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TECHNICAL REPORT 11-04

Limiting Factors of the Abundance of Okanagan and Wenatchee Sockeye Salmon in 2010

Jeffrey K. Fryer, Howie Wright, Skyeler Folks and Kim Hyatt

June 30, 2011

Columbia River Inter-Tribal Fish Commission
503.238.0667
www.critfc.org
729 NE Oregon, Suite 200
Portland, OR 97232

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

Jeffrey K. Fryer
Columbia River Inter-Tribal Fish Commission

Howie Wright and Skyeler Folks
Okanagan Nation Alliance

Kim Hyatt
Department of Fisheries and Oceans, Canada

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ABSTRACT

A total of 913 sockeye salmon, *Oncorhynchus nerka*, were PIT tagged at Bonneville Dam in 2010. These fish were tracked upstream using data from detection arrays within fish ladders at Bonneville, McNary, Priest Rapids, Rock Island, Rocky Reach, Wells, Ice Harbor, Lower Granite, and Tumwater dams as well as in-river arrays in the Wenatchee and Okanagan basins. Upstream survival steadily declined as the migration progressed; Bonneville-Rock Island survival declined from as much as 90% for sockeye salmon passing Bonneville Dam in early June to less than 75% during July. There was also a significant linear relationship between decreasing survival and increasing water temperature. The estimated stock composition of sockeye salmon passing Bonneville Dam was 81.8% Okanagan 17.3% Wenatchee, and 0.9% Snake.

The median travel time of sockeye salmon between Bonneville and Rock Island dams was 12.9 days, resulting in a median travel rate of 37.8 km per day. Fish passing Bonneville Dam later in the migration traveled upstream faster than those earlier in the migration.

In the Okanagan Basin, PIT tag antennas were installed at Zosel Dam fish ladders on September 2, 2010. Between startup and March 31, a total of 27 sockeye, 10 Chinook, and 1 steelhead were detected.

At Wells Dam, 400 PIT tags, 64 acoustic tags, and 52 temperature tags were deployed on 400 sockeye salmon. The detection rate at the Okanagan Channel PIT tag detection array (OKC) for fish only PIT tagged at Wells Dam was 73.7% compared to 70.7% for sockeye passing Wells Dam that we PIT tagged at Bonneville Dam. Sockeye with both PIT and acoustic tags were 25.8% less likely to be detected at OKC than those only PIT tagged, while sockeye with both PIT and temperature tags were 25.3% less likely to be detected at OKC. The OKC PIT tag array detected 90.2% sockeye with both an acoustic and PIT tag, while the OKC acoustic receiver detected 97.6% of these fish.

ACKNOWLEDGMENTS

The following individuals assisted in this project: Joseph Connor of Bonneville Power Authority, Ryan Branstetter, Melissa Edwards, David Graves, Doug Hatch, Jon Kane, Denise Kelsey, Jacinda Mainord, Phil Roger, and Marc Whitman of the Columbia River Inter-Tribal Fish Commission; John Arterburn, Jennifer Panther, and Brian Miller of the Confederated Tribes of the Colville Reservation; Ben Hausmann, Tammy Mackey, Jon Rerecich, and Casey Welch of the US Army Corps of Engineers; Ryan Benson, Richard Bussanich, Jacqueline Pizzey, Amanda Stevens, Camille Rivard - Sirois, and Lynnea Wiens of the Okanagan Nation Alliance, Steve Epple of the South Okanagan Water Dive Rescue Team, Tom Scott of the Okanagan-Tonasket Irrigation District; Dave Marvin of the Pacific States Marine Fisheries Commission; Andrew Murdoch of Washington Department of Fish and Wildlife; and Keely Murdoch, Corey Kampaus, Greg Robison, Tom Scribner, Ben Truscott, Barry Hodges, Kraig Mott, Jenifer Panther, Jason Hickman, Tim Jeffris, Arlene Heemsah and Michelle Teo of the Yakama Nation.

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

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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-1800's, however, the sockeye salmon run has severely declined, reaching a low of fewer than 9,200 fish in 1995 before rebounding in recent years. The 2010 estimate of 386,525 sockeye at Bonneville Dam was the highest since counts began in 1938, with a mean escapement for the most recent four year period (2007-2010) of 200,600 fish (DART 2011, Fish Passage Center 2011).

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

Figure 1. Map of the Columbia Basin showing fishery Zones 1-5 and 6, mainstem dams, and the two major sockeye salmon production areas.

System (Wenatchee stock) and second in the Okanagan[1] River-Osoyoos 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.

The Okanagan sockeye run is the Columbia Basin's sole remaining transboundary salmon stock. The fish 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. This run has 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).

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 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 several upstream dam fish ladders with detection capability (McNary, Priest, Rock Island, Rocky Reach, and Wells dams on the Columbia River, Ice Harbor and Lower Granite dams on the Snake River, and Tumwater Dam on the Wenatchee River) as well as at in-stream tributary antennas.

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

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 most tributaries are without detection facilities 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 to earlier in the year over the past 70 years (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 2009 (Fryer 2007b, Fryer 2008, Fryer 2009, Fryer et al. 2010) 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 (PTAGIS 2010) in natal streams in the Wenatchee Basin (Little Wenatchee and White rivers), making it possible to track Wenatchee sockeye to the spawning grounds. No similar detection system is available in the Okanagan Basin; therefore in both 2009 and 2010 the goals of this project included funding the installation and maintenance of PIT tag detection in the Okanagan Basin. In the 2009 project, a PIT tag antenna array, known at www.ptagis.org as OKC, was installed in the Okanagan River upstream of Zosel Dam (Fryer et al. 2010). To further investigate the mortality rate of Okanagan sockeye in the Okanagan Basin, in 2009 this project also established an acoustic network in the Okanagan basin and acoustic tagged sockeye salmon at Wells Dam.

For the Wenatchee stock, this project has funded a hydroacoustic survey of Lake Wenatchee to initiate standardized smolt abundance estimation there for comparison with similar estimates already available for Okanagan sockeye in Lake Osoyoos. This estimate was to be used to estimate juvenile survival and will be compared to Wenatchee River smolt trap smolt estimates.

METHODS

Adult PIT and acoustic tag detection infrastructure

Lower Okanagan River (Canada) PIT tag detection

We contracted with Biomark to design, fabricate, and install a PIT-tag monitoring system in the two fish ladders at Zosel Dam on the Okanagan River. The system was designed to detect PIT-tagged adult sockeye salmon as they ascend the Okanagon River, although the system will detect other PIT tagged fish such as steelhead and Chinook salmon as well. The system consisted of a FS1001M multiplexing transceiver and associated electronics, remote communication hardware, an electronics enclosure (NEMA4), and antennas. A total of four antennas were installed, two in each fish ladder.

Okanagan acoustic tag network

An acoustic tag network was deployed in the Okanagan Basin to monitor survival and timing of fish acoustically tagged at Wells Dam. The system consisted of 23 VR5W receivers ranging from the Monse Bridge, near the mouth, to Okanagan Falls, in Canada at the upper end of the portion of the basin accessible to sockeye salmon. The 12 receivers in the U.S. portion of the basin were deployed and maintained by the Confederated Tribes of the Colville Reservation, while the 11 receivers in the Canadian portion of the basin were deployed and maintained by the Okanagan Nation Alliance. Data from these receivers were used to estimate mortality from Wells Dam to Zosel Dam and Osoyoos Lake as well as passage time.

Adult Sampling at Bonneville and Wells dams

Bonneville Dam

Sockeye salmon were sampled and tagged at the Adult Fish Facility located adjacent to the Second Powerhouse at Bonneville Dam (river km 235) in conjunction with the sampling of steelhead (*O. mykiss)* and summer Chinook salmon (*O. tshawytscha)*. Sampling and tagging typically occurred between 0900 and 1500 hours four to five days per week. A picket weir diverts fish ascending the Washington Shore fish ladder into the adult sampling facility collection pool. An attraction flow is used to draw fish through a false weir where they may be selected for sampling. 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), fin clips, wounds, and condition. They were measured for length, and four scales were removed for later age analysis (Fryer 2007a). PIT tags were inserted into the pelvic girdle of the sockeye salmon using standard techniques (CBFWA 1999). The fish were scanned for the PIT tag number, which was stored in a Destron Fearing FS 2001 PIT tag reader. If there was no tag detected, due to either the tag being shed or a malfunction, then no effort was made to implant another tag to eliminate the possibility of double tagging. Sockeye salmon were allowed to recover prior to release. All PIT tag and sampling information was uploaded to the Columbia Basin PIT Tag Information System (PTAGIS) database (www.ptagis.org).

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

A PIT tag reader was supplied for use during Okanagan River spawning ground surveys and brood stock collection activities.

Wells Dam

Sockeye at Wells Dam were sampled using both the west and east bank fish traps. At both ladder traps, fish were netted out of the trap and placed in a small anesthetic tank. Like at Bonneville Dam, sockeye were examined for tags (including PIT tags), fin clips, wounds, and condition. They were also measured for length and had four/five scales removed for later age analysis. All data were recorded onto datasheets. All sockeye salmon sampled at Wells Dam were tagged with PIT tags and floy tags.

Vemco© acoustic tags with a projected battery life of 132 days were

surgically implanted into the body cavities of 64 sockeye salmon. Thirty-two of these tags were model V9 2H (29 x 9 mm, weight 4.7 grams), while the remaining 32 were V9TP 2H tags (47 x 9 mm, weight 6.4 grams). Internal implantation followed methods of Langford et al. (1977) where an incision just smaller than the transmitter was made into the body cavity on the midline of the ventral surface halfway between the pectoral and pelvic fins. The transmitter was disinfected before placement into the body cavity. Once the transmitter was secured inside the fish, the body-wall incision was closed utilizing two simple interrupted sutures of sterile non-absorbable monofilament suture.

Upstream Migration Analysis

Stock classification

Sockeye salmon stock determinations were made by the last detection point. Those individuals last observed at or upstream of Rocky Reach Dam were classified as being Okanagan stock, those last observed at or upstream of Tumwater Dam were classified as Wenatchee stock, those last observed at or upstream of Ice Harbor or Lower Granite Dam were classified as being Snake River stock, and those last observed downstream of these sites were considered as unknown and were also considered mortalities. Fish never detected after release were subtracted from the number of fish tagged for subsequent analysis.

Escapement

Escapement to McNary, Priest Rapids, Rock Island, Rocky Reach, and Wells dams was estimated as:

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

where N was the estimated escapement at a particular upstream dam, B_i is the weekly visual count passing Bonneville Dam in week i (DART 2011, Fish Passage Center 2011), 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.

Mortality

PIT tagged sockeye salmon that were detected at least once but were not last detected at terminal locations (at or upstream of Tumwater, Wells, and Lower Granite dams) were recorded as mortalities. Mortality rates were computed by week of passage at Bonneville Dam between dams with detection capabilities

and correlated with temperatures and flows at The Dalles Dam (for Bonneville to McNary mortality) and Priest Rapids Dam (for McNary to Rock Island mortality).

Detection Efficiencies

Any fish detected at an upstream dam should also be detected at lower dams (except at Bonneville, McNary, and Ice Harbor dams, which have navigation locks fish could pass through, thus bypassing PIT tag detection antennas). The percentage of PIT tagged sockeye salmon missed at each dam with PIT tag detection arrays was calculated; for example the percentage missed at Rocky Reach Dam was calculated as:

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

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

Compiled for placement in Appendix A (Table A1) of this report was the probability of detection at the different sites, hereafter referred to as weirs, at dam fish ladders. PIT tag detection antennas in fish ladders are always located at a minimum of two weirs in relatively close proximity. Therefore, if a fish is detected at one weir, it should also be detected at the rest of the weirs in that same ladder. This allows a probability of detection at the individual weirs to be calculated by comparing it with other weirs in that same ladder. Detection probabilities were calculated as:

$$Pi = \frac{N_i}{Max(N_i)}$$

where N_i is the number of fish detected at a given weir and $Max(N_i)$ is the total number of fish detected by any weir in that ladder. An overall probability of detection was calculated as:

$$1 - \prod_i (1 - P_i)$$

Also calculated was the percentage of sockeye salmon using each ladder at dams with multiple ladders.

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 and correlated with temperatures and flows at The Dalles Dam (for Bonneville to McNary migration rates) and Priest Rapids Dam (for McNary to Wells migration rates).

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 a 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* (such that $\sum_j A_{i,j,k} = 1$) and W_k was the percentage of the run that passed Bonneville Dam in week *k.*

The variance was estimated as

$$Var(T_{i,j}) = \sum_k Var(A_{i,j,k}) * W_k^{\ 2}$$

where

$$Var(A_{i,j}) = \frac{\sum_k A_{i,j,k}(1 - A_{i,j,k})}{n_{i,k}}$$

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 weir was used as an approximation for passage time as this weir was closer to the fish counting window than the lower most weir (where the first detection would be made). This was the case at all weirs except at BO4 near the fish counting facility on the Washington shore at Bonneville Dam (Figure A1), where the distance between the upper-most and lower-most weirs is only about 15 meters.

Acoustic trawl surveys for juvenile sockeye abundance

Night-time juvenile sockeye salmon densities in Osoyoos Lake were estimated by executing specialized acoustics and trawl based survey (ATS) methods. 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 fish 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 between November 2009 and April 2010. 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.

RESULTS

Zosel Dam fish ladder PIT tag detection installation

The PIT tag antennas were ready to install at Zosel Dam (Figure 2) in early July, 2010. However, high water temperatures precluded shutting down the fish ladders for installation so this was deferred until early September (Figure 3). The PIT tag antennas were operational beginning September 2, 2010. Between September 2 and March 31, 2011, a total of 27 PIT tagged sockeye, 10 PIT tagged Chinook, and 1 PIT tagged steelhead were detected at this site. Of these fish, all but one Chinook and the steelhead were tagged by CRITFC at Bonneville or Wells dams.

Figure 2. Zosel Dam fish ladders (Photo courtesy Confederated Tribes of the Colville Reservation).

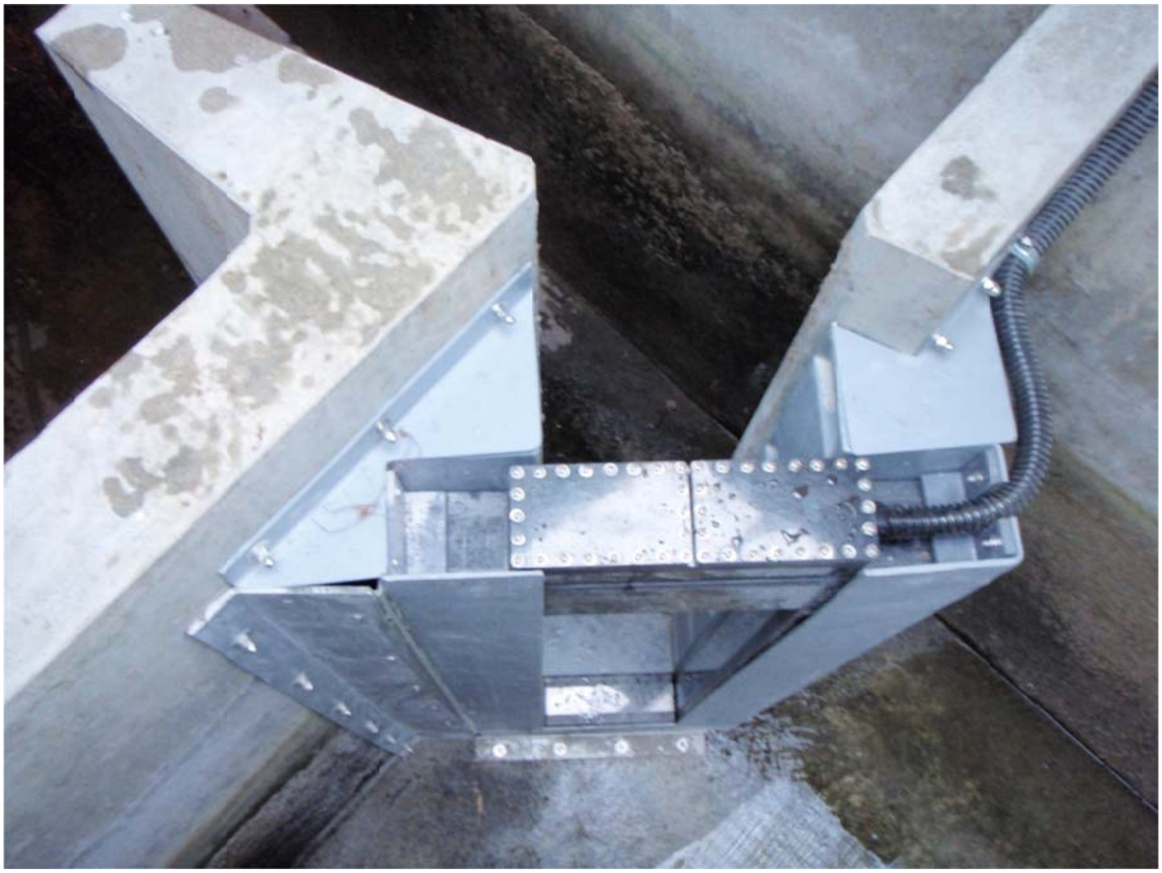


Figure 3. PIT tag antennas installed in Zosel Dam fish ladders.

Okanagan acoustic tag network installation and monitoring

A total of 23 receivers were deployed between Monse Bridge (rkm 6) and Okanagan Falls (rkm 176) in 2010 (Table 1 and Figure 4). Although tagging began on June 28, 2010, receivers could not be deployed until early July, due to high river levels making deployment dangerous. Maintenance of receivers at Driscoll Pool, which is reputed to be a cool-water location where sockeye salmon hold when Okanagan River temperatures are high, proved to be a problem. Receiver 3 was missing when checked on September 13, while receiver 4 was found on the bank once and knocked over a second time. All other receivers operated properly from installation until removal, which occurred in October for U.S. receivers and November for Canadian receivers.

Table 1. Acoustic receivers deployed in the Okanagan Basin, their location, and date of deployment in 2010. See Figure 4, map for this table.

