



**NOAA
FISHERIES**

2015 Adult Sockeye Salmon Passage Report



**NOAA Fisheries in Collaboration with
The U.S. Army Corps of Engineers and Idaho Department of Fish and Game**

Contents

List of Figures.....	3
List of Tables	5
1. Introduction.....	7
1.1 Snake River Sockeye Salmon	7
1.2 Lake Wenatchee and Okanogan River Sockeye Salmon	9
2. Environmental Conditions	11
2.1 Flow and Temperature Conditions.....	11
2.2 Mainstem Reservoir Environment and Thermal Stratification.....	15
2.2.1 Thermal Effects of Upstream Storage Reservoirs	15
2.2.2 Reservoir Environment in the Lower Snake River	17
2.2.3 Water Temperature Control Operations at the Lower Snake River Projects	18
2.2.4 Reservoir Environment in the Lower Columbia River.....	20
2.3 Effects of Elevated Temperatures on the Survival of Adult Salmon.....	20
3. Adult Sockeye Salmon Migration Timing and Survival in 2015	23
3.1 Survival Rates in the Bonneville to McNary Reach	23
3.2 Survival Rates in the McNary to Rock Island / Wells Reach and the Okanogan River	27
3.3 Survival Rates in the McNary to Lower Granite Reach and the Mainstem Salmon River	27
3.4 Summary of Mainstem and Tributary Survival and Detection Histories	30
4. In-Season Management Decisions and Actions.....	34
4.1 Project-Specific Operations	35
4.1.1 Operations at Lower Granite Dam	36
4.1.2 Operations at Little Goose Dam.....	38
4.2 Adult Sockeye Salmon Transportation	41
5. Discussion.....	50
5.1 System Operations	50
5.2 Lower Granite Dam Operations.....	51
5.3 Little Goose Dam Operations	51
5.4 Adult Sockeye Transportation	52
5.5 New Actions at Lower Granite Dam	52
6. Recommendations	53
7. References	59

Appendices:

Appendix A: Analysis of Emergency Sockeye Operation at Little Goose Dam..... 64

Appendix B: NMFS Determination Take Letter 66

List of Figures

Figure 1. Map of the Columbia River Basin showing large hydroelectric projects.....	8
Figure 2. Columbia River temperature at Bonneville Dam and McNary Dam (forebays) in 2015 relative to the prior 10-year average.....	13
Figures 3a and 3b. Temperatures in the Okanogan (a) and Salmon (b) rivers during 2015.	14
Figure 4. Water temperatures recorded at the mouth of the Snake River (Sacajawea, WA) during 1955-58, and mean water temperatures for the four years.....	15
Figure 5a. Outflow temperatures at Grand Coulee Dam compared to upstream Columbia River temperatures at the international boundary.....	16
Figure 5b. Outflow temperatures at Hells Canyon Dam compared to upstream Snake River temperatures near Weiser, Idaho.	17
Figure 6. Dworshak Dam reservoir elevations, outflows, and water temperature releases, June 1 to August 31, 2015.....	19
Figure 7. Adult sockeye salmon ladder counts at Bonneville Dam in 2015 compared to the 2005-2014 average.....	23
Figure 8. Weekly adult sockeye survival estimates from Bonneville to McNary dam in 2015 for Upper Columbia River sockeye salmon, Snake River sockeye salmon that migrated inriver as juveniles), and Snake River sockeye that were transported as juveniles with water temperatures at The Dalles Dam.	24
Figure 9. Video capture of an adult sockeye near Drano Lake during mid-July, 2015	25
Figure 10. Annual adult survival estimates from Bonneville to McNary dams for upper Columbia River sockeye stocks and Snake River sockeye salmon that migrated inriver or were transported as juveniles.....	26
Figure 11. Tailrace temperatures at The Dalles Dam from June 1 to August 31 (2010-2015).....	26
Figure 12. Proportion of total PIT-tagged Snake River sockeye salmon detected at Bonneville Dam that survived to each subsequent detection point (The Dalles, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams and the Sawtooth Hatchery weir) in 2015 compared to average for 2010-2014.	28
Figure 13. Water temperatures measured in the forebay and tailrace at Little Goose Dam during June and July, 2015, and 10-year average temperatures at these locations	29
Figure 14. 2015 PIT tag detection histories for adult UCR sockeye salmon stocks and Snake River sockeye salmon that migrated inriver (middle panel) or were transported as juveniles	33
Figure 15. Tailrace conditions at Lower Granite Dam in July 2013 showing the reverse eddies with Turbine Unit 2 operating and improved downstream flow with Unit 1 operating	36
Figure 16. Sockeye salmon ladder counts, ladder exit pool temperature, and tailrace temperature (WQM Tailrace) at Lower Granite Dam during 2015.	38
Figure 17. Adult sockeye passage counts and hourly ladder exit temperatures at Little Goose Dam in 2015	39
Figure 18. Cumulative number of PIT tag detections per hour near the counting window in the fish ladder at Lower Granite Dam during 2011-2014	43
Figure 19. Number of adult sockeye salmon trapped and transported from Lower Granite Dam to Eagle Fish Hatchery and the daily window counts.....	44

