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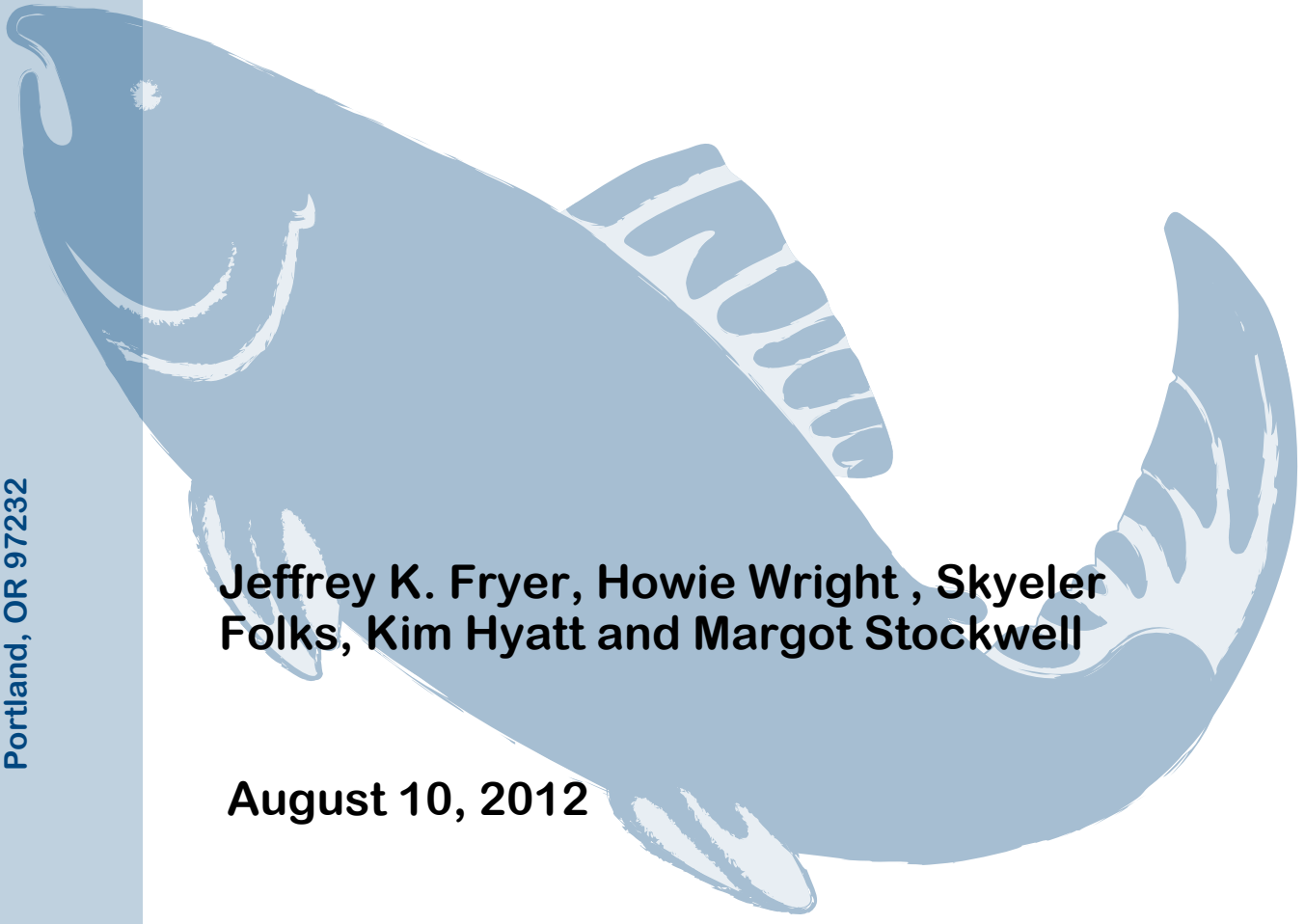
TECHNICAL REPORT 12-08

Limiting Factors of the Abundance of Okanagan and Wenatchee Sockeye Salmon in 2011



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

August 10, 2012

Limiting Factors of the Abundance of Okanagan and Wenatchee Sockeye Salmon in 2011

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

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ABSTRACT

A total of 763 sockeye salmon, *Oncorhynchus nerka*, were PIT tagged at the Bonneville Dam Adult Fish Facility in 2011. These fish, in addition to three previously PIT tagged sockeye salmon we sampled at Bonneville Dam, 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. The estimated stock composition of sockeye salmon passing Bonneville Dam was 76.8% Okanagan 21.9% Wenatchee, and 1.3% Snake.

The median travel time of sockeye salmon between Bonneville and Rock Island dams was 14.2 days, resulting in a median travel rate of 34.4 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 installed and maintained by this project at Zosel Dam (ZSL) and the Okanagan Channel (OKC) were operational for the entire year with the exception of some outages at OKC during periods minimal fish passage would be expected. Between April 1, 2011 and March 31, 2012, at Zosel Dam, 23 Chinook, 34 steelhead, and 15 sockeye were detected, while at OKC 5 Chinook, 6 steelhead, and 726 sockeye were detected. Most sockeye salmon as well as some Chinook salmon passed Zosel Dam during periods of high flow when it was possible to pass upstream through the spillways, bypassing PIT tag detection in the fish ladders. at Zosel Dam fish ladders.

At Wells Dam, 600 PIT tags, 60 acoustic tags, and 200 temperature tags were deployed on 600 sockeye salmon. The detection rate at the Okanagan Channel PIT tag detection array (OKC) for fish only PIT tagged at Wells Dam was 72.3% compared to 76.0% for sockeye passing Wells Dam that we PIT tagged at Bonneville Dam. Sockeye with both PIT and acoustic tags were 3.0% less likely to be detected at OKC than those only PIT tagged, while sockeye with both PIT and temperature tags were 8.9% less likely to be detected at OKC. The OKC PIT tag array detected 92.5% of sockeye with both an acoustic and PIT tag.

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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 to record highs. In 2011, 185,796 sockeye salmon were counted at Bonneville Dam and the most recent four year mean escapement (2008-2011) was a record 240,900 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.

Okanagan sockeye salmon spawn in the Canadian portion of the Okanagan River and then rear in Osoyoos Lake, through which runs the border between the United States and Canada. 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 (Okanogan).

The fact that there are only two significant Columbia Basin sockeye salmon stocks passing through multiple Columbia River dams with PIT tag detection makes the species ideal for a PIT tag study. Determination of migration timing and mortality for other salmon and steelhead species is difficult, since many tributaries are without detection facilities 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 2010 (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 was available in the Okanagan Basin; therefore in 2009 this project funded installation of a PIT tag antenna on the Okanagan River upstream of Osoyoos Lake (known at www.ptagis.org as OKC) and in 2010 funded installation of antennas at both Zosel Dam fishways (ZSL). In 2011, this project funded maintenance of these antennas. To further investigate the mortality rate of Okanagan sockeye in the Okanagan Basin, since 2009 this project has funded an acoustic network in the Okanagan basin and acoustic tagged sockeye salmon at Wells Dam.

Since 2010 this project has funded a hydroacoustic survey of Lake Wenatchee to initiate standardized sockeye salmon smolt abundance estimation for the Wenatchee stock for comparison with similar estimates already available for Okanagan sockeye in Lake Osoyoos. This estimate will be used to estimate juvenile survival and compared to Wenatchee River smolt trap smolt estimates.

METHODS

Adult PIT and acoustic tag detection infrastructure

Okanagan River (Canada) PIT tag detection

The year 2011 marked the first year in which the two Okanagan River PIT tag detection sites funded by this project were operational for the entire year. The first site (OKC), installed in November 2009 (Fryer et al. 2010), is a channel width array at river km 147 just downstream of Vertical Diversion Structure 3 near Oliver, BC. The second (ZSL), installed in September 2010, consists of two antennas in each of the two fish ladders at Zosel Dam in Oroville, WA. These systems were designed to detect PIT-tagged adult sockeye salmon as they ascend the Okanagan River

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 21 Vemco VR2W receivers ranging from Pateros just upstream of Wells Dam to Okanagan Falls, in Canada at the upper end of the portion of the basin accessible to sockeye salmon. When it became apparent that sockeye were passing the Okanagan Falls Dam at the outlet to Skaha Lake, an additional receiver was deployed at the Penticton Channel between Skaha Lake and Okanagan Lake. The 9 receivers in the U.S. portion of the basin were deployed and maintained by Confederated Tribes of the Colville Reservation staff, while the 13 receivers in the Canadian portion of the basin were deployed and maintained by Okanagan Nation Alliance staff. Data from these receivers were used to estimate mortality and passage time upstream of Wells Dam.

Adult sampling at Bonneville, Wells, and Tumwater 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 0800 and 1300 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). In 2011, we tested newly available 9 mm TX149011B tag by using this tag on one in every five fish, with the remainder tagged with standard 12.5mm TX1400SST tags. 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; Zosel Dam on the Okanagan River, and Tumwater Dam on the Wenatchee River (array configurations are available at www.ptagis.org) as well as several in-stream detection arrays. PIT tag detection data from these arrays are automatically uploaded several times daily to the PTAGIS database where they are immediately accessible to users of the site. If a tag was not detected after the fish was released, we removed it from further analysis.

Tumwater and Wells dam sampling

Sockeye were trapped at the Wells East Bank, Wells West Bank, and Tumwater Dam ladder fish traps. At all three traps, fish were netted out of the trap and placed in a small anesthetic tank. As 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 scales removed and placed on scale cards for later age analysis. All data were recorded onto datasheets. All sockeye salmon sampled at Wells Dam were tagged with PIT tags (if not already present) and Floy tags while sockeye sampled at Tumwater Dam were Floy-

tagged only.

Vemco© acoustic tags with a projected battery life of 132 days were surgically implanted into the body cavities of 60 sockeye salmon. Thirty of these tags were model V9 2H (29 x 9 mm, weight 4.7 grams), while the remaining 30 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 with a solution of Chlorhexidine 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.

Unlike in 2009 and 2010 when recovered sockeye were primarily transported and released into Wells forebay, in 2011 these fish were primarily released into the fish ladder just upstream of the trap and downstream of the PIT tag antennas at those ladders.

Upstream migration analysis

Comparison of 9.5 and 12.5 mm tags

A statistical test comparing the proportions of independent samples (Snedecor and Cochrane, 1980) was used to evaluate whether similar proportions of sockeye salmon tagged with the two tag types was observed at mainstem dams and weirs with PIT tag detection.

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. Individuals which were last observed at or upstream of Tumwater Dam were classified as Wenatchee stock. Sockeye which were last observed at or upstream of Ice Harbor or Lower Granite Dam were classified as being Snake River stock. All remaining sockeye salmon last observed downstream of the aforementioned sites were recorded as mortalities. Released tagged fish not detected at or upstream of PIT tag detectors located near the fish viewing windows at Bonneville Dam were removed 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

Mortality rates were calculated for sockeye at upstream points as a percentage of sockeye passing Bonneville Dam weighted by the proportion of sockeye salmon counted by Bonneville Dam during the week tagged. Mortality rates were computed by week of passage at Bonneville Dam between dams with detection capabilities

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 that sockeye salmon 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 and Okanagan Channel PIT tag antenna operation

The year 2011 marked the first complete year that PIT tag antennas were operational at both the Okanagan Channel (OKC) and Zosel Dam (ZSL) during the entire year. OKC had two outages reported, between 8:48 AM October 31 and 4:22 PM November 9, 2011 and from 11:35 AM December 2 and 9:38 AM December 13, 2011 and from January 6 until March 22, 2012. All outages were due to faulty equipment which was ultimately returned for repair.

A total of 726 sockeye, 6 steelhead, and 5 Chinook were detected passing OKC between April 1, 2011 and March 31, 2012 (Figure 2). Only 15 sockeye, 33 steelhead, and 23 Chinook were detected passing Zosel Dam fish ladders (Figure 3) as high summer flows meant most fish passed by Zosel Dam through the unwired spillway rather than through the fishways where they could be detected by PIT tag antennas. Salmon tagged by CRITFC tagging projects (adult Wells sockeye and adult Bonneville sockeye, Chinook, and steelhead tagging) comprised 29.6% of PIT tagged fish detected at Zosel and 91.3% of PIT tagged fish detected at OKC (Tables 1 and 2).

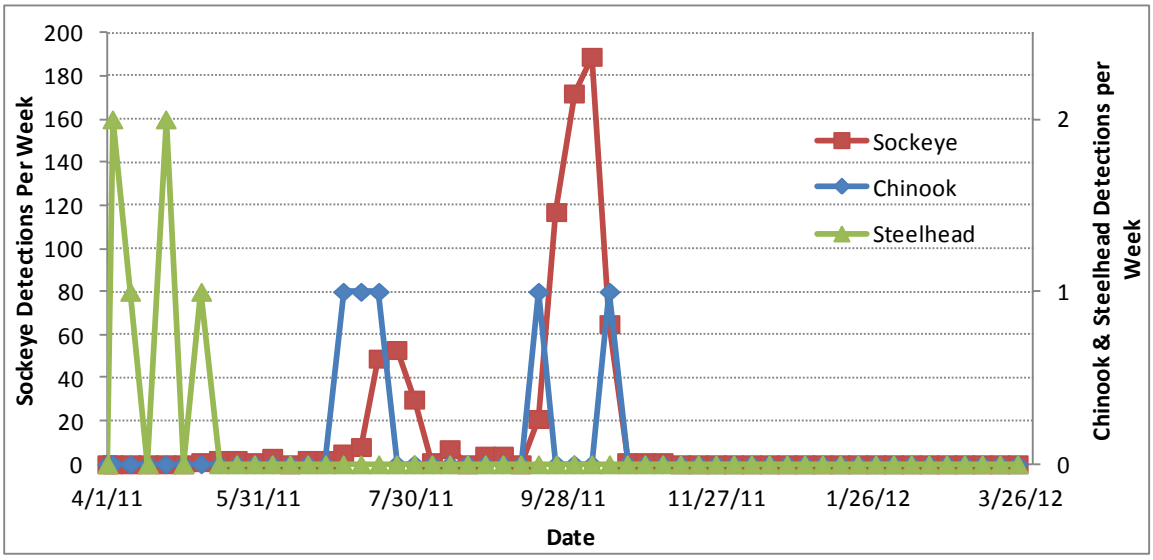


Figure 2. Number of PIT tagged sockeye and Chinook salmon, and steelhead detected passing the Okanagan Channel PIT tag site from April 1, 2011 to March 31, 2012.

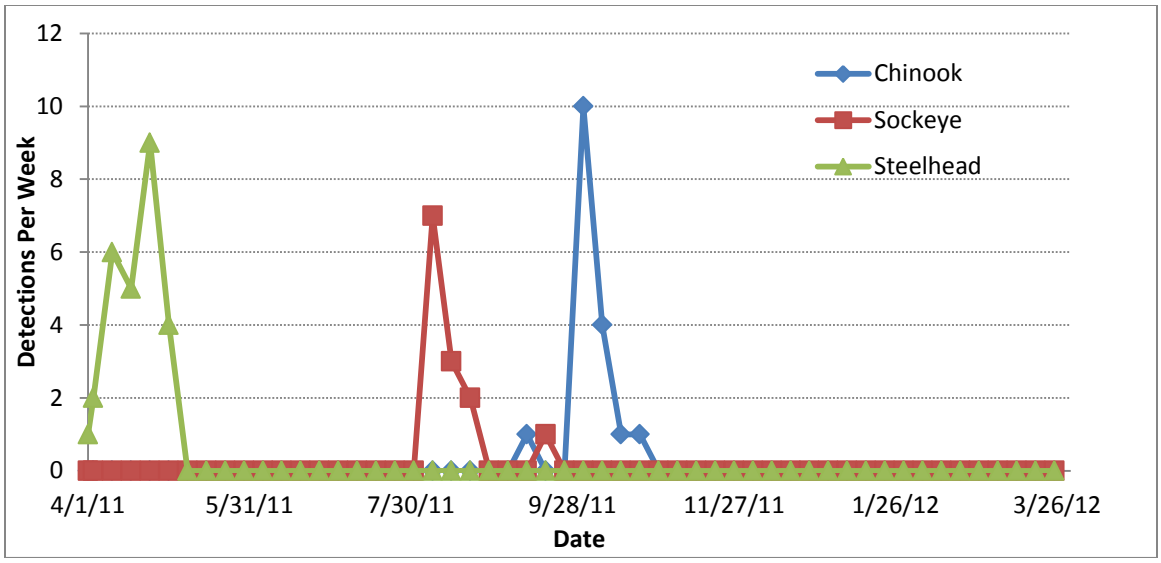


Figure 3. Number of PIT tagged sockeye and Chinook salmon, and steelhead detected passing the Zosel Dam PIT tag site from April 1, 2011 to March 31, 2012.

Table 1. Number of PIT Tagged Chinook, Steelhead, and Sockeye detected at Zosel Dam by release site and life stage between April 1, 2011 and March 31, 2012.

Release Site	Life Stage at Release	Chinook	Steelhead	Sockeye	Total
Bonneville Dam	Adult	5	3	5	13
Priest Rapids Dam	Adult	1	18		19
Wells Dam	Adult	10	10	8	28
Eastbank Hatchery	Juvenile	1			1
Lower Granite Dam	Juvenile		1		1
Ringold Hatchery	Juvenile	4			4
Rock Island Dam	Juvenile	2	1	2	5
Twisp River	Juvenile		1		1
Total		**23**	**34**	**15**	**71**

Table 2. Number of PIT Tagged Chinook, Steelhead, and Sockeye detected at the Okanagan Channel (OKC) by release site and life stage between April 1, 2011 and March 31, 2012.

Release Site	Life Stage at Release	Chinook	Steelhead	Sockeye	Total
Bonneville Dam	Adult	1		294	295
Priest Rapids Dam	Adult		1		1
Wells Dam	Adult	4	3	378	385
Cassimer Bar Hatchery	Juvenile		1		1
Lower Granite Dam	Juvenile		1		1
McNary Dam	Juvenile			3	3
Rock Island Dam	Juvenile			50	50
Wanapum Dam	Juvenile			1	1
Total		**5**	**6**	**726**	**737**

There were an additional 15 tags detected at OKC between May 23 and July 9 from adult sockeye salmon tagged between 2002 and 2009. Presumably, these were tags deposited on the river bottom after these fish died that were washed downstream over the OKC antenna by high flows.

Okanagan acoustic tag network installation and monitoring

A total of 20 receivers were deployed in the Okanagan Basin between Monse Bridge (rkm 6) and Okanagan Falls (rkm 176) in 2011 (Table 3 and Figure 4). An additional receiver was deployed at Pateros (Columbia River km 843), 13 rkm upstream of Wells Dam.

Table 3. Acoustic receivers deployed in the Okanagan Basin, their location, and date of deployment in 2011. See Figure 4 for the map for this table.

Map No.	Location	rkm	Latitude	Longitude	Date Deployed	Date Retrieved
1	Pateros Dock (Columbia River)	843	48.05396	-119.89696	7/1/2011	10/10/2011
2	Monse Bridge, west	6	48.14020	-119.67378	7/12/2011	10/10/2011
3	Monse Bridge, east	6	48.14009	-119.67336	7/12/2011	10/10/2011
4	East Driscoll Island	120	48.91524	-119.42362	7/18/2011	11/8/2011
5	Cross Channel Pool	120	48.91780	-119.42359	7/18/2011	11/8/2011
6	West Driscoll Island, Similkameen River	5	48.91128	-119.43565	7/18/2011	9/22/2011
7	Similkameen Canyon	11	48.94934	-119.46531	6/30/2011	11/15/2011
8	Pump Intake, west bank	124	48.94582	-119.43193	7/13/2011	11/10/2011
9	Pump Intake, east bank	124	48.94597	-119.43204	7/13/2011	11/10/2011
10	Haynes Point South	132	49.017153	-119.441520	6/30/2011	11/6/2011
11	Haynes Point Nav Buoy	132	49.021028	-119.438471	6/30/2011	11/6/2011
12	Central Basin Hwy 3 bridge	134	49.025882	-119.460621	6/30/2011	11/6/2011
13	North Basin Hwy 3 bridge	134	49.030160	-119.458506	6/30/2011	11/6/2011
14	North Basin West Coop	138	49.052791	-119.490928	6/30/2011	5/1/2012
15	North Basin Micca Crk	139	49.065626	-119.488012	6/30/2011	5/1/2012
16	North Basin Inkaneep Crk	140	49.069864	-119.504282	6/30/2011	5/1/2012
17	OKR Mouth East	141	49.078516	-119.520948	6/30/2011	11/6/2011
18	OKR Mouth West	141	49.079039	-119.522138	6/30/2011	11/6/2011
19	OKR Hwy 97 Bridge	162	49.229759	-119.541799	6/30/2011	11/6/2011
20	McIntyre Dam	165	49.256762	-119.528122	6/30/2011	11/6/2011
21	Okanagan Falls	176	49.342544	-119.580325	6/30/2011	11/6/2011
22	Penticton Channel Outlet	189	49.452064	-119.598144	9/15/2011	11/6/2011

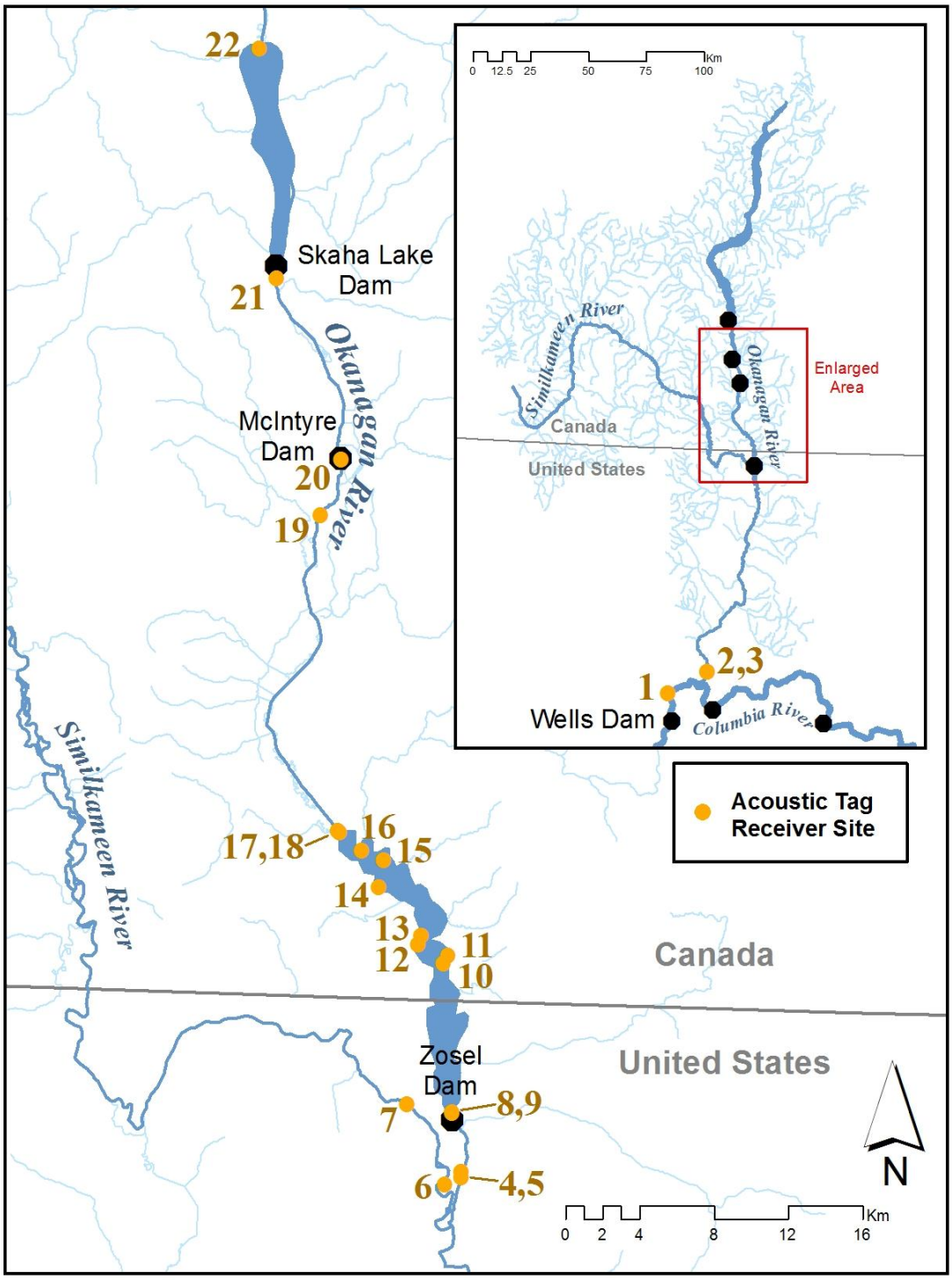


Figure 4. Okanagan Basin acoustic receiver sites in 2011. Location numbers reference sites listed in Table 1.