Map No.	Location	rkm	Latitude	Longitude	Date Deployed
1	Monse Bridge west bank	6	48.14020	-119.67378	July 9
2	Monse Bridge Center	6	48.14009	-119.67336	July 9
3	Driscoll Pool (Similkameen)[2]	6	48.91989	-119.43337	July 9
4	Above Driscoll Pool (Similkameen)[3]	6	48.91951	-119.43788	July 9
5	Similkameen Canyon	11	48.94934	-119.46531	July 9
6	Oroville railroad bridge left bank (below Zosel Dam)	122	48.93129	-119.42006	July 9
7	Oroville railroad bridge right bank (below Zosel Dam)	122	48.93136	-119.42022	July 9
8	Above Zosel left bank	122	48.93388	-119.41962	July 9
9	Above Zosel middle	122	48.93393	-119.41990	July 9
10	Above Zosel right bank	122	48.93402	-119.42014	July 9
11	Oroville pump intake left bank	124	48.94582	-119.43193	July 15
12	Oroville pump intake right bank	124	48.94597	-119.43204	July 15
13	South of Haynes Point west*	132	49.01719	-119.44152	July 8
14	Haynes Point	132	49.02103	-119.43847	July 8
15	Central Basin*	134	49.02588	-119.46062	July 8
16	Northern Basin Whitesand Beach*	136	49.04980	-119.45647	July 8
17	Northern Basin-Coop plant*	138	49.05178	-119.48842	July 8
18	Northern Basin-Micca Creek*	139	49.06563	-119.48801	July 8
19	Osoyoos Lake near Inkaneep*	140	49.06986	-119.50428	July 8
20	Northern Basin-river mouth*	141	49.07462	-119.51897	July 8
21	Okanagan River VDS 3	147	49.11399	-119.56588	July 6
22	McIntyre Dam downstream	165	49.25567	-119.52780	July 6
23	Okanagan Falls	176	49.34254	-119.58033	July 6

[2] This receiver was found to have disappeared September 13.
[3] This receiver was found on the bank August 2 and found knocked over on September 13.

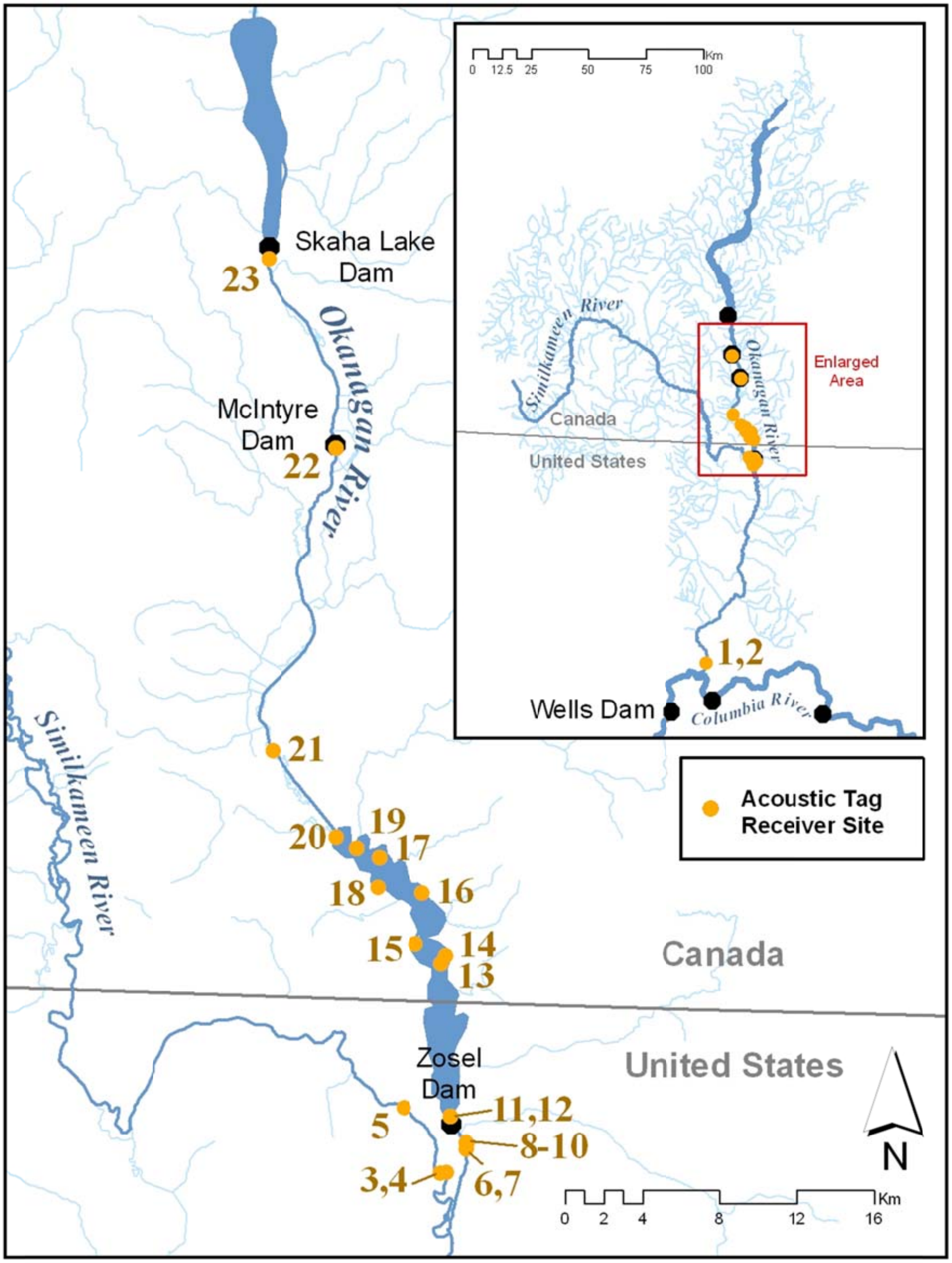


Figure 4. Okanagan Basin acoustic receiver sites in 2010. Location numbers reference sites listed in Table 1.

All receivers, except receivers located deep in Osoyoos Lake, were checked and downloaded at least once per month. The deep water receivers required divers to install, remove, and download data, and thus they were only retrieved at the end of the season.

Upstream Migration Analysis

Sample Size

A total of 918 sockeye salmon were sampled between May 27 and July 14, 2010 (Table 2). We halted sampling when PIT tag detections at Ice Harbor and Lower Granite dams indicated we had exceeded our permitted sample size of three ESA-listed Snake River sockeye salmon. Less than 1.5% of the sockeye run passed Bonneville Dam subsequent to the termination of sampling. Of the 918 fish sampled, a total of 913 sockeye salmon were released with working PIT tags (Table 2). The remaining five fish were either not PIT tagged, or were PIT tagged, but the tags were not detected when scanned. An additional 43 fish were not detected after release. These fish may have shed their tags, had defective tags, or died. It was also possible that sockeye salmon passed downstream without being detected as they often pass over the top of weirs in the fish ladder rather than through the underwater slots in those weirs where the antennas in the vicinity of the fish trap are located (Table A1). It is less likely that sockeye salmon pass upstream undetected as they must swim through antennas at fish counting windows, but data from 2006-2010 indicates it does happen (Table 3) particularly at dams with navigation locks that fish can pass through (Bonneville, McNary, Ice Harbor, and Lower Granite). PIT tag detection data were last downloaded from www.ptagis.org on March 4, 2011.

Table 2. Number of PIT tagged sockeye salmon tracked at Bonneville Dam by date and statistical week in 2010.

Sampling Dates	Statistical Week	Sampled (n)	Number Tagged	Number Tracked
5/27,6/1,2,3,4	22-23	34	34	33
6/7,8,9,10,11,	24	62	62	60
6/14,15,16,17,18	25	224	224	215
6/22,23,24,25	26	262	262	244
6/28,29,30,7/1,2	27	206	203	197
7/7,8,9	28	84	84	80
7/12,13,14	29	46	44	41
	Total	**918**	**913**	**870**

Table 3. Percentage of PIT tagged fish by tag type not detected at dam detection sites as estimated from upstream detections in 2010 with comparison data for 2006-2009.

Dam	2010	2009	2008 (12.5mm tags only)	2007	2006	Mean
Bonneville*	0.7%	0.6%	0.4%	2.1%	0.2%	**0.8%**
McNary*	3.8%	5.0%	10.1%	6.5%	3.1%	**6.2%**
Priest Rapids	0.6%	0.3%	0.3%	0.8%	0.0%	**0.4%**
Rock Island	6.2%	2.6%	6.9%	6.8%	1.3%	**4.4%**
Rocky Reach	0.5%	0.0%	0.2%	0.7%	12.3%	**3.3%**
Ice Harbor*	0.0%	20.0%	0.0%	--	--	**10.0%**
Tumwater	0.0%	--	--	--	--	**--**

*Navigation locks at these dams permit adult sockeye to bypass weirs equipped with PIT-tag antennas.

Upstream Recoveries, mortality, and escapement:

Most of the tagged sockeye salmon that were not detected at Rock Island Dam were lost before reaching McNary Dam (Table 4, Figure 5). This reach of river is where the Zone 6 tribal fishery occurs, which was estimated to harvest 24,843 sockeye salmon (Table A2) with an additional 21 sockeye harvested by sport fishers.

Table 4. Percentage of PIT tagged sockeye salmon detected subsequent to tagging at upstream dams, estimated escapement from both PIT tags and visual means, and the difference between the PIT tag and visual escapement estimate in 2010.

Dam	Estimated percentage reaching dam	Estimated escape-ment using PIT tag data	Visual Dam count	Difference between PIT tag and visual estimate
Bonneville	100.0%	--	386525	--
McNary	81.5%	314928	278799	13.0%
Priest Rapids	78.4%	303173	357058	-15.1%
Rock Island	76.3%	294847	338310	-12.8%
Rocky Reach	63.7%	246129	295638	-16.3%
Wells	62.6%	241886	291764	-16.6%
Tumwater	13.3%	51480	35821	40.9%
Ice Harbor	0.7%	2674	1302	104.8%
Lower Granite	0.5%	2123	2201	-3.9%

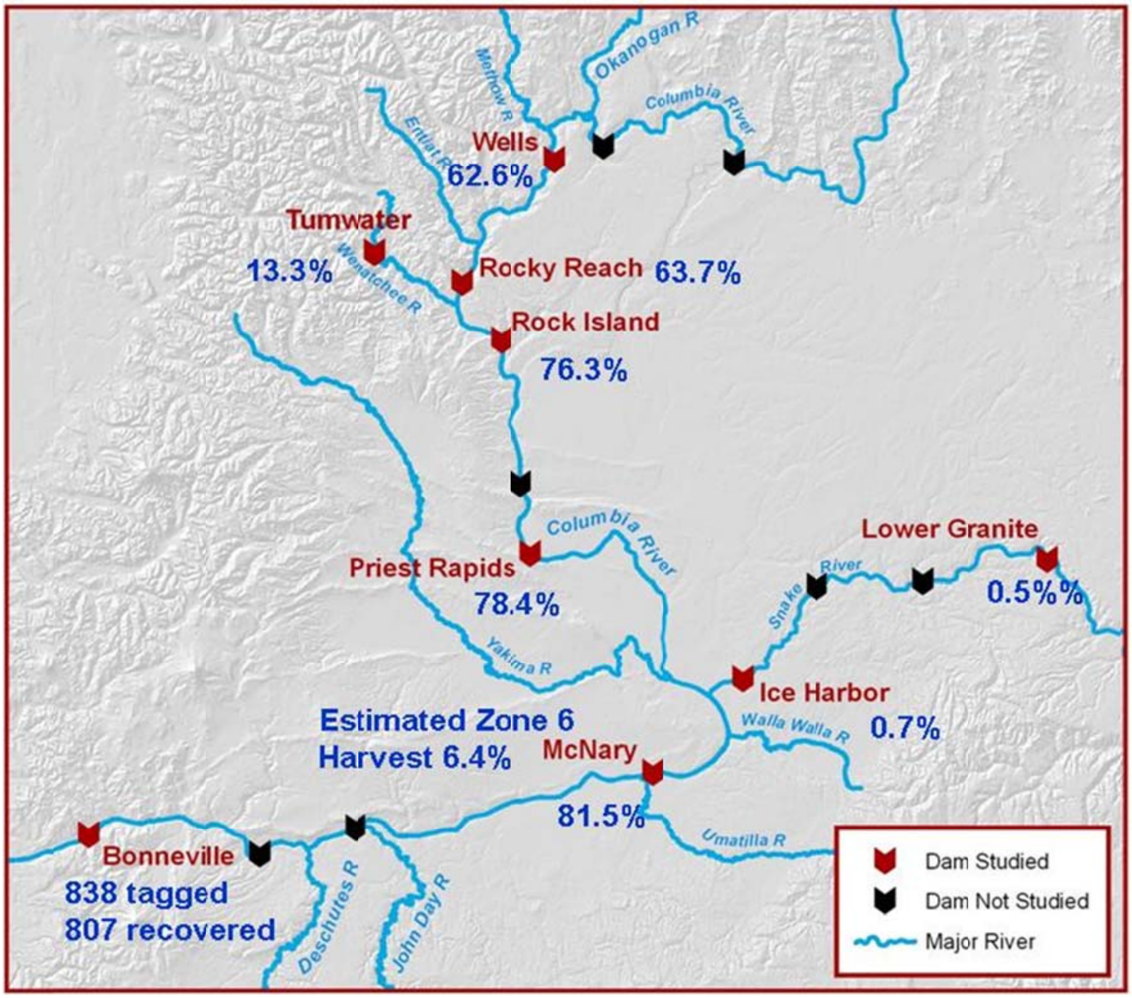


Figure 5. Map of the Columbia River Basin from Bonneville to Wells and Lower Granite dams showing the number of fish PIT tagged at Bonneville Dam, and the percentage of the run estimated to pass McNary, Priest Rapids, Rock Island, Rocky Reach, Wells, Ice Harbor, Lower Granite, and Tumwater dams in 2010.

Using detections of fish PIT tagged by this program to estimate fish counts at dams resulted in greater variation from visual fish counts than in most previous years. For instance, in 2008 estimates from this project were within 6.4% of the visual count at Priest Rapids, Rock Island, Rocky Reach, and Wells dams whereas, in 2009 these estimates differed by up to 16.1% and in 2010 by 16.6%. At McNary, Ice Harbor, and Lower Granite dams, it is possible for fish to use navigation locks to bypass fish ladders, thus avoiding both PIT tag detection and visual detection. In 2010, PIT tag estimates exceeded visual counts at McNary Dam, likely due at least in part to navigation lock passage, but at all other Columbia River dams, visual counts exceeded PIT tag estimates.

The 2010 results were similar to 2006-2009 results where there were significant linear relationships between survival within specific river segments and the statistical week in which the fish were tagged with the fish tagged later in the migration exhibiting a lower survival rate (Table 5).

Table 5. Sockeye salmon survival through selected reaches by statistical week as estimated by PIT tag detections in 2010.

Statistical Week at Bonneville Dam	Bonneville-McNary	Bonneville-Priest Rapids	Bonneville-Rock Island	Rocky Reach-Wells
23	93.5%	93.5%	93.5%	100.0%
24	91.5%	89.8%	89.8%	100.0%
25	84.2%	81.4%	79.5%	96.6%
26	81.9%	79.0%	77.4%	96.3%
27	79.7%	77.1%	74.5%	99.1%
28	76.3%	73.8%	72.5%	100.0%
29	78.0%	78.0%	73.2%	100.0%
Composite	**81.1%**	**78.4%**	**76.5%**	**97.6%**
p-value	**<0.01**	**0.01**	**<0.01**	**<0.01**

Bonneville to McNary survival significantly decreased with increasing temperatures at The Dalles Dam (p=0.01, Figure 6) but there was not a significant linear relationship with flow at The Dalles Dam (p=0.20).

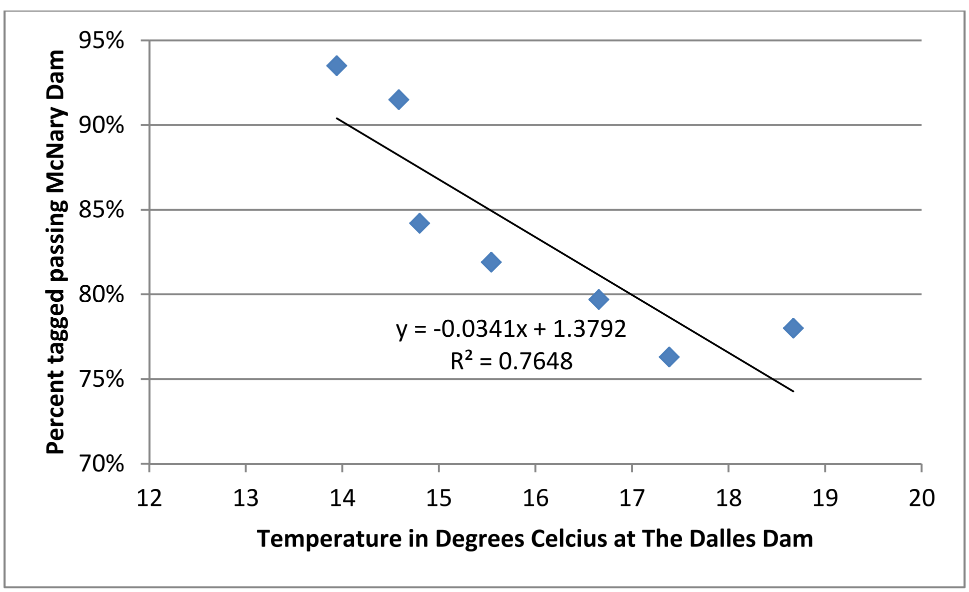


Figure 6. Figure showing the linear relationship between the survival of PIT tagged sockeye salmon from Bonneville to McNary Dam and mean water temperature at The Dalles Dam by statistical week in 2010.

Migration Timing and Passage Time

Sockeye salmon travel quickly upstream with a median travel time between Bonneville and Rock Island Dam of 12.9 days (Table 5). Sockeye salmon passing Bonneville Dam later in the migration travel upstream faster than those earlier in the migration. There is a significant (α=0.05) linear relationship between statistical week passing Bonneville Dam and passage time from Bonneville Dam to McNary, Rock Island, Rocky Reach, Tumwater, and Wells dams as well as between McNary and Rock Island, Rock Island and Rocky Reach, and Rocky Reach and Wells dams. The median difference in travel time from Bonneville Dam to all upstream mainstem dams (Table 6) except Wells Dam (where only two sockeye classified as Wenatchee stock were detected) was 1.2 days or less between the two major stocks (Table 7).

Table 6. Median sockeye salmon migration time and travel rates between dams as estimated by PIT tag detections in 2010.

Dam Pair	Distance (km)	Median Time (days)	Median Travel Time (km/day)
Bonneville-McNary	231	5.1	45.3
McNary-Priest Rapids	167	4.1	40.7
Priest Rapids-Rock Island	89	3.0	29.7
Rock Island-Rocky Reach	33	1.0	33.0
Rocky Reach-Wells	65	2.0	32.5
Rock Island-Tumwater	73	13.3	5.5
Bonneville-Rock Island	487	12.9	37.8
Bonneville-Tumwater	560	27.8	20.1
Bonneville-Wells	585	16.0	36.6

The median time between first detection and last detection was six minutes or less at all dams except for Bonneville, Lower Granite, and Tumwater dams (Table 8). At Bonneville Dam, many sockeye were detected in underwater orifices just upstream and downstream of the fish trap where sampling occurred, inflating the median passage time. At Lower Granite Dam, all fish were trapped which likely resulted in increased passage times. At Tumwater Dam, all fish were trapped during the sockeye migration, likely resulting in delays.