Figure 20. Run timing of Snake River sockeye salmon and fish assigned to an out-of-basin genetic stock collected at Lower Granite Dam from July 13, 2015, to August 13, 2015..... 46

Figure 21. Spawn timing for female sockeye salmon collected at Lower Granite Dam and transported to Eagle Fish Hatchery, females collected at the Red Fish Lake Creek trap and transported to the hatchery, and captive broodstock females reared at the hatchery..... 48

Figure 22. Adult sockeye salmon survival from Lower Granite to the Sawtooth Valley by time period and in-river migration versus transport strategy based on PIT-tag data..... 49

List of Tables

Table 1. Runoff volume for the Snake and Columbia Rivers during 2015 by location, period, rank out of 56 years, volume, and percent of the previous 30-year average	11
Table 2. Differences in monthly air temperatures at Columbia basin sites in 2015 compared to the 1981-2010 average	12
Table 3. Differences in monthly percent of average precipitation at Columbia basin sites compared to the 1981-2010 average	12
Table 4. Estimated annual survival rates of adult Snake River sockeye salmon by adult migration year and juvenile migration history from Bonneville Dam to the Sawtooth Valley	30
Table 5. Estimated annual survival rates of adult upper Columbia River sockeye salmon by migration year from Bonneville Dam to Rock Island Dam (both UCR ESUs) and Rock Island to Zosel Dam (Okanogan River sockeye salmon only).....	31
Table 6. Adult Chinook counts in the ladders at Lower Granite Dam during July 25–August 10, 2013, when emergency pumps were in operation and Turbine Unit 1 alternated with Unit 2.....	36
Table 7. Adult sockeye salmon passage at Lower Monumental and Little Goose dams during the blocked spill operations at Little Goose Dam.....	40
Table 8. Date of collection, total number of fish collected (N), number of fish collected on the juvenile bypass separator (N_{SEP}) and in the adult trap (N_{TRAP}) at Lower Granite Dam in 2015, number of fish genetically assigned to the Snake River sockeye broodstock (N_{SRS}), and number of fish assigned to an out-of-basin genetic stock and culled (N_{CULLED})	45
Table 9. Spawning results for females collected at Lower Granite Dam (LGR) and transported to Eagle Fish Hatchery (EFH) and for females collected at the Redfish Lake Creek (RFLC) trap	47

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2015 ADULT SOCKEYE SALMON PASSAGE REPORT

