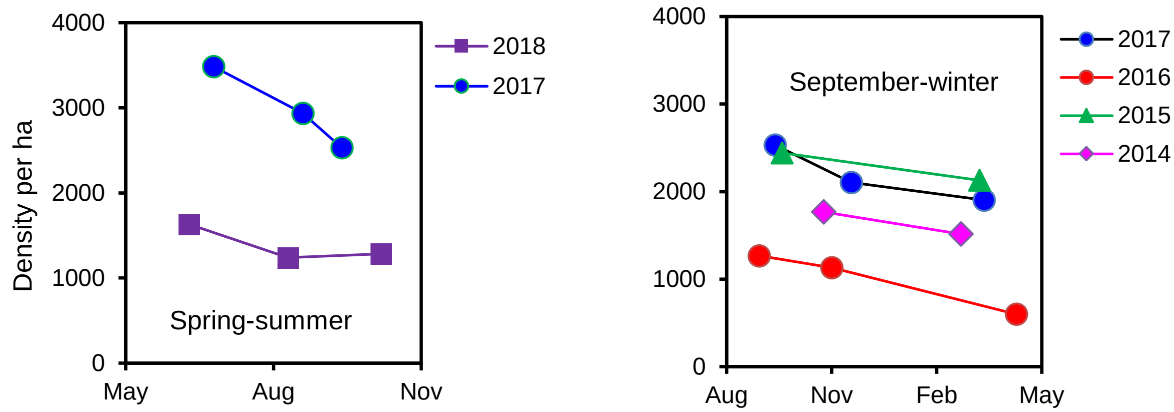
Figure 19: <u>Left panel</u> – September juvenile Sockeye mean weight with respect to average June-September zooplankton biomass; <u>middle panel</u> - September juvenile Sockeye mean weight with respect to average June-September *Hesperodiaptomus* biomass; <u>right panel</u> - September juvenile Sockeye mean weight with respect to average June-September *Daphnia* biomass.



Juvenile Sockeye survival and growth: In the early years of the Lake Wenatchee study, fish were not aged, but during 2015-18 age-0 and age-1 juvenile Sockeye were identified and enumerated (Table 14). From these data we see that age-1 fish were more abundant in 2016 than they were in 2017 when the age-1 population averaged about 1% of the total. Between-year differences of this type are often attributed to food availability during the previous year. The usual hypothesis is that when food is less available in year x, there is an increase in holdover (age-1) frequency in year x+1. In Wenatchee Lake the opposite is true. Zooplankton abundance in 2015 was substantially greater than abundance recorded in 2016 (Figure 10).

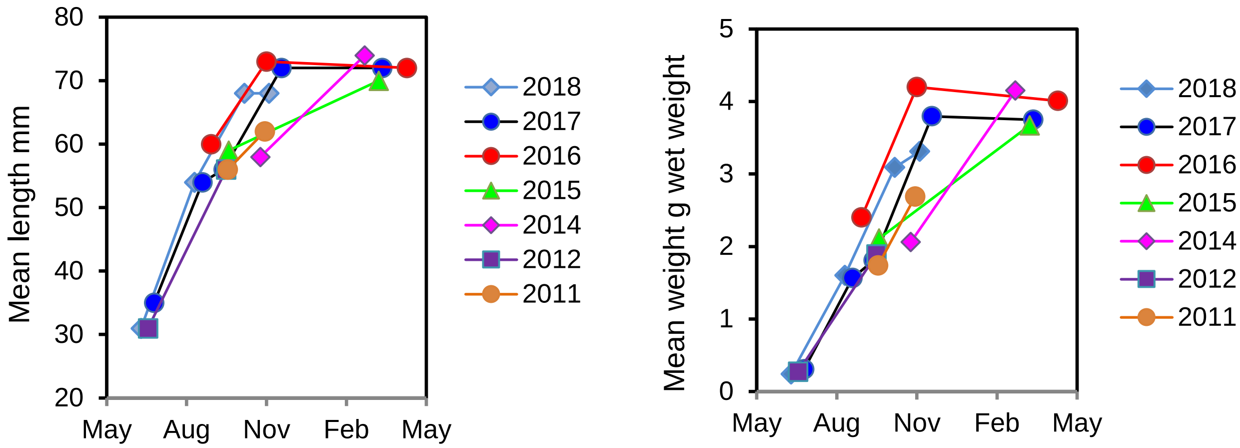
There were substantial between-year differences in fry density (Table 14), but during the four years when data were available (2014-18), rates of age-0 Sockeye fry mortality during the spring-summer and during the fall-winter were about equal (i.e. similar sloped survival curves) (Figure 20) averaging 24% in the spring-summer and 26% during the fall-winter.

Figure 20: Year 2014-17 age-0 Sockeye fry density (per ha) from September through to the winter.



During all years for which data were available, growth rates for age-0 Sockeye fry were about equal (Figure 21).

Figure 21: Year 2011-18 age-0 Sockeye fry weights and lengths from June through to the winter.



Lake Wenatchee 2018 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 conclude that density-dependent growth suppression in Sockeye fry is occurring. If production > consumption we 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. During 2018, we repeated this analysis. To do so we required 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 included in the following tables include; (1) diets for Sockeye fry, (2) vertical distribution of Sockeye fry with respect to date and temperature, and (3) zooplankton species-specific rates of production. The bioenergetics analysis also requires; weights and densities of age-0 and age-1 Sockeye fry with respect to date (shown previously in Table 15), water temperatures with respect to date and depth (shown previously in Table 5), zooplankton biomass (shown previously in Table 10), and fish and zooplankton energy density (in the methods).

(1) Sockeye diets. On two dates during 2018, Sockeye fry stomachs were examined, prey were enumerated and then averaged (per fish) (Table 16). Prey numbers where then multiplied by average prey weights (from zooplankton samples) and proportions by weight were estimated for use in the bioenergetics model.