Table 7. Median adult sockeye salmon travel time in days between dam pairs by statistical week passing Bonneville Dam, the F-statistic for a linear regression between travel time and statistical week, and mean travel time by stock as estimated using PIT tags in 2010.

Statistical Week at Bonneville Dam	Bonneville-McNary	Bonneville-Priest Rapids	Bonneville-Rock Island	Bonneville-Rocky Reach	Bonneville-Tumwater	Bonneville-Wells	McNary-Rock Island	Rock Island-Rocky Reach	Rocky Reach-Wells
23	5.9	10.3	14.6	15.4	–	17.2	8.9	1.2	2.6
24	5.2	10.0	14.8	17.0	37.6	19.3	9.2	1.8	2.8
25	5.1	9.8	13.9	14.9	28.5	17.2	8.4	1.2	2.2
26	5.2	9.4	12.7	13.6	25.0	15.9	7.1	1.1	2.1
27	5.0	8.8	11.7	12.8	22.2	15.2	6.7	1.1	2.1
28	4.8	8.8	11.6	12.4	21.8	14.5	6.4	1.0	2.1
P-value	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.02**	**<0.01**
Stock									
Okanagan	5.1	9.7	12.8	13.8	31.0	16.0	7.2	1.0	2.0
Wenatchee	5.1	9.8	14.0	14.8	27.8	21.5	8.5	0.8	--
Snake River	4.9	--	--	--	--	--	--	--	--
Unknown[4]	5.0	9.1	11.1	--	--	--	6.0	5.0	9.1

Table 8. Sockeye salmon median travel 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 2010.

Dam	Median Passage Time (Minutes)	Taking more than 12 hours (%)
Bonneville	63	6.1%
McNary	0	2.2%
Priest Rapids	6	1.2%
Rock Island	3	0.8%
Rocky Reach	1	2.1%
Wells	2	2.5%
Tumwater	8494	72.1%
Ice Harbor	5	0.0%
Lower Granite	704	50.0%

Stock composition estimates

The percentage of Wenatchee stock sockeye salmon was higher during the middle of the run when compared to the beginning and end with no significant linear relationship between weekly stock composition and statistical week ($p=0.85$, Table 9). The overall stock composition estimate was 17.3% Wenatchee, 81.8% Okanagan, and 0.9% Snake River. The Wenatchee/ Okanagan split differed by 4.8 percentage points from that estimated by Rocky

[4] Unknown stock sockeye salmon are those that passed Bonneville but were not detected at Tumwater, Rocky Reach, Wells, Ice Harbor, or Lower Granite dams.

Reach Dam counts and 6.8 percentage points from that estimated using Tumwater Dam counts (Table 9).

A total of 31 adipose clipped sockeye salmon were PIT tagged[5]. Of these, five were last detected in the Snake Basin (one of which had a ventral fin clip in addition to an adipose fin clip), 12 were last detected in the Wenatchee Basin, three were last detected at or upstream of Rocky Reach Dam, and 12 were last detected at a Columbia River dam downstream of Rocky Reach Dam

Table 9. Weekly and composite sockeye salmon stock composition at Bonneville Dam as estimated by PIT tags in 2010 and a comparison to stock composition estimates estimated using visual dam counts.

Statistical Week and Dates	Run Size	PIT Tag sample size	Percent Wenatchee	Percent Okanagan	Percent Snake River
23 (On or before June 4)	1129	34	3.2%	96.8%	0.0%
24 (June 5-11)	4776	62	11.3%	88.7%	0.0%
25 (June 12-18)	51141	224	20.4%	79.6%	0.0%
26 (June 19-25)	182178	262	19.8%	79.7%	0.5%
27 (June 26-July 2)	90356	203	16.1%	81.9%	2.0%
28 (July 2-8)	44082	84	9.4%	89.1%	1.6%
29 (On or after July 9)	12863	44	8.3%	91.7%	0.0%
Composite	**386525**	**913**	**17.3%**	**81.8%**	**0.9%**
Standard Deviation			**0.7%**	**1.5%**	**0.0%**
Visual Fish Counts at dams (using difference between Rock Island and Rocky Reach counts to estimate proportion Wenatchee)			12.5%	86.6%	
Visual Fish Counts at dams (Tumwater count to estimate the proportion Wenatchee)			10.5%	88.6%	

Okanagan and Wenatchee age and length-at-age composition

The 1.2 age class was predominant for all three stocks (Table 10). One-ocean sockeye salmon (age 1.1 and 2.1) were found predominantly in the Okanagan stock. For the Wenatchee stock, the age composition was similar whether estimated by PIT tag or by sampling at Tumwater Dam. However, this was not the case for the Okanagan stock where trap size selectivity, which was also observed in 2008 and 2009 (Fryer 2008, Fryer et al. 2010), resulted in larger fish being over represented in the sample obtained at Wells Dam. Length-at-age estimates are found in Table 11.

[5] Juvenile sockeye salmon are adipose clipped in Snake River and Lake Wenatchee hatchery programs.

Table 10. Age composition (%) of Columbia Basin sockeye salmon stocks as estimated by PIT tag recoveries as well as by sampling at Tumwater and Wells dams in 2010. Standard deviations are in parentheses.

		Age					
Stock-Method	**Sample Size**	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**
Bonneville-sample	870	1.6 (0.5)	92.2 (1.0)	2.8 (0.6)	0.4 (0.2)	3.0 (0.7)	--
Wenatchee-PIT tag estimate	110	--	81.7 (4.0)	10.2 (3.2)	--	6.6 (2.7)	--
Wenatchee-Tumwater sample	395	--	73.9 (2.8)	3.6 (1.1)	--	22.3 2.7	0.2 (2.0)
Okanagan- PIT tag estimate[6]	567	2.0 (0.7)	95.2 (1.0)	0.5 (3.4)	0.6 (0.3)	1.7 (0.6)	--
Okanagan-Wells sample	394	1.2 (0.5)	95.3 (1.0)	3.4 (0.9)	--	0.1 (0.1)	--
Snake River PIT tag estimate	5	--	72.0	28	--		--

Table 11. Length-at-age composition of Wenatchee and Okanagan stock sockeye salmon estimated by PIT tag detection and sampling at Tumwater and Wells dams in 2010.

		Age					
Stock	**Statistic**	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**
Bonneville-Mixed stock	Mean	40.8	50.1	57.3	41.9	52.2	--
	St. Dev.	2.0	4.7	2.4	1.8	2.5	--
	N	15	776	22	5	26	--
Okanagan-PIT tags	Mean	41.0	49.8	59.0	41.9	51.9	41.0
	St. Dev.	2.0	4.4	2.0	1.8	2.8	2.0
	N	13	523	3	5	8	13
Okanagan-Wells Sampling	Mean	41.1	53.0	56.4	--	51.0	--
	St. Dev.	2.3	2.4	2.4	--	--	--
	N	5	374	14	--	1	--
Wenatchee-PIT tags	Mean	--	51.9	57.3	--	52.1	--
	St. Dev.	--	1.9	1.8	--	3.5	--
	N	--	83	13	--	8	--
Wenatchee-Tumwater Sampling	Mean	--	53.9	58.0	--	54.3	60.5
	St. Dev.	--	2.0	1.6	--	2.4	--
	N	--	304	16	--	74	1

In basin detection of PIT tagged Okanagan sockeye salmon

A total of 428 sockeye salmon PIT tagged at Bonneville Dam and 268 sockeye PIT tagged at Wells Dam by this project were detected at the OKC PIT tag array in addition to 68 sockeye tagged as juveniles at Rock Island Dam, 7

[6] The estimated Okanagan stock age composition determined from otoliths collected on the spawning ground (n=501) was .1=3.5%, 1.2=87.9%, 1.3=5.4%, 2.2 =3.3% (Kim Hyatt, personal communication).

steelhead and 4 Chinook. At Zosel Dam, between installation of PIT tag antennas in both fish ladders on September 2, 2010 and March 31, 2011, 27 sockeye (all tagged by this project), 10 Chinook, and one steelhead were detected.

PIT tags from nine sockeye salmon, six tagged by this project at Bonneville Dam and three tagged at Wells Dam, were recovered during Okanagan River spawning ground surveys and brood stock collection activities.

In-river detection of PIT tagged Wenatchee sockeye salmon

Wenatchee Basin PIT tag arrays passed by sockeye salmon are located in the Tumwater Dam fish ladder, in-river just upstream of Tumwater Dam (middle Wenatchee River), and immediately downstream of sockeye salmon spawning grounds on the White and Little Wenatchee rivers (Figure 7). All sockeye salmon tagged by this study detected at sites upstream of Tumwater Dam were also detected at Tumwater Dam, suggesting a 100% or nearly-100% rate of detection for sockeye passing Tumwater Dam. The detection rate for sockeye salmon passing the White and Little Wenatchee arrays is unknown.

Of the 87 sockeye salmon detected at Tumwater Dam, 31 were subsequently detected upstream and two downstream (at Rocky Reach Dam) (Table 12 and Figure 7). None of the fish last detected at the lower Tumwater Dam fish ladder dam antenna were subsequently detected upstream and none of the fish last detected at the upper antenna were subsequently detected downstream, which suggests that each antenna detects all, or nearly all, passing PIT tagged sockeye salmon. Mean delays average 10.7 days, with sockeye last detected passing the upper antenna having a much shorter delay than sockeye last detected at the lower antenna (6.2 days versus 19.7 days, Table 13).

Table 12. Number and percentage of sockeye detected at Tumwater Dam by last detection site in the ladder, and subsequent detections in 2010.

		Number and Percentage Subsequently Detected by Site			
Tumwater Dam Antenna	**Total Last detected**	**Middle Wenatchee River**	**Little Wenatchee**	**White River**	**Rocky Reach Dam**
Upper	74	1 (1.4%)	3 (4.1%)	27 (36.5%)	--
Lower	37	--	--	--	2 (5.4%)
Total	111	1 (0.9%)	3 (2.7%)	27 (24.3%)	2 (1.8%)

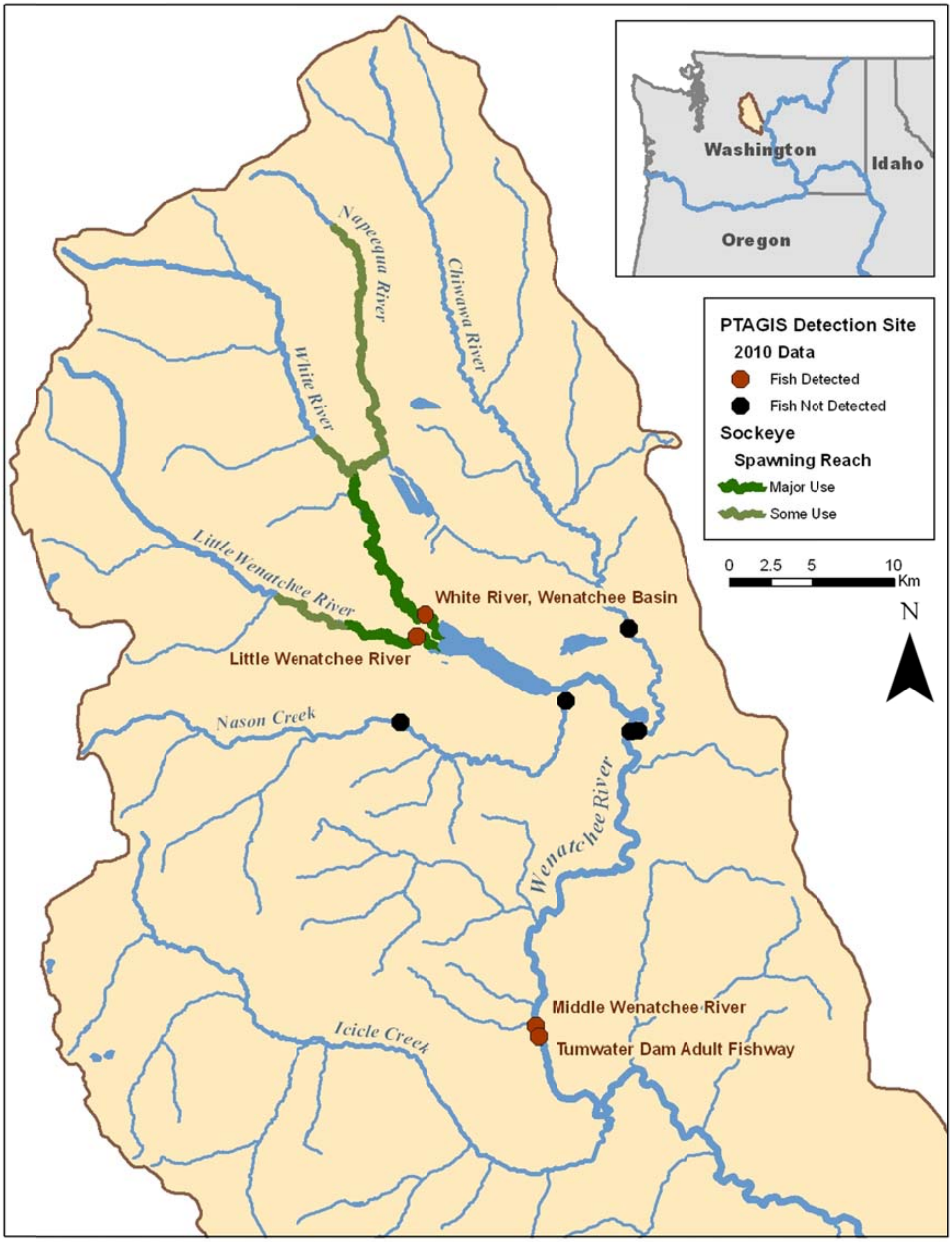


Figure 7. Portion of Wenatchee Basin with PIT detectors that could detect returning adult salmon or steelhead. Also displayed is the spawning area of sockeye.

Table 13. Passage delays of sockeye detected at Tumwater Dam and subsequent detections in 2010.

Tumwater Dam Antenna	Total Last detected	Mean Passage Delay (days) at Tumwater Dam Based on Subsequent Detections			
		Downstream	Upstream	Not Detected	All Fish
Upper	74	--	6.0	6.5	6.2
Lower	37	17.4	--	19.8	19.7
Total	111	17.4	--	13.7	10.7

New PIT tag antenna arrays in the Entiat River (which flows into the Columbia River between Rocky Reach and Wells dams) also detected two sockeye salmon. One sockeye, with tag 3D9.1C2D3F2077, passed Rocky Reach Dam on July 21 was at site ENL in the lower Entiat River, first at the upper array then 14 hours later at the lower array and was not subsequently detected. A second sockeye, with tag 3D9.1C2D3F3A74, passed Rocky Reach Dam on July 9, Wells Dam on July 13, before passing the lower Entiat antenna on August 19 and the middle Entiat antenna on August 28. We also had sockeye salmon detected in the lower Methow River on August 26 and two on September 4, with one of those latter fish being detected in the Twisp River on September 20.

Night Passage

At dams with more than five detections, Okanagan stock sockeye salmon passed dams at night (2000-0400 hours) at a higher rate than Wenatchee stock sockeye salmon (Table 14). The Bonneville Dam estimate of nighttime passage is likely biased low because tagging occurred between about 0900 and 1500 hours, and with a median passage time of 63 minutes from tagging to final detection at Bonneville Dam (Table 8), fish would be expected to pass the counting window prior to 2000 hours.

Table 14. Estimated sockeye salmon nighttime passage (2000-0400 standard time) in 2010 at mainstem Columbia River dams as estimated by PIT tag detections.

Dam	All Sockeye (includes unknown)	Okanagan Stock	Wenatchee Stock	Snake Stock
Bonneville	0.5	0.4	0.0	0.0
McNary-Oregon Shore	5.6	6.6	0.0	0.0
McNary-Washington Shore	7.7	7.3	6.4	0.0
Priest Rapids	2.2	2.6	0.0	NA
Rock Island	3.0	2.8	2.9	NA
Rocky Reach	11.4	11.3	20.0[a]	NA
Wells	12.1	12.2	0.0[a]	NA
Tumwater	9.0	*0.0	9.1	NA
Ice Harbor	0.0	NA	NA	0.0
Lower Granite	25.0[a]	NA	NA	25.0[a]
Mean of McNary, Priest Rapids and Rock Island	4.8	4.2	2.5	NA

a - Based on fewer than five fish detected at dam.

Wells Tagging

A total of 400 sockeye were PIT tagged at Wells Dam between June 28 and July 26. All sockeye tagged at Wells Dam were also floy tagged. Of these fish, 316 were subsequently detected by PIT tag arrays (Table 15). Two days of sampling during Statistical Week 27 were conducted at the east bank ladder and the fish released directly back in the ladder where they were subsequently detected by Wells ladder PIT tag antennas (Figure 8). Other fish tagged by this study were released into the Wells Dam forebay. At least five sockeye PIT tagged at Wells fell back over the dam after tagging. One sockeye salmon in each of Statistical weeks 28 and 30 which were released in the forebay were subsequently detected in the Wells Dam fish ladder. Among other sockeye tagged in Statistical Week 28, one was detected at Rocky Reach juvenile bypass, another at the same bypass and at the Tumwater Dam fish ladder, and a third at the Tumwater Dam fish ladder and the White River. Finally, a fish tagged in Statistical Week 30 was last detected in the lower Entiat River downstream of Wells Dam.

The percentage of sockeye passing Wells Dam early in the migration, that were detected at OKC, was much higher than later in the migration for sockeye salmon tagged at both Bonneville and Wells dams. For both groups of fish, there was a pronounced dip in survival in Statistical Week 30 (Table 16).

Table 15. Subsequent detections of sockeye salmon PIT tagged at Wells Dam in 2010.