1. Introduction

In 2015, low snow pack, coupled with extremely high air temperatures throughout the interior Columbia basin resulted in warm water in the major tributaries to the lower Snake and Columbia rivers. Temperatures in the mainstem Columbia River were the highest recorded from roughly mid-June to mid-July. Adult sockeye salmon, which normally migrate during this period, sustained heavy losses in the Columbia River and tributaries. ESA-listed Snake River sockeye salmon were especially affected in the mainstem migration corridor, with losses exceeding 95% between Bonneville and Lower Granite dams.¹ The purpose of this paper is to document the conditions that occurred throughout the Columbia River basin in 2015 and to describe and assess the actions that were taken to minimize these impacts by the federal hydrosystem operators (the U.S. Army Corps of Engineers (USACE), Bonneville Power Administration (BPA), and U.S. Bureau of Reclamation (Reclamation); the Idaho Department of Fish and Game; and the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA Fisheries) to reduce adult mortality. These efforts were coordinated with other state, tribal, and federal agencies through existing regional processes such as the Technical Management Team (TMT) for the hydropower system. We conclude this paper by recommending monitoring, structural, and process improvements that would enhance the ability of the federal hydrosystem operators and state and tribal fish and wildlife agencies to minimize the effects of a similar event if these conditions re-occur. Technical staff from NOAA Fisheries, USACE, and the Idaho Department of Fish and Game (IDFG) collaborated in the development of this paper. Literature reviewed in the preparation of this report included Fish Passage Center (2015).

1.1 Snake River Sockeye Salmon

Historically, anadromous sockeye salmon (*Oncorhynchus nerka*) were abundant throughout Idaho's upper Snake and Salmon River watersheds. The majority of these populations were extirpated and only the Redfish Lake population in the Sawtooth Valley (Figure 1) supported anadromy in the last part of the 20th century.² According to records kept by IDFG, University of Idaho, and NOAA Fisheries' predecessor, the U. S. Bureau of Commercial Fisheries, the escapement of adult sockeye salmon to this location ranged from a high of 4,361 (1955) to a low of 11 (1961) during 1954 through 1966. After a lapse of almost two decades, IDFG reinitiated the monitoring program in 1985. They estimated that only 61 anadromous adults returned to Redfish Lake through 1989, with zero adults returning in 1990. NOAA Fisheries listed hydropower development, water withdrawal and diversions, water storage, harvest, predation,

¹ Other species of salmon and steelhead typically migrate outside of this time period both as juvenile and adults and were not substantially impacted.

² Functional spawning aggregations of resident *Oncorhynchus nerka* persisted in the Sawtooth Valley even when the anadromous form was functionally extirpated (Waples et al. 2011).

and inadequate regulatory mechanisms as factors contributing to the decline of Snake River sockeye salmon (NMFS 1991).



Figure 1. Map of the Columbia River Basin showing large hydroelectric projects, PIT tag detectors used in this report to estimate adult sockeye salmon survival rates (grey circles), and the location of sockeye salmon spawning populations (red stars).

Along with program cooperators, the IDFG initiated the Snake River sockeye salmon captive broodstock program in May, 1991, in response to the decline of anadromous returns to central Idaho. The goal of the program was to use captive broodstock technology to avoid extinction while conserving the species' remaining genetic diversity. Twenty-five years later, these goals have been met. Current goals include using the captive broodstock program to increase the number of individuals in the population, creating a viable ESU that can provide sustained opportunities for sport and treaty harvest. Efforts are therefore underway to expand and amplify the hatchery program to increase the number of anadromous adults returning to the Sawtooth Valley. However, temperature-related passage issues for Snake River sockeye salmon could impede the success of this strategy. During low flow summers, we have observed temperatures that exceed lethal levels for salmonids in the lower Snake River, including the reach above the confluence of the Clearwater River, and in the Salmon River. Because of this concern, the 2008 FCRPS Biological Opinion (BiOp) included a provision for initiating an emergency adult trap-and-haul operation from Lower Granite Dam (LGR). These activities were more explicitly considered (i.e., with permits for handling increased numbers of fish) in the 2010 Supplemental

FCRPS BiOp and NOAA Fisheries retained the emergency trap and haul provisions in the 2014 Supplemental FCRPS BiOp.