Table 16: Average number of prey per fish gut

	Age	n	*Cyclops*	*Hesperodiaptomus*	*Daphnia*	*Bosmina*	Adult fly
13-Aug-18	0	30	2.3	6.8	18.3	0.2	0.1
	1	30	6.5	117.0	138.7	0.0	0.1
06-Nov-18	0	30	3.2	50.4	200.6	0.0	0.1
	1	no data					

(3) 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 16). These data were combined with water temperatures (Table 5) to estimate the average temperature experienced by >90% of the fish on each sample date. Specifically, the water depths included in each of the

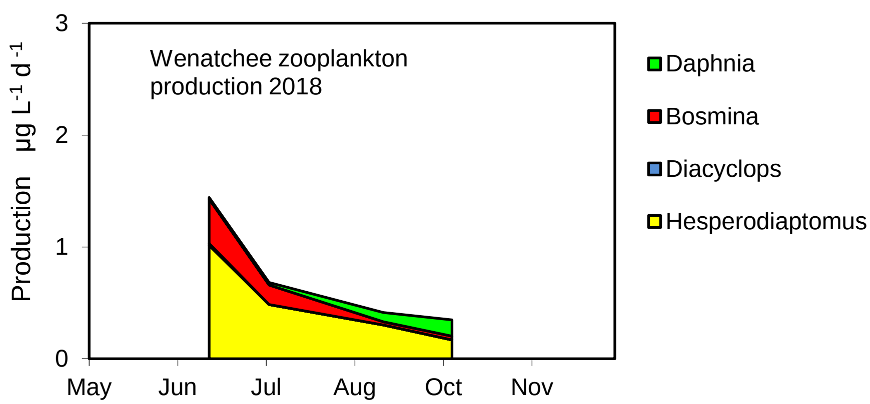
depth intervals shown in yellow in Table 16, were averaged to produce the average temperature experienced by fry on each date.

Table 16: Percent of Sockeye fry observed at each depth interval on each acoustic assessment sounding date. The yellow highlight denotes depths that include >90% of the population.

Depth	13-Jun-18	13-Aug-18	09-Oct-18	06-Nov-18
2-5	nd	nd	nd	nd
5-10	51	1	1	1
10-15	28	5	2	2
15-20	11	28	3	2
20-30	7	59	26	25
30-40	1	7	55	49
40-50	1	1	12	17
50-60	1	0	2	3

(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 22). These data show that *Hesperodiaptomus* and *Bosmina* accounted for most of the zooplankton production in the spring and that *Daphnia* were more productive during the late summer-fall. During 2018, percent P/B (production/biomass) per day for *Daphnia*, *Bosmina* and *Hesperodiaptomus* were 2.9%, 6.8% and 7.9% respectively. These values are in reasonable agreement with values from the published literature (Stockwell and Johannsson 1997).

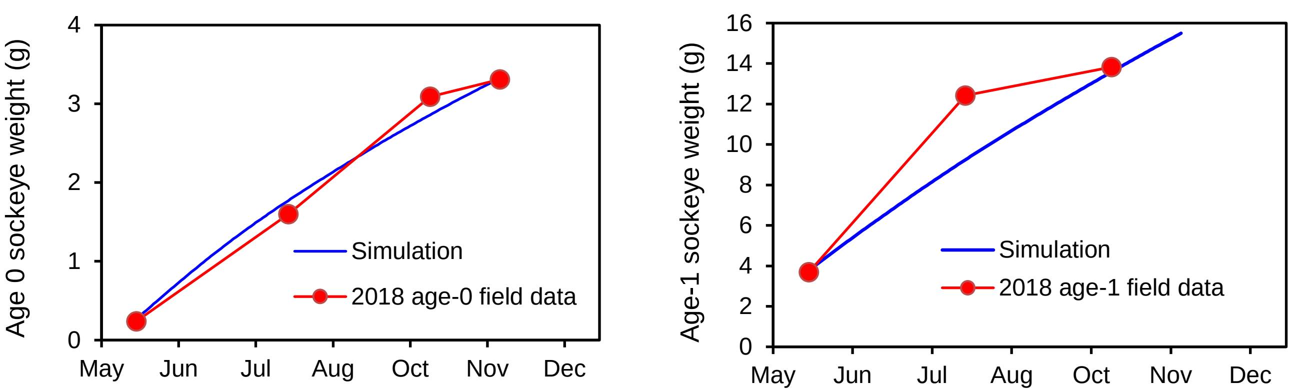
Figure 22: Lake Wenatchee 2018 zooplankton production



Year 2018 fish bioenergetics calculations: Lake Wenatchee fish bioenergetics models were run for 2018 age-0 and age-1 Sockeye fry. The assumptions and input data were as follows. (i) Through the simulation period, water temperatures occupied by the fish were based on the depth distributions observed during each survey. 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 16. (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. (iv) Through an iterative process, the model estimated the amount of food each fish 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 rates were then compared with daily rates of prey production (Figure 22).

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. Simulation parameters were adjusted until the fits were satisfactory (Figure 23). Sample sizes for the age-1 fry were limited (09 October n=5, 06 November n=0) and in order to obtain a fit the model was adjusted to produce an October weight of 13.8 g ww (the weight recorded in the field). Sample sizes for age-1 Sockeye fry taken earlier in the year were larger (n=14 and 38 respectively) and for age-0 fry, all sample sizes were large (n ranging from 56-487).

Figure 23: Lake Wenatchee 2018 field measured age-0 and age-1 weights with respect to date and simulated weights with respect to date.



The 2018 simulations were run from 13 June–06 November (146 days). These limits were dictated by the availability of diet data (Table 16) which clearly showed that *Hesperodiaptomus* and *Daphnia* were the primary prey species. This is reflected in the bioenergetics-based consumption estimates (Figure 24) which show that the primary food types consumed by Sockeye fry were *Hesperodiaptomus* and *Daphnia*. Both were well represented in zooplankton samples. However, the diet data also showed that during 2018, Lake Wenatchee Sockeye fry consumed adult flies (dipterans) which were not sampled in the field. In the model,

dipteran weights were estimated from weights obtained from dipterans sampled in Osoyoos Lake. In the 2017 report we mentioned the possible presence of *Mysis* in fish stomachs. During the spring-summer of 2019 we specifically targeted this species with a field sampling program and found none. Nor did we find them in the fish stomach samples from 2018. From this we conclude that the diet report from 2017 was in error and that *Mysis* have not invaded Lake Wenatchee.

Aside from providing species-specific estimates of prey consumption, the bioenergetics-based consumption estimates also show that age-0 Sockeye consumed more prey than age-1 Sockeye (Figure 25). Given the relative densities of the two groups (Table 14) this is expected.

Figure 24: Lake Wenatchee 2018 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.