		Site Detected							
Week	**Number tagged**	**Wells Ladder**	**Zosel Dam**	**Okanagan Channel**	**Lower Entiat**	**Rocky Reach Juvenile**	**Tumwater Dam**	**White River**	**Individual Fish Detected**
27	45	25	0	36	0	0	0	0	39
28	150	1	0	123	0	2	2	1	127
29	125	0	5	75	0	0	0	0	76
30	55	1	9	20	1	0	0	0	23
31	25	0	4	11	0	0	0	0	12
Total	**400**	**27**	**18**	**265**	**1**	**2**	**2**	**1**	**316**

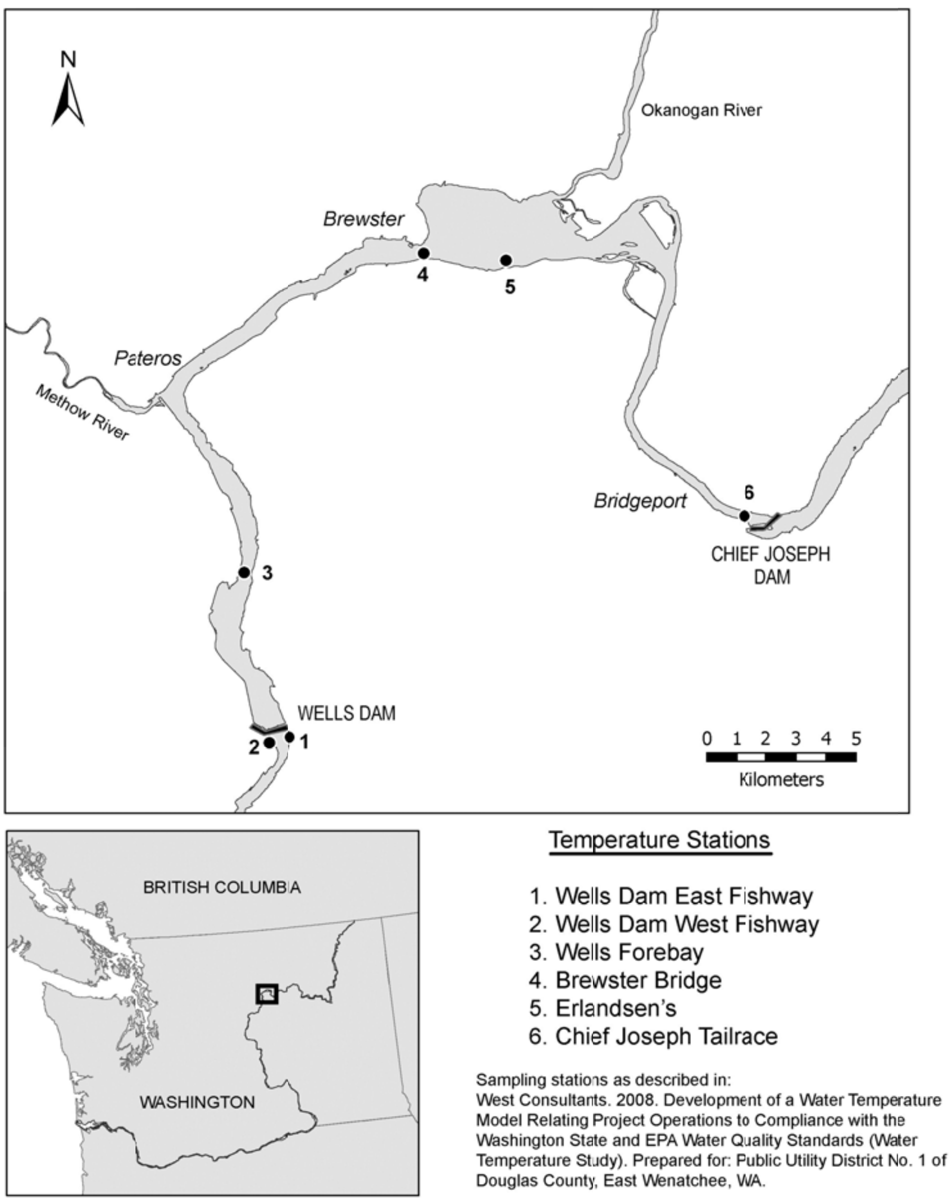


Figure 8. Area between Wells and Chief Joseph dams.

Table 16. Percentage of sockeye salmon PIT tagged at Bonneville and Wells dams detected at Okanagan Channel PIT tag array (OKC) by statistical week at Wells Dam.

Statistical Week (first detected at Wells Dam)	Tagged at Wells		Tagged at Bonneville	
	N	Detected at OKC	N	Detected at OKC
25	0	--	2	100.0%
26	0	--	16	88.9%
27	45	91.1%	69	85.2%
28	150	86.0%	174	85.7%
29	125	60.8%	110	79.7%
30	55	41.8%	29	35.4%
31	25	52.0%	22	62.9%
32	0	--	1	50.0%
Total	**400**	**70.7%**	**423**	**75.8%**

Acoustic Data Analysis

A total of 64 sockeye salmon were implanted with acoustic tags between June 29 and July 26, 2010 (statistical weeks 27-31, Table 17). High flows prevented deployment of the acoustic network until between July 6 and July 9, resulting in many fish tagged between June 28 and July 7 passing receiver sites prior to installation. Two receivers, originally planned for deployment at the Molson Road Bridge in Oroville upstream of Zosel Dam, were not deployed due to high public use of the area. These receivers were deployed upstream at the Oroville pumping station July 15-16. Of the 64 sockeye acoustic tagged, 57 were subsequently detected.

Table 17. Percentage of sockeye salmon acoustic tagged at Wells Dam passing upstream receivers and median days to selected sites in 2010.

Statistical Week Tagged	Number Tagged	% Passing Monse Bridge	% Passing Haynes Point	% Passing VDS 3	% in Similk-ameen	Median Days to Monse Bridge	Median Days to Haynes Point	Median Days to VDS 3
27	15	100.0%	100.0%	71.4%	7.1%	NA	12.7	89.9
28	15	93.3%	93.3%	80.0%	66.7%	NA	6.9	82.1
29	16	100.0%	75.0%	50.0%	37.5%	2.2	5.7	76.3
30	12	66.7%	50.0%	41.7%	16.7%	34.2	37.6	67.4
31	6	83.3%	66.7%	50.0%	0.0%	28.7	32.3	69.2
Overall	**64**	**90.5%**	**79.4%**	**60.3%**	**30.2%**	**4.1**	**8.9**	**81.3**

Earlier migrating fish passed Monse Bridge and Haynes Point at a higher rate, and migrated faster, than later migrating fish (Table 17). Sockeye passage into the Okanagan River was highly affected by temperature with 15 fish passing the Monse Bridge during the dip in temperatures below 21C July 14-17 and 9 fish passing after temperatures dropped below 22C on August 23 (Figure 9). Only

three sockeye passed during the period of high temperature between these dips, the first passing July 23 and not being subsequently detected. A second passed on July 24, migrating to the base of Zosel Dam on July 26 before being last detected in the Similkameen on July 27. A third, passing Monse on August 14 with a water temperature of 23.2C was more successful, making it to Zosel Dam and Haynes Point on August 17 and the North Basin on August 17.

Six of the 16 sockeye passing Monse Bridge, between July 14 and 17, were detected in the Similkameen River. Of these six fish, four were not detected upstream of Zosel Dam. Delays at Zosel Dam were not apparent among acoustic tagged fish as only one sockeye took more than 0.8 days from the railroad bridge below the dam to the log boom above it and only three fish took more than 0.9 days from the railroad bridge to the pumping station above Zosel Dam. All of these fish subsequently were detected in the North Basin. All sockeye detected at the log boom and/or the pumping station were subsequently detected at Haynes Point.

Of the four acoustic tagged fish captured in the Colville fishery, two were tagged in both Statistical weeks 30 and 31. Thirty seven of the 64 fish tagged were estimated to be on the spawning grounds during the spawning period (Table 18).

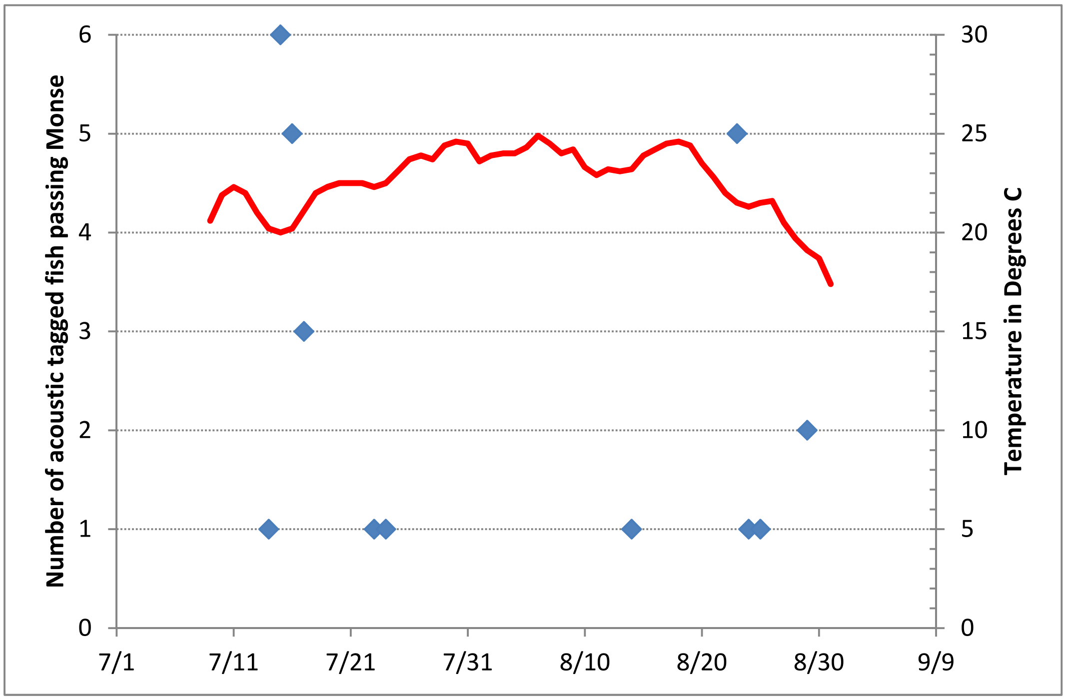


Figure 9. Okanagan River water temperature at Malott and the number of acoustic tagged sockeye salmon detected at the Monse acoustic tag receiver by date beginning on installation July 9.

Table 18. Tagging data, last detection and date, and first PIT tag detection at VDS3 for sockeye salmon acoustic tagged at Wells Dam in 2010. (Blue shading indicates combined acoustic/temperature/depth tags and green shading indicates the fish was on the spawning grounds during the spawning period.)

Tag code	Date Tagged	Final Site	Date	First PIT Tag detection at OKC (VDS3)	Comments
39019	6/28				Not detected after tagging
39020	6/28	McIntyre Dam	9/25	9/23	On spawning grounds
39021	6/28	North Basin	11/6	9/21	Tag shed and fish harvested near Inkaneep
39022	6/28	Okanagan Falls	7/18	7/13	Likely harvested at OK falls
39023	7/7	VDS3	9/28	9/28	On spawning grounds
39024	6/28	Haynes Point	7/3	7/4	Pre-spawn mortality
39025	6/28	North Basin	9/17		Pre-spawn mortality
39026	6/28	VDS3	10/10	10/9	On spawning grounds
39027	7/7	Okanagan Falls	10/5		On spawning grounds
39028	7/6	Okanagan Falls	10/12	9/12	On spawning grounds

39029	7/6	VDS3	10/22	9/25	On spawning grounds
39030	7/6	VDS3	10/27	9/24	On spawning grounds
39031	7/7	North Basin	8/18		Caught in ONA fishery
39032	7/7	Haynes Point	10/22		On spawning grounds then headed downstream
39033	7/13	North Basin	9/16		Pre-spawn mortality
39034	7/13	VDS3	9/14		On spawning grounds
39035	7/13	Driscoll Pool	7/30		Pre-spawn mortality
39036	7/13	McIntyre Dam	10/11	10/2	On spawning grounds
39037	7/14	McIntyre Dam	10/11	9/26	On spawning grounds
39038	7/14	North Basin	7/30		Pre-spawn mortality
39039	7/14	North Basin	11/21		Likely tag shed in July, final destination unknown
39040	7/14	McIntyre Dam	10/17	9/25	On spawning grounds
39041	7/19	Monse Bridge	7/23		Pre-spawn mortality
39042	7/19	VDS3	9/24	9/23	On spawning grounds
39043	7/19	Haynes Point	7/26		Harvested in Colville Fishery
39044	7/20	McIntyre Dam	10/2	9/25	On spawning grounds
39045	7/20	Upper Similkameen	7/27		Pre-spawn mortality
39046	7/20	McIntyre Dam	10/1	9/27	On spawning grounds
39047	7/26				Harvested in Colville Fishery
39048	7/26	VDS3	10/9	10/9	On spawning grounds
39049	7/26	North Basin	7/26		Harvested in Colville Fishery
39050	7/26	VDS3	10/3	10/2	On spawning grounds
39051	7/26	VDS3	9/24	9/24	On spawning grounds
39052	7/26	Monse Bridge	8/29		Pre-spawn mortality
39053	7/20				Not detected after tagging
39054	7/20	McIntyre Dam	9/26	9/23	On spawning grounds
39055	7/20				Harvested in Colville Fishery
39056	7/19				Not detected after tagging
39057	7/19	VDS3	9/24	9/24	On spawning grounds
39058	7/19				Not detected after tagging
39059	7/14	Haynes Point	8/1		Pre-spawn mortality
39060	7/14	Driscoll Pool	7/25		Pre-spawn mortality
39061	7/14	VDS3	10/4	10/4	On spawning grounds
39062	7/14	VDS3	10/31	10/9	On spawning grounds

39063	7/13	North Basin	11/21	9/23	Mobile tracked on spawning grounds
39064	7/13	Driscoll Pool	7/23		Pre-spawn mortality
39065	7/13	Okanagan Falls	10/17	9/28	On spawning grounds
39066	7/13	Driscoll Pool	7/23		Pre-spawn mortality
39067	7/7	North Basin	9/27	9/27	On spawning grounds
39068	7/7	VDS3	10/20	10/20	On spawning grounds
39069	7/7	VDS3	10/9	10/9	Mobile tracked on spawning grounds
39070	7/7	Okanagan Falls	10/3	9/23	On spawning grounds
39071	7/6	VDS3	9/26	9/26	On spawning grounds
39072	7/6	McIntyre Dam	10/1	9/22	Mobile tracked on spawning grounds
39073	7/6				Not detected after tagging
39074	7/6	VDS3	10/20	10/17	On spawning grounds
39075	6/29	North Basin	9/22		Mobile tracked on spawning grounds
39076	6/29	McIntyre Dam	10/9	9/27	Mobile tracked on spawning grounds
39077	6/29	VDS3	10/3	10/3	Mobile tracked on spawning grounds
39078	6/29	McIntyre Dam	10/8	9/24	On spawning grounds
39079	6/29	VDS3	10/7		Mobile tracked on spawning grounds
39080	6/29	VDS3	9/21	9/20	Mobile tracked on spawning grounds
39081	6/29	McIntyre Dam	10/19	9/25	Mobile tracked on spawning grounds
39082	6/29	VDS3	9/28	9/28	On spawning grounds

Many of our receivers were deployed at choke points located at key locations where we expected to be able to detect all, or nearly all, passing sockeye salmon. The detection rates at these choke points were good at all locations except for the Zosel log boom (Table 19).

Table 19. Detection rate of Okanagan Basin acoustic network at choke points in 2010.

Site	Detection Rate	Number Detected
Monse Bridge	100.0%	27
Oroville Railroad Bridge	94.9%	37
Zosel Log Boom	77.1%	27
Oroville pumping station	95.7%	22
Haynes Point	95.7%	45
VDS 3	100.0%	38
McIntyre Dam	100.0%	19

Rate was estimated by, for the period when the site was in operation, dividing the number of sockeye passing a site undetected by the total number of sockeye estimated to have past that site.

Of the 41 sockeye salmon which were both PIT- and acoustic-tagged and detected at VDS3, 37 PIT tags (or 90.2%) were detected and 40 (97.6%) acoustic tags were detected.

Acoustic Trawl Survey for juvenile abundance

A single acoustic trawl survey of Lake Wenatchee estimated greater juvenile abundance than was found in Lake Osoyoos (Table 20, Appendix B)

Table 20. Estimates of juvenile sockeye salmon abundance from Osoyoos Lake acoustic trawl surveys between April 2010 and March 2011.

Lake	Date	Juvenile Abundance	Smolt/ha (95% CI)
Osoyoos	October 21, 2010	1,114,000	1200 (±400)
Wenatchee	Sept 21, 2010	1,637,000	1600 (±200)

Migration Behaviour and Thermal History of Okanagan Sockeye Salmon in 2010

Fryer et al. (2010) have described the general design and methodology used in the current tagging study of Columbia River sockeye migration behavior. The 2010 tagging program included the application of combinations of PIT tags, archival *i*-button tags, and VEMCO acoustic tags that enabled us to track the behavior and thermal history of adult Okanagan sockeye salmon migrating between Wells Dam and their spawning grounds in the Okanagan River near Oliver, B. C. (Table 21 and Figure 10).

Table 21. Descriptions of temperature stations found on the map in Figure 9/10.