As in 2010, high flows affected deployment dates and locations. Although tagging began on July 6, 2011, Okanagan River receivers, as well receivers at the mouth of the Similkameen River, could not be safely deployed until July 12th to the 18th due to high flows. An additional receiver (number 22 in Table 3 and Figure 4) was deployed in the Penticton Channel on September 15, 2011 when sockeye, due to high flows, were observed passing through the normally impassible spillway at Okanagan Falls Dam. All receivers were operational until retrieval on dates indicated in Table 3.

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, therefore were not downloaded until they were retrieved.

Upstream migration analysis

Sample size and age composition

A total of 766 sockeye salmon were sampled between June 6 and July 19, 2011 (Table 4). 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. Only 1.6% of the sockeye run passed Bonneville Dam subsequent to the termination of sampling. Of the 766 fish sampled, all were PIT tagged prior to release with the exception of three that were already tagged (Table 4). A total of 19 sockeye were not detected after release[2]. These fish may have shed their tags, had defective tags, or died. It

Table 4. Number of PIT tagged sockeye salmon tagged at Bonneville Dam and tracked upstream by date and statistical week at Bonneville in 2011.

			Tagged		Recaptures of Previously Tagged Fish	Tracked Upstream of Bonneville	
Sampling Dates	Statistical Week	Sampled (n)	12 mm	9 mm	12 mm	12 mm	9 mm
6/6,7,9,10	24	19	17	2		17	2
6/13,14,15,16,17	25	82	68	14		66	12
6/20,21,22,23	26	127	102	24	1	100	25
6/27,28,29,30,7/1	27	211	172	38	1	169	37
7/5,6,7,8,	28	177	142	34	1	141	32
7/11,12,13,14	29	125	101	24		100	22
7/18,19	30	25	21	4		20	4
Total		**766**	**623**	**140**	**3**	**613**	**134**

[2] PIT tag detection data were last downloaded from www.ptagis.org on April 9, 2012.

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 where PIT tag antennas are located in the lower portions of Bonneville Dam fish ladders. It is less likely that sockeye salmon pass upstream undetected as, at Bonneville Dam, they must pass through PIT tag antennas near the fish counting window. At Bonneville Dam (as well as McNary, Ice Harbor, and Lower Granite dams) fish can pass upstream through the navigation locks. All other dams with PIT tag detection have antennas in fish ladders that sockeye salmon must pass through, however data from 2006-2011 indicates that PIT tagged sockeye salmon are missed, although the percentage is normally low (Table 5).

Table 5. Number and percentage of PIT tagged fish, by tag type, not detected at dam detection sites as estimated from upstream detections in 2011 along with comparison data for 2006-2010.

Dam	2011 (12.5 mm) N	%	2011 (9 mm) N	%	2010	2009	2008	2007	2006
Bonneville*	11	1.8%	4	3.0%	0.7%	0.6%	0.4%	2.1%	0.2%
McNary*	57	12.1%	24	24.5%	3.8%	5.0%	10.1%	6.5%	3.1%
Priest Rapids	2	0.4%	5	5.2%	0.6%	0.3%	0.3%	0.8%	0.0%
Rock Island	23	5.4%	34	38.2%	6.2%	2.6%	6.9%	6.8%	1.3%
Rocky Reach	5	1.4%	6	9.1%	0.5%	0.0%	0.2%	0.7%	12.3%
Wells	0	0.0%	0	0.0%	0.0%	--	--	--	--
Ice Harbor*	0	0.0%	--	--	0.0%	20.0%	0.0%	--	--

Sockeye salmon tagged with 9 mm tags were less likely to be detected at all dams with the exception of Wells Dam, which was the only dam where no PIT tagged sockeye were missed based on upstream detection data. At Rock Island, Priest Rapids, and Rocky Reach dams, the percentage of 9mm tagged fish missed was 6-14 times that of 12.5 mm tagged fish being missed, although the number of fish missed at both Priest Rapids and Rocky Reach dams was small. At Rock Island, a lightning strike on May 31, 2011 disabled the PIT tag detection system at the left bank fish way until it was fixed on June 29, 2011, however the number of PIT tagged sockeye salmon missed was likely extremely small as less than 0.5% of the sockeye salmon counted at Rock Island fish ladders passed during this outage.

The predominant age class at Bonneville Dam was Age 1.2, comprising an estimated 65.2% of the run (Table 6). The percentage of Age 1.1 sockeye generally increased as the run progressed, while Age 1.3 sockeye decreased and the percentage of Age 1.2 sockeye remained relatively consistent.

Table 6. Weekly and total age composition of sockeye salmon at Bonneville Dam as estimated from scale patterns in 2011.

Statistical Week	N Ageable	Age Class					
		1.1	1.2	1.3	2.1	2.2	2.3
24	19	15.8%	63.2%	15.8%	0.0%	5.3%	0.0%
25	79	5.1%	60.8%	25.3%	2.5%	6.3%	0.0%
26	125	8.8%	63.2%	19.2%	2.4%	6.4%	0.0%
27	201	10.9%	71.1%	11.4%	1.0%	5.5%	0.0%
28	171	25.7%	64.3%	6.4%	1.2%	2.3%	0.0%
29	123	33.3%	56.9%	3.3%	5.7%	0.8%	0.0%
30	24	29.2%	62.5%	0.0%	4.2%	0.0%	4.2%
Composite	**742**	**17.6%**	**65.2%**	**10.9%**	**2.0%**	**4.1%**	**0.1%**

Comparison of 9 and 12mm tags

At all sites but Tumwater Dam and the lower Bonneville Dam Washington shore ladder the percentage of tagged sockeye detected with 9mm tags was less than the 18.3% of sockeye that were tagged with 9 mm tags (Table 7). Only at Rock Island Dam and at in-stream arrays in the Okanagan River and White River was this difference significant. Data from both tag types was pooled for most subsequent analyses presented in this report.

Table 7. Percentage of tags detected that are 9 mm by site (10 detection minimum) with the p-value for a comparison with the percentage of 9 mm tags deployed (18.3%). Significant differences (α=0.05) are in bold.

Detection Location	PTAGIS Site Code	Tags Detected	% 9 mm	P-value
Bonneville Dam, Washington Shore Upper	BO4	725	17.8%	0.404
Priest Rapids Dam	PRA	536	17.2%	0.303
Rock Island Dam	**RRF**	**460**	**12.0%**	**0.002**
Rocky Reach Dam	RIA	404	14.9%	0.069
Wells Dam	WEA	403	15.6%	0.128
Bonneville Dam, Washington Shore Lower	BO3	397	19.1%	0.641
Okanagan Channel antenna	**OKC**	**294**	**12.9%**	**0.018**
McNary Dam - Washington Shore	MC1	256	14.8%	0.105
McNary Dam - Oregon Shore	MC2	238	15.5%	0.167
Tumwater Dam	TUF	103	21.4%	0.775
White River Antenna	**WTL**	**19**	**0.0%**	**0.020**
Little Wenatchee River Antenna	LWN	13	15.4%	0.394

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 8, Figure 5). This reach of river is where the tribal Zone 6 fishery occurs that was estimated to harvest 12,849 sockeye salmon (Table A2) with an additional 197 sockeye harvested by sport fishers (Stuart Ellis, U.S. v. Oregon Technical Advisory Committee, personal communication). However, adding this harvest to our estimated escapement to McNary Dam (141,337) still leaves 31,413 sockeye salmon unaccounted for between Bonneville and McNary dams.

Table 8. Percentage of PIT tagged sockeye salmon detected subsequent to tagging at upstream dams, estimated escapement from both PIT tags (12.5 mm only) and visual means, and the difference between the PIT tag and visual escapement estimate in 2011.

Dam	Estimated Percentage Reaching Dam	Estimated Escapement Using PIT Tag Data	Visual Dam Count	Difference Between PIT Tag and Visual Estimate
Bonneville	100.0%	--	185796	--
McNary	76.1%	141337	113952	24.0%
Priest Rapids	71.9%	133567	145070	-7.9%
Rock Island	68.9%	128036	146111	-12.7%
Rocky Reach	55.3%	102686	132096	-22.2%
Wells	53.9%	100132	111508	-10.2%
Tumwater	14.2%	26311	18622	41.3%
Ice Harbor	1.1%	2054	1141	80.0%
Lower Granite	1.1%	2054	1502	36.7%

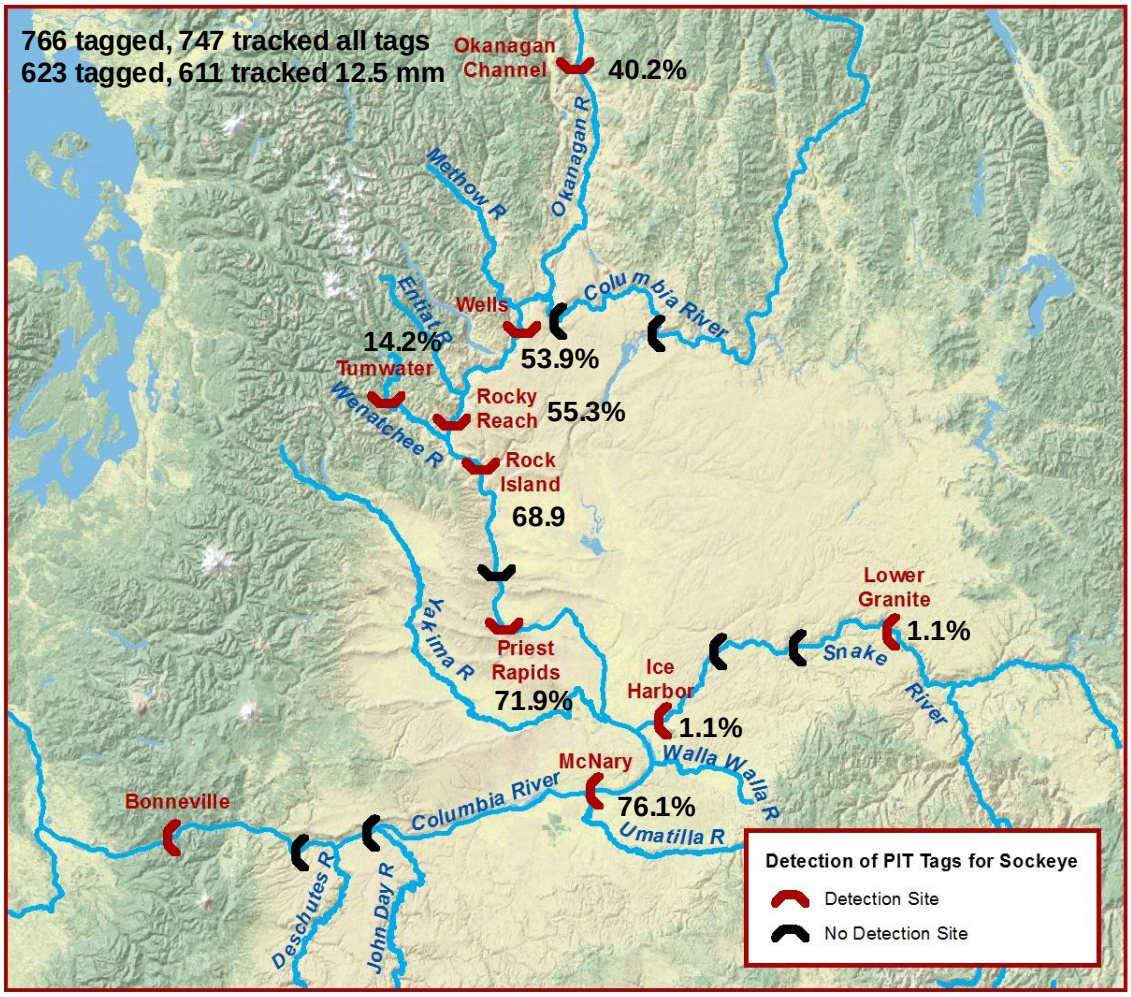


Figure 5. Map of the Columbia River Basin from Bonneville to Wells and Lower Granite dams showing the number of fish PIT tagged at Bonneville Dam, and the percentage of the run estimated to pass McNary, Priest Rapids, Rock Island, Rocky Reach, Wells, Ice Harbor, Lower Granite, and Tumwater dams and the Okanagan Channel in 2011.

Using detections of fish PIT tagged by this program to estimate fish counts at dams resulted in estimates that varied from actual visual fish counts by 7.9% to 80.0% (Table 8). 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 2011, as in previous years, PIT tag estimates exceeded visual counts at McNary Dam, likely due at least in part to navigation lock passage. At all other Columbia River dams visual counts exceeded PIT tag estimates.

Unlike previous years of this study, survival from Bonneville to McNary, Priest Rapids, and Rock Island, did not decline linearly as tagging progressed (Table 9, Figure 6). Rather, survival was highest in Statistical weeks 24 and 30, and lowest in Statistical Week 26. The Zone 6 harvest may have contributed to lower survival in Weeks 27 and 28 as 71.6% of the harvest was during these weeks.

Table 9. Sockeye salmon survival through selected reaches by statistical week as estimated by PIT tag detections in 2011.

Statistical Week at Bonneville Dam	Bonneville-McNary	Bonneville-Priest Rapids	Bonneville-Rock Island	Rocky Reach-Wells
24	100.0%	100.0%	94.7%	100.0%
25	70.5%	69.2%	66.7%	97.7%
26	68.0%	68.0%	64.0%	95.2%
27	75.7%	71.4%	67.0%	100.0%
28	75.6%	70.9%	66.9%	98.0%
29	81.5%	76.6%	75.0%	96.2%
30	91.7%	87.5%	87.5%	81.3%
Composite	**75.3%**	**71.8%**	**71.8%**	**97.4%**
p-value	**0.05**	**0.22**	**<0.01**	**0.10**

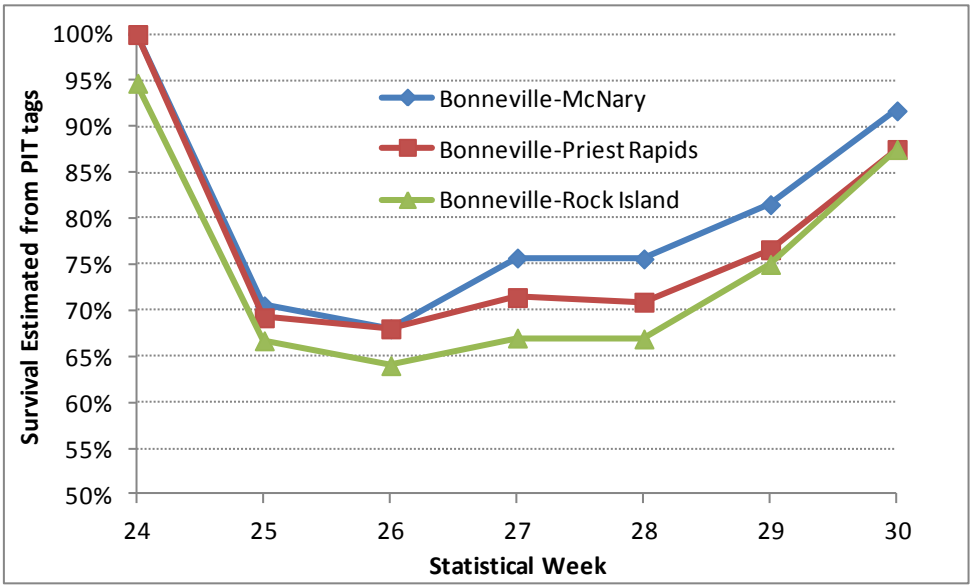


Figure 6. Survival from to McNary, Priest Rapids, and Rock Island dams by statistical week tagged at Bonneville Dam as estimated by PIT tags in 2011.

Migration timing and passage time

Sockeye salmon travel quickly upstream with a median travel time between Bonneville and Rock Island Dam of 14.2 days (Table 10). Sockeye salmon passing Bonneville Dam later in the migration travel upstream faster than those earlier in the migration (Table 11). 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 except Wells Dam (where only six sockeye classified as Wenatchee stock were detected) was one day or less between the two major stocks (Table 12).

Table 10. Median sockeye salmon migration time and travel rates between dams as estimated by PIT tag detections in 2011.

Dam Pair	Distance (km)	Median Time (days)	Median Travel Time (km/day)
Bonneville-McNary	231	5.8	39.9
McNary-Priest Rapids	167	4.8	34.8
Priest Rapids-Rock Island	89	3.2	28.1
Rock Island-Rocky Reach	33	1.1	28.7
Rocky Reach-Wells	65	2.2	29.5
Rock Island-Tumwater	73	20.3	3.6
Bonneville-Rock Island	487	14.2	34.4
Bonneville-Tumwater	560	35.3	15.9
Bonneville-Wells	585	18.0	32.6

Table 11. Adult sockeye salmon travel median 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 2011.

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
24	6.7	14.2	17.5	18.9	--	22.0	10.9	1.6	2.9
25	7.2	15.4	18.2	20.7	47.4	23.7	10.5	1.6	2.7
26	5.8	11.9	15.8	17.3	41.2	20.0	9.9	1.4	2.3
27	5.8	10.8	14.5	15.7	35.1	18.2	8.5	1.1	2.4
28	5.6	10.1	13.6	14.6	31.1	16.8	8.0	1.1	2.0
29	5.1	9.7	12.7	13.7	25.5	15.8	7.4	1.0	2.0
30	5.5	9.7	12.6	13.7	26.7	15.2	6.7	1.0	1.8
P-value	**0.01**	**0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Stock									
Okanagan	5.7	10.7	14.0	15.7	--	17.9	8.7	1.2	2.2
Wenatchee	5.9	11.0	15.0	16.7	35.3	20.3	9.6	0.9	3.1
Snake River	6.0	--	--	--	--	--	--	--	--
Unknown[3]	6.1	11.6	15.8	--	--	--	8.1	--	--

Table 12. 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 2011.

Dam	Median Passage Time (Minutes)	Taking More Than 12 Hours (%)
Bonneville	56	3.0%
McNary	0	5.9%
Priest Rapids	6	1.9%
Rock Island	4	2.4%
Rocky Reach	1	3.7%
Wells	3	5.5%
Tumwater	6	12.6%
Ice Harbor	3	0.0%
Lower Granite	262	16.7%

The median time between first detection and last detection was six minutes or less at all dams except for Bonneville and Lower Granite dams (Table 12). 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 pass through the adult fish trap which likely results in increased passage times.

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

Night passage

At dams with more than six detections, Okanagan stock sockeye salmon passed dams at night (2000-0400 hours) at a higher rate than Wenatchee stock sockeye salmon (Table 13). The Bonneville Dam estimate of nighttime passage is likely biased low because tagging occurred between about 0800 and 1300 hours, and with a median passage time of 56 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 13. Estimated sockeye salmon nighttime passage (2000-0400 standard time) in 2011 at mainstem Columbia River dams as estimated by PIT tag detections.

Dam	All Sockeye (includes unknown)	Okanagan Stock	Wenatchee Stock	Snake Stock
Bonneville	0.3%	0.0%	0.0%	0.0%
McNary-Oregon Shore	3.4%	3.7%	2.4%	0.0%
McNary-Washington Shore	5.9%	6.0%	5.8%	0.0%
Priest Rapids	1.9%	2.5%	0.0%	NA
Rock Island	4.1%	5.0%	0.0%	NA
Rocky Reach	4.2%	4.3%	0.0% [a]	NA
Wells	11.7%	11.6%	0.0% [a]	NA
Tumwater	9.7%	NA	9.7%	NA
Ice Harbor	16.7%	NA	NA	16.7% [a]
Lower Granite	0.0%	NA	NA	0.0% [a]
Mean of McNary, Priest Rapids and Rock Island	3.6%	4.1%	1.4%	NA

a - Based on six or fewer detections.

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 14). The overall stock composition estimate was 21.9% Wenatchee, 76.8% Okanagan, and 1.3% Snake River. The Wenatchee/ Okanagan stock composition estimate differed by 12.4 percentage points from that estimated by Rocky Reach Dam counts and 10.5 percentage points from that estimated using Tumwater Dam counts after taking into account Snake River sockeye salmon (Table 14).