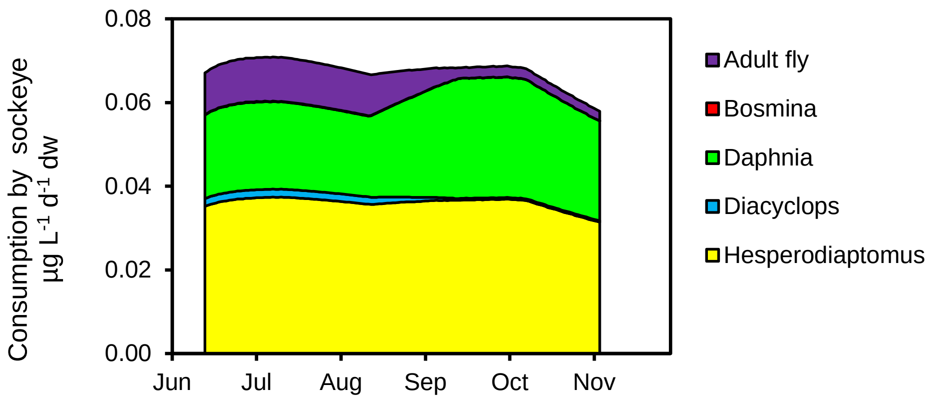
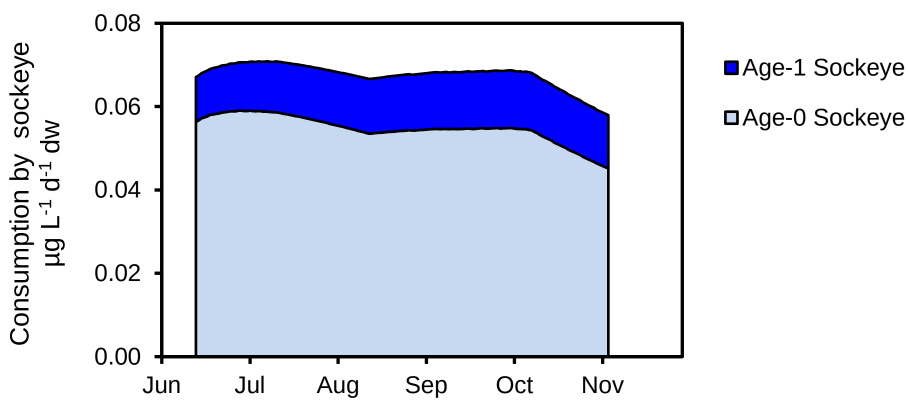


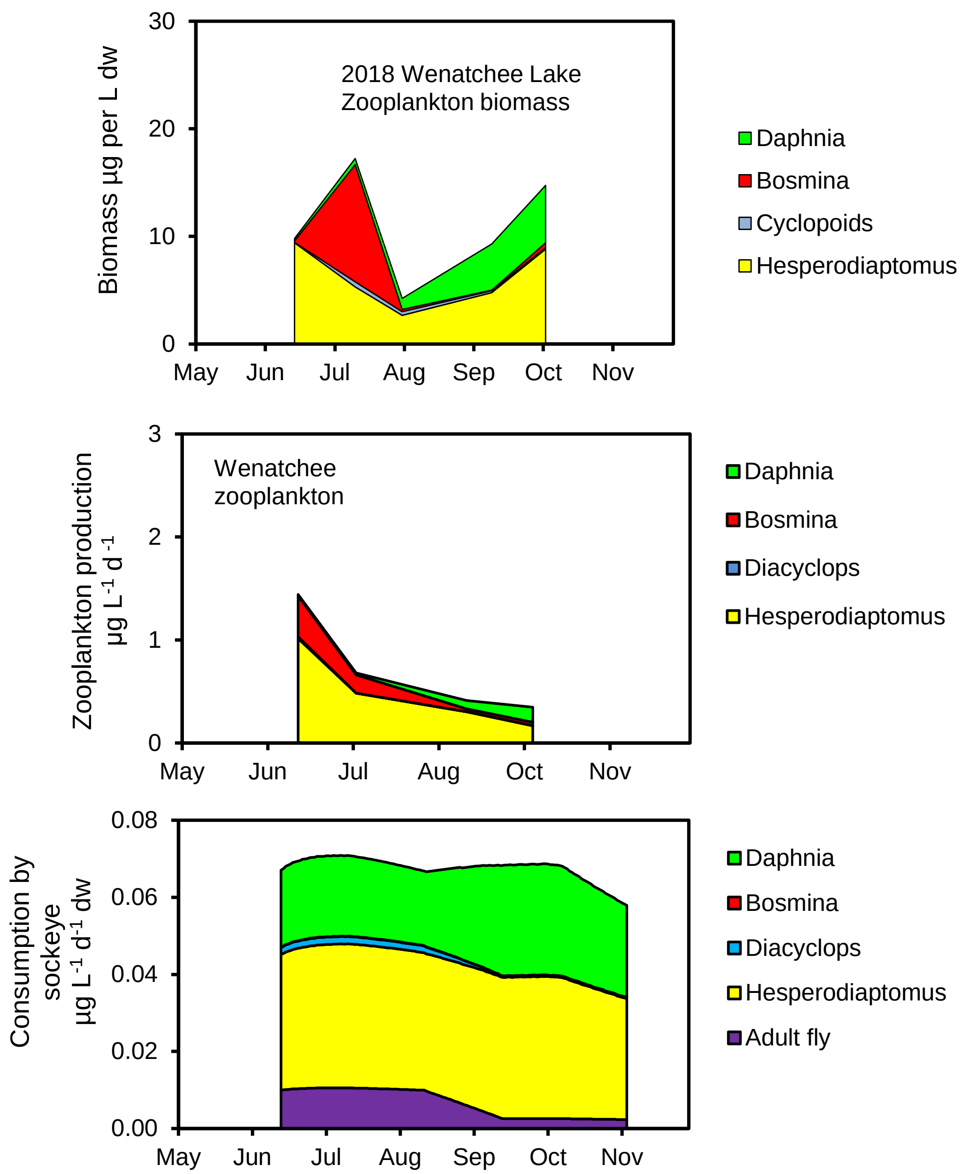
Figure 25: Lake Wenatchee 2018 bioenergetics-based estimates of consumption rate (µg L^{-1} d^{-1} dry weight) by age-0 plus age-1 Sockeye fry.



Year 2018 comparison of consumption by fish with production by zooplankton: A comparison of consumption by fish with zooplankton biomass and rates of zooplankton production, clearly shows that age-0 and age-1 Sockeye fry were able to consume only a very small portion of prey biomass and prey production. When figures for zooplankton biomass,

zooplankton production and consumption by fish are plotted together (Figure 26), we see that during 2018, Lake Wenatchee Sockeye fry consumed an average of 0.5% of prey biomass per day and 9% of prey production per day (Table 17). Clearly Lake Wenatchee Sockeye fry had no discernible impact on their food supply and Figure 19 suggests that Sockeye growth rates were not mediated by prey availability. We conclude that Lake Wenatchee is capable of supporting a larger population of Sockeye fry.