Map Number	Location	Adminstrator	Web Access
1	Okanagan River at Okanagan Falls (ID 08NM002)	Environment Canada, Real-Time Hydrometric Data	http://www.wateroffice.ec.gc.ca/index_e.html
2	Okanagan River at Oroville (ID 12439500)	USGS Real-Time Data for Washington	http://waterdata.usgs.gov/wa/nwis/rt.
3	Similkameen River at Oroville (ID 49B070)	Washington Department of Ecology, River and Stream Flow Monitoring (WRIA 49 Okanagan)	http://www.ecy.wa.gov/apps/watersheds/wriapages/index.html
4	Bonaparte Creek at Tonasket (ID 49F070)		
5	Tunk Creek near Riverside (ID 49E080)		
6	Omak Creek near St. Mary's Mission (ID 49C100)		
7	Wells Dam Forebay	Columbia River D.A.R.T., River Environment Data	http://www.cbr.washington.edu/dart/river.html
8	Chief Joseph Tailrace		
9	Brewster Bridge site	WEST Consulting for DCPUD. 2008 or Anonymous 2008	Full report can be obtained at: http://relicensing.douglaspud.org/
10	Erlandsen's Site		

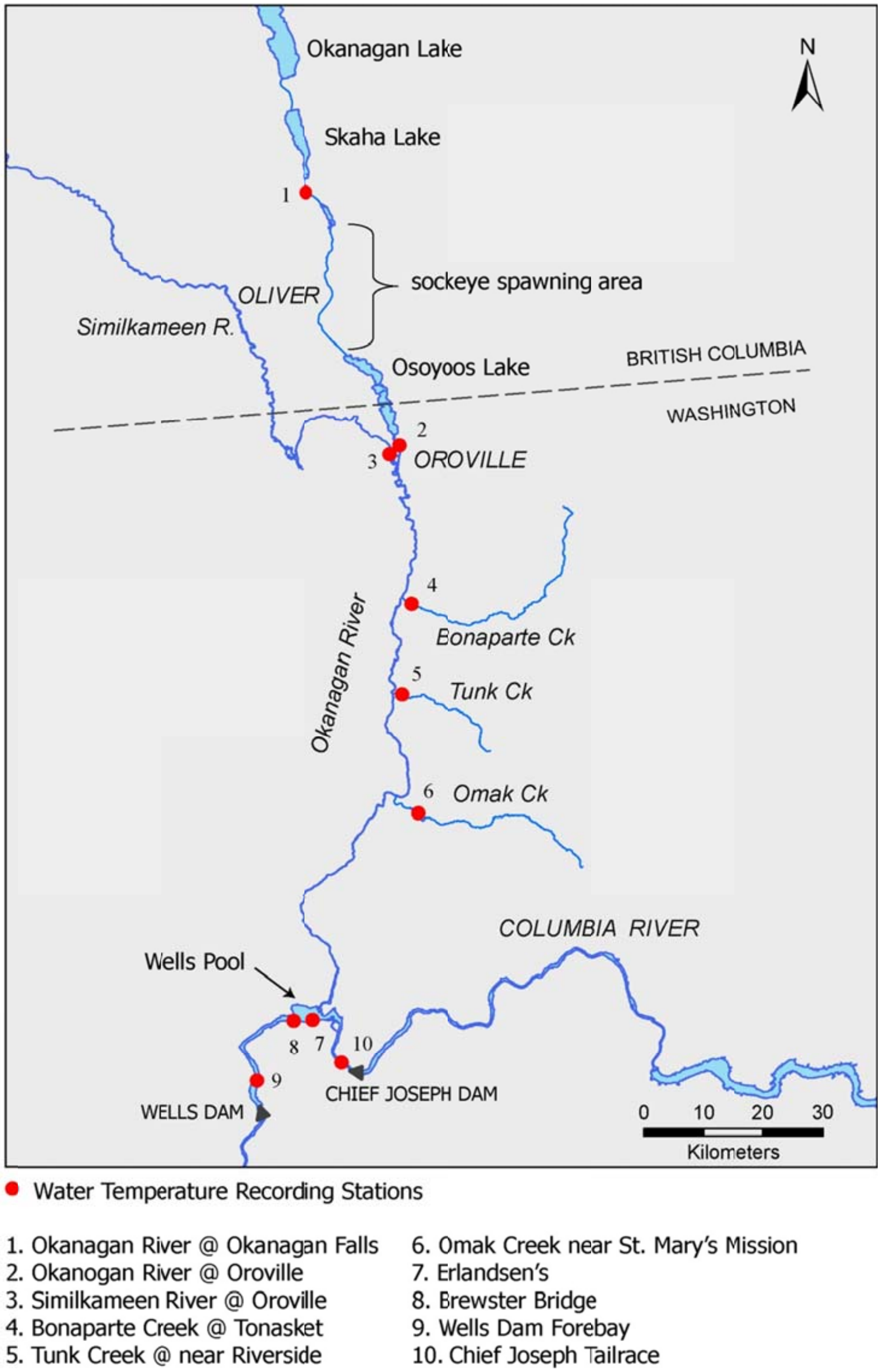


Figure 10. Map of spawning grounds of Okanagan sockeye salmon and location of temperature stations.

Button-tags from Wells Pool

Four of 50 button-tags applied to adult sockeye at Wells Dam during summer 2010 were subsequently returned from either fisheries executed in Lake Pateros behind Wells Dam (4 tags in total, Figure 8) by the Colville Confederated Tribes. Two additional tags were recovered from sockeye at Haynes Point and near the Okanagan River's entry point to Osoyoos Lake's north basin (Figure 11).

Figure 11. Map of Osoyoos Lake and features.

Temperatures recorded by *i*-button tags from four adult sockeye holding in Wells Pool (Figure 12) for three to twenty-three days in late summer (July 19-August 17) consistently exhibited mean values between 18-20 degrees Celsius (range 18-22). These values closely approximated daily means of surface

temperatures observed for Wells Pool at the Wells Dam Forebay (Figures 8 and 13). The absence of a substantive difference between temperatures selected by holding adult sockeye and near-surface temperatures in Wells Pool were not unexpected because turbulent river flow through Wells Pool generally results in isothermal conditions in these waters from surface to bottom throughout the late summer (West Consultants, 2008). Although it is conceivable that cooler water may have existed in near-bottom locations near groundwater seeps, none of the subject sockeye adults appear to have located such areas. Two fish did exhibit brief spikes of >20^{o}C water generally associated with locations immediately adjacent to entry points near the mouth of the Okanagan River known to have temperatures in excess of those in Wells Pool during mid-to-late summer intervals (West Consultants, 2008).

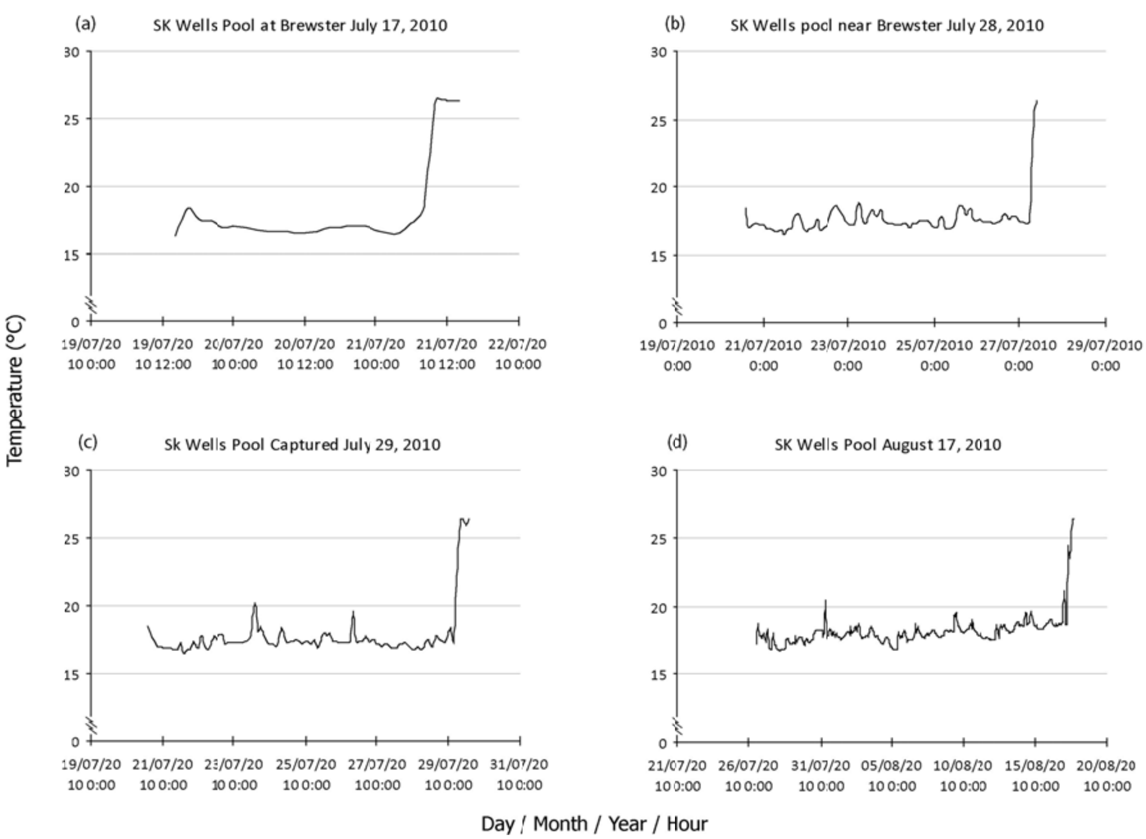


Figure 12. The temperature profiles from tags in four individual sockeye salmon holding in the Wells Dam pool over several days.

Figure 13. Water temperatures measured between Wells and Chief Joseph dams at the same time period as i-button tagged sockeye were present.

Button-tags from Okanagan River-Osoyoos Lake

Hyatt et al. (2003) have described several sets of historic results that suggest active migration of sockeye adults from the Columbia River at Wells Pool to the Okanagan River may virtually stop as seasonal water temperatures in the Okanagan River increase and exceed 21^{o}C and then restart when seasonal temperatures decrease and fall below 21^{o}C. During the summer of 2010, temperatures in the Okanagan River generally remained below 21^{o}C until after July 13th (Figure 14). Consequently, recovery of two *i*-button tags, their thermal history and the fate of two adult sockeye that initiated migration up the Okanagan River after this date, are of some interest. Because Wells Pool, the Okanagan River, tributaries to the Okanagan River (e.g. Omak Creek, Similkameen R. etc.) and Osoyoos Lake all exhibit distinctive seasonal thermal "signatures" (Figure 14), the thermal history of each of these fish may be used to characterize their migrations in both space and time.

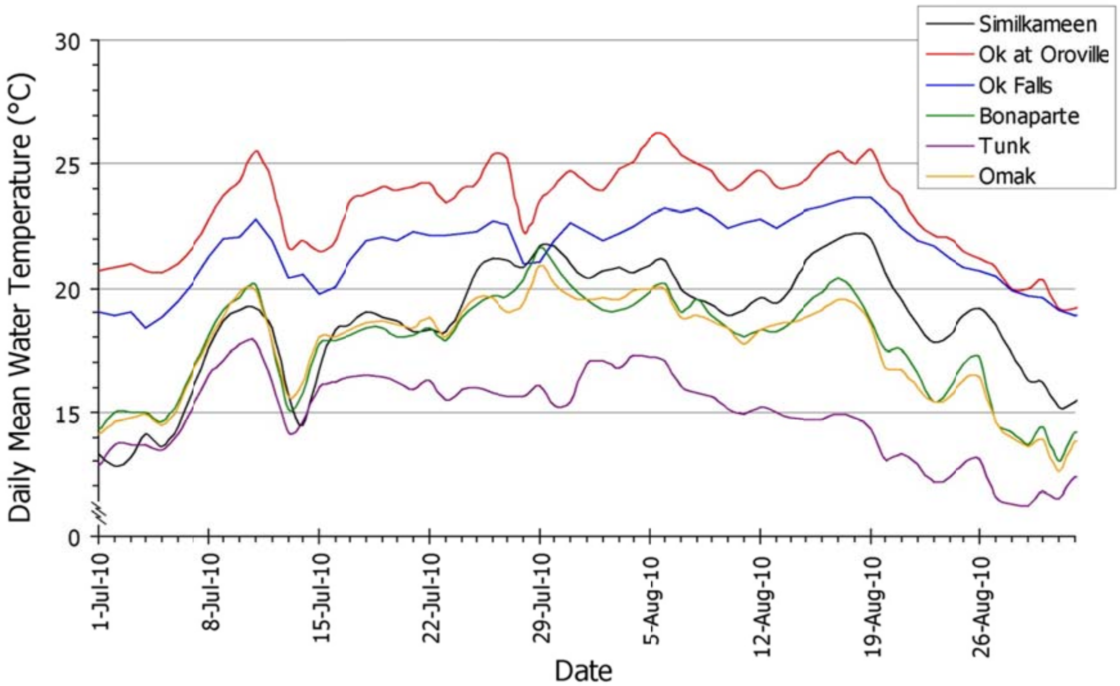
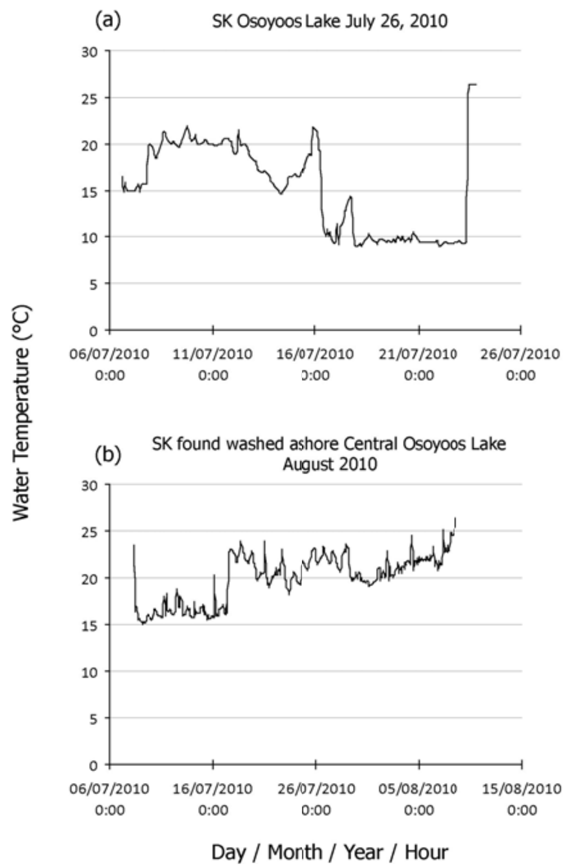


Figure 14. Water temperature profiles of selected rivers and streams of the Okanagan Basin.

The first adult sockeye was tagged and released at Wells Dam on July 6th and remained in Wells Pool for less than 2 days (Figure 15(a), temp. near 15°C). It entered the Okanagan River July 8th-9th and moved upstream over the next 4 days (Figure 15(a), temp between 19-22°C as per Ok-at-Oroville, Figure 14) to reach the Similkameen River on July 14th (temp near 15°C, Figures. 15(a), 14) where it halted for several hours before moving swiftly through Zosel Dam (temp near 22°C) and into the deeper and cooler waters (temp near 10°C, Figure 16) of the north basin of Osoyoos Lake on July 16th-17th. This sockeye was captured on July 24th (temp >26°C, Figure 15(a) by the Okanagan Nation Alliance fishery near the Okanagan River where it enters the north basin of Osoyoos Lake. The second adult sockeye was tagged and released at Wells Dam on July 9th and remained in Wells Pool for about 9 days (Figure 15(b), mean temp near 17°C). It entered the Okanagan River on July 18th encountering predominantly 20-24°C water prior to reaching the Similkameen-Okanagan confluence on July 23rd (Figure 15b), temp at 18°C, Figure 14). Between July 25th and 29th this fish resumed upstream migration past Zosel Dam (temp 22-23°C), through the south and central basins of Osoyoos Lake, but then expired around August 7th (temp

reaches 25°C, Figure 15(b)) before reaching the cooler, deeper waters of Osoyoos' north basin, and was recovered as a mortality in the area of Haynes Point on August 8th.



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Acoustic-tag Observations from Osoyoos Lake

An array of several receivers recorded approximately 36,000 signal detections of holding depth from 20 adult sockeye in the north basin of Osoyoos Lake over an average interval of 63 days (range 7-120) during mid-June to mid-October of 2010. Temperatures available to fish during this period ranged from a low of less than 8°C at the lake bottom (around 52 m) in June to maxima in excess of 20°C at the lake surface from mid-July to late-August (Figure 16). The average temperature across all instantaneous depths recorded as occupied by adult sockeye while holding in the north basin was 11.8°C (Figure 17(a), range

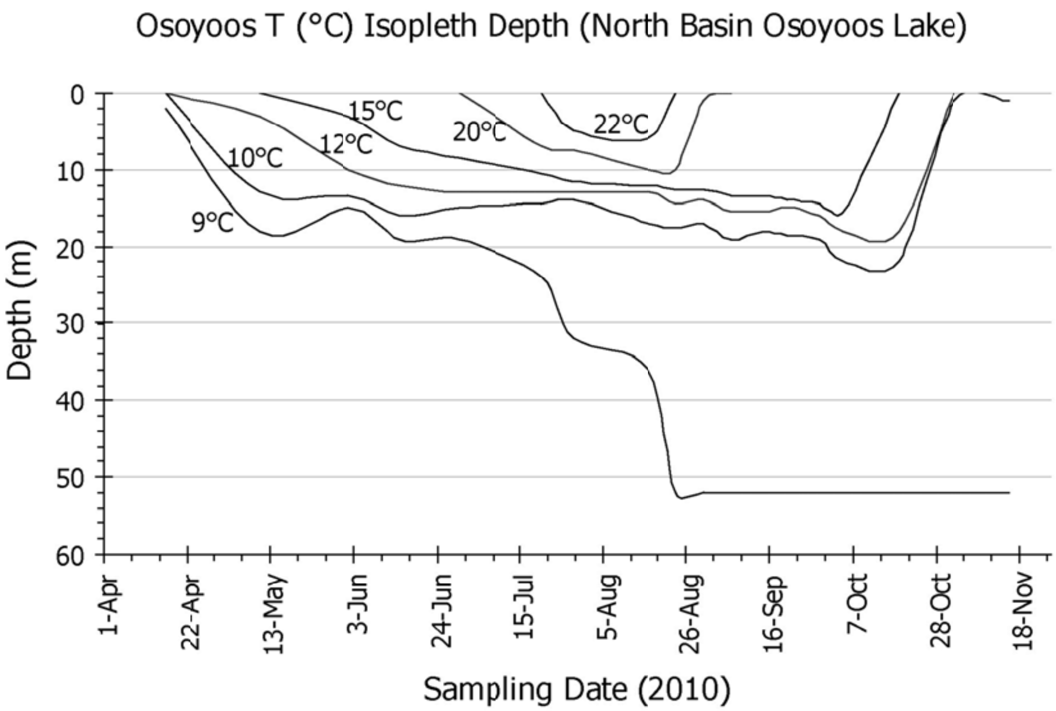

Figure 16. Water temperature and depth measured in the North Basin of Osoyoos Lake at the same time period as i-button tagged sockeye were present.

9.2-22). Sockeye tag #39046 (signal detections over 31 days) exhibited the most stenothermal pattern of depth-temperature selection (Figure 17(b)) while sockeye tag #39048 (signal detections over 42 days) exhibited the most eurythermal pattern of depth-temperature selection (Figure 17(c)). Although water >14^{o}C was available throughout the interval when adult sockeye were holding in Osoyoos Lake (Figure 16), they generally avoided such depth-temperature combinations (<7% of all observations). By contrast, the apparent truncation of depth-temperature combinations at <10^{o}C may be an artifact due to the very small volume of water exhibiting temperatures less than 10^{o}C during mid-June to late-September. Accordingly, it is possible that adult sockeye would have chosen even lower depth-temperature combinations if these had been more readily available in Osoyoos Lake (but see below).