Six sockeye salmon were detected at both Wells and Tumwater dams. In all cases, these fish first passed Wells Dam, then moved downstream through both Wells and Rocky Reach dams, before being detected passing Tumwater Dam.

Table 14. Weekly and composite sockeye salmon stock composition at Bonneville Dam as estimated by PIT tags in 2011 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
24 (June 6-10)	1,048	19	0.0%	100.0%	0.0%
25 (June 13-17)	9,304	78	15.7%	84.3%	0.0%
26 (June 20-23)	34,753	125	24.4%	75.6%	0.0%
27 (June 27-July 1)	60,531	206	29.0%	68.8%	2.2%
28 (July 5-8)	53,023	173	16.4%	81.9%	1.7%
29 (July 11-14)	21,521	122	14.1%	84.8%	1.1%
30 (July 18-19)	5,616	24	25.0%	75.0%	0.0%
Composite	**185,796**	**747**	**21.9%**	**76.8%**	**1.3%**
Visual Fish Counts at dams (using difference between Rock Island and Rocky Reach counts to estimate proportion Wenatchee)			9.5%	89.2%	
Visual Fish Counts at dams (Tumwater count to estimate the proportion Wenatchee)			12.7%	87.3%	

A total of 43 adipose clipped sockeye salmon were PIT tagged[4]. Of these, 5 were last detected in the Snake Basin (2 of which had ventral fin clips in addition to an adipose fin clip), 12 were last detected in the Wenatchee Basin, 5 were last detected at or upstream of Rocky Reach Dam (1 in the Twisp River), and 21 were last detected at a Columbia River dam between Bonneville and Rock Island dams. We had 2 additional fish with ventral fin clips, 1 left and 1 right, which were last detected at OKC.

Okanagan and Wenatchee sex, age, and length-at-age composition

Age 1.2 sockeye salmon predominated in both our Wells and Tumwater samples (Tables 15 and 16). At Wells Dam, Age 1.1 sockeye increased through the migration while Age 1.3 sockeye decreased, with Age 1.2 fish staying relatively constant. The age distribution of males had a much higher percentage of Age 1.1 and 1.3 fish, and a lower percentage of Age 1.2 fish than females. After weighting the weekly sex composition by run size, males comprised an estimated 63.8% of the run at Wells Dam.

The Wenatchee sockeye run at Tumwater Dam overwhelmingly passed during Statistical Week 32 and consisted almost entirely of Age 1.2 and 1.3 sockeye. An estimated 61.2% of the run at Tumwater Dam was female and, like

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

at Wells Dam, females were more likely to be Age 1.2 and less likely to be Age 1.3.

Table 15. Age composition by week and sex for sockeye salmon sampled at Wells Dam in 2011.

Stat Week	Sampling Dates	Run Size	N	N Ageable	1.1	1.2	1.3	2.1	2.2	2.3
≤28	7/6,7/7	5,501	21	20	0.0%	45.0%	35.0%	10.0%	10.0%	0.0%
29	7/11,7/12	27,615	117	114	5.3%	38.6%	38.6%	2.6%	13.2%	1.8%
30	7/18,7/19	44,039	175	173	13.9%	49.1%	31.8%	1.2%	4.0%	0.0%
31	7/25,26,27	26,038	213	209	32.5%	46.9%	14.8%	2.4%	3.3%	0.0%
≥32	8/1,2,3	8,315	77	76	39.5%	40.8%	9.2%	5.3%	5.3%	0.0%
Composite		**111,508**	**603**	**592**	**17.3%**	**45.2%**	**28.0%**	**2.6%**	**6.5%**	**0.4%**
Variance					**1.4%**	**2.2%**	**2.0%**	**0.7%**	**1.1%**	**0.3%**
Males			392	385	21.7%	37.4%	32.3%	3.7%	4.6%	0.4%
Females			211	207	8.5%	60.1%	20.4%	1.0%	9.4%	0.5%

Table 16. Age composition by week and sex for sockeye salmon sampled at Tumwater Dam in 2011.

Stat Week	Sampling Dates	Run Size	N	N Ageable	1.1	1.2	1.3	2.1	2.2	2.3
≤32	8/1,8/2,8/3	13,969	209	207	--	77.3%	19.8%	--	2.9%	--
33	8/8,8/9,8/10	3,321	144	143	--	96.5%	2.1%	--	1.4%	--
≥34	8/15	1,344	6	6	--	83.3%	16.7%	--	0.0%	--
Composite		**18,634**	**359**	**356**	**--**	**81.2%**	**16.4%**	**--**	**2.4%**	--
Std. Dev.						**2.5%**	**2.4%**		**0.9%**	
Males			142	141	--	76.0%	21.9%	--	2.2%	--
Females			216	214	--	84.8%	12.6%	--	2.6%	--

The estimated Wenatchee sockeye age composition estimate (Wenatchee-Tumwater sample Stock-Method, Table 17) was very similar to that estimated from sockeye salmon PIT tagged at Bonneville Dam that were subsequently detected at Tumwater Dam (Wenatchee-PIT tag Stock-Method, Table 17). In contrast, the estimated age composition at Wells Dam estimated from sampling differed considerably from that estimated from sockeye salmon PIT tagged at Bonneville Dam that were subsequently detected at Wells Dam. Wells sampling estimated more Age 1.3 sockeye and fewer Age 1.1 and Age 1.2 sockeye. This is consistent with past years where we have observed that the Wells Dam fish traps appear selective for larger sockeye (Fryer et al. 2011).

Wenatchee length at-age-composition estimates were similar using the two different methodologies; with mean length estimates differing by less than 2 cm for a given age class (Table 18). Okanagan length-at-age composition estimates were more variable, differing by up to 3.4 cm for Age 2.2. For both stocks, the mean length for fish sampled at upstream dams was greater than that of mean length at tagging for Bonneville tagged fish passing through the dam in

question. At Wells Dam, the mean length of all sampled fish was 50.8 cm, compared to 47.8 for sockeye salmon PIT tagged at Bonneville Dam passing Wells Dam. At Tumwater Dam, the mean length of all sampled fish was 53.7 cm, compared to 52.2 cm for sockeye salmon PIT tagged at Bonneville Dam passing Tumwater Dam. Morphological changes caused by maturation between the time the fish were sampled at Bonneville Dam and the upstream dams, along with a trap bias at Wells Dam, are likely explanations for this difference.

Table 17. 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 2011. Standard deviations are in parentheses.

		Age					
Stock-Method	**Ageable Sample Size**	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**
Bonneville-sample	727	18.0 (1.4)	64.9 (1.8)	10.8 (1.2)	2.1 (0.5)	4.2 (0.8)	0.1 (0.1)
Wenatchee-PIT tag estimate	103	--	81.1 (3.5)	14.4 (3.3)	--	4.5 (2.1)	--
Wenatchee-Tumwater sample	395	--	81.2 (2.8)	16.4 (1.1)	--	2.4 (2.7)	0.2 (2.0)
Okanagan- PIT tag estimate	394	26.1 (2.3)	59.2 (2.6)	7.7 (1.4)	3.1 (0.9)	3.7 (1.0)	0.2 (0.2)
Okanagan-Wells sample	592	17.3 (1.4)	45.2 (2.1)	28.0 (2.0)	2.6 (0.7)	4.3 (0.3)	1.9 (0.6)
Snake River PIT tag estimate	5	18.4	81.6	--	--	--	--

Table 18. Length-at-age composition of Wenatchee and Okanagan stock sockeye salmon estimated by PIT tag detection and sampling at Tumwater and Wells dams in 2011.

		Age					
Stock	**Statistic**	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**
Bonneville-Mixed stock	Mean	39.8	50.8	56.9	42.2	51.2	57.5
	St. Dev.	1.7	2.3	2.2	1.8	2.1	--
	N	131	475	83	17	30	1
Okanagan-PIT tags	Mean	39.9	50.2	56.5	42.1	50.7	57.5
	St. Dev.	1.7	2.4	2.4	1.9	1.8	--
	N	101	232	32	14	16	1
Okanagan-Wells Sampling[5]	Mean	40.1	52.3	57.5	44.1	54.1	58.0
	St. Dev.	2.0	2.2	2.4	2.0	3.4	4.2
	N	128	267	144	16	35	2
Wenatchee-PIT tags	Mean	--	51.3	57.4	--	52	--
	St. Dev.	--	2.0	1.3	--	2.4	--
	N	--	81	15	--	4	--
Wenatchee-Tumwater Sampling	Mean	--	53.0	58.7	--	53.8	60.5
	St. Dev.	--	2.6	3.5	--	3.5	--
	N	--	300	44	--	8	1

[5] The estimated Okanagan stock age composition determined from otoliths collected on the spawning ground (n=335) was .1.1=18.2%, 1.2=66.4%, 2.1=4.3%, 1.3=7.1%, 2.2 =4.0% (Margot Stockwell, personal communication).

In-river detection of PIT tagged Wenatchee sockeye salmon

In 2008-2010, this study documented that sockeye were delayed at Tumwater Dam, with 33.3% of detected sockeye salmon last detected at the downstream antenna, suggesting that they did not pass Tumwater (Fryer et al. 2009, 2010, 2011). In 2011, trapping operations were changed and delays were greatly reduced from 8494 minutes in 2010 to 6 minutes in 2011 (Table 12). In addition, 99.0% of the sockeye PIT tagged at Bonneville Dam detected at Tumwater Dam last detected at the upstream antenna suggesting successful upstream passage.[6]

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 as a paired set of arrays (upper and lower) located immediately downstream of sockeye salmon spawning grounds on both 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% rate of detection for sockeye passing Tumwater Dam. No sockeye detected at Tumwater Dam were subsequently detected at any location other than the White and Little Wenatchee river arrays. This included the Middle Wenatchee site where it is possible that high flows in 2011 may have resulted in sockeye salmon migrating too high in the water column to be detected at this site.

Among the sockeye tagged with 12.5 mm tags at Bonneville Dam that passed Tumwater Dam, 13.6% were detected at Little Wenatchee antennas and 23.5% were detected at White River antennas. Likely due to poorer detection at in-river antennas, only 9.1% of sockeye with 9mm tags passing Tumwater were detected in the Little Wenatchee River and none were detected in the White River. At both arrays, by looking at the percentage of PIT tagged sockeye detected at the upper array that were detected at the lower array, the efficiency of the lower array can be estimated. The efficiency of the lower Little Wenatchee array was 63.6% for 12.5 mm tags (7 of 11) and 0% (0 of 2) for the 9mm tags. At the White River, 16 out of 19 12.5 mm-tagged sockeye missed the lower array and no 9mm tagged sockeye were detected at either array. During part of migration period the White River arrays where malfunctioning making it difficult to

[6] The sole exception was a sockeye tagged with a 9 mm tag that generated only two detections on its upstream migration, suggesting a bad tag.

accurately estimate detection efficiency (Josh Muraskus, Chelan PUD, personal communication).

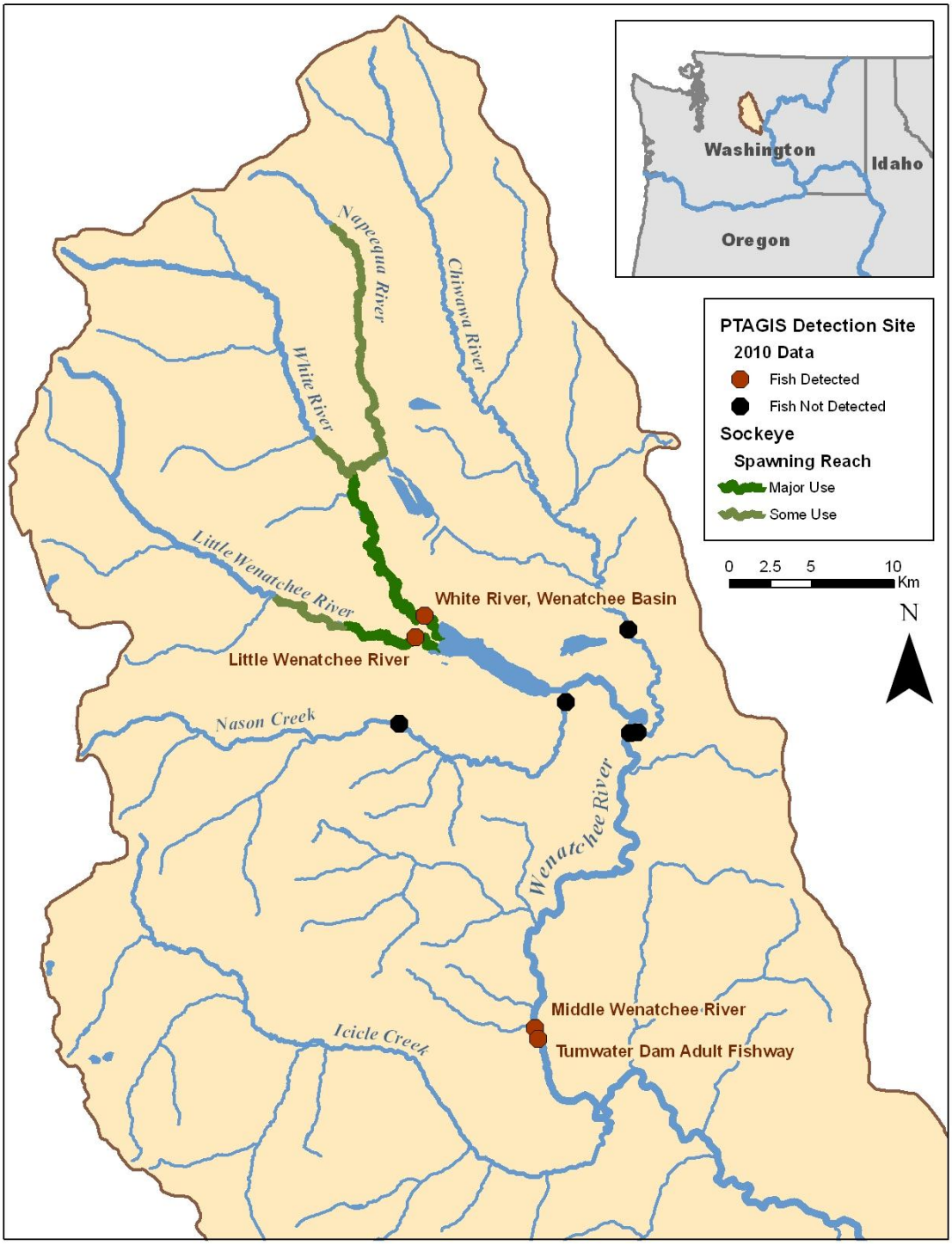


Figure 7. Portion of Wenatchee Basin with PIT detectors that could detect returning adult salmon or steelhead. Also displayed is the spawning area of sockeye.

Wells tagging

An additional group of 600 sockeye salmon was PIT and Floy tagged at Wells Dam between July 6 and August 3, 2011 (Table 19). Two additional fish PIT tagged at Bonneville were sampled (and given a Floy tag), bringing our sample size at Wells Dam to 602. Our sample was deliberately weighted towards the end of the run when we expected higher river temperatures were more likely to adversely affect survival upstream. During statistical weeks 31 and 32 we collected 48.2% of our total sample although only 30.9% of the run passed (Table 19). Sockeye not detected after tagging represented 2.8% of the run (Table 19). Discarding these undetected sockeye as having died, lost tags, or otherwise been adversely affected by tagging, we estimated that 69.0% of the run at Wells migrated upstream of our Okanagan River Channel (OKC) PIT tag detection site (Table 19), while 2.4% migrated downstream where they were detected at Rocky Reach Dam and/or in the Wenatchee and Entiat rivers (Table 19). An additional 0.3% of the run was last detected in the Methow River, and 27.3% were last detected at Wells Dam. There were relatively small differences in the distribution of last detection site for fish tagged at the east and west ladders (Table 20). A small number of sockeye tagged in Week 31 were accidently mixed in with Chinook from another program and were released upstream. A smaller percentage of these fish were subsequently detected; however this is likely primarily due to the fact that these fish were released upstream of Wells Dam PIT tag detection (Table 20). Over 15% of the tagged fish released in each fish ladder crossed over to the fish ladder on the other side of the dam prior to ascending (Table 20).

Table 19. Number of PIT tagged sockeye released at Wells Dam in 2011 with the estimated percentage subsequently detected by site (weighted by weekly run size).

			Last Detection Site							
Week	**Proportion of Run at Wells**	**N**	**Wenatchee River**	**Rocky Reach**	**Entiat**	**Wells Dam**	**Methow**	**Zosel Dam**	**OKC**	**Not Detect-ed**
28	4.9%	21	0.0%	0.0%	0.0%	38.1%	0.0%	0.0%	61.9%	0.0%
29	24.8%	117	0.9%	0.0%	0.0%	23.1%	0.0%	0.0%	76.1%	0.0%
30	39.5%	175	1.7%	0.6%	0.6%	19.4%	0.0%	0.0%	77.1%	0.6%
31	23.4%	213	0.0%	1.9%	0.0%	31.0%	0.9%	0.5%	59.6%	6.1%
32	7.5%	76	1.3%	5.3%	1.3%	53.9%	1.3%	2.6%	18.4%	15.8%
Weighted Total		602	1.0%	1.1%	0.3%	26.5%	0.3%	0.3%	67.7%	2.8%
Only Sockeye Subsequently Detected		576	1.0%	1.2%	0.4%	27.8%	0.4%	0.3%	69.0%	--

Table 20. Last detection site of sockeye salmon PIT tagged and released in the Wells Dam East and West fish ladders as well as the Wells Dam forebay.

Release Site	Weeks Released	N	Last Detection Site				Crossed to Opposite Ladder Prior to Passing
			Upstream	Downstream	Wells Dam	Not Detected	
East Ladder	28-32	521	62.8%	1.7%	31.3%	4.2%	15.4%
West Ladder	28, 30, 31	68	67.6%	1.5%	30.9%	0.0%	18.5%
Forebay	31	13	58.3%	0.0%	0.0%	41.7%	NA
Unweighted Total		**602**	**63.1%**	**1.7%**	**30.6%**	**4.7%**	**15.7%**

Only 1.7% of Bonneville tagged sockeye salmon were detected in both Wells Dam fish ladders compared to 15.7% of the Wells tagged sockeye which passed upstream at the opposite ladder from that which they were tagged (Tables 20 and 21). Sockeye tagged at Wells Dam, and Bonneville Dam tagged fish detected at Wells Dam, were equally likely to be subsequently detected downstream of Wells Dam (Tables 20 and 21) but Bonneville tagged sockeye were more likely to be detected upstream of Wells Dam.

Table 21. Detection information for sockeye PIT tagged at Bonneville Dam passing Wells Dam.

Initial Detection Ladder	Number	Last Detected at or after Wells Dam			Crossed to Opposite Wells Fish Ladder
		Upstream	Downstream	Wells Dam	
East Ladder	279	75.6%	1.1%	23.3%	0.4%
West Ladder	124	68.6%	3.2%	28.2%	4.6%
Unweighted Total	**403**	**73.4%**	**1.7%**	**24.8%**	**1.7%**

Sockeye salmon tagged at Wells Dam during Statistical Weeks 29 and 30 were more likely to be detected at OKC than those tagged in other weeks (Table 22). Survival of sockeye salmon tagged in Week 28 may have been adversely affected by the fact that 20 out of 21 fish were also acoustic or temperature tagged while the decrease in survival in weeks 31 and 32 may be attributable to higher temperatures adversely affecting sockeye salmon tagged at Wells Dam.

The weighted percentage of Wells-tagged sockeye which were detected at OKC was highest for the PIT (and Floy) tagged group (Table 22) at 72.3% compared to 76.0% for the Bonneville PIT tagged sockeye detected at Wells Dam that were subsequently detected at OKC. Wells PIT plus acoustic tagged sockeye had a weighted 70.1% detection rate at OKC while PIT plus temperature tagged sockeye had a weighted 65.9% detection rate.

Females tagged at Wells Dam were more likely to be detected at OKC than males (Table 23), while Age 1.2 sockeye from both Wells and Bonneville were most likely to be detected at OKC followed by Age 1.3 sockeye then Age 1.1 sockeye.

Table 22. Estimated detection rate of sockeye salmon tagged at Bonneville and Wells Dam which passed Wells Dam to OKC with a cumulative percentage weighted by Wells Dam weekly run size.

			Wells Dam						Bonneville Dam	
	Mean Temperature		PIT + Floy Tagged Only		PIT+ Floy+Acoustic Tagged		PIT+Floy+ Temperature Tagged		PIT tagged Only	
Week	Wells	Okan. River (Mallot)	N	% at OKC	N	% at OKC[7]	N	% at OKC	N	% at OKC
27	13.1	13.3	--	--	--	--	--	--	10	50.0%
28	14.0	15.0	1	100.0%	7	57.1%	13	61.5%	28	75.0%
29	14.6	15.2	38	81.6%	12	66.7%	67	74.6%	77	87.0%
30	15.5	16.2	101	74.3%	12	83.3%	61	82.0%	113	71.7%
31	16.3	17.8	146	65.8%	17	70.6%	37	51.4%	85	75.3%
32	17.1	20.0	36	33.3%	11	18.2%	17	0.0%	27	66.7%
Weighted			**322**	**72.3%**	**59**	**70.1%**	**195**	**65.9%**	**340**	**76.0%**

Table 23. Percentage of sockeye passing Wells Dam detected at the Okanagan Channel PIT tag antenna as estimated using sockeye PIT tagged at Wells and Bonneville dams.

	Wells Dam		Bonneville Dam	
Group	Number Detected at or Upstream of Wells	Weighted Conversion Rate to OKC	Number Detected at or Upstream of Wells	Weighted Conversion Rate to OKC
PIT tagged only	322	72.3%	340	76.0%
All tagged sockeye at Wells	576	69.0%	NA	NA
PIT plus acoustic tagged	59	70.1%	NA	NA
PIT plus temperature tagged	195	65.9%	NA	NA
Males	373	67.0%	NA	NA
Females	203	72.0%	NA	NA
Age 1.1	116	64.9%	88	64.4%
Age 1.2	256	69.1%	192	78.2%
Age 1.3	143	67.9%	27	71.6%

In-basin detection of PIT tagged Okanagan sockeye salmon

PIT tags from 23 sockeye salmon were recovered during Okanagan River spawning ground surveys and brood stock collection activities, 22 of which were from this project. Four PIT tags were deployed by this project at Bonneville Dam and 18 at Wells Dam. Sex was correctly identified at Wells Dam for all 18 sockeye sampled at that location compared to 3 out of 4 at the Bonneville Dam location. One tag recovered was deployed on a smolt outmigrant at Rock Island Dam on May 18, 2009.