1.2 Lake Wenatchee and Okanogan River Sockeye Salmon

In addition to the ESA-listed Snake River sockeye salmon ESU that spawns in Idaho's Sawtooth Valley, there are two unlisted ESUs that spawn in the upper Columbia basin in Washington State and British Columbia (Gustafson 1997). Okanogan River sockeye salmon spawn in areas upstream from Lake Osoyoos, in Lake Osoyoos, and in a downstream tributary to the Okanogan, the Similkameen River (below Enloe Dam near Oroville, Washington). Although the principal spawning and main rearing area for this ESU is in British Columbia, the migration corridor for both juveniles and adults from all the spawning areas used by Okanogan sockeye salmon is through the Columbia River in Washington and Oregon. Lake Wenatchee sockeye salmon spawn above or in Lake Wenatchee and rear in Lake Wenatchee and also migrate through the Columbia River. Both spawning areas are at relatively low elevations (Lake Osoyoos is at 278 m in the Okanogan basin and Lake Wenatchee is at 572 m) compared to Redfish Lake in Idaho's Sawtooth Valley, used by Snake River sockeye salmon (1,996 m above sea level; Appendix Table B-1 in Gustafson 1997). The juvenile and adult migration corridors for both of the Washington ESUs (986 and 842 km, for Okanogan River and Lake Wenatchee fish, respectively) are much shorter than for Snake River sockeye salmon (1,448 km). In addition to these two ESUs, the Yakama Nation started a program to reintroduce sockeye salmon into Lake Cle Elum in 2009, using adult sockeye captured at Priest Rapids Dam for broodstock.

Based on escapements above 10,000 (1992-1996), which were probably a substantial fraction of each ESU's historical abundance, NOAA Fisheries Biological Review Team (BRT) concluded that neither the Okanogan River or Lake Wenatchee sockeye salmon ESU was in danger of extinction, nor likely to become endangered in the foreseeable future (Gustafson 1997). However, the BRT noted that very low returns in the three most recent years suggested that the status of each ESU should be reconsidered if abundance remained low. More recently, sockeye salmon in the upper Columbia basin rebounded to modern day records: over 645,100 adult sockeye returned to the Columbia River in 2014, the largest sockeye run counted since the construction of Bonneville Dam in 1938 (WDFW 2016). The final adult sockeye salmon count at Bonneville Dam in 2015 was 510,706 fish. Based on PIT tag detection data, NOAA Fisheries estimates that 7.2% of PIT tagged Upper Columbia sockeye salmon were fallbacks that reascended the ladder and were counted at least twice. Using this rate to correct ladder counts, we estimate that about 476,405 Upper Columbia River sockeye salmon ascended Bonneville Dam. Using juvenile PIT tagging rates and adult PIT tag detections, IDFG estimates that 4,069 adult Snake River sockeye salmon passed Bonneville Dam in 2015.³ Therefore, more than 470,000 of the sockeye salmon that returned to Bonneville Dam were bound for the upper Columbia basin.

³ We derived this estimate by expanding the PIT tag detections at Bonneville Dam by the ratios of tagged to untagged smolts for specific release groups.

Adult returns to the spawning basins have been high during the period 2005-2014, averaging 93,300 to Zosel Dam, (also near Oroville, Washington, at the outlet to Lake Osoyoos) and 51,500 at Tumwater Canyon Dam (on the Wenatchee River near Leavenworth, Washington) (Columbia River DART 2016a, b). Only 37,624 sockeye salmon passed the underwater video camera at Zosel Dam (Schaller 2016) and about 30,000 fish returned to Tumwater Dam in 2015 (Columbia River DART 2016b), reflecting losses in the lower Columbia as described in this report and through the mid-Columbia reach.

2. Environmental Conditions

In the following sections, we review the environmental conditions that caused the salmon managers concern during the 2015 sockeye migration season.

2.1 Flow and Temperature Conditions

During 2015, winter through summer (January–July) and spring and summer (April–August) runoff volumes at The Dalles and Lower Granite ranked near the lowest observed in a 56-year water record (Table 1).