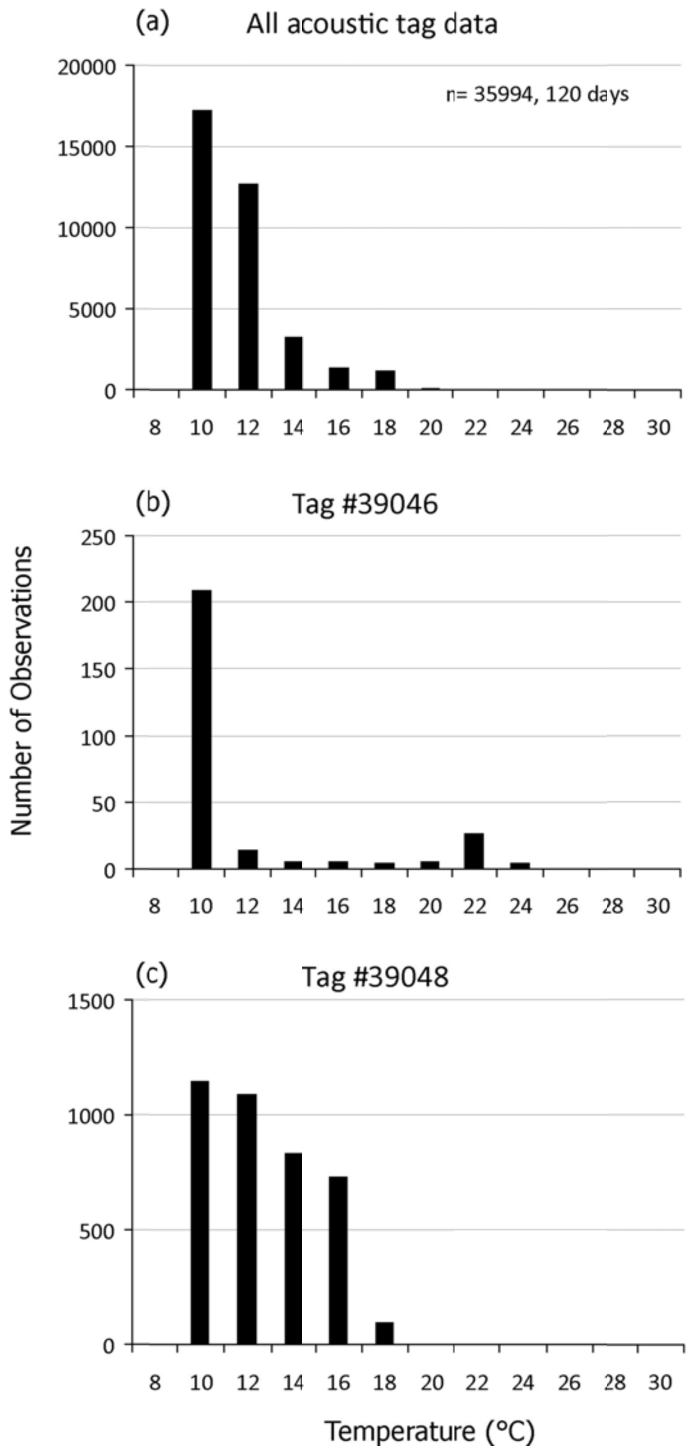

Figure 17. Depth/temperature patterns of tagged sockeye salmon in north basin of Osoyoos Lake; (a) all tags and two individual sockeye salmon (b) and (c).

Hydroacoustics Observations from Osoyoos Lake

Hydroacoustics surveys have been completed on several dates in Osoyoos and Skaha lakes each year since 2001 as part of a multiyear program

to assess seasonal changes in the distribution, abundance and biological traits of wild (Osoyoos Lake) and hatchery-origin (Skaha Lake) sockeye salmon, present as either rearing juveniles or pre-spawning adults (McQueen et al. 2010). A detail of survey gear, dates, transects and procedures for processing acoustics records and biological samples are provided by McQueen et al. (2010). However, here we provide results from a Sept. 6th, 2010 survey on the depth-temperature distributions of adult sockeye on 10 Osoyoos Lake transects surveyed with a dual-beam, Biosonics DT-X, echosounder. Post-survey processing of acoustics observations employed Sonar5-Pro software to determine the percentage of fish in length categories (generally >300 mm) corresponding to adult sockeye. Earlier surveys, executed at times when adult sockeye were not present in Osoyoos Lake, confirmed that adult sockeye would represent the vast majority of all large targets (adult sockeye like targets or ASLT's) observed on survey transects during the late summer to fall interval in Osoyoos Lake. In addition, gillnetting activities at times when adult sockeye were present in the late summer of 2010 confirmed that pre-spawning adult sockeye represented the majority of large fish present in Osoyoos Lake (H. Wright, ONA, pers. comm.)

On the night of Sept. 6th, 396 acoustics targets large enough to represent adult sockeye were detected throughout Osoyoos Lake. The highest concentration of ASLT's occurred at a depth of approximately 18m just below the thermocline (Figure 18). Temperatures available to fish at this time ranged from a low of less than 9^{o}C, at depths >30 m, to >18^{o}C at the lake surface. The average temperature across all instantaneous depths recorded as occupied by ASLT's on transects in the north basin was 10.2^{o}C (Figure 17, range 9.3-18.3) and more than 85% of all ASLT's occupied depth intervals exhibiting temperatures of 10-11^{o}C. Although water >15^{o}C and <10^{o}C was available throughout Osoyoos Lake at depths >12m and >20m respectively (Figure 18), adult sockeye generally avoided such depth-temperature combinations (<12% of all observations).

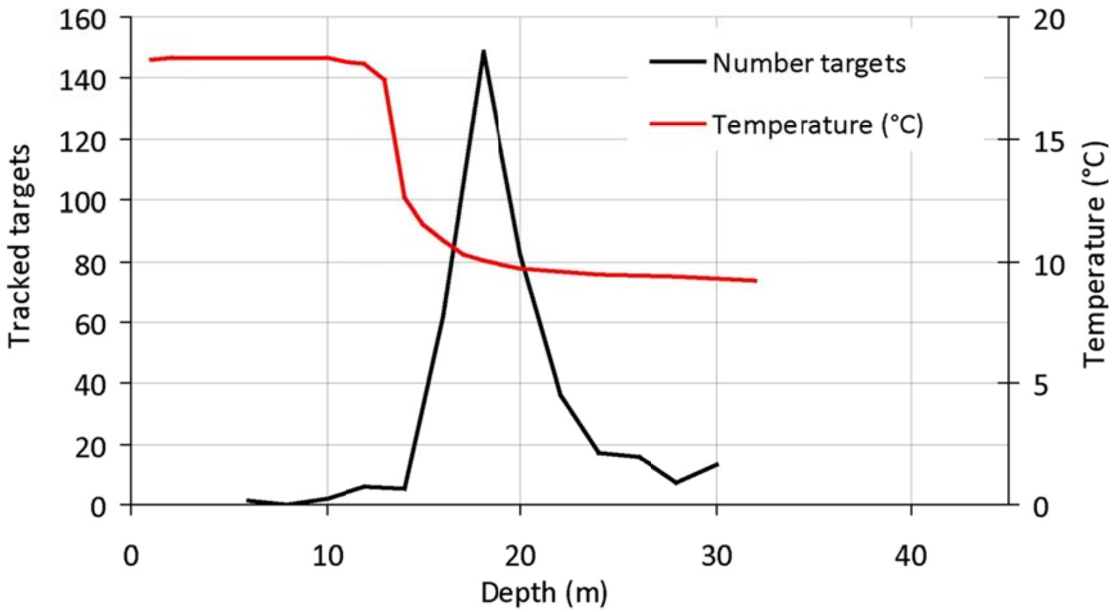

Figure 18. Acoustic targets tracked with an echosounder and believed to be sockeye graphed against the water temperature in which they were found.

Observations from the Okanagan River Spawning Grounds

Adult sockeye began to arrive on their spawning grounds in the Okanagan River near Oliver around the middle of September in 2010 (Figure 19) when river temperatures had declined to less than 18°C from earlier maxima in excess of 23°C. Adult sockeye numbers continued to rise as temperatures declined from mid-September to mid-October with peak recruitment and spawning activity occurring during the Oct. 16th spawning ground survey coincident with river temperatures of 12°C. Active spawning was virtually complete by the time river temperatures had declined to less than 10°C.

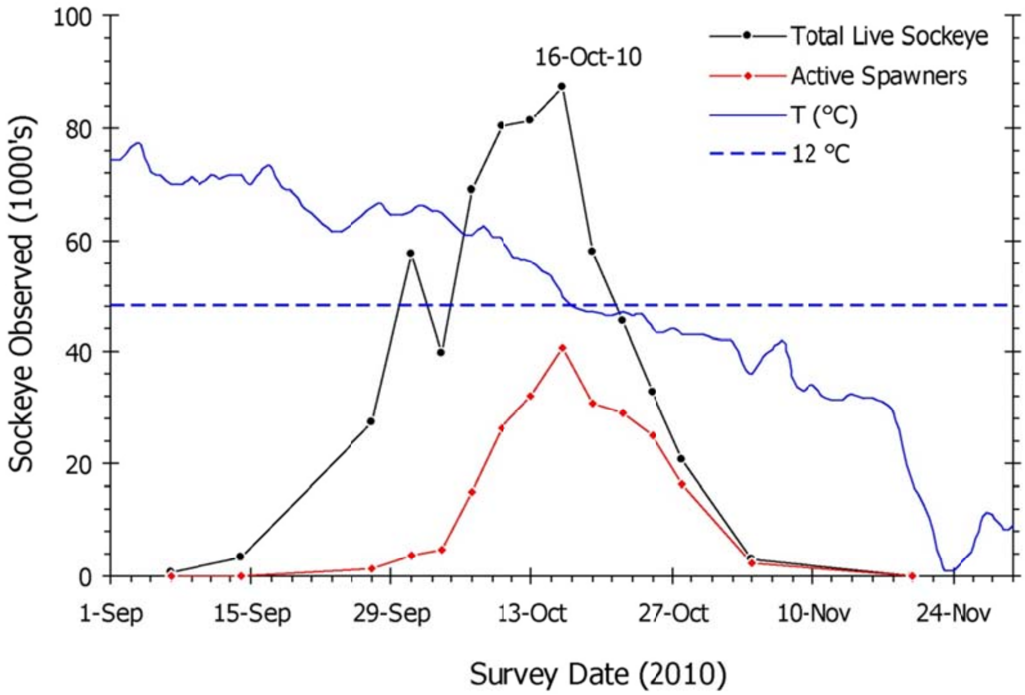

Figure 19. Spawning sockeye activity compared to water temperatures on the spawning grounds in the Okanagan River near Oliver.

DISCUSSION

This study adds to results of previous studies using PIT tags to assess adult sockeye salmon migration, timing, escapement, Wenatchee and Okanagan stock age and length-at-age composition, and mortality rates, and the weekly and total stock composition at Bonneville Dam. In addition, we installed PIT tag detection at Zosel Dam fish ladders to supplement the in-stream PIT tag array installed last year in the Okanagan River upstream of Osoyoos Lake. We also implemented an acoustic tagging and monitoring program for Okanagan sockeye salmon.

Wenatchee-Okanagan stock composition estimates produced by this study (17.3% Wenatchee and 81.8% Okanagan) differed from those using Tumwater and Rocky Reach dam counts (12.5% Wenatchee and 86.6% Okanagan, Table 9). A possible explanation for this difference is that we may not be getting a representative sample at the Bonneville Dam Adult Fish Facility. Data from Wenatchee sockeye salmon PIT tagged as juveniles estimates that 50.3% of these fish were detected in Washington shore fish ladders. However, visual counts at that station estimate that 55.0% of all sockeye actually passed that station. This suggests that Wenatchee stock sockeye salmon disproportionately used the Oregon shore ladder where they would not be subject to tagging. If Wenatchee stock fish are underrepresented in our sample, we'd expect to under, rather than overestimate this stock's abundance.

Six sockeye salmon PIT tagged by this project were detected at both Rocky Reach and Tumwater dams. Four of these fish passed Rocky Reach (one also passing Wells Dam) Dam before proceeding to Tumwater, while two were detected at, but likely did not pass, Tumwater Dam before proceeding upstream of Rocky Reach Dam. One of these fish (3D9.1C2D3CAE16) passed Rocky Reach Dam on July 1, arrived at Tumwater Dam on July 16 and until August 7 was detected 166 separate times at that site before being last detected at Rocky Reach Dam on August 7.

As in both 2008 and 2009, there was not a significant linear relationship between run timing at Bonneville Dam and stock composition. In both 2006 and 2007, as well as in several years of past sockeye stock identification studies (e.g. Fryer 1995, 2006) using scale pattern analysis, there was a significant relationship between run timing and stock composition. These results suggested

a higher percentage of the Wenatchee stock migrated in the early portion of the run and a higher percentage of the Okanagan stock migrated in the latter portion of the run.

PIT tagged sockeye salmon passed Rock Island and McNary dams undetected at much higher rates than at other dams with 6.4% and 3.8% of passing sockeye undetected respectively, compared to less than 1% at other dams. Rock Island has only two antennas per ladder and is known for having lower rates of detection than other mainstem dams due to electrical interference (Dave Marvin, PTAGIS, personal communication). However, McNary has many more antennas and is not noted for any detection problems. The high rate of missed fish at this dam is likely due to sockeye salmon passing the dam undetected via the navigation locks. In 2010, as in both 2008 and 2009, there was also a large disparity in visual dam counts, with McNary Dam estimating over 21% less passage than either Priest Rapids or Rock Island dams (both of which are located upstream of McNary Dam). These results also suggest significant bypass of fish through navigation locks at these dams. However, the dam count disparity is far greater than the percentage of missed PIT tagged fish.

Unlike in 2009 when four PIT tags from sockeye salmon tagged by this project were recovered at the Badger Island Pelican Colony in the McNary Pool, no tags were recovered from bird colonies in 2010.

Beginning in 2008, this study has been documenting delays in passage at Tumwater Dam that is likely attributable to 24 hour operation of the trap at that facility. Fish have been observed “stacking up” in the fish ladder below the trap (Keely Murdoch, Yakama Nation, personal communication), and it is evident that it caused significant delays. In 2008, this study found that sockeye salmon had a median delay of 4.6 days but this declined to 159 minutes in 2009. This study has also found evidence that fish are not passing Tumwater Dam. In 2008, we speculated (Fryer 2009) that “it is possible that some sockeye salmon were not passing the Tumwater Dam due to the passage delays – 7.6% of those sockeye salmon detected at Tumwater Dam were last detected at the lower detection site suggesting that these fish turned around and went downstream and were not detected again”.

In-stream detection arrays at sites upstream of Tumwater installed in 2009 allowed testing of the hypothesis that many fish did not pass Tumwater Dam

(Table 12 and Figure 7). In 2010, of the 111 sockeye detected at Tumwater Dam, 74 (66.7%) were last detected at the upstream antenna (A1) and 33.3% were last detected at the downstream antenna (A2). Of those fish last detected at the A1, 33 (44.6%) were subsequently detected upstream. Of those last detected at the A2, none were detected upstream and two were detected at Rocky Reach Dam. Furthermore, the median delay for those detected last detected A1 was 6.0 days for those detected upstream which is similar to the median delay 6.5 days for those not subsequently detected. For those sockeye last detected at A2, the median delay was 17.4 days for those last detected downstream which was similar to the median delay of 19.8 days for those not subsequently detected. The similarly in delays suggests that sockeye last detected at the upstream antenna likely make it upstream, while those last detected at the lower antenna likely do not. If this is the case 33.3% of sockeye reaching Tumwater Dam are not passing the dam. This fits well with data presented in Table 4 where the PIT tag estimated escapement to Tumwater Dam was 51,480 fish. If 33.3% of these did not pass the dam, then the estimated number of sockeye salmon passing through the trap based on PIT tags was 34,320 which is very similar to the 35,821 estimated by visual counts at the trap.

We conducted a similar analysis for the 2009 migration (Fryer et al. 2010) and estimated that 22.4% of sockeye reaching Tumwater Dam did not pass upstream.

Our tagging at both Wells and Bonneville dams, in addition to acoustic and temperature tagging at Wells Dam, combined with PIT and acoustic detection at OKC offered the opportunity to assess the affect of different tagging regimes on sockeye salmon (Table 22). Sockeye PIT (and floy) tagged at Wells Dam had a 2.1 percentage point (or 2.8%) lower detection rate to OKC when compared to sockeye passing Wells Dam that had been PIT tagged at Bonneville Dam, suggesting that this may be a measure of the effect of sampling and tagging at Wells Dam. When compared to sockeye solely PIT (plus floy) tagged at Wells Dam, sockeye with PIT and acoustic tags were 25.8% less likely to be detected at OKC, sockeye with PIT and temperature tags were 25.3% less likely to be detected at OKC, and sockeye with PIT, temperature, and acoustic tags were 14% less likely to be detected at OKC (Table 22).

Table 22. Percent of sockeye salmon passing Wells Dam detected by the OKC PIT tag array in 2010. (Note all sockeye tagged at Wells Dam were also floy tagged.)

Statistical Week at Wells Dam	Wells Temp + PIT tagged	Wells Temp + Acoustic + PIT tagged	Wells Acoustic +PIT tagged, no temp tag	Wells Acoustic +PIT tagged	Wells PIT tagged only	All Wells PIT Tagged	Bonneville tagged
27	--	--	93.3%	93.3%	90.0%	91.1%	86.1%
28	73.3%	85.7%	62.5%	73.3%	89.0%	86.0%	85.7%
29	33.3%	50.0%	41.7%	43.8%	66.3%	60.8%	79.7%
30	42.9%	33.3%	44.4%	41.7%	40.6%	41.8%	35.4%
31	45.5%	0.0%	60.0%	50.0%	55.6%	52.0%	62.2%
Weighted	**55.1%**	**63.4%**	**54.7%**	**59.4%**	**73.7%**	**70.7%**	**75.8%**
Total Tagged	**37**	**15**	**47**	**62**	**301**	**400**	**413**

2010 was the first year this project conducted an acoustic trawl survey for juvenile abundance in Lake Wenatchee. It was a surprise, given recent large escapements to Osoyoos Lake, that the juvenile abundance in Lake Wenatchee was greater than that in Osoyoos Lake. Osoyoos egg-to-fry survival was estimated to be 1%, versus the 4% expected. We speculate that this low survival may be the result of the failure of an earthenworks irrigation dam in spring 2010 that resulted in a torrent of debris and mud entering the Okanagan River and the North Basin of Lake Osoyoos immediately after juvenile recruitment to the area and/or an in-lake fish kill due to an outbreak of *Columnaris*.

In 2011, we will continue to deploy PIT tags at Bonneville and Wells dam with detection at Zosel and OKC operational throughout the migration. We also will deploy a similar acoustic network in the Okanagan Basin.

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APPENDIX A

Table A 1. Probability of detection at PIT tag detectors by weir at mainstem Columbia Basin fish ladders, and the overall probability of detection, for sockeye salmon in 2010.