[7] Based solely on PIT tag detections at OKC

Acoustic data analysis

A total of 60 sockeye salmon were implanted with acoustic tags between July 6 and August 2, 2011 (Statistical weeks 28-32, Table 24). High flows prevented deployment of the acoustic receivers at Monse Bridge, the three Similkameen channel sites, and the pumping station until between July 12 and 18, resulting in many missed fish which had been tagged prior to these dates. Of the 60 sockeye acoustically tagged, 58 were subsequently detected. However, there were PIT tag detections for the two missing acoustic tagged fish. One sockeye (PIT tag 3D9.1C2DAE9F6E, 117837, Table 26) tagged on July 25 turned and went downriver and was last detected by PIT tag in the Rocky Reach Juvenile Bypass (RRJ) on August 3. Another sockeye tagged on July 25 (3D9.1C2DAE9EB3, 117864) appeared to have an inoperative or rejected acoustic tag as it generated no detections, though the PIT tag was detected at OKC on October 9. One acoustic tagged sockeye salmon (117839) was adipose clipped, suggesting that it was likely a Wenatchee hatchery fish. This acoustic tag was detected at the Pateros acoustic receiver immediately upstream of Wells Dam but it was not subsequently detected. Two other acoustic tagged sockeye (11829 and 117872) were tagged on July 25 and captured in the Colville fishery on 7/26 and 7/28, released, and were detected on the spawning grounds.

Table 24. Percentage of sockeye salmon acoustic tagged at Wells Dam passing upstream receivers and median days to selected sites in 2011.

Statistical Week Tagged	Number Tagged	% Passing Monse Bridge	% Passing Haynes Point	% Passing OKC Array	% in Similk-ameen	Median Days to Monse Bridge	Median Days to Haynes Point	Median Days to OKC
28	6[8]	100%	100.0%	83.3%	0.0%	NA	7.2	85.1
29	12	100%	100.0%	83.3%	0.0%	1.4	5.6	84.2
30	12	100%	100.0%	83.3%	0.0%	1.3	5.9	71.9
31	18	94.4%	88.9%	72.2%	5.6%	1.5	5.3	76.0
32	11	54.5%	36.4%	18.2%	18.2%	1.3	5.0	67.8
Overall	**59**	**95.3%**	**92.7%**	**75.9%**	**2.7%**	**1.3**	**5.8**	**76.0**

Earlier migrating fish passed Monse Bridge and Haynes Point at a higher rate, but migrated at a slower rate, than later migrating fish (Table 24). Later migrating fish passed all sites at a much lower rate than earlier migrating fish with the exception being those sites in the Similkameen (Figure 4). Three of the six sockeye detected in the Similkameen did not make it to Osoyoos Lake. Five of

[8] Excludes one acoustic tagged sockeye where the acoustic tag was not subsequently detected, although the PIT tag was detected at OKC.

the last six fish passing Monse Bridge did not make it to the Okanagan spawning grounds.

Thirty six of the 60 fish tagged were estimated to be on the spawning grounds during the spawning period (Table 25).

Table 25. Tagging data, last detection and date, and first PIT tag detection at OKC PIT tag array for sockeye salmon acoustic tagged at Wells Dam in 2011. (Blue shading indicates combined acoustic/temperature/depth tags and green text indicates the fish was on the spawning grounds during the spawning period.)

Tag code	Date Tagged	Final Acoustic Detection Site	Date	First PIT Tag Detection at OKC	Comments
1117829	7/25	Okanagan Falls	8/3	8/1	Released from CCT fishery 7/28, harvested in ONA fishery
1117830	7/19	Highway 97	10/1	9/25	Spawn
1117831	7/19	Highway 97	10/2	9/29	
1117832	7/19	OKC PIT array	9/30	9/30	
1117833	7/19	Osoyoos North	8/5		Harvested in ONA fishery
1117834	7/26	Okanagan River mouth	10/10	10/10	
1117835	7/26	Highway 97	10/22	10/16	
1117836	7/25	Okanagan River mouth	10/9	10/9	Collected as broodstock
1117837	7/25	No detections			PIT tag detected at Rocky Reach juvenile bypass 8/3
1117838	7/25	McIntyre Dam	10/20	10/15	
1117839	8/2	Pateros	8/3		Ad-clipped, possibly moved downstream
1117840	8/1	OKC PIT array	10/8	10/8	
1117841	8/1	Osoyoos north	8/6		Harvested in ONA fishery
1117842	7/26	Highway 97	10/3	9/30	
1117843	7/26	McIntyre Dam	10/31	10/12	
1117844	7/6	Highway 97	10/8	10/3	
1117845	7/6				PIT detected at Wells 7/6
1117846	7/6	McIntyre Dam	7/20		Harvested in ONA fishery
1117847	7/11	Okanagan Falls	10/19		
1117848	7/11	Osoyoos North	7/16		Harvested in ONA fishery
1117849	7/12	Okanagan River Mouth	10/9	10/9	
1117850	7/12	Osoyoos North	8/17		Harvested in ONA fishery
1117851	7/12	Highway 97	10/20	10/3	
1117852	7/11	Highway 97	10/8	10/2	
1117853	7/11	Okanagan River Mouth	10/4	10/4	
1117854	7/18	Okanagan River Mouth	10/10	10/10	
1117855	7/18	Okanagan River	10/10	10/10	

		Mouth			
1117856	7/18	Highway 97	8/31	7/23	Harvested in ONA fishery
1117857	7/18	Penticton Channel	11/2	7/24	
1117858	7/12	Okanagan River Mouth	10/13	10/13	
1117859	7/26	Okanagan Falls	10/11	10/3	Mobile tracked, spawner
1117860	7/26	Okanagan River Mouth	10/6	10/6	Spawner
1117861	8/1	Monse Bridge	8/2		
1117862	8/1	Pateros	8/5		Ad clipped, possibly moved downstream
1117863	8/1	Okanagan mouth	11/14	10/8	Pre-spawn mortality
1117864	7/25	Similkameen	8/27		
1117865	7/25	NA		10/9	Bad/lost acoustic tag
1117866	7/26	Okanagan River mouth	10/3	10/3	Mobile tracked, spawner
1117867	7/26	Osoyoos North	7/31		Harvested in ONA fishery
1117868	7/26	Okanagan Falls	9/4	8/3	Spawner
1117869	7/19	McIntyre Dam	8/3	8/1	Unknown??
1117870	7/19	Highway 97	10/7	10/3	Mobile tracked
1117871	7/25	Okanagan mouth	11/7		Spawner
1117872	7/25	Okanagan River Mouth	10/8		Released from CCT fishery, Mobile tracked, spawner
1117873	7/25	Okanagan River Mouth	10/11	10/11	Spawner
1117874	7/6	Okanagan River Mouth	10/9	10/9	Mobile tracked, brood stock
1117875	7/6	Penticton Channel	10/20	7/13	Spawner
1117876	7/6	Highway 97	10/9	9/26	Mobile tracked, spawner
1117877	7/6	Osoyoos North	7/14		Harvest
1117878	7/11	Okanagan River mouth	10/3	10/3	Mobile tracked, spawner
1117879	7/18	Highway 97	11/1	10/10	Mobile tracked, spawner
1117880	7/18	Osoyoos North	7/23		Harvested in ONA fishery
1117881	7/12	Okanagan River Mouth	10/6	10/6	Spawner
1117882	7/12	McIntyre Dam	7/19	7/17	Harvested
1117883	7/11	McIntyre Dam	7/20		Mobile tracked, harvested
1117884	8/2	Similkameen	9/12		
1117885	8/2	Osoyoos North	8/20		Harvest or pre-spawn mortality
1117886	8/2	Pateros	8/8		
1117887	8/2	Similkameen	8/8		
1117888	8/2	Pateros	8/12		

Many of our receivers were deployed at confined locations on the migration corridor where we expected to be able to detect all, or nearly all,

passing sockeye salmon. The detection rates for passing acoustic tagged sockeye salmon were 90% or better at six of these sites (Table 26).

Table 26. Detection rate of Okanagan Basin acoustic network passing receivers at narrow confined locations on the upstream migration.

Site	Number of Receivers	Detection Rate	Number Detected
Pateros	1	100.0%[9]	57
Monse Bridge	2	100.0%	44
Oroville pumping station	2	100.0%	46
Haynes Point	1	98.0%	48
Central Basin Highway 3	1	40.8%	20
North Basin Highway 3	1	100.0%	49
Okanagan River Mouth	2	100.0%	43
Okanagan River-Hwy 97	1	78.3%	18
McIntyre Dam	1	92.9%	13
Okanagan Falls	1	71.4%	5

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 passed that site.

Of the 40 sockeye salmon which were both PIT- and acoustic-tagged and detected at OKC (by PIT tag) or upstream of OKC (by acoustic tag), 37 were detected at OKC suggesting a detection efficiency of 92.5% for the OKC PIT tag array for 2011 compared to 90.2% in 2010 (Fryer et al. 2011).

Acoustic and trawl survey for juvenile abundance

A single acoustic trawl survey (ATS) of Lake Wenatchee in 2010 estimated greater juvenile abundance than was found in Lake Osoyoos in 2010 (Table 27). By contrast, paired surveys during Sept and Nov of 2011 indicated juvenile sockeye were over twice as abundant, on average, in Osoyoos Lake, than in Lake Wenatchee. Deep snow prevented access to Lake Wenatchee in between January and March 2012, so no ATS work was completed there to compare against the March 2012 survey at Osoyoos Lake. However, sequential estimates at Osoyoos Lake between Sept 2011 and March 2012 suggest little mortality of sockeye fry in Osoyoos Lake through the fall and winter of 2011-12. Observations to date also indicate that at roughly equivalent levels of abundance, Lake Wenatchee sockeye fry grow to only about half the weight of Osoyoos Lake fry (Figure 8) in keeping with the lower nutrient content, seasonal temperatures and zooplankton food supplies found in Lake Wenatchee.

[9] One tagged sockeye was detected at Monse bridge prior to being detected at Pateros indicating that the fish was missed on the upstream migration but subsequently detected when it dropped back downstream.

Table 27. Estimates of juvenile sockeye salmon abundance from Osoyoos Lake acoustic trawl surveys between April 2010 and March 2012.

Lake	Date	Juvenile Abundance	Fry/ha (95% CI)
Osoyoos	October 21, 2010	1,114,000	1200 (±400)
Wenatchee	Sept 21, 2010	1,637,000	1600 (±200)
Osoyoos	Sept 7, 2011	3,927,296	4232 (±492)
Wenatchee	Sept 20, 2011	2,352,900	2300 (±667)
Osoyoos	Nov 28, 2011	4,754,144	5123 (±576)
Wenatchee	Nov 1, 2011	2,005,080	1960 (±451)
Osoyoos	March 5, 2012	4,130,528	4451 (±456)
Wenatchee	No data	No data	No data

Additional limnological samples will be obtained during the summer through fall of 2012 to serve as the basis for a bioenergetics-based determination of the potential upper limit of the carrying capacity of Lake Wenatchee relative to Osoyoos Lake (e.g. Hyatt et al 2011).

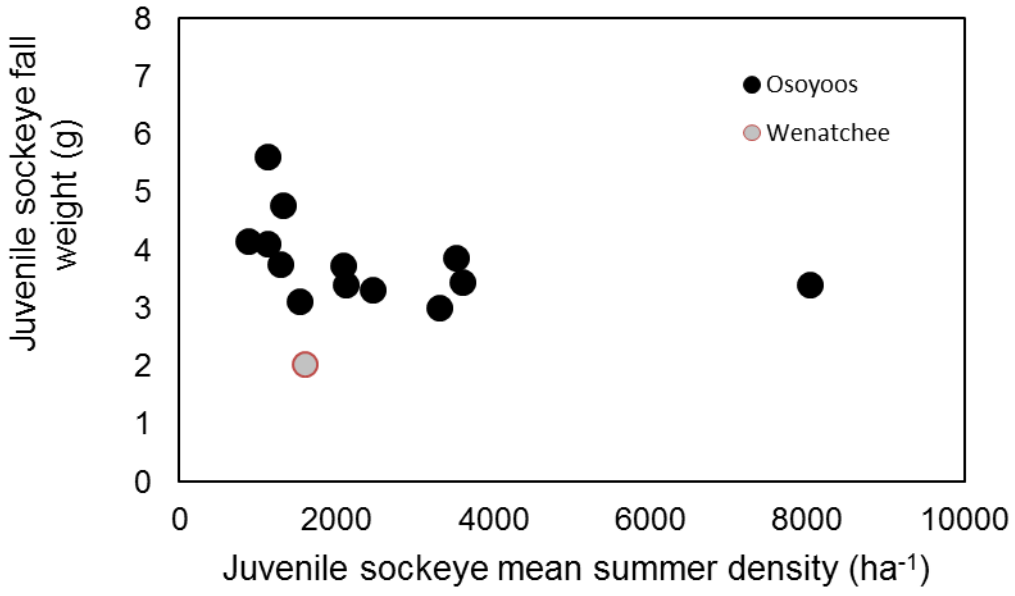


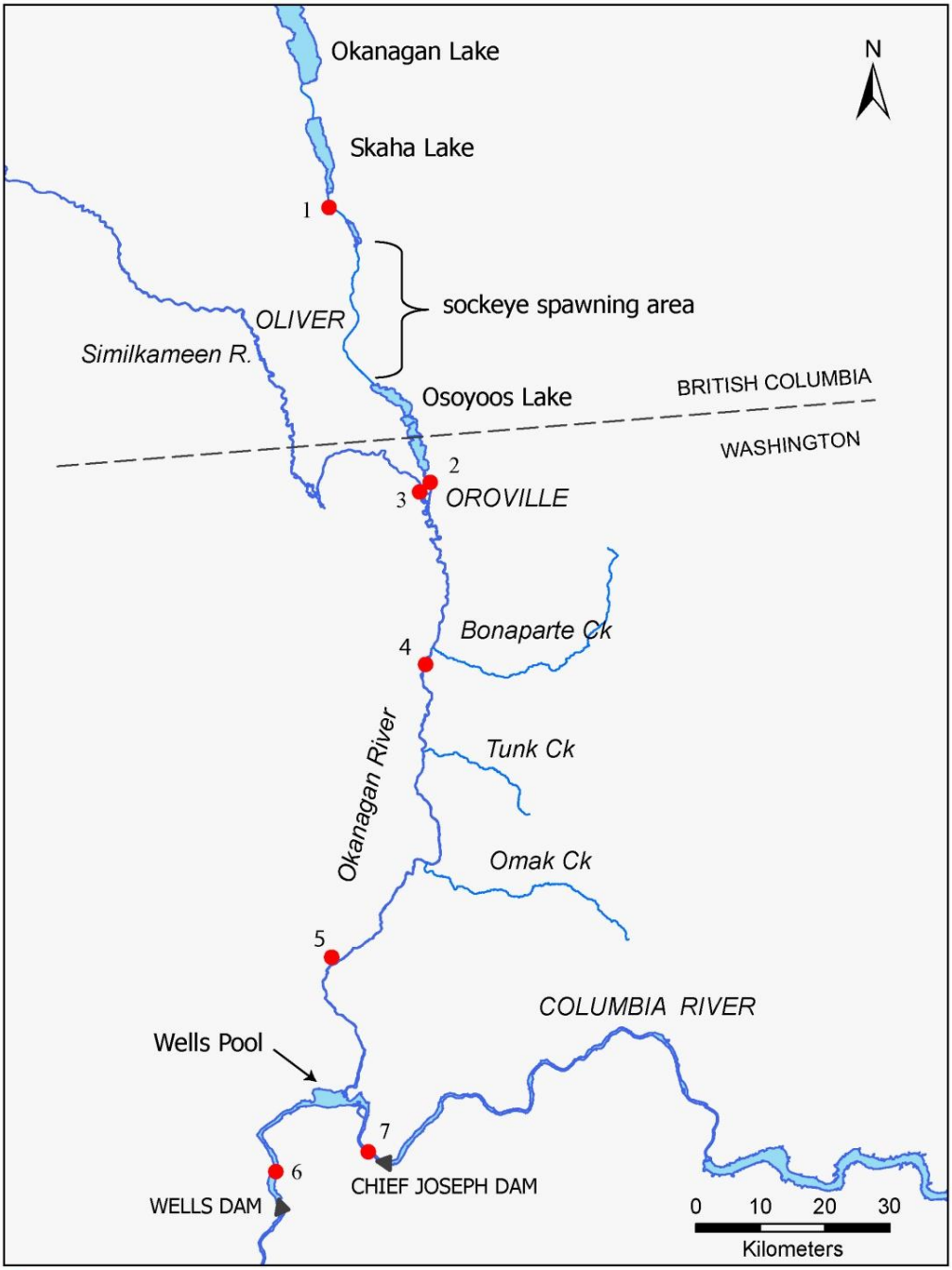
Figure 8. Juvenile sockeye fall weights from Lake Wenatchee by comparison with Osoyoos survey observations to date.

Migration behaviour and thermal history of Okanagan sockeye salmon in 2011

The 2011 tagging program included the application of combinations of PIT tags, archival **i**Button® tags (hereafter simply "button-tags"), and 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 28 and Figure 9).

Table 28. Descriptions of temperature stations found on the map in Figure 9.

Map Number	Location	Administrator	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	Okanogan 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 Okanogan)	http://www.ecy.wa.gov/apps/watersheds/wriapages/index.html
4	Okanogan River at Tonasket (ID 12445000)	USGS Real-Time Data for Washington	http://waterdata.usgs.gov/wa/nwis/rt.
5	Okanogan River near Malott (ID 12447200)		
6	Wells Dam Forebay	Columbia River D.A.R.T., River Environment Data	http://www.cbr.washington.edu/dart/river.html
7	Chief Joseph Tailrace		



● Water Temperature Recording Stations

1. Okanagan River @ Okanagan Falls
2. Okanogan River @ Oroville
3. Similkameen River @ Oroville
4. Okanogan River near Tonasket
5. Okanogon River near Malott
6. Wells Dam Forebay
7. Chief Joseph Tailrace

Figure 9. Map showing the location of temperature stations upstream of Wells Dam and the Okanagan spawning grounds.

Button-tags from Wells Pool

The bulk of the sockeye run returning to the Okanagan River did not pass Wells Dam as early in 2011 (time to 50% passage around July 20th) as they did in 2010 (time to 50% passage around July 10th, Figure 10), Thus, because virtually all button-tagging was completed at Wells Dam between July 6th and 27th, button-tagged fish were drawn from between the 3rd to 85th percentile of the population passing Wells. Twenty-eight of 201 button-tags, applied to adult sockeye at Wells Dam during summer 2011, were subsequently returned from fisheries executed in the Okanagan River immediately upstream of Wells Pool (2 tags), fisheries executed principally in the North Basin of Osoyoos Lake (15 tags, Figure 11), during brood-stock collection in the Okanagan River above Osoyoos lake (4 tags) and during dead pitch of carcasses in the Okanagan River subsequent to spawning (6 tags). In addition, the carcass of one button-tagged

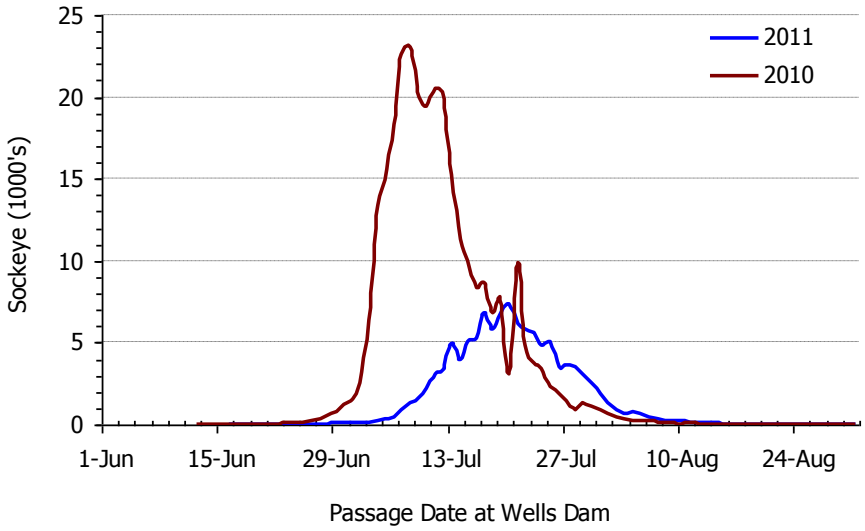


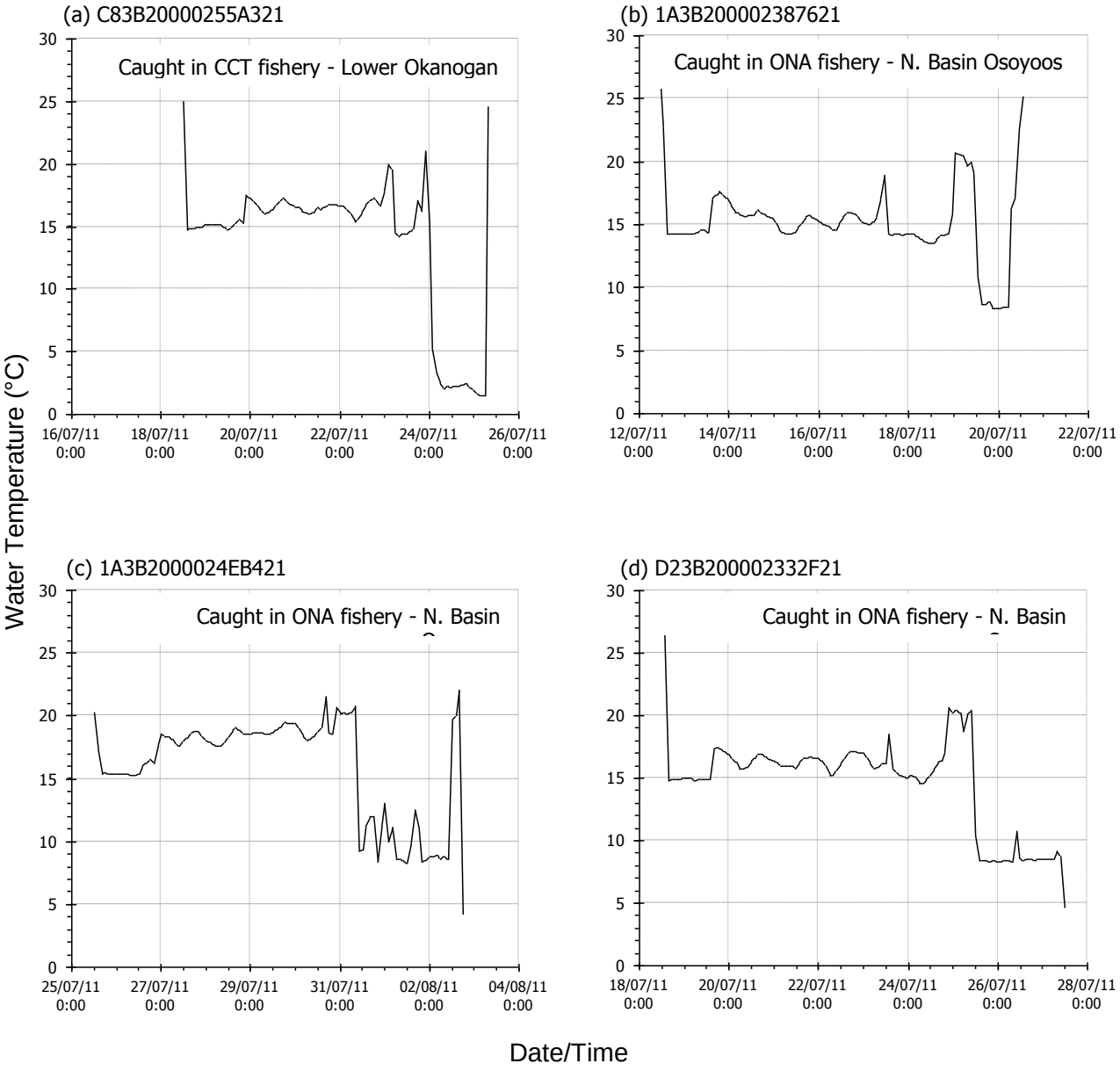
Figure 10. Sockeye migration timing through Wells Dam in 2010 (brown line) and 2011 (blue line). See Table 28 for data source information.