Figure 26: Lake Wenatchee 2018 zooplankton biomass, production (from Figure 22) and consumption by fish (from Figure 24).



This conclusion is supported by earlier results which showed that the relationship between age-0 sockeye density (x variable) and total zooplankton biomass (y variable) was positive rather than negative (Figure 18). Also, the relationship between zooplankton biomass (x

variable) and age-0 sockeye growth rate (y variable) was “not significant” (Figure 19) rather than positive as predicted by the density-dependent hypothesis.

Table 17: A summary of 2018 bioenergetics input and output data.

Year 2018		
Average spring-fall density age-0	1386	per ha
Average density age-1	81	per ha
Average zooplankton biomass	14	µg per L dw
Average zooplankton production	0.7166	µg per L per day dw
Average consumption by fish	0.0655	µg per L per day dw
% biomass consumed per day	0.5	%
% production consumed per day	9.1	%

Between-year comparison of production-consumption data: Comparisons of consumption by fish with zooplankton biomass and production were detailed in earlier reports and are summarized here for inlake years 2012, 2013 and 2017 (Table 18).

Table 18: Summary of production-consumption data for inlake years 2012, 2013 and 2017. Data quality varied from year to year. In 2012, fish were sampled twice, temperature measured 4 times and diets assessed on one date. In 2013, fish were sampled twice, temperature measured 4 times. In 2013, diets were not recorded and the 2012 diet data was substituted. In 2017, fish were sampled on 4 dates, temperatures measured on 4 dates and diets recorded on 3 dates. In 2018, fish were sampled on 4 dates, temperatures on 10 dates and diets on 2 dates.

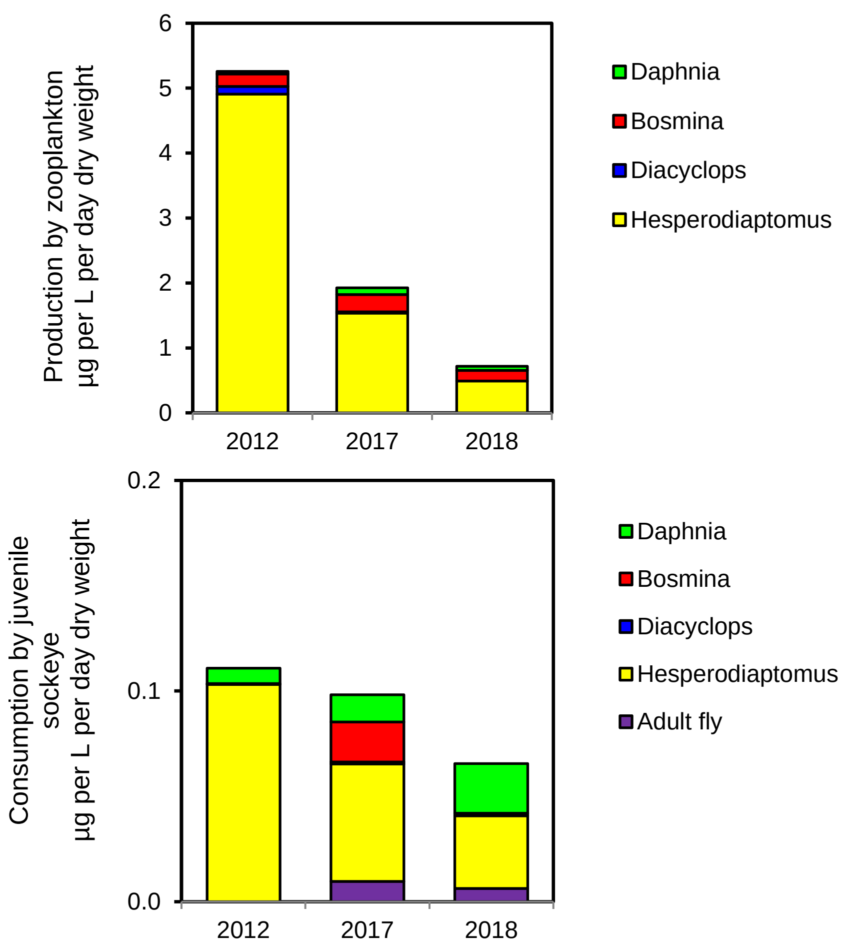
Year 2012		
Average density age 0	2194	per ha
Average density age 1	86	per ha
Average zooplankton biomass	23.1	µg per L dw
Average zooplankton production	5.3	µg per L per day dw
Average consumption by fish	0.1	µg per L per day dw
% biomass consumed per day	0.5	%
% production consumed per day	2.1	%

Year 2013		
Average density age 0	2704	per ha
Average density age 1	0	per ha
Average zooplankton biomass	20.1	µg per L dw
Average zooplankton production	0.8	µg per L per day dw
Average consumption by fish	0.1	µg per L per day dw
% biomass consumed per day	0.5	%
% production consumed per day	11.9	%

Year 2017		
Average spring-fall density age-0	2317	per ha
Average density age-1	29	per ha
Average zooplankton biomass	33	µg per L dw
Average zooplankton production	1.9	µg per L per day dw
Average consumption by fish	0.1	µg per L per day dw
% biomass consumed per day	0.3	%
% production consumed per day	5.2	%

Despite year to year weaknesses in data availability the basic results from all four years (2012, 2013, 2017 and 2018) are remarkably similar. The percentage prey biomass consumed per day is 0.5% in three of the years and 0.3% in one year and the percentage of prey production consumed per day ranges from 2.1% to 11.9% per day. In no case is there any indication that age-0 plus age-1 fry are capable of having a negative effect on prey abundance (Figure 27).

Figure 27: Three year comparison of production by zooplankton vs. consumption by Lake Wenatchee age-0 plus age-1 Sockeye fry.



Many of the preceding conclusions are based on the assumption that the bioenergetics-based production and consumption values accurately reflect estimates based on independent field and laboratory work. Comparisons with laboratory studies show that the Lake Wenatchee fish consumed food and grew at rates similar to those recorded in the laboratory. (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 and 2018 weight gains were 2.1% and 1.7% per day for very small (age 3-5 months) age-0 sockeye and 1.5% and 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 during 2017 and 2018, was 11.5% and 10.6% for age-0 Sockeye and 5.1% and 4.5% for age-1 Sockeye fry. This suggests that the wild Lake Wenatchee fish spent more energy feeding than the laboratory fish used by Brett et al. (1969). (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. The Lake Wenatchee Sockeye fry consumed more food per day and grew more quickly than the Bevelhimer and Adams (1993) juvenile kokanee.