Dam, Site, Tag Type, and Number		Weir and Probability of Detection at Weir				Overall Detection Probability
Bonneville	**N**	**1**	**2**	**3**	**4**	
BO4-12.5	744	99.2	98.9	98.9	99.3	100.0
BO1-12.5	108	99.1	98.1	99.1	97.2	100.0
McNary	**N**	**1**	**2**	**3**		
MC1-12.5	187	99.5	99.5	NA		100.0
MC2-12.5	490	99.6	99.6	98.8		100.0
Priest Rapids	**N**	**3**	**7**			
East-12.5	592	98.8	99.5			100.0
	N	**3**	**5**			
West-12.5	85	95.3	100.0			100.0
Rock Island	**N**	**1-2**	**3-4**			
Left-12.5	149	100.0	100.0			100.0
	N	**5-6**	**7-8**			
Middle-12.5	89	77.0	100.0			100.0
	N	**09-0A**	**0B-0C**			
Right-12.5	379	97.3	75.6			99.3
Rocky Reach	**N**	**1-2**	**3-4**			
12.5	557	97.7	95.7			99.9
Wells	**N**	**1-2**	**3-4**			
Left-12.5	357	99.8	100			100.0
	N	**5-6**	**7-8**			
Right-12.5	197	100	100.0			100.0
Tumwater	**N**					
12.5	108	100.0	99.1			100.0

Right or left is determined by looking downstream at the dams, thus the right bank at Wells would be the west bank.

Table A 2. Harvest by fishery for Columbia Basin sockeye salmon in 2010.

Location	Fishery Type	Source		Totals
Zone 1-5	Commercial	TAC	0	
	Sport	TAC	319	
	Non-retention mortality in shad fisheries	TAC	3	
	Below Bonneville Dam treaty	TAC	1282	
				1145
Zone 6	Commercial, Ceremonial and Subsistence	TAC	24,843	
	Sport	TAC	21	
				24,864
Lake Wenatchee	Sport (2285 harvested, 57 released)	WDFW		4,129
Priest Rapids to Chief Joseph Dam	Sport	WDFW		10,662
Okanagan River	Colville Tribe Tangle Net	CTCIR		289
Okanagan River	Colville Tribe Purse Seine			16214
Chief Joseph Dam Tailrace	Colville Snag Fishery	CTCIR		27
Upstream of Lake Osoyoos	Okanagan tribal	ONA		18,069
Lake Osoyoos	Recreational	ONA		243

Table A 3. Distribution of sockeye salmon by fish ladder for dams with multiple fish ladders as estimated by PIT tag detections in 2010.

Dam	Right Bank	Left Bank	Center
Bonneville	87.3%	12.7%	
McNary	72.8%	27.2%	
Priest Rapids	87.4%	12.6%	
Rock Island	57.8%	28.5%	13.8%
Wells	35.6%	64.4%	

Right or left is determined by looking downstream at the dams, thus the right bank at Wells would be the west bank, at McNary it would be the Washington shore.

APPENDIX B

Salmon in Regional Ecoregions Program Report

by

D. Paul Rankin, R. Ferguson and K. D. Hyatt

titled

Wenatchee Lake, WA: Juvenile Nerkid Abundance
and Lake Survey Status Report.

Wenatchee Lake, WA: Juvenile Nerkid Abundance and Lake Survey Status Report.

D. Paul Rankin, R. Ferguson and K. D. Hyatt

Fisheries and Oceans Canada
Salmon in Regional Ecosystems Program
Salmon and Regional Ecosystems Section
Science Branch
Pacific Biological Station
Nanaimo, B.C.
V9T 6N7

Juvenile Salmon Index Data System Reports (JSIDS SRe.'s) facilitate timely exchange of information and results on assessments of juvenile salmon abundance, their biological traits and associated habitat variables, in response to requests from a variety of "clients" both within and external to the Department of Fisheries and Oceans. Information contained in status reports is often preliminary in nature and contact with the authors is recommended to clarify any uncertainties associated with interpretation or use of status report contents.

Citable As:

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

Distribution (as of 25Jan2011)

1. Mr. Mark Saunders, Director, Salmon and Freshwater Ecosystems Division, Fisheries and Oceans Canada, Nanaimo B.C. V9T 6N7. Telephone: (250) 756-7145.
2. Dr. Arlene Tompkins, Head, Salmon Assessment Section, Salmon and Freshwater Ecosystems Division, Pacific Biological Station, Fisheries and Oceans Canada, Nanaimo, B.C., V9T 6N7, Telephone: (250) 729-8382.
3. Mr. Dennis Biech, Regional Director, Washington Department of Fish and Wildlife, 1550 Alder Street NW, Ephrata, WA, 98823-9699. Telephone: (509) 754-4624.

Wenatchee Lake, WA: Juvenile Nerkid Abundance and Lake Survey Status Report.

Report Origin(s) and/or Contact(s)

Mr. D.P. Rankin; Telephone: (250) 756-7195; E-mail: paul.rankin@dfo-mpo.gc.ca; Dr. K.D. Hyatt; Telephone: (250) 756-7217; E-mail: kim.hyatt@dfo-mpo.gc.ca; Fisheries and Oceans Canada, Salmon In Regional Ecosystems Program, Salmon Section, Stock Assessment Division, Pacific Biological Station, Nanaimo, B.C. V9T 6N7

Client Contact(s):

Dr. Jeff Fryer, Columbia River Inter-Tribal Fisheries Commission, 729 NE Oregon St., Portland, OR 97232. Telephone: (503) 731-1266; E-mail: fryj@critfc.org

Survey Type: [X] acoustics and trawl, [ ] spawning ground, [ ] other.

Survey Rationale:

1. Regional Salmon Stock Assessment activities
2. Asked by the regional director of the Washington Department of Fish and Wildlife, Mr. Dennis Beich, to survey Wenatchee Lake.
3. Only 2 significant stocks of sockeye salmon are left on the Columbia/Okanagan Rivers, Osoyoos Lake and Wenatchee Lake (Hyatt and Rankin, 1999). The Salmon In Regional Ecosystems (**SIRE**) Program has been monitoring the Osoyoos Lake sockeye stock for 12 years, and assisting the Okanagan Nation Alliance Fisheries Department in their attempts to extend the range of Okanagan sockeye into Skaha Lake. In order to better understand the production dynamics of the 2 stocks, basic data are required from Wenatchee Lake using standard assessment techniques employed by the Salmon in Regional Ecosystems program. This work is endorsed by the Okanagan Nation Alliance Fisheries Department and by the Columbia River Intertribal Fisheries Commission.

Survey Resources.

All direct costs associated with the surveys, survey instrumentation, sample analysis, data assembly, data analysis and reporting were covered through a collaborative agreement between the Okanagan Nation Alliance Fisheries Department and **SIRE**. **SIRE** supported surveys with approximately 9 days of time for survey support and analysis (P. Rankin, 4d; R. Ferguson, 4d; K. Hyatt, 1d).

Survey Subjects:

Abundance of juvenile nerkids, zooplankton and water quality parameter measurements in Wenatchee Lake (Figure 1).

Survey Dates:

21September2010

Survey Crew(s):

Rick Ferguson and Paul Rankin

Survey Status:

The September trip was executed without incident. The weather was good except for the full moon which probably reduced the trawl catch. Summary figures, forms and tables are attached: (i.) types of samples and records obtained during surveys (Table 1); (ii.) acoustic (Biosonics 200kHz DTX) and trawl based estimates of fish abundance (Tables 2&3). Figures attached in Appendix 1 includes figures (1.) survey location, (2) nerkid vertical distribution, (3) nerkid size distribution, (4) fall weight vs. average density in Osoyoos and Wenatchee, (5) Secchi disc depths (m) for Wenatchee, Osoyoos and Skaha lakes, (6) total Phosphorous levels from Wenatchee and other Northwest juvenile sockeye nursery lakes, (7) Nitrate levels, and (8) chlorophyll levels. (9) zooplankton size and abundance, and (10) zooplankton species composition.

Status of Samples:

Acoustic records, biological samples and survey observations will be incorporated (yes [X], no [ ]) into sample inventories or databases maintained by **SIRE** at **PBS** for future reference.

Status of Sample Analysis*:*

Acoustic records have been processed using Sonar5 Pro v 4.9.8 to provide population estimates reported in Table 2. Additional sample analysis will be completed (yes [X], no [ ]) in support of a report identified below. Sample types from which additional information **may** be extracted include juvenile sockeye size, zooplankton and water chemistry.

Status of Data Analysis and Reporting:

Additional data analysis and/or reporting will be completed (yes [**X**], no [ ] as time and annual work plan assignments permit. Such data will be managed as part of our multi-year, juvenile sockeye index data sets (**JSIDS**) for incorporation into future stock assessment and research publications on interactions between sockeye/kokanee stocks in coastal British Columbia lakes*.*

Preliminary Conclusions or Recommendations:

1. Our late summer estimates of limnetic fish abundance suggest average densities in Wenatchee and Osoyoos Lakes (1,600 and 1,200 fish/ha respectively). The survey coverage was sufficient to yield confidence intervals of 26 and 16% respectively. Trawl catches consisted entirely of juvenile nerkids, no other fish were caught in the limnetic zone.

2. The juvenile sockeye population is estimated at 1,637,000 (1,114,000 in Osoyoos). Most of the fish were distributed between 20 and 40 metres (Figure 2),
3. Juvenile sockeye caught in the trawl ranged from 42 to 76 millimeters in size. Average length was 58mm, average wet weight, 2.02g (Figure 3). Osoyoos juveniles caught at the beginning of October were 71mm and 3.9g.
4. Wenatchee juvenile sockeye sit well below the “density growth” trajectory represented by Osoyoos Lake (Figure 4). This is not surprising given the location of the lake (572 m, elevation) and the surrounding land use patterns when compared to those in the Okanagon valley around Osoyoos (278m, elevation).
5. Water transparency was slightly less than that observed in Osoyoos and Skaha lakes at the same time of year (Figure 5).
6. Total phosphorus levels were lower than those observed in Osoyoos and Skaha Lakes, which is to be expected given the different land-use patterns (Figure 6). Phosphorous was about double that observed in oligotrophic juvenile sockeye nursery lakes, Great Central (GCL) and Sproat, on Vancouver Island in British Columbia.
7. Nitrate nitrogen was very low in the epilimnion and relatively high in the hypolimnion (Figure 7). This pattern was equivalent to that in Great Central Lake which was fertilized in 2010. Hypolimnion nitrate levels in Sproat Lake, an unfertilized lake, were about ½ to ¼ those observed in Wenatchee.
8. Epilimnial chlorophyll levels reflect the distribution of phosphorus concentrations observed in the 5 lakes examined. Wenatchee has less chlorophyll than either Osoyoos or Skaha Lakes but more than observed at the same time in GCL or Sproat lakes (Figure 8).
9. Wenatchee zooplankton abundance was relatively low and numerically dominated by rotifers (Figure 9). As expected, mean size of all zooplankton was relatively small (~.2mm). Both Osoyoos and Skaha had much higher concentrations of copepods and cladocerans and which is reflected in larger mean sizes from 0.6mm to 0.7mm respectively.
10. The zooplankton community of Wenatchee was dominated by rotifers, copepod nauplii, Diaptomids, Daphnids and cyclopoids in order of decreasing abundance (Figure 10a). No Bosminids were observed in the samples. By contrast densities in Osoyoos and Skaha were generally an order of magnitude higher where cyclopoids, nauplii, Diaptomids, rotifers, Bosminids and Daphnids appeared in decreasing abundance.
11. Wenatchee Lake zooplankton biomass was dominated by Diaptomids and Daphnids (Figure 10b).

Completed By: Paul Rankin and Kim Hyatt **Date:** 12Apr2011

References

Hyatt, K.D. and D.P. Rankin. 1999. A habitat based evaluation of Okanagan sockeye salmon escapement objectives. Canadian Stock Assessment Secretariat Research Document 99/181.

Table 1: Wenatchee Lake summer 2010 survey dates and samples collected.

Date Surveyed	Water Sample	Temp Profile	Secchi Depth	Zoopl Sample	Stickle Trapping	Beach Seining	Acoustic	Fish Trawling
21Sep2010	X	X	X	X			X	X

Table 2: Wenatchee Lake juvenile "nerkid" and limnetic sticklebacks population estimates during the 2010 survey.

Date Surveyed	Juvenile "nerkid" Abundance	Limnetic Stickleback Abundance	Total Fish Density (#/hectare)	95% CI (%)	Mean length (mm)/fresh standard wt (g)	Comments #
21Sep2010	1,637,000		1,600	26%	58/2.02	**1**

1. No other fish were caught.

Table 3: Osoyoos Lake juvenile "nerkid" and limnetic sticklebacks population estimates during the 2010 survey.

Date Surveyed	Juvenile "nerkid" Abundance	Limnetic Stickleback Abundance	Total Fish Density (#/hectare)	95% CI (%)	Mean length (mm)/fresh standard wt (g)	Comments #
02Oct2010	1,114,000		1,200	16%	71/3.9	

Appendix 1

Figures

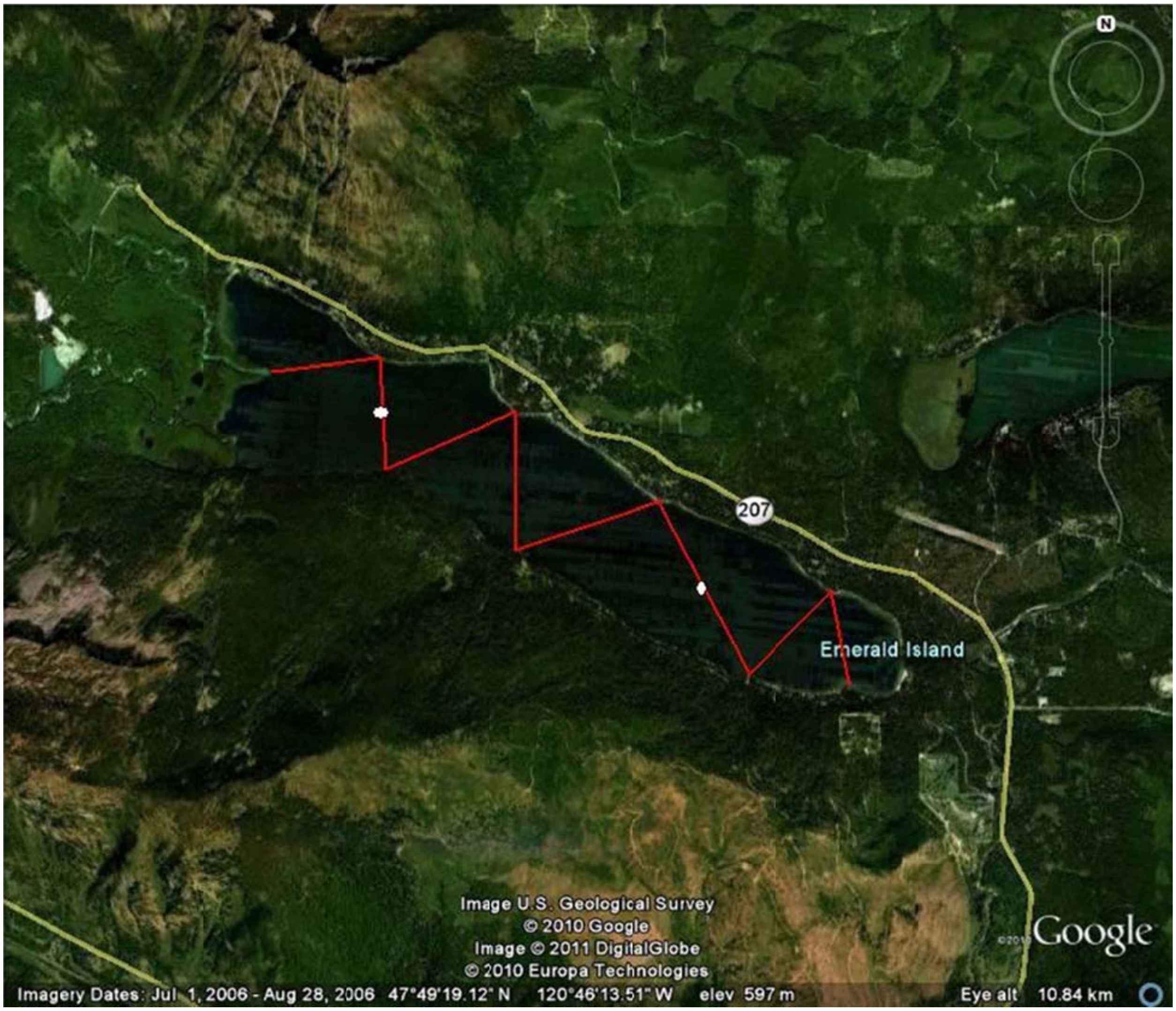

Figure 1. Google Earth map of Wenatchee Lake showing acoustic transects (red) and water/zooplankton sampling stations (white circles)

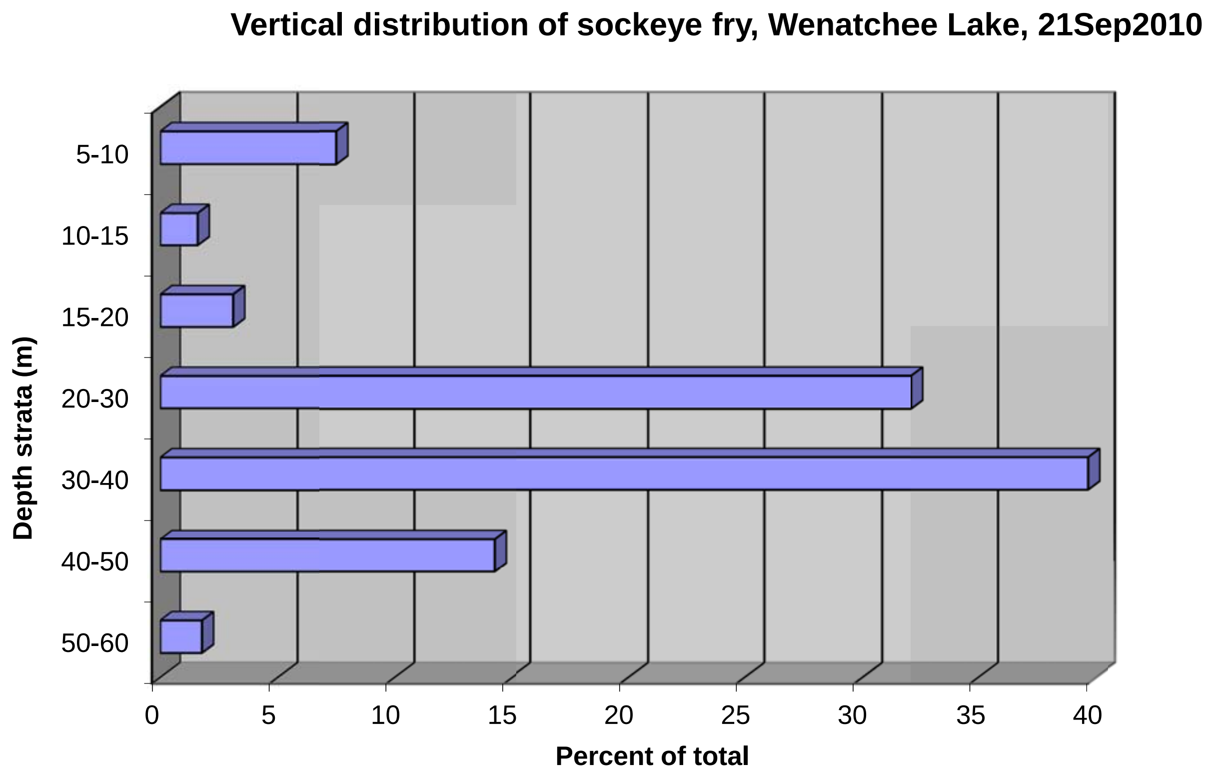

Figure 2. Vertical distribution of acoustic targets in Wenatchee Lake, 21Sep2010.