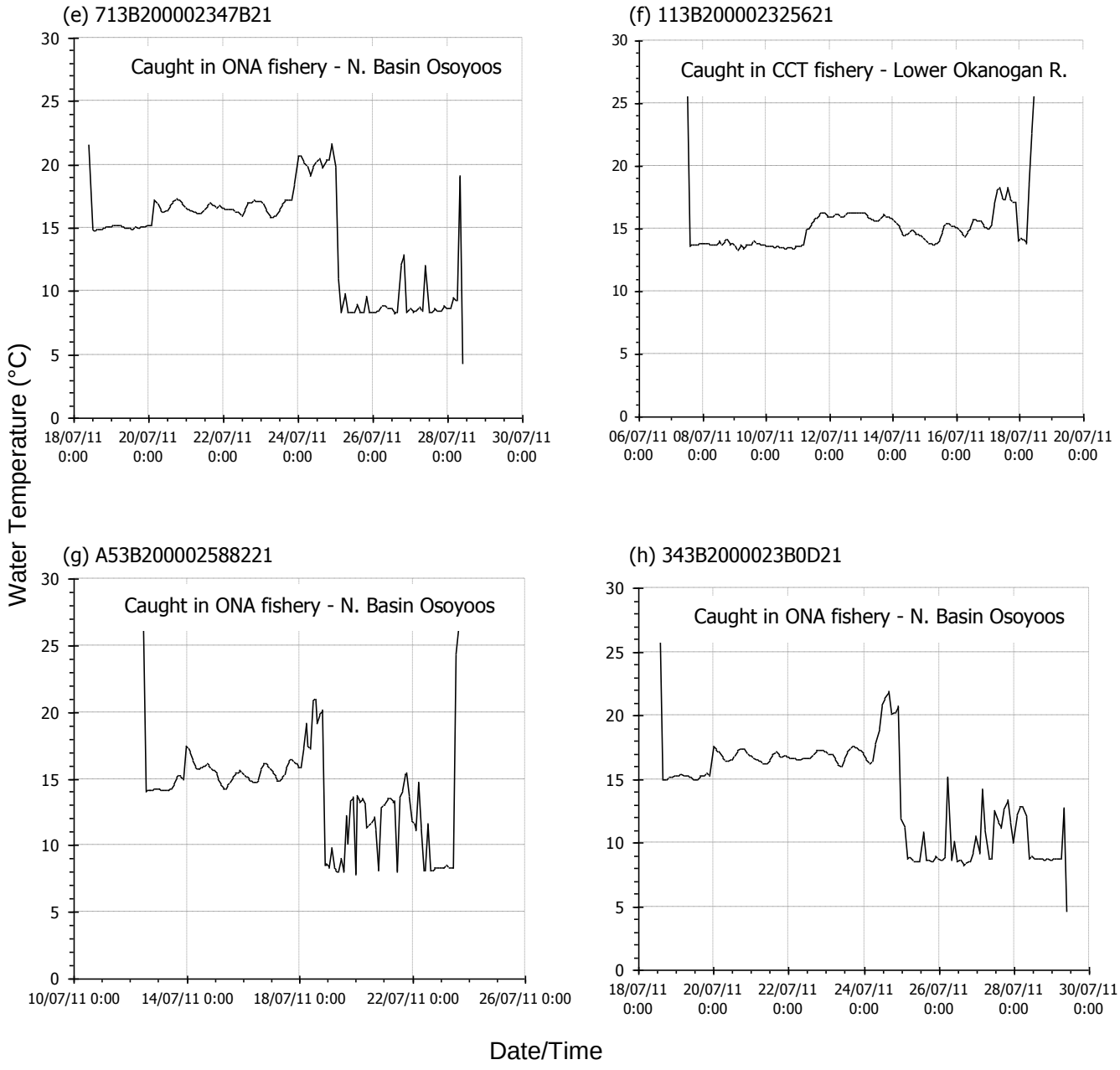
fish was found in the lower Okanogan R. shortly after leaving Wells pool. Records for the remaining 27 button-tag recoveries indicated an initial exposure of adult sockeye to temperatures exhibiting mean values between 13-16 °C (Figure 12 a-z). These values closely approximated daily means of surface temperatures observed for Wells Pool at the Wells Dam Forebay (Figure 13). The absence of a substantive difference between temperatures selected by adult sockeye holding in Wells pool and near-surface temperatures there is not unexpected because turbulent river flow through Wells Pool generally results in

Figure 11. Map of Osoyoos Lake and features.

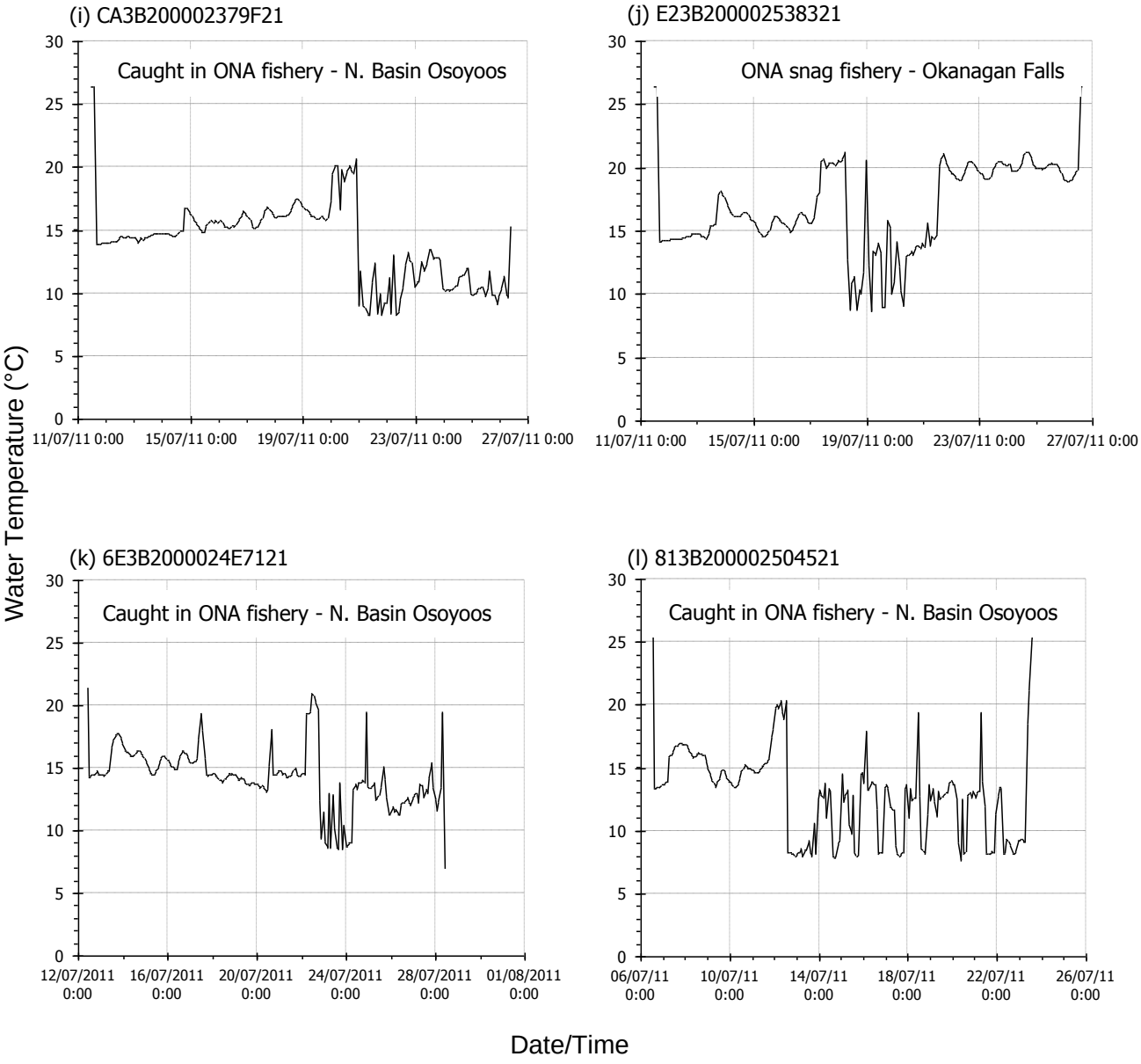
isothermal conditions in these waters from surface to bottom throughout the late summer (West Consultants, 2008). Although it is conceivable that cooler water may have existed in near-bottom locations, near groundwater seeps, none of the subject sockeye adults appear to have located such areas.

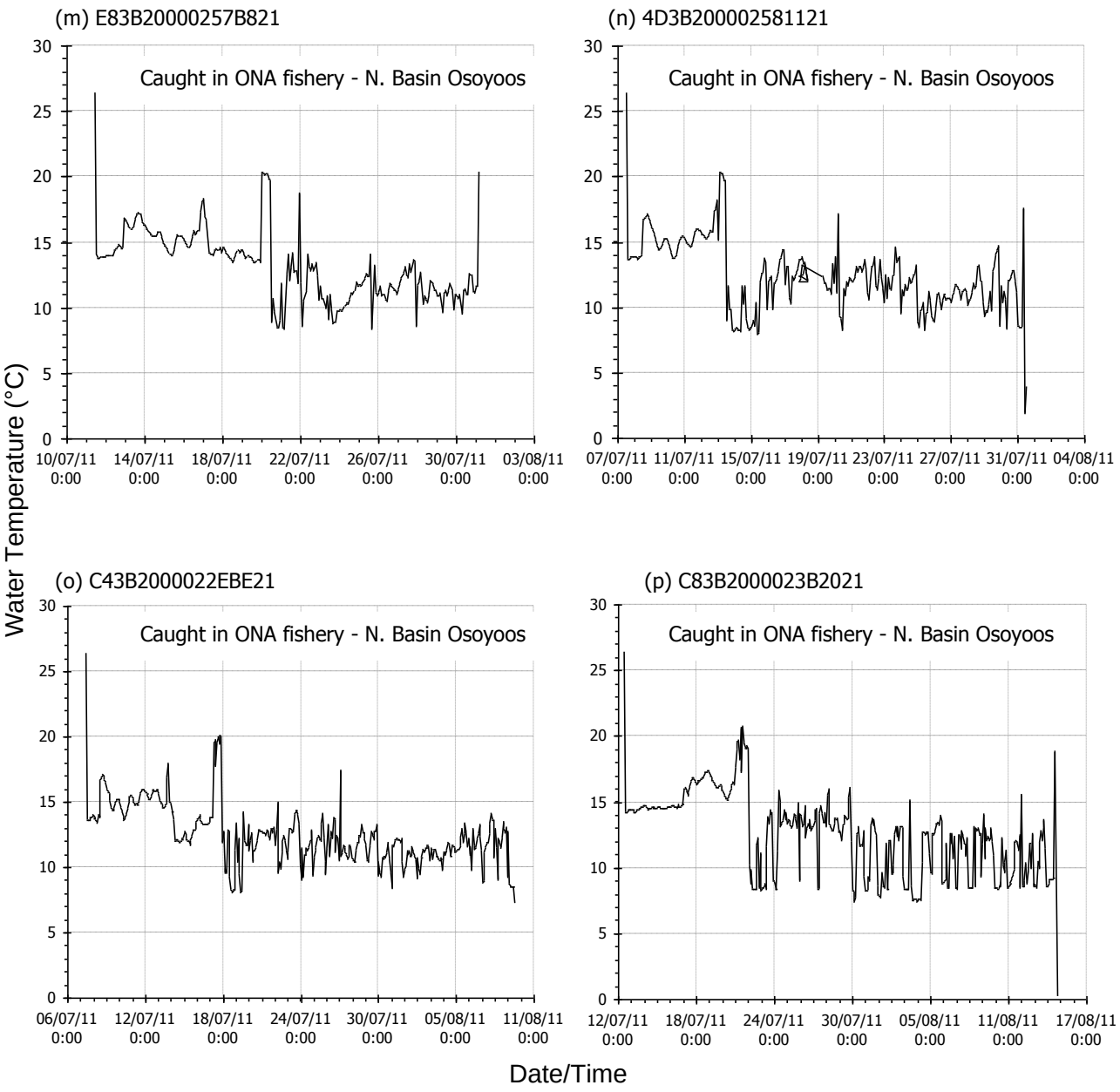
(1) Button-tags retrieved 0-14 days post deployment in Wells Pool



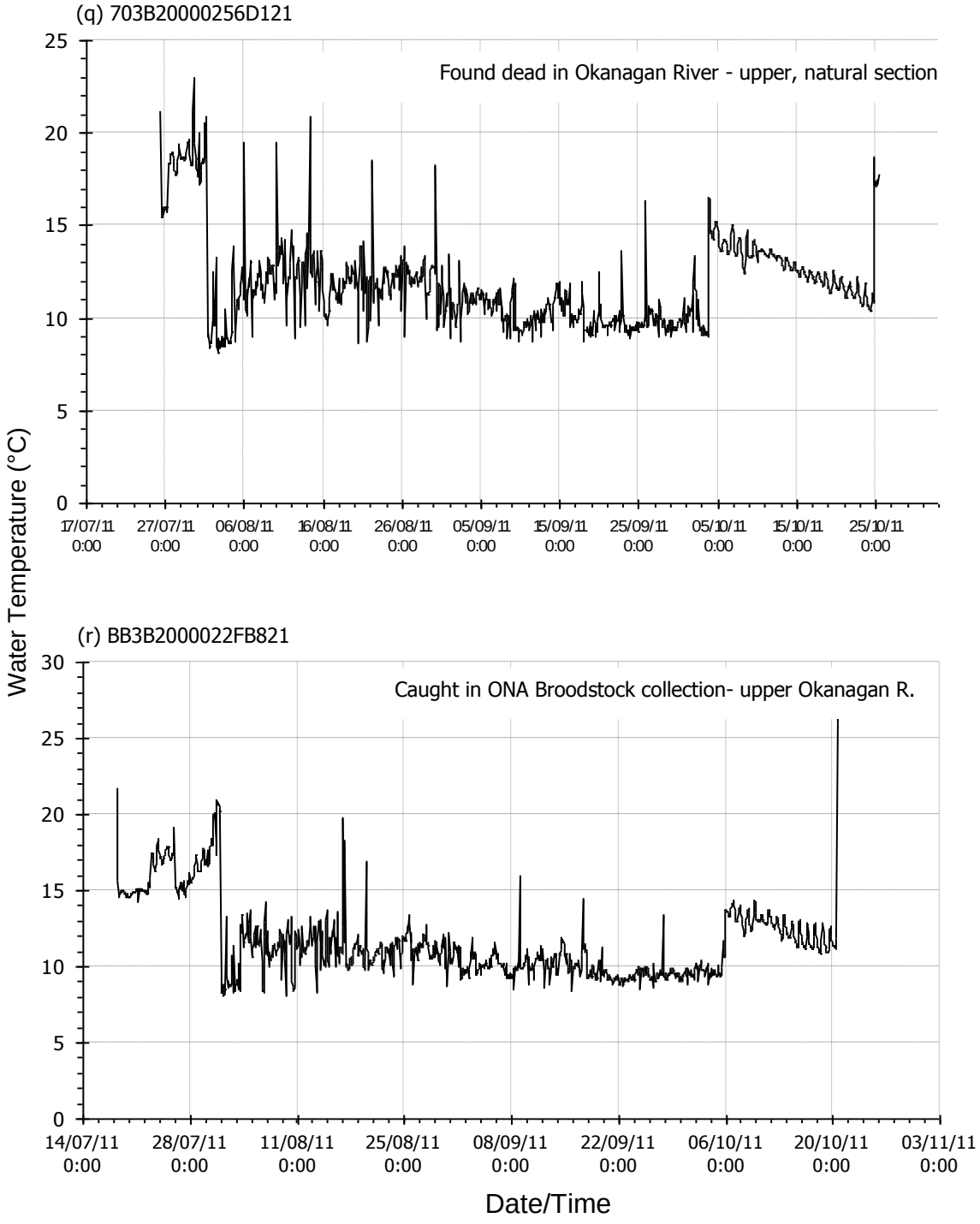

(e) 713B200002347B21
Caught in ONA fishery - N. Basin Osoyoos
(f) 113B200002325621
Caught in CCT fishery - Lower Okanogan R.
(g) A53B200002588221
Caught in ONA fishery - N. Basin Osoyoos
(h) 343B2000023B0D21
Caught in ONA fishery - N. Basin Osoyoos
Water Temperature (°C)
Date/Time

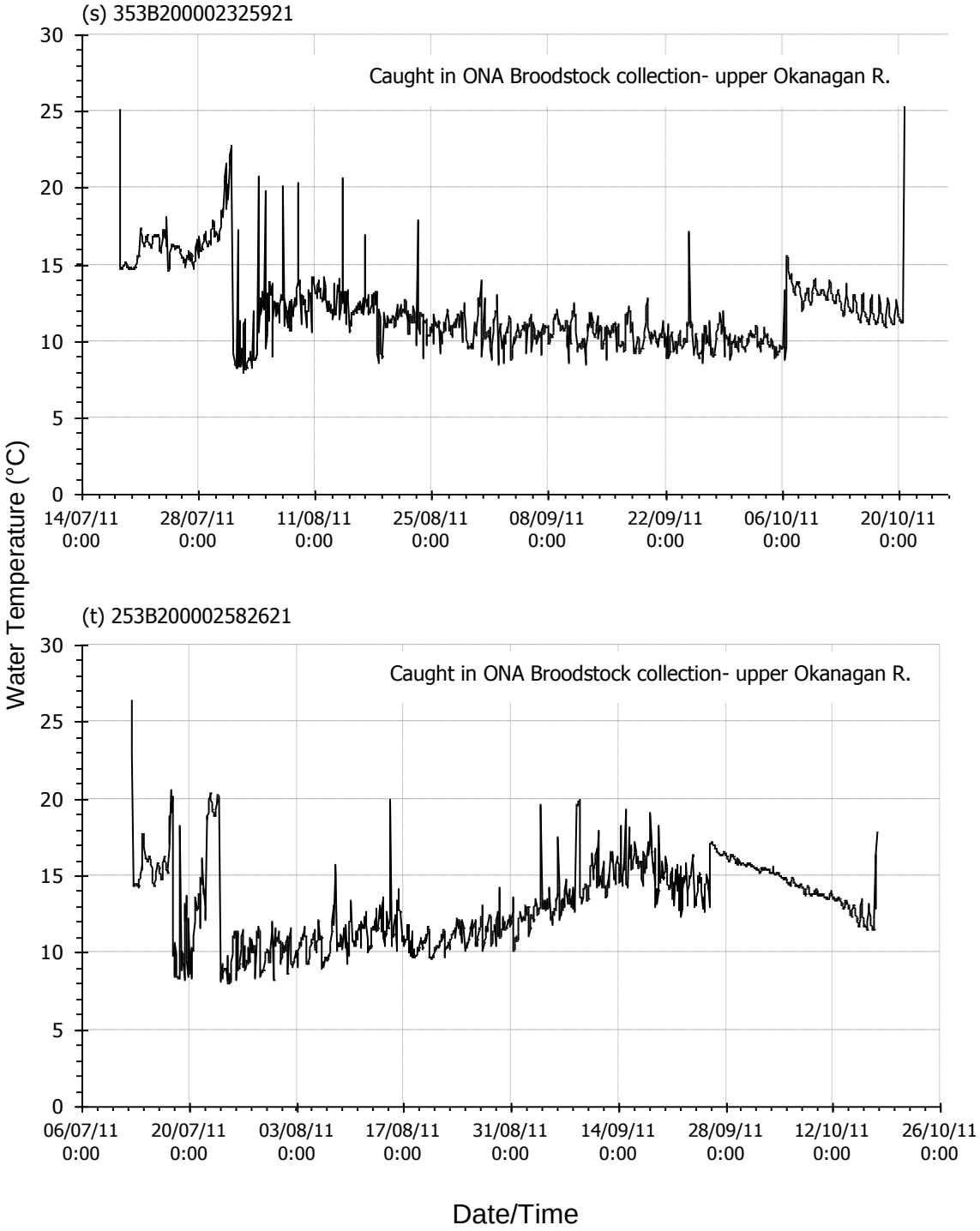
(2) Button-tags retrieved 15-33 days post deployment in Wells Pool