But note, in Lake Wenatchee *Hesperodiaptomus* were the primary prey consumed by juvenile Sockeye. At the moment we do not have enough data to estimate the total production potential for this species, but we do know that *Hesperodiaptomus* may reproduce only once (summer) or perhaps twice (spring and summer) per year. Therefore if the age-0 Sockeye population is large enough to consume most of the available copepodids and adults, this important food supply will not be replaced and Sockeye growth and survival rates may be negatively affected. The same applies to the spring population of age-1 Sockeye which could conceivably consume substantial portions of the *Hesperodiaptomus* population early in the season before the age-0s enter the lake to begin feeding. At the moment we sample zooplankton from June to October. During in-lake surveys for 2019 *Hesperodiaptomus* have been sampled every month from March to November 2019, and three winter 2020 samples are planned. When these samples are available, we will have some or all of the critical data needed to understand more about the *Hesperodiaptomus* life cycle and whether observed variations in Sockeye numbers and predation have the potential to control *Hesperodiaptomus* and induce density-dependent growth of fry.

SUMMARY

The most important result is that the Lake Wenatchee 2018 Sockeye fry population were able to consume only a very small portion of prey biomass and prey production. During the spring-summer, 2018 Lake Wenatchee Sockeye fry consumed only 0.5% of prey biomass per day and 9% of prey production per day. Lake Wenatchee Sockeye fry had no discernible impact on their food supply and Sockeye growth rates were not mediated by competition for prey. Lake Wenatchee is potentially capable of supporting much larger populations of Sockeye fry, but care must be taken not to overexploit the *Hesperodiaptomus* copepods that are the most important food source for Lake Wenatchee Sockeye fry.

River discharge and lake-turnover: During 2012-18, rates of river discharge and lake-turnover were recorded during the spring and early summer (01 May – 01 August). Mean spring-summer lake-turnover times ranged from 40-129 days. The lowest turnover time (i.e. highest rate of river discharge) was recorded in 2012 and the longest turnover time (i.e. lowest rate of river discharge) was recorded in 2015. Rates of river discharge during the late summer-fall (August-October) were much lower and rates of lake-turnover were much longer. Phytoplankton and zooplankton biomasses were not associated with rates of river discharge, but there was a significant negative relationship between river discharge and epilimnetic temperature. During low discharge years the lake was warmer.

Temperature and oxygen: During 2012-18 Lake Wenatchee had a well oxygenated, cold water hypolimnion. During most years the lake stratified relatively late in the summer (late-July, August) and for most of the spring-summer, Sockeye Salmon were able to feed throughout the water column. However during 2015, the lake stratified in early July and epilimnetic water temperatures increased to >17^{O}C. It is likely that this reduced the time that Sockeye Salmon spent in the epilimnion.

Water chemistry: Nutrient chemistry was measured during 2012 and again in 2017. Lake Wenatchee was found to have low concentrations of total phosphorus and nitrogen suggesting oligotrophic conditions. Calcium varied from 1.5-2.7 mg L^{-1}, which is low compared to Okanagan Lakes, but just high enough to support most species of *Daphnia*. If funds allow, calcium monitoring should be continued.

Phytoplankton: During 2012-18, Lake Wenatchee total phytoplankton biovolume averaged 240 $mm^3 m^{-3}$ and the edible biovolume averaged 175 $mm^3 m^{-3}$. During most months, the ratio of edible to total phytoplankton was exceptionally high suggesting that most of the algal species found in Lake Wenatchee had sizes, shapes and digestibility that make them excellent food sources for freshwater zooplankton. It seems likely that grazing by zooplankton had significant negative impacts on phytoplankton biomass.

Zooplankton: The Lake Wenatchee zooplankton community comprised two dominant copepods (*Diacyclops thomasi*, *Hesperodiaptomus kenai*). The community also included two small bodied cladocerans (*Bosmina longirostris, Eubosmina coregoni*) and two large bodied cladocerans (*Daphnia*, *Leptodora kindtii).* Zooplankton biomass varied substantially from year to year. *Hesperodiaptomus* biomass was negatively associated with water temperature (i.e. cold water species) and *Daphnia* biomass was positively associated with water temperature (higher rates of egg production in warm water).

***Hesperodiaptomus kenai*:** is a very large species that is an excellent food source for juvenile Sockeye Salmon. During 2018, Sockeye diet samples were collected in August and

November. *Hesperodiaptomus* comprised 53% of prey biomass consumed and *Daphnia* were the next most important accounting for 36% of the prey biomass consumed by age-0 Sockeye. Remaining prey included dipterans and cyclopoids.

Sockeye Salmon: Between 2010 and 2018, there has been a notable increase in sampling frequency and in the number of fish-related parameters recorded. The sample frequency for years 2017 and 2018 were exemplary and should be repeated whenever funding allows.

Through the period 2010-18, the fall population density for Lake Wenatchee Sockeye fry averaged 2115 ha^{-1}. Over the years there was a slight increase to 2532 ha^{-1} recorded in 2017 but a decrease to 1387 ha^{-1} recorded in 2018. There were substantial between-year differences in fry density, but during the four years when data were available, rates of age-0 Sockeye fry mortality from September through to the winter, were about equal averaging about 25%. During 2017 when a complete data set was available, mortality observed between June and September was 26% and roughly equalled mortality observed from September through winter. Total mortality from June to the following winter was about 50%. During all years for which data were available, growth rates for age-0 Sockeye fry were about equal. In the early years, fish were not aged, but during 2015-18 age-0 and age-1 juvenile Sockeye were identified and enumerated. Age-1 Sockeye comprised 4%, 10%, 1% and 5% of the total Sockeye fry population in 2015, 2016, 2017 and 2018 respectively.

There were weak (not statistically significant) negative relationships between age-0 Sockeye lengths and weights recorded in September and the density of Sockeye fry recorded during the same time period. There were no bottom-up relationships between fry weight and total zooplankton biomass or between fry weight and *Hesperodiaptomus* biomass. There was no top-down relationship between fry density and zooplankton biomass.

Bioenergetics: Bioenergetics-based production and consumption analysis allowed 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 we were also able to compare these with rates of production by each of the major zooplankton species. During 2012, 2013, 2017 and 2018 Lake Wenatchee Sockeye Salmon fry were capable of consuming only a small portion of the available prey population and we conclude that Sockeye fry were not capable of regulating zooplankton biomass. Lake Wenatchee Sockeye fry were not food limited.

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).