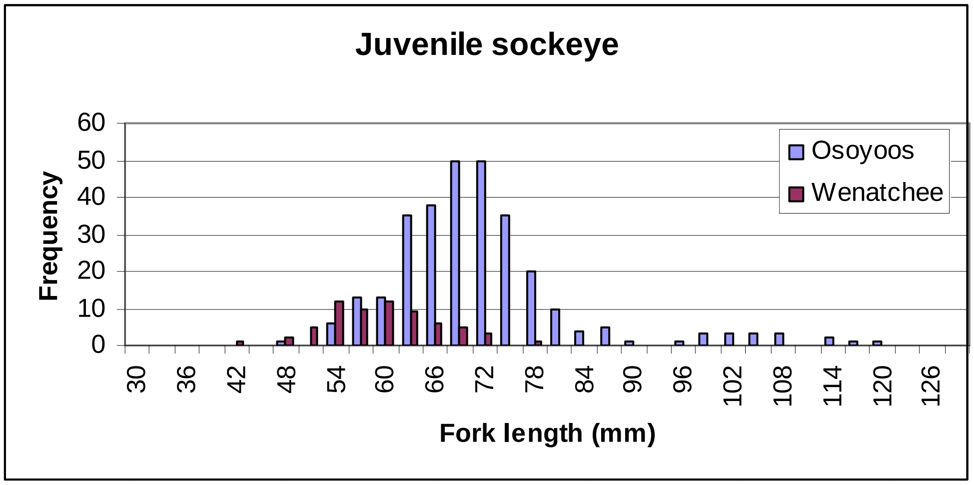

Figure 3. Length frequency distribution of trawl-caught juvenile sockeye in Osoyoos Lake (02Oct2010) and Wenatchee Lake, 21Sep2010.

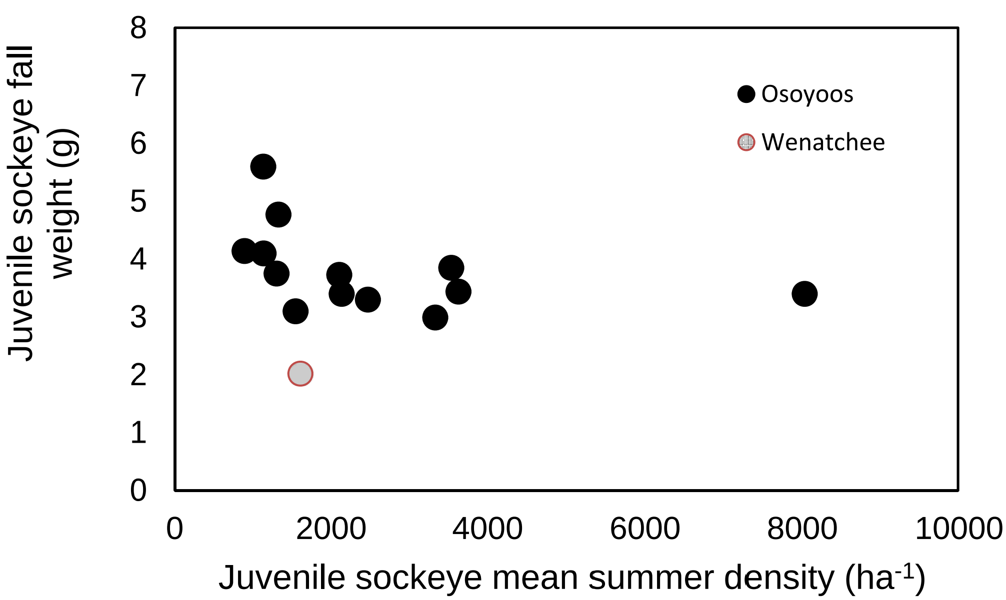

Figure 4. Juvenile sockeye fall weights from Osoyoos and Wenatchee.

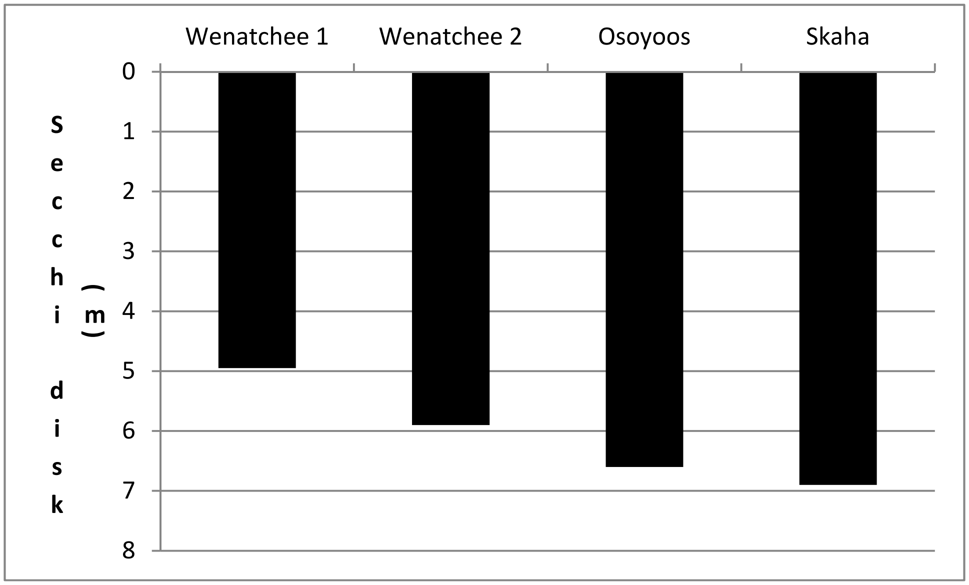

Figure 5. Water transparency (Secchi disk in metres) from Wenatchee (21Sep2010), Osoyoos (27Sep2006) and Skaha (27Sep2006) Lakes.

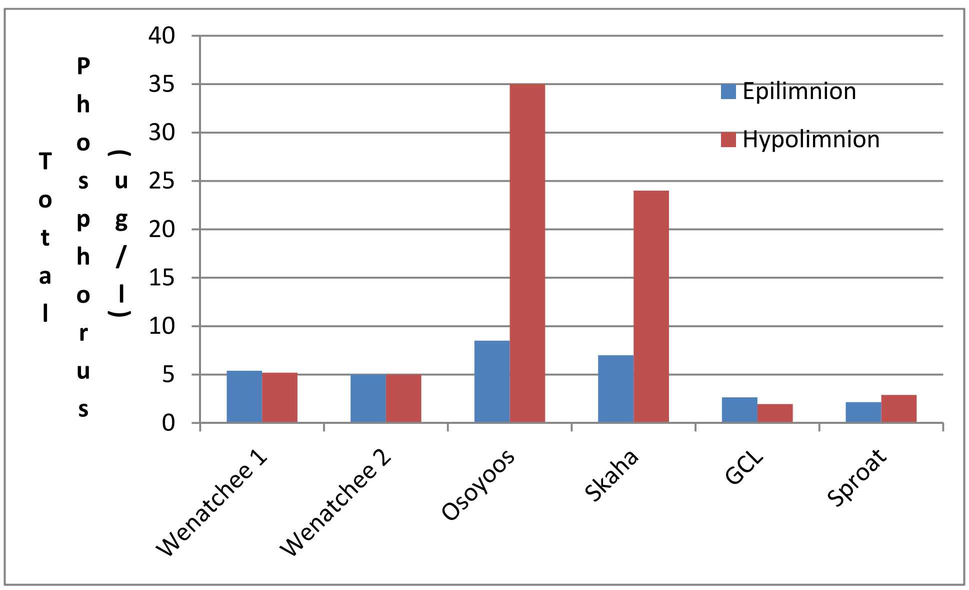

Figure 6. Total Phosphorus (ug/l) in Wenatchee and other Pacific northwest juvenile sockeye lakes

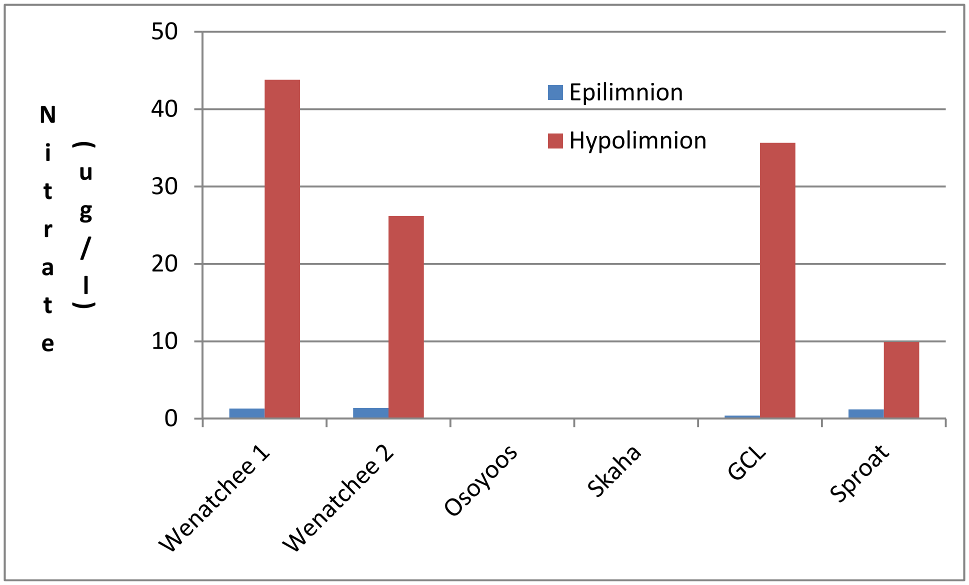

Figure 7. Nitrate (ug/l) in Wenatchee and other Pacific northwest juvenile sockeye lakes

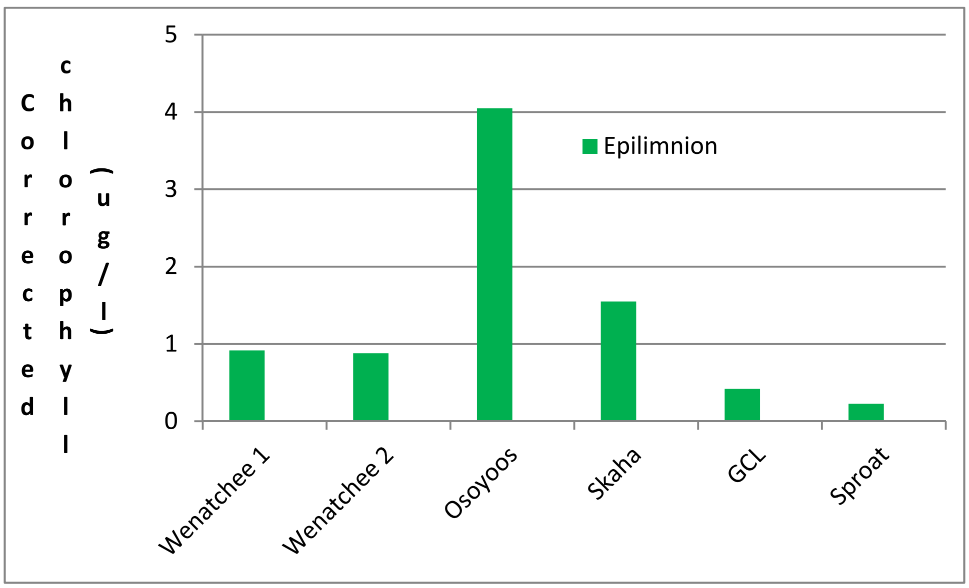

Figure 8. Corrected chlorophyll (ug/l) in Wenatchee and other Pacific northwest juvenile sockeye lakes

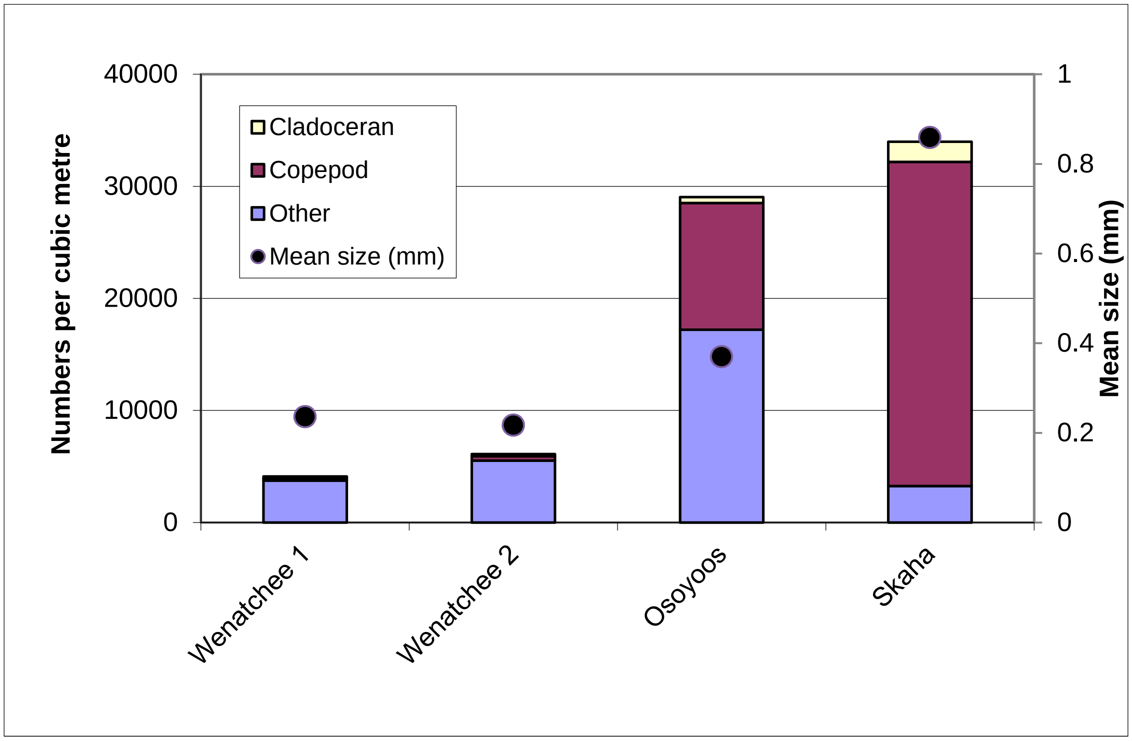

Figure 9. Zooplankton density (#/m^3) by "prey" group. "Other" generally refers to nauplii and rotifers.

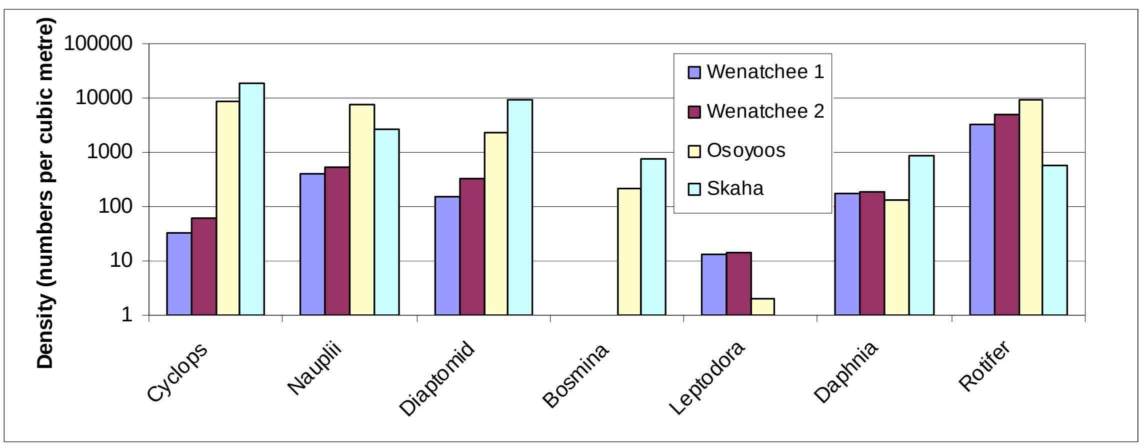

Figure 10a. Lake specific zooplankton densities, late September, 2010. Note the log scale.

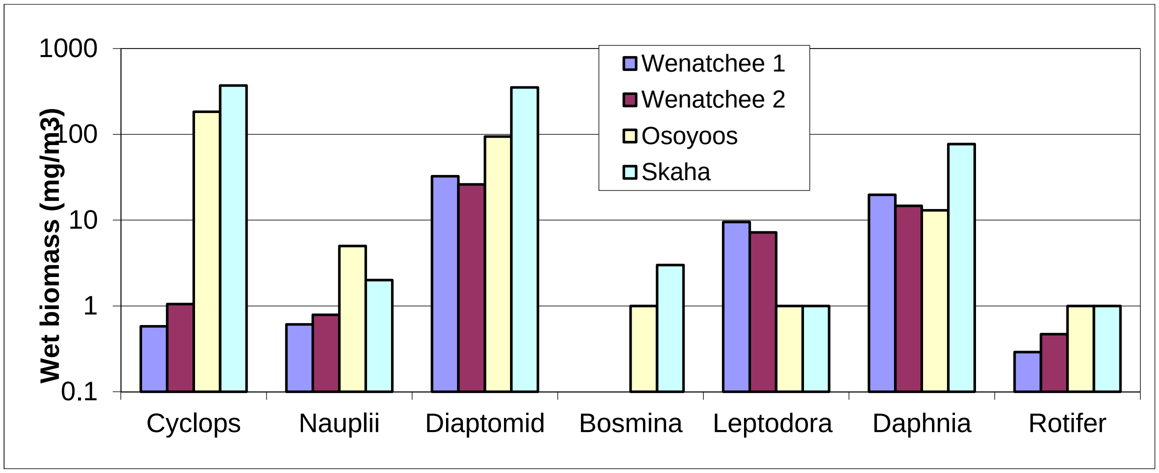

Figure 10b. Wenatchee Lake species specific zooplankton biomass, late September, 2010. Note the log scale.