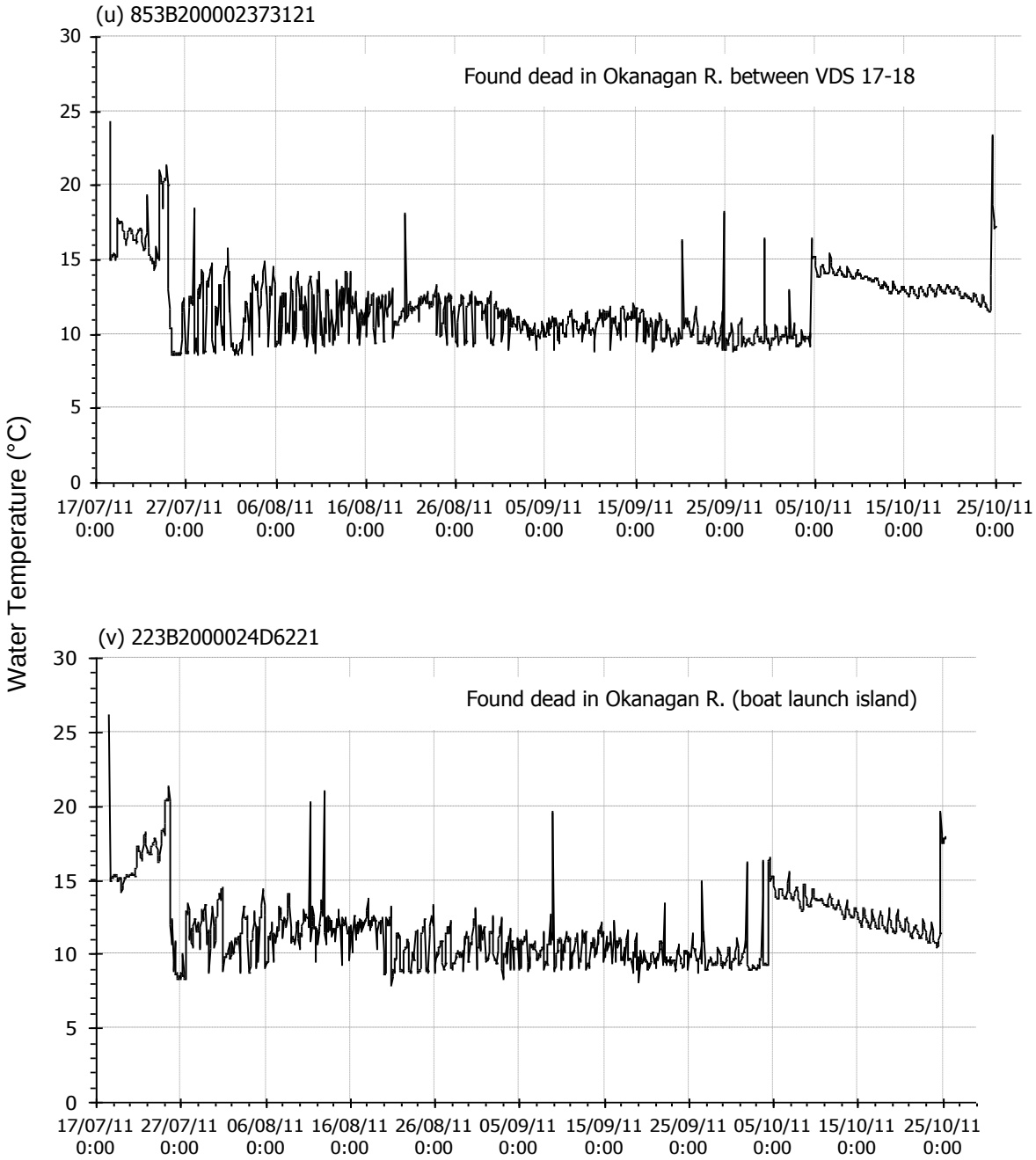


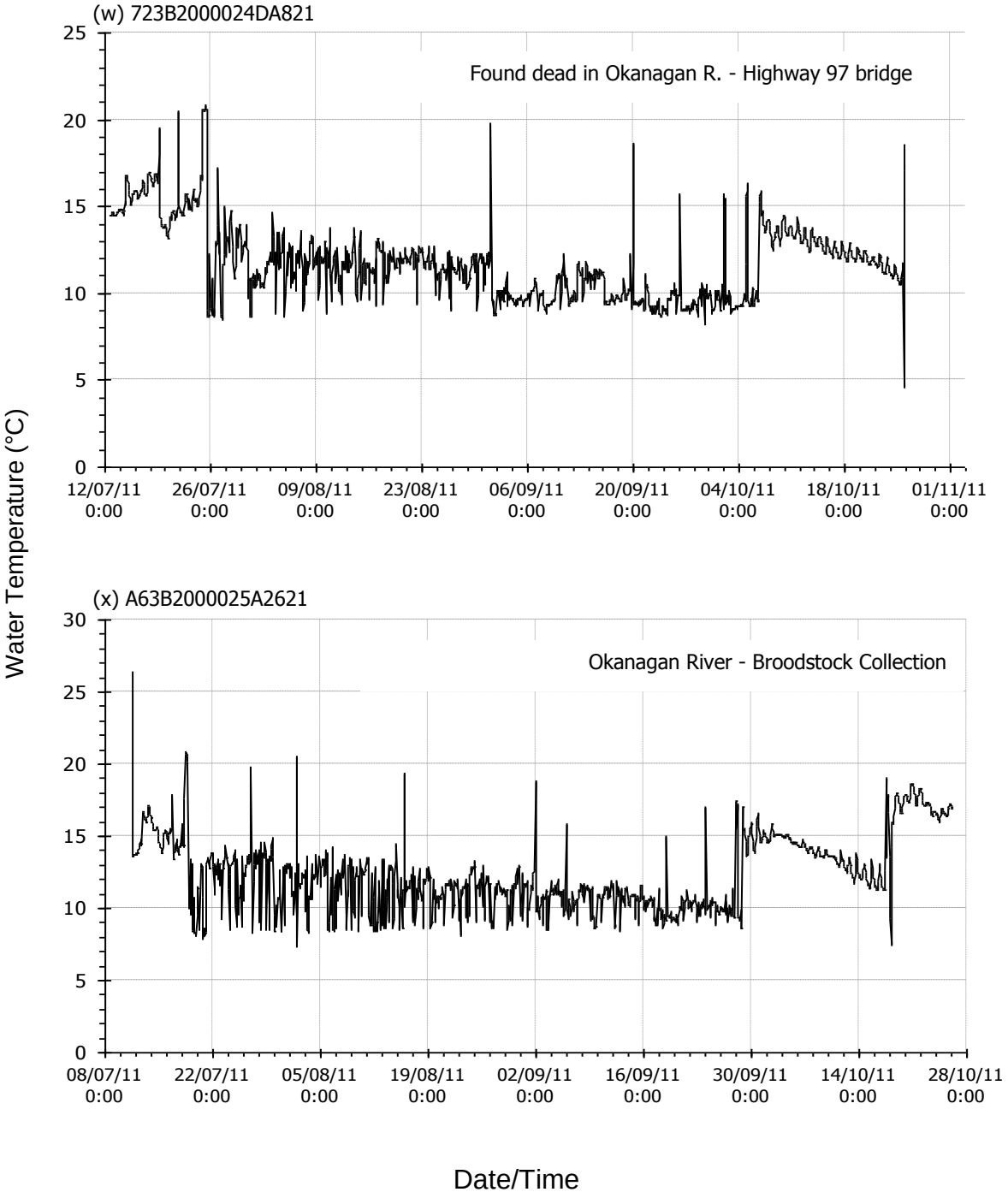

(m) E83B20000257B821
Caught in ONA fishery - N. Basin Osoyoos
(n) 4D3B200002581121
Caught in ONA fishery - N. Basin Osoyoos
(o) C43B2000022EBE21
Caught in ONA fishery - N. Basin Osoyoos
(p) C83B2000023B2021
Caught in ONA fishery - N. Basin Osoyoos
Water Temperature (°C)
Date/Time

(3) Button-tags retrieved 91-107 days post deployment in Wells Pool




(s) 353B200002325921
Caught in ONA Broodstock collection- upper Okanagan R.
(t) 253B200002582621
Caught in ONA Broodstock collection- upper Okanagan R.
Water Temperature (°C)
Date/Time
0
5
10
15
20
25
30
14/07/11 0:00
28/07/11 0:00
11/08/11 0:00
25/08/11 0:00
08/09/11 0:00
22/09/11 0:00
06/10/11 0:00
20/10/11 0:00
06/07/11 0:00
20/07/11 0:00
03/08/11 0:00
17/08/11 0:00
31/08/11 0:00
14/09/11 0:00
28/09/11 0:00
12/10/11 0:00
26/10/11 0:00


(u) 853B200002373121
Found dead in Okanagan R. between VDS 17-18
(v) 223B2000024D6221
Found dead in Okanagan R. (boat launch island)
Water Temperature (°C)
0
5
10
15
20
25
30
17/07/11 0:00
27/07/11 0:00
06/08/11 0:00
16/08/11 0:00
26/08/11 0:00
05/09/11 0:00
15/09/11 0:00
25/09/11 0:00
05/10/11 0:00
15/10/11 0:00
25/10/11 0:00
Date/Time


(w) 723B2000024DA821
Found dead in Okanagan R. - Highway 97 bridge
25
20
15
10
5
0
12/07/11 0:00
26/07/11 0:00
09/08/11 0:00
23/08/11 0:00
06/09/11 0:00
20/09/11 0:00
04/10/11 0:00
18/10/11 0:00
01/11/11 0:00
(x) A63B2000025A2621
Okanagan River - Broodstock Collection
30
25
20
15
10
5
0
08/07/11 0:00
22/07/11 0:00
05/08/11 0:00
19/08/11 0:00
02/09/11 0:00
16/09/11 0:00
30/09/11 0:00
14/10/11 0:00
28/10/11 0:00
Water Temperature (°C)
Date/Time

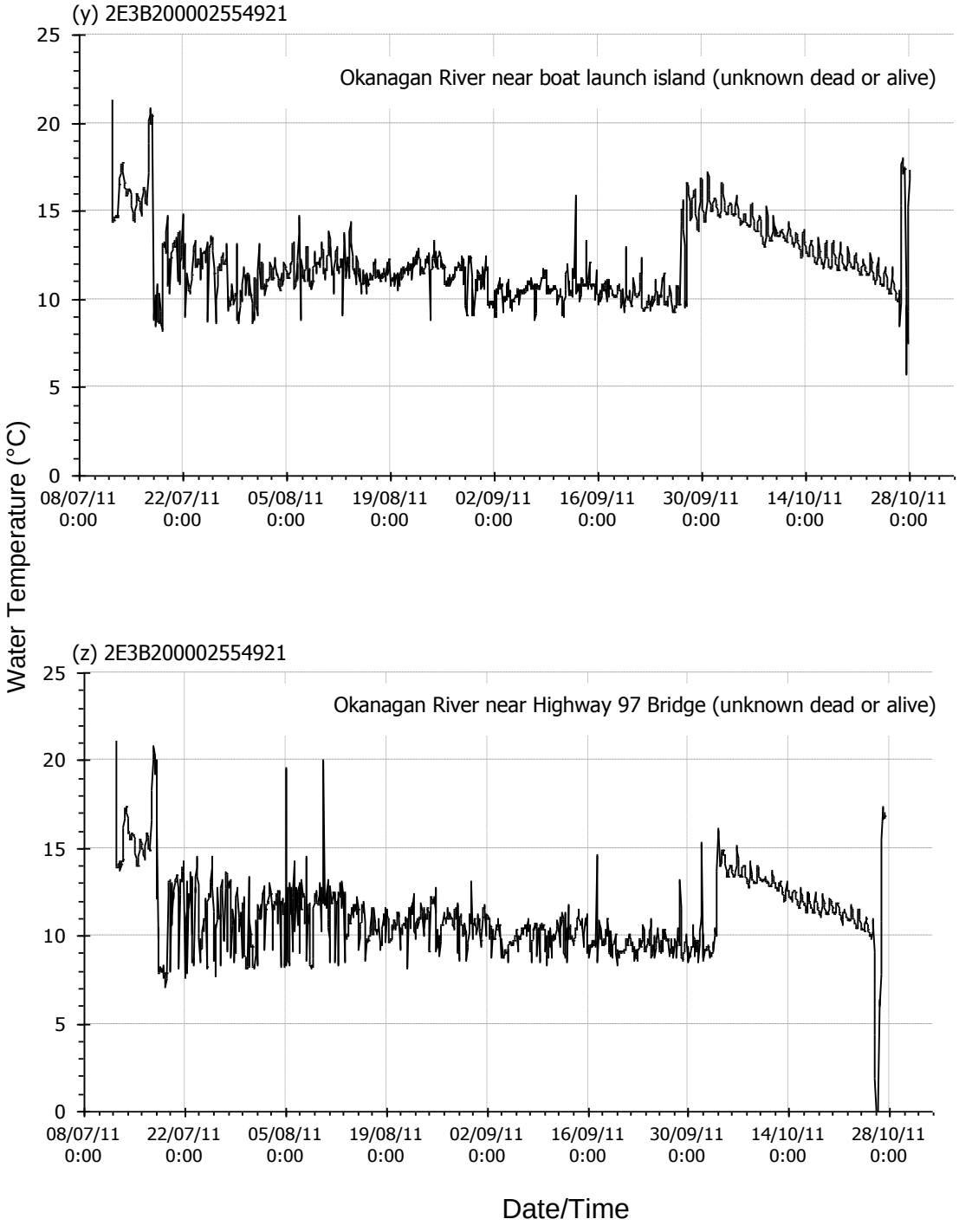


Figure 12. Temperature profiles from tags of 26 individual sockeye salmon migrating from Wells Dam Pool to the Okanagan River spawning grounds between July and October 2011. Tags are grouped by (1) 0-14 days post deployment at Wells; (2) 15-33 days post deployment; and (3) 90-110 days post deployment to catch or death.

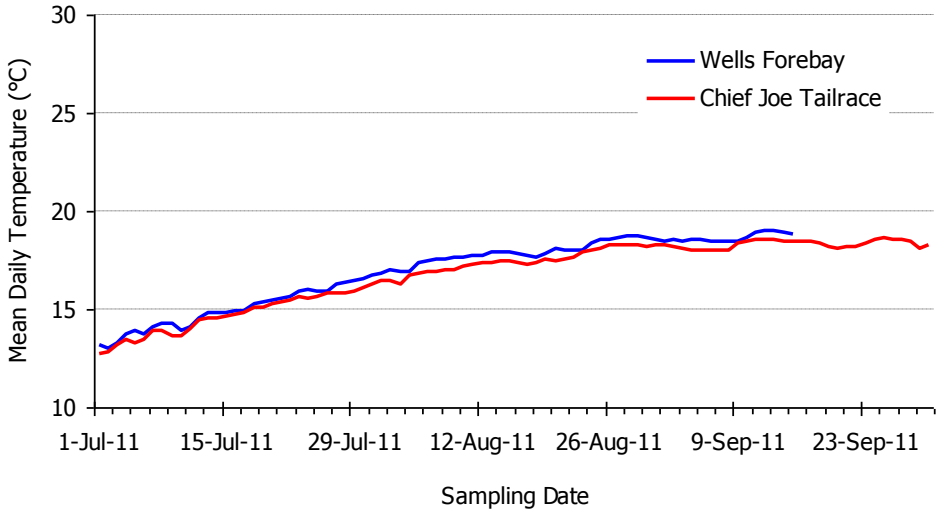


Figure 13. Water temperatures measured between Wells and Chief Joseph dams at the same time period as button-tagged sockeye were present (see Table 28 for source data information).

Hyatt et al. (2003) have described several sets of historic results that suggest active migration of sockeye adults exiting Wells Pool on the Columbia River may virtually stop as seasonal water temperatures in the Okanagan River between Malott and Oroville increase and exceed 21°C. Migration appears to restart when seasonal temperatures decrease and fall below 22 °C. During the summer of 2011, temperatures in the Okanagan River between Malott and Oroville generally remained below 21°C until after July 27th (Figure 14) which should have promoted a continuous migration by button-tagged fish with little evidence of excessive delays. Although Okanagan River temperatures were low enough to promote continuous migration in 2011, they were still elevated sufficiently above Wells Pool temperatures (compare same date temperatures in Figures 13 and 14) to indicate times of entry by adult sockeye into the Okanagan River or conversely their length of stay in Wells Pool. All adult sockeye from which button-tags were recovered in 2011 remained in Wells Pool for less than 1 day to a maximum of four days after tagging (Figure 12 a-z). This contrasted sharply with results from 2010 when fish tagged at Wells Dam remained in Wells Pool for 3-23 days before either being caught by the CCT fishery in Wells Pool or entering the Okanagan River (Fryer et al. 2011). Extended holding by adult sockeye in Wells Pool during 2010 allowed the CCT fishery to harvest 16,214 sockeye from a total run of 291,764. By contrast, in spite of the occurrence of another relatively large run of 111,508 sockeye through Wells Dam in 2011, the CCT fishery was able to harvest only 845 sockeye because fish moved through

Wells Pool without an extended interval of holding (Michael Rayton, CCT, pers. comm.).

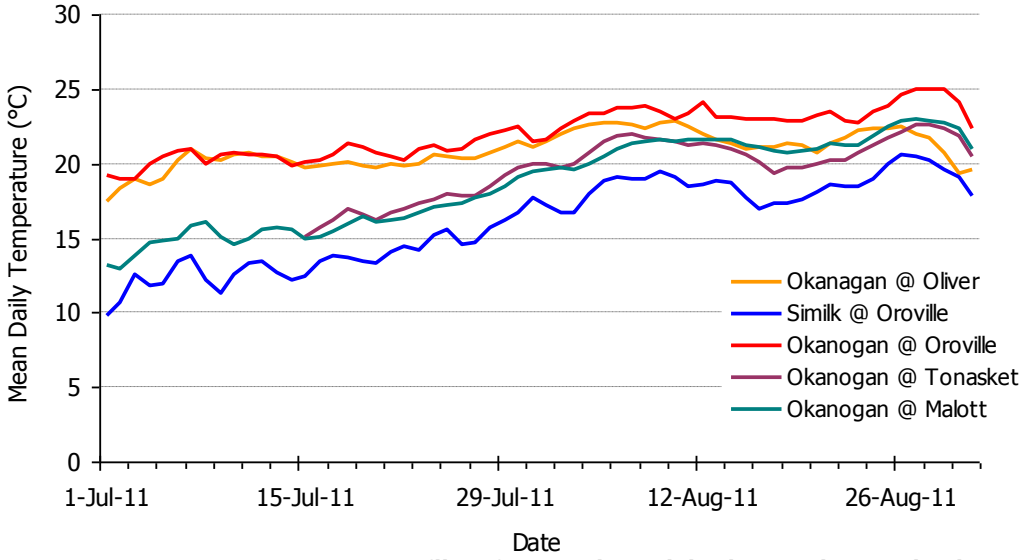


Figure 14. Water temperature profiles from selected hydrometric monitoring stations within the Okanagan River sockeye migration region (see Table 28 for source data information.

Button-tags from Okanagan River-Osoyoos Lake

Wells Pool, key locations upstream in the Okanagan River (USGS monitoring stations), tributaries to the Okanagan River (e.g. Similkameen R.) and Osoyoos Lake all exhibit distinctive seasonal thermal "signatures" (Figures 9, 13, 14, and 15). Thus, the thermal history from each button-tag, upon return, may be used to characterize the migrations of individual fish in both space and time. Without exception, all button-tagged fish exhibited a persistent >2 $^{\circ}$C elevation in temperature after leaving Wells pool and entry into the Okanagan River during the July 7 - 27th interval (compare same-day temperatures at Wells Dam fore-bay in Figure 15 and, the Okanagan River at Malott in Figure 14). Button-tagged sockeye that moved further up the Okanagan River encountered temperatures ranging between <18 $^{\circ}$C at Malott and <20 $^{\circ}$C at Oroville (Figure 14) during a migration interval between Wells Pool and the confluence of the Similkameen River (temps generally 3-4 $^{\circ}$C lower than the Okanagan R. at Oroville, Figure 16), that lasted an average of 5 days (range 3-9 days, Figure 12 a-z). Upstream of the Similkameen-Okanagan, confluence, sockeye encountered temperatures between 20-23 $^{\circ}$C for between 18-48 hours (Figure 12 a-z) as they approached Zosel Dam, and then traversed the surface waters of the south and central basins of Osoyoos Lake. Entry of button-tagged sockeye into the north Basin of

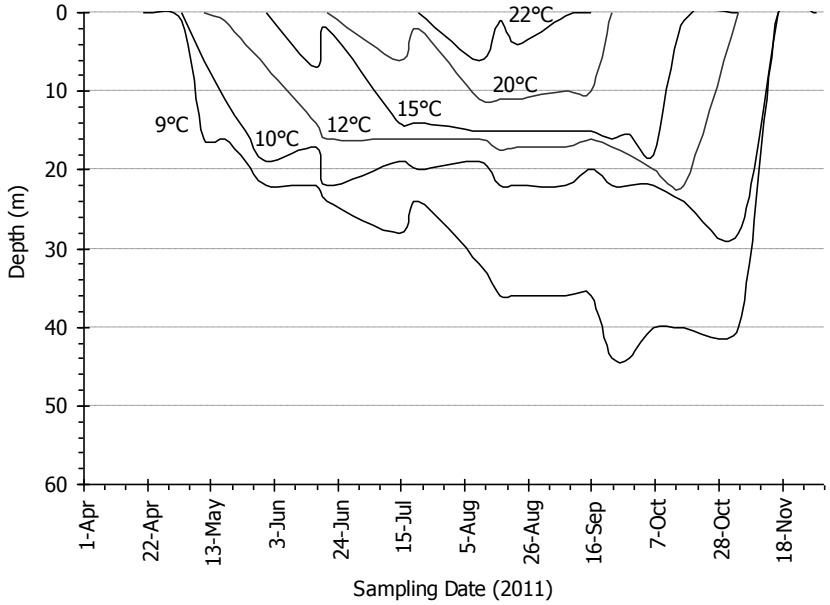


Figure 15. Water temperature and depth measured in the north basin of Osoyoos Lake at the same time period as button-tagged sockeye were present.