SUGGESTIONS FOR THE 2020 LAKE WENATCHEE SAMPLING PROGRAM

Since the program 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.
(6) Fish should be sampled (trawl and echosounder) 5 times during early-July, mid-August, mid-September, November and winter.
(7) 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 1).

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.

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.

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.

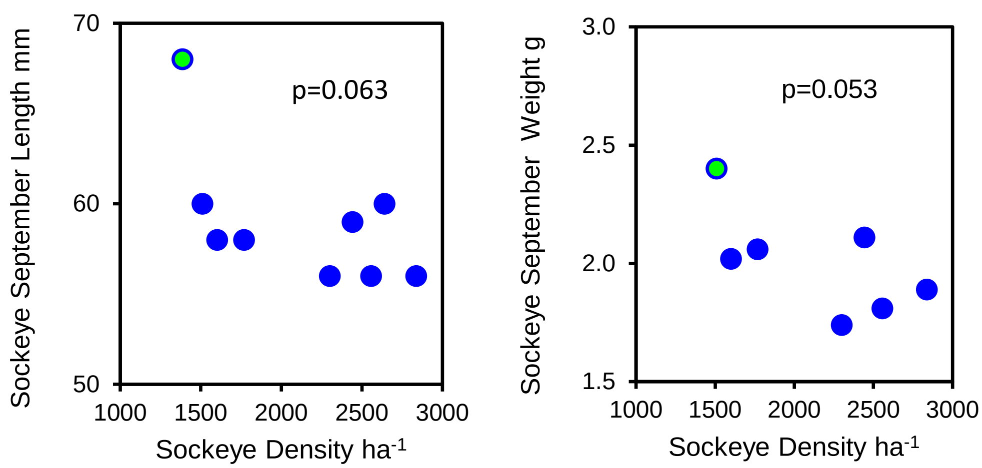
Walters CJ, Martell SD (2004) Fish. Ecol. Manag., Princeton University Press, Princeton, New Jersey.

APPENDIX 1

On page 36 we investigated the hypothesis that the growth rates of Lake Wenatchee Sockeye fry could be influenced by Sockeye fry density. The rationale is that since juvenile Sockeye feed primarily on zooplankton, increased Sockeye densities should be associated with reduced biomasses of zooplankton. This would result in reduced availability of food which should feedback to reduce juvenile Sockeye growth.

When we investigated the relationship between Sockeye fry lengths and weights with respect to Sockeye fry density, we found the relationships reproduced below (Figure 17 reprinted here). As expected under the density dependent hypothesis, the relationships were negative, but several factors led to skepticism (i) both relationships were not statistically significant, (ii) data from a single year (2018) had a large effect on both correlations (iii) age-0 and age-1 sockeye were not separated during 2010-16 but were separated in 2016-18 (iv) the expected negative correlation between zooplankton biomass with respect to Sockeye fry density was not observed (Figure 18) and (v) the expected correlation between Sockeye fall weight with respect to zooplankton biomass was also not observed (Figure 19).

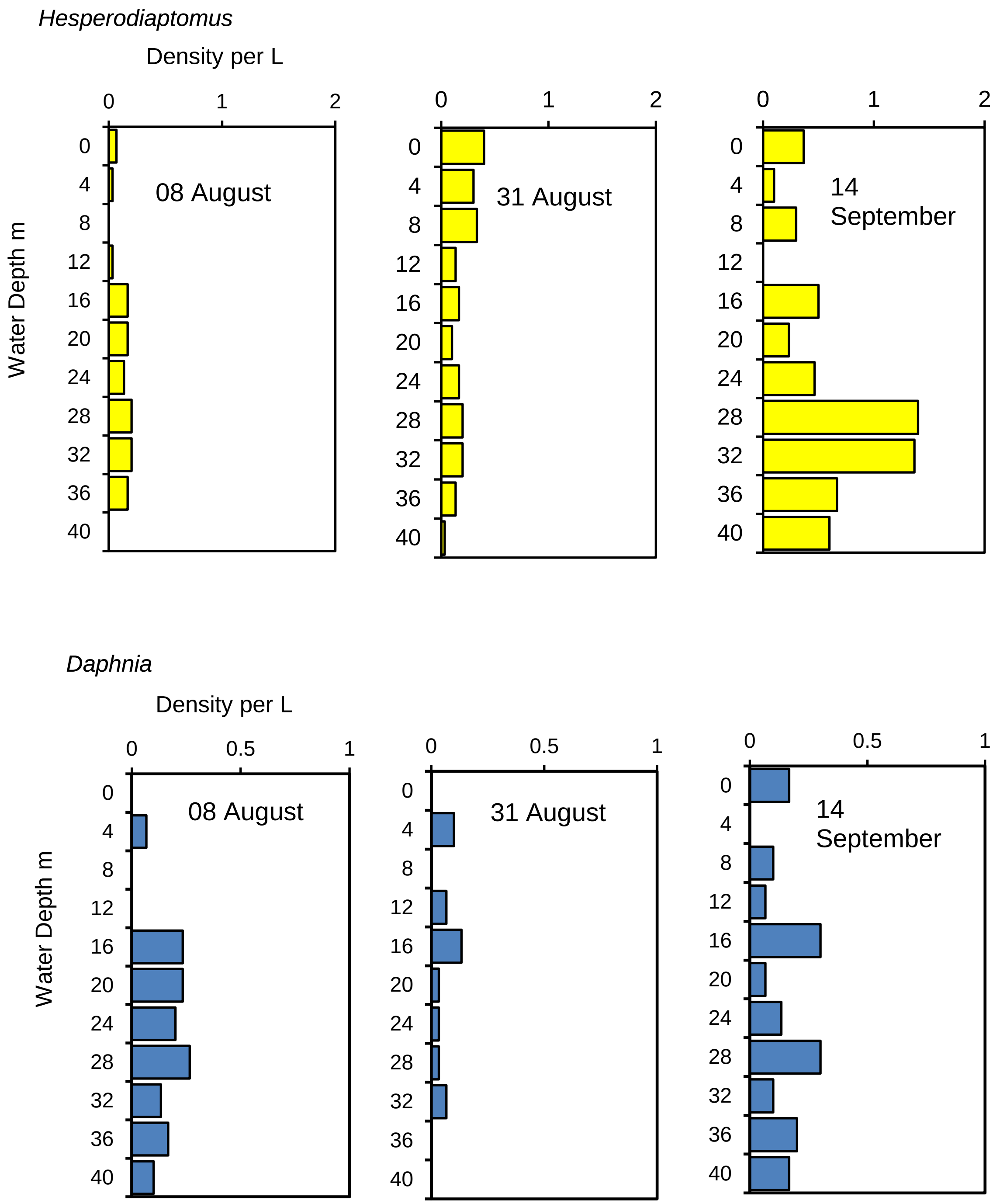
Figure 17: Sockeye fry September-October length (left figure) and weight (right figure) with respect to September fry density. Green data point = 2018



Despite all of this contrary evidence we wanted to pursue the matter further because food-based density dependent growth is a strongly held belief among salmon biologists. It could be argued that seasonal averaging of data from vertical plankton hauls 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 the context of Lake Wenatchee, 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*).

Figure A1.1: 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.



The plankton trap data were collected at night. They show 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 A1.1). 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. From this we might conclude that the use of average zooplankton biomasses in Figure 17 was conservative. However, the experiment was flawed.

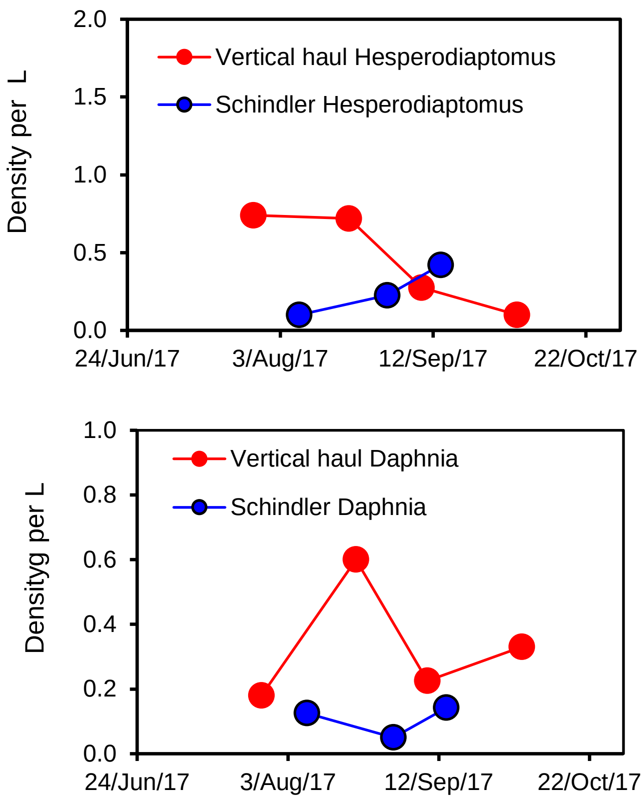
Table A1.1: Water temperatures with respect to depth. The shaded area includes the depths were acoustic sampling (Table 16) showed that >90% of the Sockeye fry population was aggregated.

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 A1.2). 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 A1.2: Comparison of *Hesperodiaptomus* and *Daphnia* densities from the vertical hauls and the plankton-traps.



If funding allows, during 2020, 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. In addition, more training should be devoted to the proper use of the Schindler-Patalas trap.

End of Report

APPENDIX H

Memo 2018 DIDSON Trials, Osoyoos Lake

OKANAGAN NATION ALLIANCE

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February 1, 2019

To: Jeff Fryer, Columbia River Inter-Tribal Fish Commission
From: Nicholas Yaniw, Fisheries Biologist, Okanagan Nation Alliance
Subject: 2018 DIDSON Trials, Osoyoos Narrows

In 2018 the Okanagan Nation Alliance (ONA), in partnership with CRITFC trialed the use of a DIDSON (Dual-Frequency Identification Sonar) at the narrows in Osoyoos Lake (Highway 97 Bridge) in an attempt to determine where in the water column adult sockeye salmon were travelling. The goal of this study was to determine if setting up an onsite PIT array would be feasible and aid in setting up the PIT array to maximize detection efficiency.

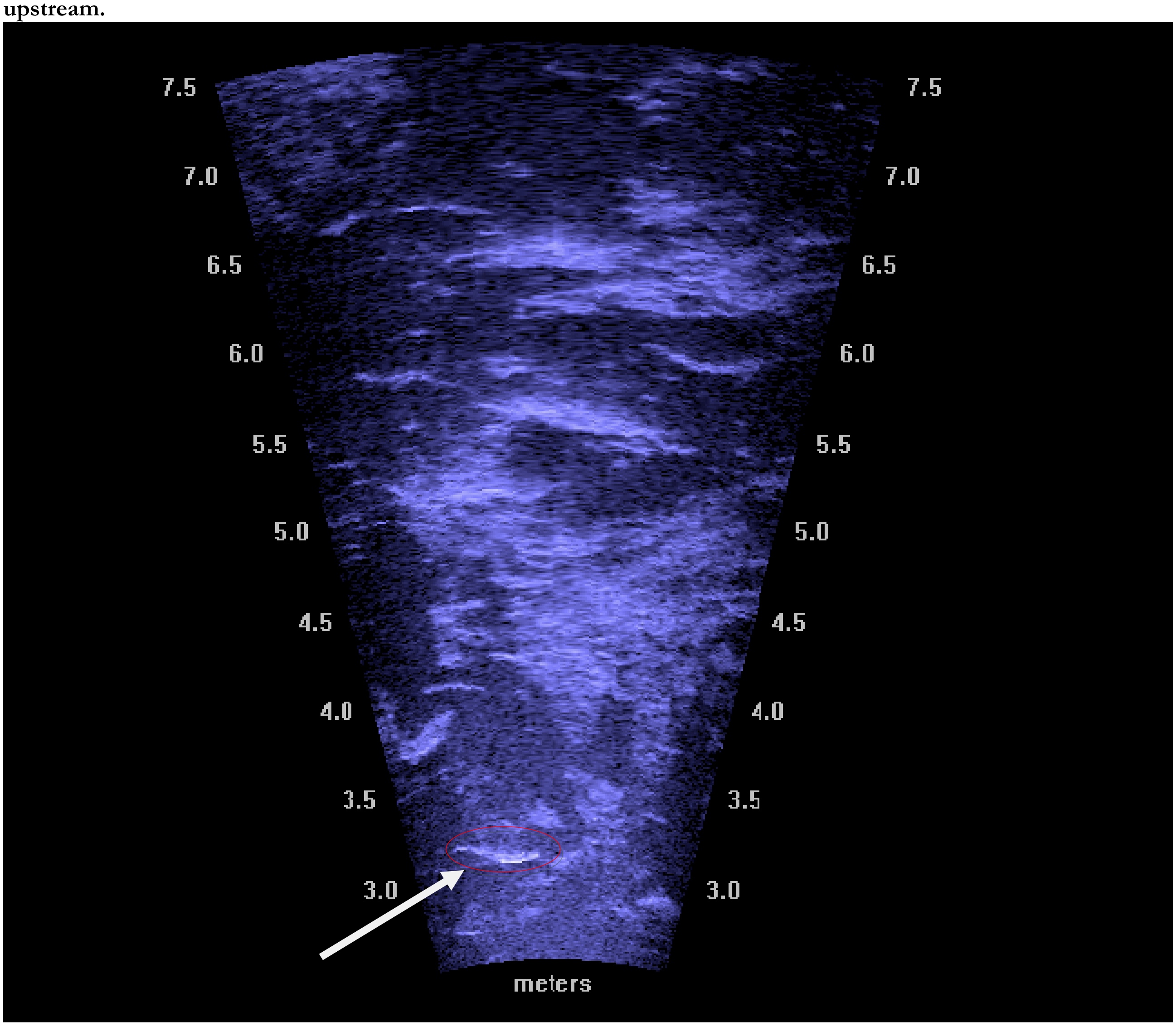
After a tank test at the ONA hatchery in Penticton that afternoon, Fisheries Biologists Skyeler Folks and Nicholas Yaniw set the DIDSON up at the Osoyoos narrows in the evening of July 16, 2018. The unit was set up in approximately 1 metre of water from the west shore of the narrows (Image 1). Orientation was perpendicular to river flow, facing East. The unit was deployed at 21:00 for a period of three hours. Settings were adjusted numerous times as we experimented with the unit.