Osoyoos Lake in all cases was marked by a minimum 5-12 degree drop in temperatures (i.e. from >20 °C to 8-15 °C) as adult sockeye descended to hold in deeper, cooler waters there (Figure 15). Thus, tracking temperature signatures of button-tagged sockeye, after tagging, suggests they required an average of 7 days to cover the distance from Wells Dam to Osoyoos Lake which compares favorably to the more precisely estimated average of 6.2 days recorded for 30 sockeye to cover the same distance following application of acoustic tags at Wells Dam and their detection between July 9-27th, 2011 by receivers installed at Haynes Point (Figure 11).

Button and acoustic-tag observations from Osoyoos Lake

Button-tagged adult sockeye remained in Osoyoos Lake for an average of 33.72 days (range 0.5 to 78.0). Fourteen of 24 button-tagged fish that entered the north basin of Osoyoos Lake were either (a) removed at variable times after lake entry (0.5 to 23.6 days, Figure 12 a-p) by the Okanagan Nation Alliance fishery in Osoyoos Lake or (b) were recovered on the Okanagan River spawning grounds in October (10 of 24 button-tagged fish) after a longer interval of lake residence (63.8 – 73.0 days, Figure 12 q-z). Temperatures potentially available to button-tagged sockeye, while in the north basin of Osoyoos Lake, ranged from < 8°C at the lake bottom (around 52 m) in June through November to maxima in excess of 23°C at the lake surface from mid-July to mid-Sept (Figure 15). However, the fish spent greater than 80% of their time between 8.5°C and 15°C

(Figure 12 a-z) and registered an average temperature of 10.8°C (n = 8,959 from 23 tagged fish) over their entire in-lake interval. Button-tagged sockeye exhibited no significant differences between day and night intervals. Sockeye that held in Osoyoos Lake for less than 25 days exhibited no clear trend in temperatures selected over time (Figure 12 a-p), However, 9 of 10 fish present for intervals lasting longer than 60 days displayed a clear tendency to select a lower mean and narrower range of temperatures with increasing time elapsed between lake entry in late July (mean temp selection around 12°C) and late September (mean temp selected around 9.5°C) just prior to lake exit to the spawning grounds (Figure 12 q-z).

An array of six receivers (Table 29) deployed on the bottom of the north basin of Osoyoos Lake recorded 35,849 signal detections from 22 adult sockeye tagged earlier at Wells Dam with VEMCO acoustic transponders. These observations indicate depth and associated temperatures for adult sockeye holding in Osoyoos Lake, prior to spawning, over an average interval of 55 days (range 1-103) during mid-June to mid-October of 2011. The average temperature across all instantaneous depths, occupied by adult sockeye while holding in the north basin, was 11.2°C (Figure 16a, range 6 – 21°C). Temperatures available to fish during this period ranged from a low of 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 14). Sockeye tag #1117871 (signal detections over 101 days) exhibited the most stenothermal pattern of depth-temperature selection (Figure 16b) while sockeye tag #1117873 (signal detections over 71 days) exhibited the most eurythermal pattern of depth-temperature selection (Figure 16c). Although water >14°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 < 8°C may be an artifact due to the very small volume of water exhibiting temperatures less than 8°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.

Table 29. Locations of acoustic receivers, average temperature of observations by receiver and number of observations received in 2011 from acoustic-tagged sockeye in Osoyoos L.

Station Name	Observation	Value
North Basin, Highway 3	mean temperature (^{0}C) no. of observations	16.35 157
North Basin, Mica Creek	mean temperature (^{0}C) no. of observations	11.21 6,890
North Basin, Inkaneep Creek	mean temperature (^{0}C) no. of observations	10.83 17,079
North Basin, West Coop Packing Plant	mean temperature (^{0}C) no. of observations	11.07 8,676
Okanagan River Mouth Near Launch	mean temperature (^{0}C) no. of observations	13.29 1,730
Okanagan River West Bank at Launch	mean temperature (^{0}C) no. of observations	13.47 1,317
Average Temp Across All Records		**11.20**
Total Observations		**35,849**

Hydroacoustics observations from Osoyoos Lake

Hydroacoustics surveys have been completed on several surveys 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) have published descriptions of: survey dates, instruments, transect locations and procedures for processing acoustic records and biological samples. However, here we provide results from a Sept. 7th, 2011 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 and purse seining activities at times when adult sockeye were present in the late summer of 2011 confirmed that pre-spawning adult sockeye represented the vast majority of large fish present in Osoyoos Lake (H. Wright, ONA, pers. comm.)

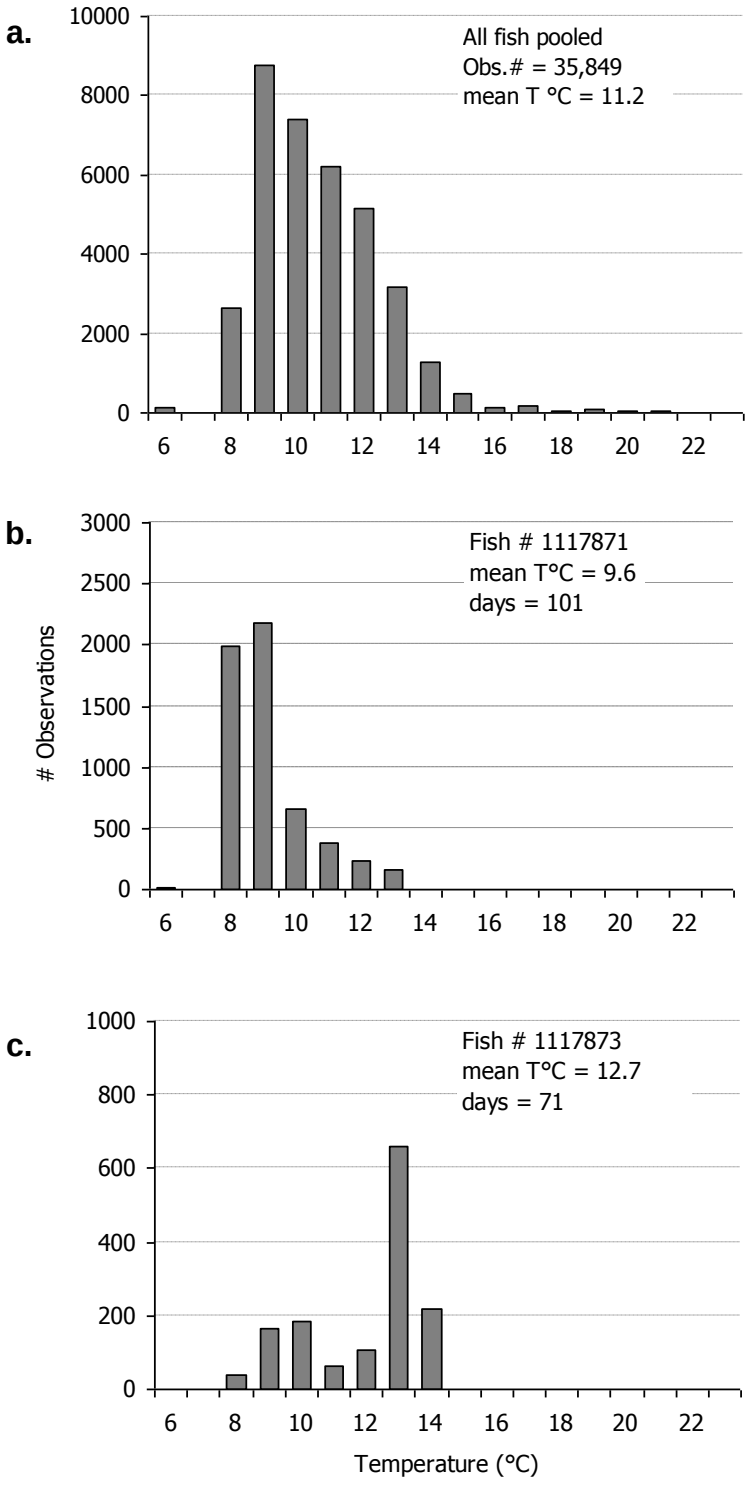


Figure 16. Depth/temperature patterns of acoustically-tagged adult sockeye salmon in the north basin of Osoyoos Lake; (a) all tags and two individual sockeye salmon (b) and (c).

On the night of Sept. 7th, 431 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 17). Temperatures available to fish at this time ranged from a low of less than 9°C, at depths >36 m, to >22°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 10.12°C (Figure 17, range 9.3-17.5) and more than 90% of all ASLT's occupied depth intervals exhibiting temperatures of 9-11.5°C. Although water >11.5°C and <9.0°C was available throughout Osoyoos Lake at depths <12m and >36m respectively (Figure 17), adult sockeye generally avoided such depth-temperature combinations (<12% of all observations). These results, reflecting temperature-depth choices of 431 individual fish on the night of Sept 7th, are generally consistent with a much larger volume of repeated observations of temperature-depth choice made on smaller numbers of button-tagged and acoustic-tagged sockeye present in the north basin of Osoyoos Lake during Sept. of 2011 (Table 30).

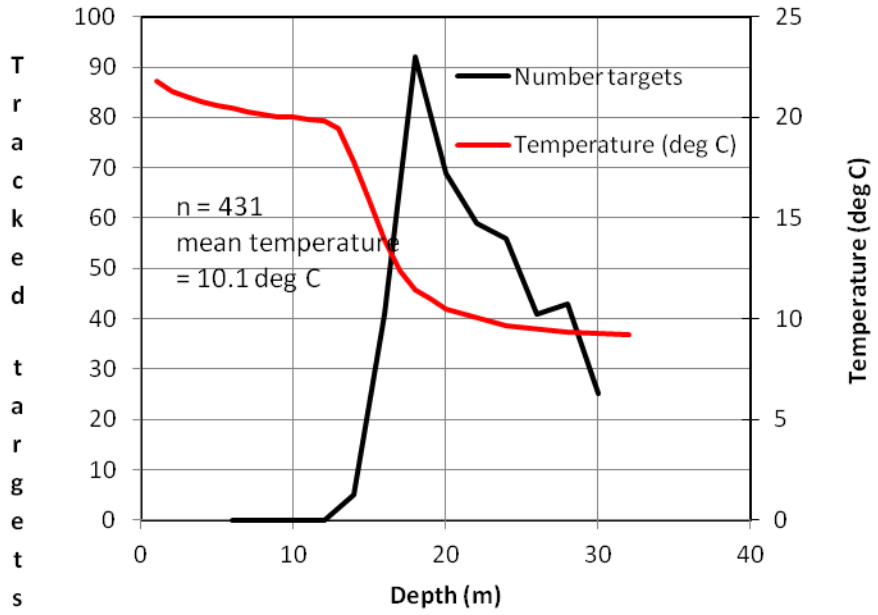


Figure 17. Depth distribution and associated temperatures of acoustic targets identified as adult sockeye in the north basin of Osoyoos Lake during the night of Sept 7, 2011.

Table 30. A comparison of button-tag, acoustic-tag, and hydroacoustic-survey results of temperatures selected by adult sockeye holding in Osoyoos L. in September of 2011.

Observation Type	# of Observations	# of Adult Sockeye	Mean Temp (°C)	Standard Deviation
Button Tags	3,240	9	10.3	1.24
Acoustic Tags	13,054	14	10.92	1.37
Hydroacoustic Surveys	431	431	10.12	1.25

Observations from the Okanagan River spawning grounds

Ten of 26 button-tagged sockeye were recovered from the Okanagan River spawning grounds near Oliver, B.C. in 2011. We inferred dates of river entry based on sudden, persistent changes in button-tag temperatures from multi-day averages of 9-10°C, available only at depth in Osoyoos Lake, to averages of between 14-17°C, characteristic of the surface of Osoyoos Lake and the Okanagan River during late-Sept to mid-Oct (Figure 12 q-z). According to these observations, button-tagged sockeye entered the Okanagan River during an 11 day interval from Sept. 26th to Oct 6th when temperatures ranged between 14.0-17.0 °C (mean of 14.9°C). There was also evidence of relatively synchronous activities for 7 out of 10 button-tagged fish that apparently entered the Okanagan River during just a 3 day interval between Oct. 4th to 6th (Figure 12, panels q, r, u, v, w, z).

Direct visual observations to assess the distribution and abundance of adult sockeye spawning in the Okanagan River indicated that adult sockeye began to arrive on their spawning grounds near Oliver around the end of September in 2011 (Figure 18). River temperatures had declined, at this time, to less than 15°C from earlier maxima in excess of 23°C. Adult sockeye numbers continued to rise as temperatures declined from late-September to late-October with peak recruitment and spawning activity occurring during the Oct. 21st spawning ground survey coincident with river temperatures of 12°C. Active spawning was virtually complete by Nov. 4th when river temperatures had declined to less than 8°C.

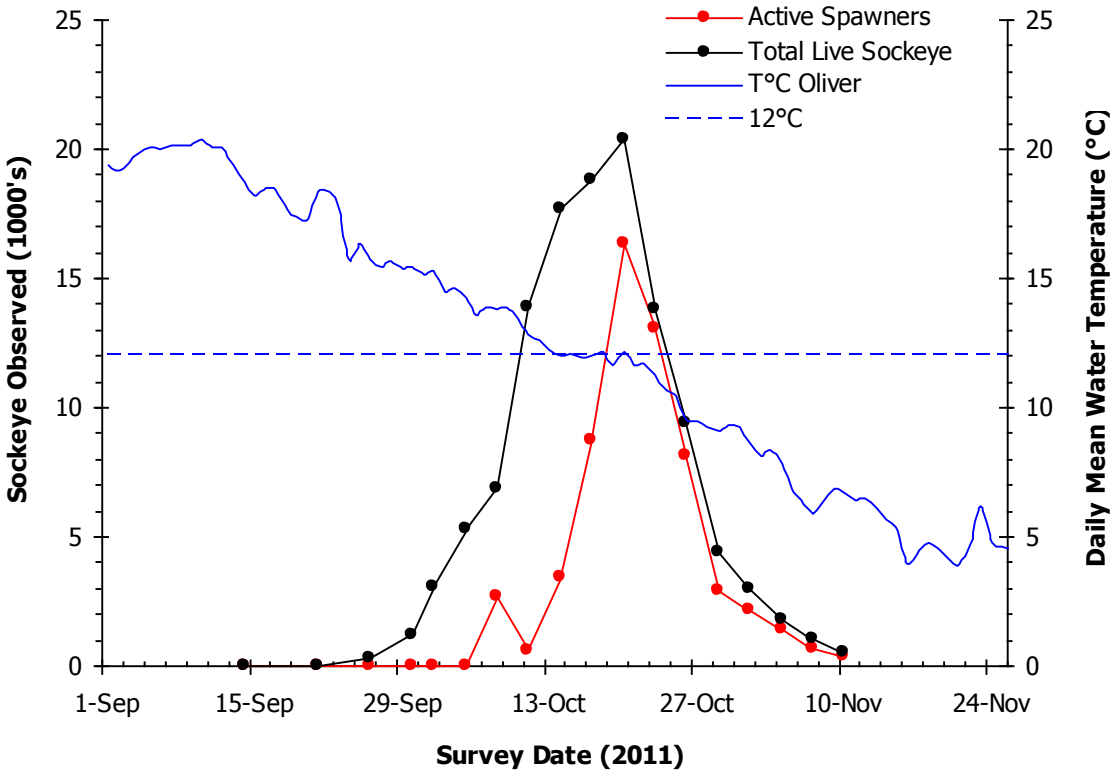


Figure 18. Spawning sockeye activity compared to water temperatures on the spawning grounds in the Okanagan River near Oliver.

DISCUSSION

This completes the third year of this study. 2011 was the first full year in which we had fully operational PIT tag detection sites whose installation and maintenance is funded by this project at Zosel Dam (ZSL) and OKC in the Okanagan River near Oliver, B.C. The OKC site worked well during the sockeye migration, with detection rates above 90% for acoustic+PIT tagged sockeye despite high flows increasing the likelihood of sockeye traveling higher in the water column, thus decreasing the probability of detection. The ZSL detection site was disappointing as the vast majority of sockeye salmon passed upstream through the spillway due to high flows. This event has led to discussion of expanding the ZSL site to include detection of PIT tagged fish moving through the western spillway. If the expansion were done, the site could also be used to detect smolts tagged above Zosel Dam that migrate through the spillways.

Wenatchee-Okanagan stock composition estimates produced by this study for 2011 (21.9% Wenatchee and 76.8% Okanagan) differed from those using visual counts at dams (9.5-12.7% Wenatchee and 87.3-89.2% Okanagan, Table 14). A possible explanation for this difference is that we may not be getting a representative sample of the stocks at the Bonneville Dam Adult Fish Facility on the Washington Shore ladder. However, analysis of the data from Wenatchee sockeye salmon PIT tagged as juveniles, estimates that 55.4% of these fish were detected in Washington shore fish ladders, which is very close to the visual counts that estimated that 55.7% of all sockeye salmon used the Washington shore ladders. Furthermore, the cumulative run distribution of previously PIT tagged Wenatchee sockeye salmon was nearly identical to that of Wenatchee sockeye salmon passing Bonneville Dam estimated by this study (Figure 19). This would suggest that our sample should be representative of the previously PIT tagged Wenatchee sockeye salmon. However, all previously tagged fish are of hatchery origin, which make up only a small portion of the entire Wenatchee run and may not represent the natural run component.

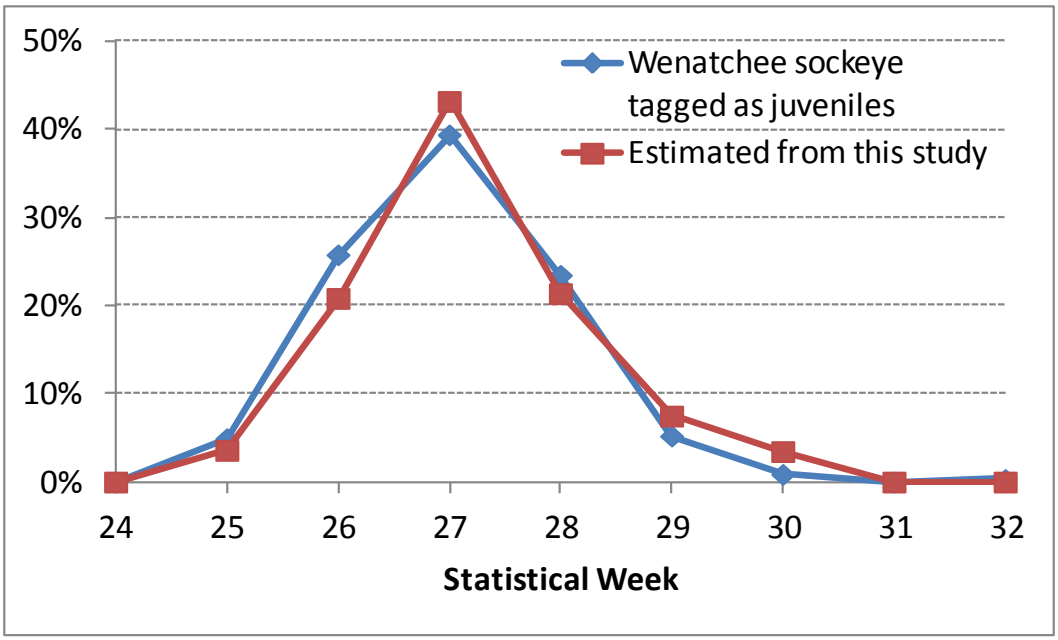


Figure 19. Cumulative distribution of Wenatchee sockeye salmon at Bonneville Dam in 2011.

A total of eight sockeye salmon tagged at Bonneville Dam and detected at Wells Dam were subsequently detected at locations other than the Okanagan Basin (Table 31 and Figure 20). All of these fish were detected at a Wells Dam fish ladder upper antenna, and then next appeared either downstream or one or more days later at a Wells Dam fish ladder lower antenna suggesting that they passed over the dam only to fall back downstream. Four of these fish likely fell back over Wells Dam multiple times (3D9.1C2DB2052E three times and 3D9.1C2DB1E51A, 3D9.1C2DAC4468, and 3D9.1C2DB20496 twice). Two these fish were next detected in the Entiat River downstream of Wells Dam, with one proceeding on to Tumwater Dam. Six of the other sockeye in Table 31 were detected at Tumwater Dam. Another sockeye (3D9.1C2DAC4468) fell back over Wells Dam twice after ascending July 17 and 26 before ascending once again on July 31 and then was detected in the lower Twisp River on August 9 and 23. On August 12, this fish was trapped at the Twisp River Weir and released upstream. There were no sockeye salmon PIT tagged at Bonneville Dam and detected at Tumwater Dam that were subsequently detected at any sites except on the Wenatchee spawning grounds. There were also no sockeye tagged at Bonneville Dam, other the eight aforementioned, that deviated from their upstream migration to the Okanagan or Wenatchee spawning grounds. None were detected at any tributary sites, nor did any sockeye salmon fall back over more than one consecutive dam (e.g. no sockeye were detected at Rocky Reach Dam then next detected at Priest Rapids Dam).

Table 31. Sockeye salmon PIT tagged at Bonneville Dam that passed or attempted to pass Wells Dam in 2011 and were subsequently detected downstream. Shown are the PTAGIS site name, the date of passage with shading indicating whether the fish was last detected at an upstream or downstream antenna. Figure 20 shows site locations listed in this table.