Image 1 – DIDSON configuration when deployed from the West Shore.

On the evening of July 18, ONA staff, Yaniw and Fisheries Technician Paul Snow returned to the site to continue the trial. Due to a heavy human presence on the west shore, the crew set up on the east shore. The unit was aimed perpendicular to river flow, this time facing West. Different configurations and settings were adjusted, and 10 files were recorded from 21:00 to 00:00 (3 hours). The DIDSON was tilted approximately 6 degrees downward for the duration. At one point, the DIDSON mount was rotated 90 degrees in an attempt to acquire data on vertical distribution of fish (as per recommendations in the literature).

Overall, results were better on July 18. One possible cause is that river flows on the Okanagan River were reduced from 56 to 44 cubic metres/second on July 18. Fish were observed swimming upstream through the narrows. These fish were measured (using the DIDSON measurement tool) to be approximately 45 cm, indicating they are likely adult Sockeye (Image 2, Video 2).

Image 2 - Sockeye swimming upstream.



2018-07-18_04A_OKC_settings_hi.clipped.avi

Video 1 – Sockeye Swimming Upstream

The best settings for this site were:

- Frequency: High
- Gain: 40
- Frame rate: 7-8
- Reverse: Checked
- Smooth: Checked
- Colour palette: COOL2
- Intensity: 100%
- Threshold: 15%
- Window Start: 2.5m
- Window Length: 5.0m
- Range: 2.5 - 7.5m

Observations were most reliable using a narrow window length (~5 m length) and became increasingly less clear as the window start and/or window length was increased. High frequency settings were used to a range of 15m with mixed success. Low frequency settings were used to a range or 40 m, but it was more difficult to detect fish at this long range (Video 2). A window length of 5.0 m was ideal, but output was decent up to a window length of 10.0 m.

2018-07-18_02_Qualark_settings_LoFr.clipped.avi

Rotating the DIDSON 90 degrees proved unsuccessful in acquiring vertical fish distribution data as the resulting imagery was cluttered and unreadable (Image 3). This should be attempted again, preferably in higher or lower river flows to determine if the results differ. It is also possible that not enough fish were present at the time the DIDSON was rotated to detect them successfully. In the future this configuration should be used for a minimum of 1 hour with the file being recorded.

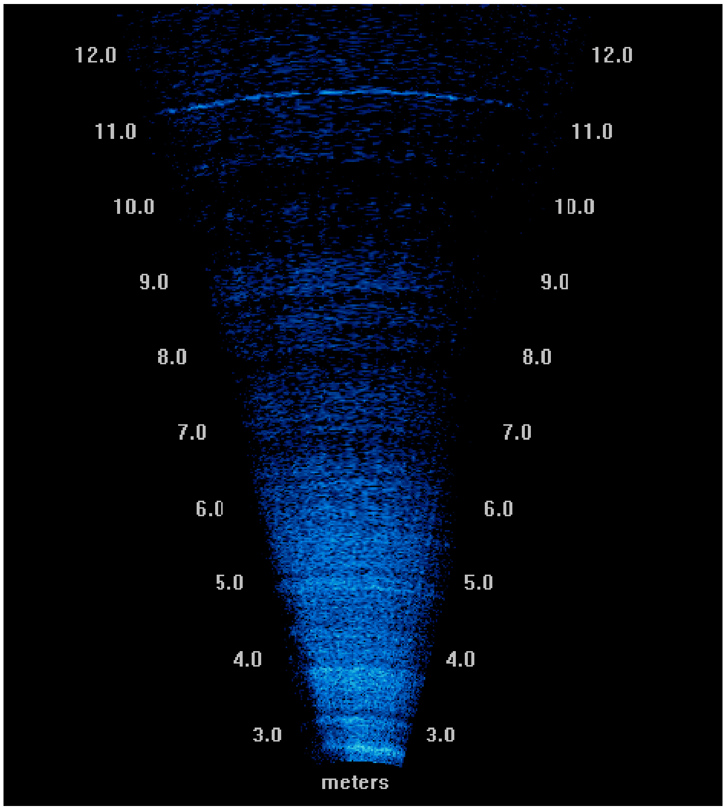


Image 3 – Sample output with DIDSON rotated 90 degrees.

Although the DIDSON was unsuccessful in determining where fish were distributed vertically, it may have value as an enumeration tool and should be revisited annually. Ideally the DIDSON would be used in conjunction with a fish partial weir that funnels the fish into a narrower area where the DIDSON would be able to better detect them. Even this narrow section of the river was too wide to enumerate effectively. If a weir is not feasible, DIDSON may prove to be effective when used in tributaries.

Disadvantages of DIDSON as an enumeration include that it is highly labour intensive, requiring 24 hour set-up and monitoring in order to capture all fish passing a given site. Additionally, the standard method of analysis requires re-watching the imagery in the office and manually counting detected fish. Automated counting methods exist within the DIDSON software package but these are difficult to master. Automated counting methods would also need to be calibrated with another enumeration method to be considered valid.

Nicholas Yaniw,
Okanagan Nation Alliance