Tag Code	Wells Dam (WEA)	Entiat River (ENL and ENA)	Rocky Reach Dam (RRJ)	Lower Wenatchee River (LWE)	Twisp River (TWR and TWISPW)	Tumwater Dam (TUF)	Little Wenatchee River (LWN)	White River (WTL)
3D9.1C2DB2052E	July 18th - Westbank Ladder July 23rd - Westbank Ladder July 28th - Westbank Ladder	July 26th - Lower Site (ENL)	Juvenile Bypass- August 2nd	August 2nd		August 16th	September 4th	
3D9.1C2DB1E51A	July 22nd - Eastbank Ladder July 23rd - Eastbank Ladder July 31st - Eastbank Ladder August 1st - Eastbank Ladder	August 5th - Lower Site (ENL) August 7th - Upper Site (ENA)						
3D9.1C2DAC4468	July 17th - Westbank Ladder July 26th - Westbank Ladder July 31st - Westbank Ladder				August 9th - Lower Site (TWR) August 12th - Weir (TWISPW) September 23rd - Lower Site (TWR)			
3D9.1C2DB0793F	August 2nd - Eastbank Ladder			August 5th		August 23rd		September 9th
3D9.239F8649B8	July 21st - Westbank Ladder					August 23rd	September 19th	
3D9.1C2DB20496	July 18th - Eastbank Ladder July 22nd - Westbank Ladder					August 3rd		
3D9.1C2DAC6294	July 23rd - Westbank Ladder					August 4th		
3D9.1C2DB20B55	July 29th - Westbank Ladder			August 1st		August 17th		
			Key - - -	Upstream	Downstream			

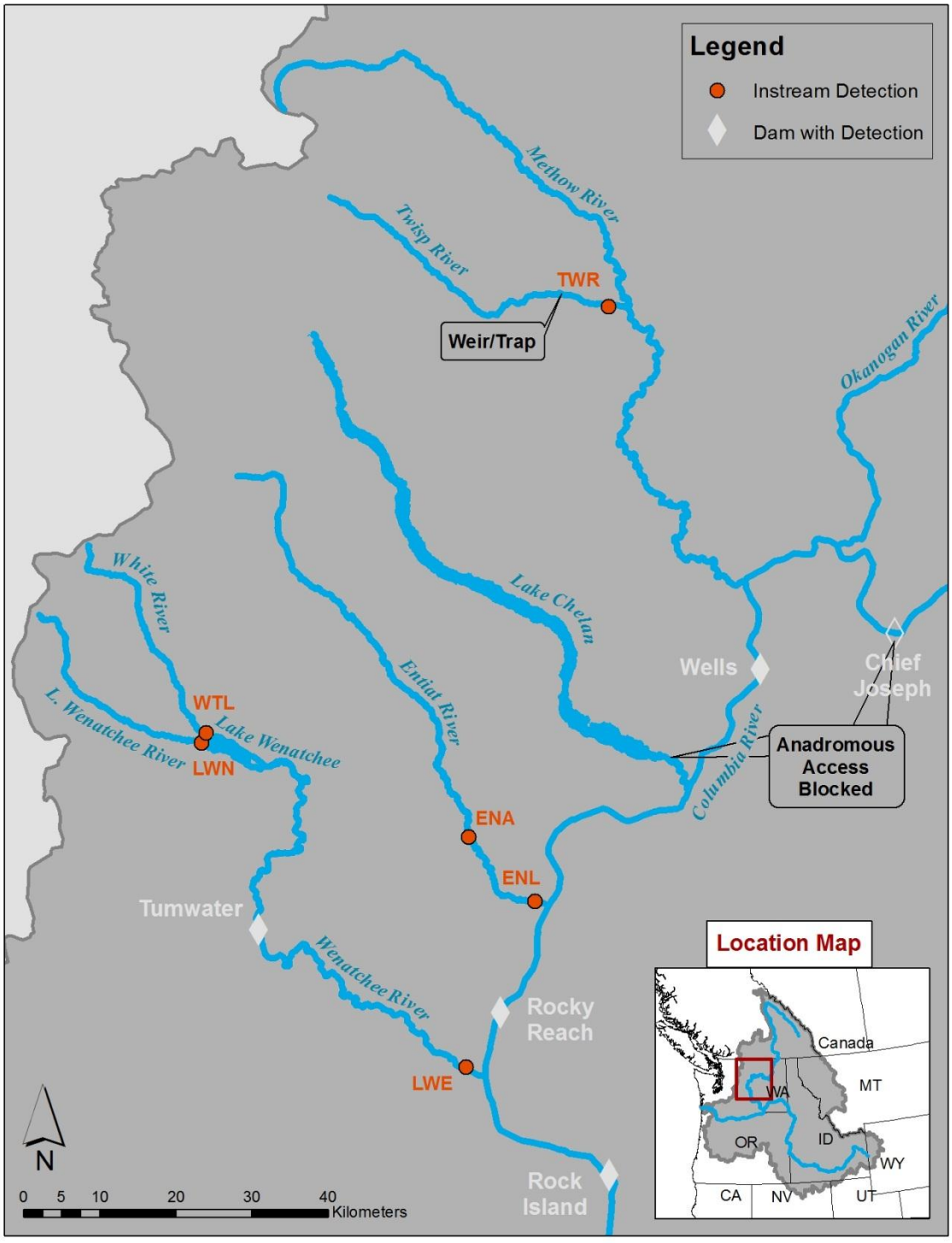


Figure 20. Map that accompanies Table 31 showing the location of dams and instream sites where sockeye were detected after passing or attempting to pass Wells dam.

As has been the case since 2008, there was not a significant linear relationship between run timing at Bonneville Dam and stock composition. PIT tag studies in 2006 and 2007, as well several scale pattern studies in past years (e.g. Fryer 1995, 2006), found 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. In recent years, the proportion of Okanagan stock sockeye relative to the Wenatchee has increased early in the run.

In 2011, we tested the use of 9 mm tags. These tags were developed primarily for use in tagging studies in juvenile salmon where tag size can be a limiting factor in the size of juveniles which can be tagged. In development, these tags are tested to ensure adequate detection at juvenile detection systems at Snake and Columbia river mainstem dams. Their detection efficiency at adult fish ladders as well as in-stream detection arrays is unknown. Therefore tests, such as what we carried out in 2011, are valuable in determining how well these new tags will be detected at these sites when juveniles with these tags return as adults. Based on the results of this study, we recommend using the traditional 12.5 mm tags on juveniles wherever possible, especially if detection at in-river antennas is important. We found the 9mm tags were detected at a significantly lower rate at the Okanagan River and White River antennas (although the latter had outages which could have influenced this result). We also found significantly worse detection at Rock Island Dam and the detection at Rocky Reach Dam was significant at the 90% confidence level. In addition, at almost all sites, although the results were not significant, the percentage of sockeye detected with 9 mm tags was less than the percentage deployed. In addition, the percentage of sockeye tagged with 9 mm tags missed at PIT tag detection sites at mainstem dams was greater than that for the 12.5 mm tagged fish for all sites except Wells Dam where all sockeye were detected.

PIT tagged sockeye salmon passed Rock Island and McNary dams undetected at much higher rates than at other dams. Of the 12.5mm tagged sockeye 12.1% missed detection at McNary Dam with 5.6% missed at Rock Island Dam. For 9mm tags, the numbers were 20.5% and 40.0%. At McNary Dam it is likely that sockeye are using the navigation locks which are located on the north side of the dam just downstream from the Snake River (which enters the Columbia River from the south side). Corroborating evidence for this theory

is that the visual count of sockeye salmon at McNary Dam was 21.5% less than that at Priest Rapids Dam. At 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 (Fryer et al. 2011). In 2011, a lightning strike did disable PIT tag detection on the left ladder of Rock Island Dam from May 31 to June 29. However, visual counts indicate that only 0.5% of the sockeye run passed during this period and PIT tag detection records indicate that only 21.5% of the sockeye use the left ladder; thus the number of PIT tagged sockeye that may have been missed would be expected to be very small.

In 2011, two sockeye salmon PIT tags were recovered from the Badger Island Pelican Colony at Columbia River km 512. The two fish were small Age 1.1 fish, lengths 37.5 and 41.0 cm; both were tagged and released on July 8, 2011. One fish was detected passing McNary Dam on July 13 while the other was not detected at McNary Dam. The tags were recovered on September 28.

From 2008 and 2010, this study documented delays in passage at Tumwater Dam that was likely attributable to 24 hour operation of the trap at that facility. The median delay reported was up to 4.6 days (in 2008) and PIT tag detection records suggested that up to 33.3% (in 2010) of sockeye salmon reaching Tumwater Dam never passed over it. Trap operations were changed in 2011 so that passage through the fish ladder was not blocked 24 hours per day. The result was that the median delay dropped to 6 minutes in 2011 and it was likely that all sockeye detected at Tumwater Dam successfully passed over it. There was only one sockeye (9 mm tag) that was last detected at the lower antenna at Tumwater Dam. This particular 9 mm tag generated so few detections on its upstream migration that the tag was likely defective.

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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 and 23). In 2011, the estimated impact on survival for PIT tagged fish was greater than in 2010 (Table 32), but the impact on acoustic and temperature tagged sockeye was less than in 2010. Increased mortality in 2011 occurred primarily in the last two weeks of sampling. This was especially apparent for sockeye salmon that were both PIT and temperature tagged with no sockeye so tagged during the last week of sampling being detected at OKC. The reason for this is unclear. Sampling sockeye at higher temperatures, present at

the end of the migration, could be a factor. However, although temperatures were rising through the migration, they were still relatively low (17.1C) when sampling ended. Indeed, temperatures were higher in Statistical Week 30 at Bonneville Dam (18.0C) during PIT tagging and sockeye tagged during this week had the second highest weekly survival to McNary Dam.

Table 32. Decrease in survival to the Okanagan Channel for sockeye salmon PIT, acoustic, and temperature tagged at Wells Dam compared to sockeye salmon PIT tagged at Bonneville Dam and detected at Wells Dam.

	Tags Deployed at Wells Dam		
Year	PIT and Floy	PIT, Floy, and Acoustic	PIT, Floy, and Temperature
2010	-2.8%	-25.8%	-25.3%
2011	-4.9%	-7.8%	-13.3%

This study also noted that Wells tagged sockeye salmon were more likely to change ladders than sockeye PIT tagged at Bonneville Dam, although the percentage of tagged fish at Wells Dam that ended up being detected downstream was the same for both groups. One possible explanation for this is that tagged sockeye returned to the fish ladder after sampling and tagging may move downstream after the barrier that diverts fish into the trap is removed. If they attempt to move upstream the following morning, they may find their way blocked by the trap barrier[10] that is back in place for more sampling and tagging. They may then move back downstream and cross over to the other fish ladder rather than entering the trap again. For future study work, in 2012 we had hoped to deploy some acoustic receivers in and below the Wells Dam fish ladder to see if we can better understand the behavior of acoustic tagged sockeye in the ladders, but our request to do so was denied.

The application of temperature archiving, button-tags along with acoustic tags in this study have provided us with a detailed record of the behavior of adult sockeye salmon in 2010 and 2011 over a 135 km segment of their annual migration between Wells Dam on the Columbia River and their terminal spawning area in the Okanagan River near Oliver, B.C. In keeping with results from an earlier study (Hyatt et al. 2003), we found that temperatures in excess of 20-21 ^{o}C at the confluence of the Okanagan and Columbia rivers discouraged entry by

[10] Our sampling crew did report seeing Floy tagged sockeye salmon milling about at the trap barrier early in mornings after sampling.

adult sockeye into the Okanagan River from the cooler waters (<17 ^{o}C) of Wells Pool. For example, 24 of 27 acoustically tagged fish in 2010 (Fryer et al 2011) entered the lower Okanagan River from Wells Pool either before temperatures in the former exceeded 21 ^{o}C (during July 14-17th in 2010) or after they declined to <22 ^{o}C (after Aug 23rd, 2010). As a consequence, many sockeye from the latter third of the run that passed Wells Dam during 2010 were delayed in Wells Pool for an interval of roughly a month. By contrast, a much smaller number of sockeye from the tail-end of the run passing Wells Dam in 2011 were affected by delays in Wells Pool because temperatures in the Okanagan R. remained below 20-21 ^{o}C until after August 6th (Figure 14) by which time virtually the entire run had passed Wells Dam (Figure 10).

Results from acoustic-tags applied to adult sockeye at Wells Dam from early July to early August in both 2010 and 2011 allow us to compare the migratory performance of sockeye as environmental conditions in the Okanagan River varied over this interval. In 2010, earlier migrant fish travelled at much faster rates between Wells Dam and Haynes Point at Osoyoos Lake than later migrants. Median days of travel for fish tagged during the July 1-13 versus July 23-Aug 3rd intervals in 2010 averaged 9.9 and 34.9 days respectively (Fryer et al 2011). By contrast, median days of travel for fish tagged during the July 9-20th versus July 30- Aug 11th intervals in 2011 (this report) were quite similar averaging 6.4 and 5.2 days respectively. Thus, late-run sockeye experienced far greater delays in 2010 than in 2011. Both acoustic and button-tagged fish generally required about 5-8 days to travel between Wells Pool and Haynes Point, consequently temperature and flow conditions during the week preceding arrival at Haynes Point are relevant to this portion of their migration. Consideration of these conditions suggests that late-run fish in both 2010 and 2011 experienced temperatures between 20-22 ^{o} C and moderate flows by comparison with earlier-run fish. However, late-run fish in 2010 survived at significantly lower rates to Haynes Point than earlier-run fish in both years (i.e. 50-67% late versus 93-100% early) or than late-run fish in 2011 (i.e. 50-67% in 2010 versus 89-100% during the same weeks in 2011).

Because late-run fish encountered very similar temperature and flow conditions during migration in both 2010 and 2011, the higher mortality of the 2010 late-run fish is not easily ascribed to simply excessive temperature along the migration route. Rather, the principal difference between these two groups of

fish as well as between these and their earlier-run counterparts would appear to be the occurrence of an extended delay in Wells Pool where 2010 late-run fish spent almost a month of time holding at temperatures between 17 and 19 ^{o} C. Only the latest-run fish in 2011 exhibited lower survival rates (36.4% in Statistical Week 32, Table 24) during their migration through the Okanagan River to Haynes Point in association with a temperature spike of 22-23 ^{o} C in the days prior to reaching Haynes Point (Figure 14). Moreover, this difference in survival rates between relatively early versus late-run fish continued to be expressed (only 50% of sockeye tagged at Wells Dam in Week 32 and detected passing Haynes Point were detected at OKC) as fish exited Osoyoos Lake, after holding there for a period of weeks, prior to recruiting to the upstream terminal spawning area in the Okanagan River near Oliver, B.C.

Linkages between migratory stress and subsequent thermoregulatory behavior during pre-spawn holding intervals in lakes have been identified in a number of earlier studies of sockeye salmon undertaking relatively short freshwater migrations to return to neighboring rivers in northwest Washington State (i.e. Lake Washington, Newell and Quinn 2005) and southwest British Columbia (i.e. Harrison Lake, Mathes et al. 2010). Authors in both of these studies advanced several hypotheses for the adaptive significance of adult sockeye thermoregulatory behavior including: energy conservation, recovery from stressful migration, predator avoidance, control of parasites and pathogens and development of optimal gamete quality. Newell and Quinn concluded that depth and temperature choices displayed by sockeye in Lake Washington were not obviously related to predator avoidance but were beneficial to energy conservation and sexual maturation. Mathes et al (2010) concluded that use of lakes as thermal refugia by early-timed fish likely reduced rates of disease and aided from physiological stress associated with migration during intervals of high temperature. Further exploration of the relative merits of these competing hypotheses as the basis for the thermoregulatory behavior of adult sockeye is warranted to separate major from minor influences.

In 2012 this project will continue PIT tagging sockeye salmon at Bonneville and Wells dams but there will be five major changes in other sections of the study:

1.) In the Wenatchee basin, we are adding monthly limnological surveys of Lake Wenatchee to help estimate the sockeye smolt capacity of the

lake. The results of these estimates should help better explain why the annual returns of the Wenatchee stock have stayed relatively constant over the past 10 years while the Okanagan stock has shown large increases.

2.) Tumwater Dam sockeye sampling, which has largely been funded by another project, will be dropped in 2012 due to funding cuts in that project.

3.) Acoustic tags with temperature and depth sensors will not be deployed since our study results duplicate those from acoustic trawl surveys that confirm the expected distribution of sockeye in Osoyoos Lake.

4.) We will purchase 200 temperature tags for deployment at Wells Dam, but they will only be deployed if a significant temperature blockage appears likely to form at the mouth of the Okanagan River. If the tags are unused in 2012, they will be saved for a future year when a temperature blockage is likely.

5.) Budgeting funds for some genetics analysis to determine whether the stock composition of sockeye salmon tagged at Bonneville Dam that do not pass to Rocky Reach, Tumwater, or Ice Harbor dams compares with fish that do reach these dams. Genetics analysis will also confirm sex composition at Wells Dam, which visual assessment in 2011 estimated was high weighted towards males.

REFERENCES

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

DART (Columbia River Data Access in Real Time). 2011. Online at: http://www.cbr.washington.edu/dart/dart.html

Fish Passage Center. 2011. Adult fish counts online at: http://www.fpc.org.

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

Fryer, J.K. 2006. Identification of Columbia Basin sockeye salmon stocks in 2005. Columbia River Inter-Tribal Fish Commission Technical Report 06-04. Portland.

Fryer, J.K. 2007a. Identification of Columbia Basin sockeye salmon stocks in 2006. Columbia River Inter-Tribal Fish Commission Technical Report 07-03. Portland.

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

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

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

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

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

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

Hyatt, Kim , M., R. Bussanich, L. Wiens and P. Askey. In preparation. Okanagan Fish and Water Management Tools Project Assessments: Brood Year 2011 Salmon(Oncorhynchus nerka) Abundance and Biological Traits. Report to file: JSIDS- SRexx-12. Salmon in Regional Ecosystems Program, Fisheries and Oceans Canada, Nanaimo, B.C. V9T 6N7.

Hyatt, Kim. D., Donald J. McQueen, D. Paul Rankin and Eric Demers. 2011. Density-dependent growth in juvenile sockeye salmon (*Oncorhynchus nerka*). The Open Fish Science Journal 4: 53-65

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

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

Hyatt, Kim D., M. Stockwell, and D. P. Rankin. 2003. Impact and adaptation responses of Okanagan River sockeye salmon (Oncorhynchus nerka) to climate variation and change effects during freshwater migration: stock restoration and fisheries management implications. In: Climate Change and Water in the Georgia Basin: Special Issue of Canadian Water Resources Journal 28(4): 689-713.

Langford, T.E., J.M. Fleming and N.P.James, 1977. The tracking of salmonids in the Afon Seiont River System, using ultrasonic tagging techniques. Central Electricity Research Laboratories, Lab. Note RD/L/N51/77, 16 p.

Mathes, M. Todd, Scott G. Hinch, Steven J. Cooke, Glenn T. Crossin, David A. Patterson, Andrew G. Lotto and Anthony P. Farrell. 2010. Effect of water tempersture, timing, physiological condition and lake thermal refugia on migrating adult Weaver Creek sockeye salmon (*Oncorhynchus nerka*). Can. J. Fish. Aquat. Sci. 67: 70-84.

McQueen, D., K.D. Hyatt, H. Wright, D.P. Rankin, S. Lawrence, C. Mathieu, and L. Wiens. 2010. Annual Report for year 2009 [2008 brood year]: Evaluation of the experimental introduction of sockeye salmon (Oncorhynchus nerka) into Skaha Lake and assessment of sockeye rearing in Osoyoos Lake. Okanagan Nation Alliance, Westbank, BC.

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

Newell, Jennifer. C. and Thomas P. Quinn. 2005. Behavioral thermoregulation by maturing adult sockeye salmon (*Oncorhynchus nerka*) in a stratified lake prior to spawning. Can. J. Zool. 83: 1232-1239.

PTAGIS (Columbia Basin PIT Tag Information System). 2011. Online at http://www.ptagis.org.

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

West Consultants. 2008. Development of a water temperature model relating project operations to compliance with the Washington State and EPA water quality standards (water temperature study). Prepared for: Public Utility District No. 1 of Douglas County, East Wenatchee, WA.

APPENDIX A

Table A1. 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 2011.

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	596	97.1	96.1	98.5	96.1	100.0
BO4-9	129	85.3	72.1	92.2	52.7	99.8
BO1-12.5	6	100.0	100.0	100.0	100.0	100.0
BO1-9	2	100.0	100.0	100.0	100.0	100.0
McNary	**N**	**1**	**2**	**3**		
MC1-12.5	201	96.5	95.5			99.8
MC1-9	37	94.6	94.6			99.7
MC2-12.5	203	93.1	99.5	94.9		100.0
MC1-9	32	84.2	100.0	97.4		100.0
Priest Rapids	**N**	**3**	**7**			
East-12.5	428	88.3	97.4			98.9
East 9	**70**	61.4	97.1			97.6
	N	**3**	**5**			
West 12.5	93	93.5	88.2			97.7
West-9	16	81.3	87.5			99.2
Rock Island	**N**	**1-2**	**3-4**			
Left-12.5	75	98.7	70.7			99.6
Left-9	22	90.9	77.3			97.9
	N	**5-6**	**7-8**			
Middle-12.5	52	76.9	98.1			99.6
Middle-9	6	33.3	100.0			100.0
	N	**09-0A**	**0B-0C**			
Right-12.5	261	84.3	80.5			96.9
Right-9	25	80.0	40.0			88.0
Rocky Reach	**N**	**1-2**	**3-4**			
12.5	344	85.2	88.1			98.2
9	60	71.2	76.7			93.4
Wells	**N**	**1-2**	**3-4**			
Left-12.5	224	98.2	96.9			100.0
Left 9	43	95.3	97.7			99.9
	N	**5-6**	**7-8**			
Right-12.5	104	99.0	98.0			100.0
Right 9	100.0	100.0	100.0			100.0
Tumwater	**N**					
12.5	81	100.0	100.0			100.0
9	9	95.5	90.9			99.6

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

Table A2. Harvest by fishery for Columbia Basin sockeye salmon in 2011. (Data compiled by Hyatt et al. in preparation)

Location	Fishery Type	Source	Totals
Zone 1-5	Sport and Commercial	TAC	1568
Zone 6	Commercial, Ceremonial and Subsistence	TAC	12,849
	Sport	TAC	197
	Total		13,046
Priest Rapids Tailrace	Wanapum Ceremonial and Subsistence	TAC	91
Lake Wenatchee	Sport	WDFW	0
Priest Rapids to Chief Joseph Dam	Sport	DFO	2,818
Colville Harvest (Lake Pateros and Okanogan River)	Colville Tribal Net	DFO	86
	Colville Tribal Purse Seine	DFO	756
	Chief Joseph Tailrace	DFO	12
	Total		854
Canada Okanagan Basin	Okanagan Nation Alliance Communal	DFO	5225
	Okanagan Nation Alliance Economic Demo	DFO	778
	Recreational	DFO	439
	Total		6,442
Priest Rapids Dam	Yakama Broodstock Removals[11]	DFO	4550

Table A3. Distribution of sockeye salmon by fish ladder for dams with multiple fish ladders as estimated by PIT tag detections in 2011.

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	31.2%	68.8%	

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.

[11] Although not a true "harvest", the Yakima Nation collect live, adult sockeye salmon at Priest Rapids Dam each year and place them in Cle Elum and Cooper Lakes to spawn. This sockeye reintroduction project was initiated in 2009.