Table 1. Runoff volume for the Snake and Columbia Rivers during 2015 by location, period, rank out of 56 years, volume, and percent of the previous 30-year average. Source: Norris (2015).

Location	Period	Rank (out of 56 years)	Runoff volume (kaf)	Percent (of 30-year avg)
Columbia River at The Dalles	January – July	46	82,951	83
Columbia River at The Dalles	April – August	54	58,407	67
Snake River at Lower Granite	January – July	53	12,397	56
Snake River at Lower Granite	April – August	53	11,466	54

The low spring runoff volume was the result of two factors: above average winter air temperatures (Table 2) and below average precipitation during April–August (Table 3). Air temperatures throughout the basin during key snow accumulation months of January through March were 5.1–7.6°F⁴ above average and much of the precipitation fell as rain instead of snow. The combination of low snow levels in the interior basin and low spring precipitation resulted in below average tributary and mainstem flows. These were combined with June air temperatures that were 5.4–7.6°F degrees above average, resulting in unseasonably high water temperatures in both the tributaries and mainstem rivers. Flows and water temperatures in the Columbia River during the month of June, 2015, resembled conditions that we normally see during late-July and August.

⁴ To convert a difference in degrees Fahrenheit to degrees Celsius, divide degrees Fahrenheit by 1.8.

Table 2. Differences in monthly air temperatures at Columbia basin sites in 2015 compared to the 1981-2010 average (monthly temperatures more than 5 degrees above the 1981-2010 average are shown in red). Source: NOAA/NWS NWRFC

Temperature Departure °F	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Avg °F
Arrow	3.8	-1.8	3.4	5.9	6.3	3.9	0.1	3.0	4.9	2.4	0.0	2.9
Grand Coulee	4.4	-2.2	3.2	5.5	6.2	4.6	0.2	2.7	6.4	2.4	1.5	3.2
Ice Harbor	4.3	-1.1	4.7	5.6	7.6	6.0	0.5	2.3	7.4	0.2	1.6	3.6
The Dalles	4.6	-1.4	4.0	5.9	7.0	5.6	0.4	2.9	7.4	1.9	1.9	3.7
Willamette	3.9	-0.1	2.8	5.1	5.0	4.6	-0.3	2.2	5.4	3.3	1.7	3.1

Table 3. Differences in monthly percent of average precipitation at Columbia basin sites compared to the 1981-2010 average (red text indicates values less than 80% of the 1981-2010 average). Source: NOAA/NWS NWRFC

Precip %	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Oct-Mar	Apr-Aug
Arrow	135	163	69	81	125	141	95	89	82	87	140	119	99
Grand Coulee	118	150	81	80	111	131	55	63	59	67	78	112	64
Ice Harbor	60	111	112	53	80	52	53	129	32	128	56	78	80
The Dalles	98	119	92	64	92	86	51	97	44	83	64	92	68
Willamette	163	80	105	41	92	76	60	57	19	24	65	93	45

Both of the unlisted upper Columbia (Lake Wenatchee and Lake Osoyoos) spawning populations and listed Snake River sockeye salmon use the Columbia River as a migration corridor. The temperatures they experienced at Bonneville and McNary dams during their June – July, 2015, upstream migration period were up to 4°C warmer than the recent 10-year average (Figure 2).⁵ Upper Columbia River sockeye headed for Lake Osoyoos migrate through the Okanogan River, which reached a temperature of 28°C at the Malott, Washington gage in early July (Figure 3a). Snake River sockeye experienced temperatures up to 25°C at the White Bird gage on the Salmon

⁵ Temperatures can be converted to degrees Fahrenheit using the following formula:

$$\text{Degrees Fahrenheit} = \left(\text{Degrees Celsius} * \frac{9}{5} \right) + 32.$$

River during the same period (Figure 3b). We describe the biological significance of these elevated temperatures in Section 2.3, below.

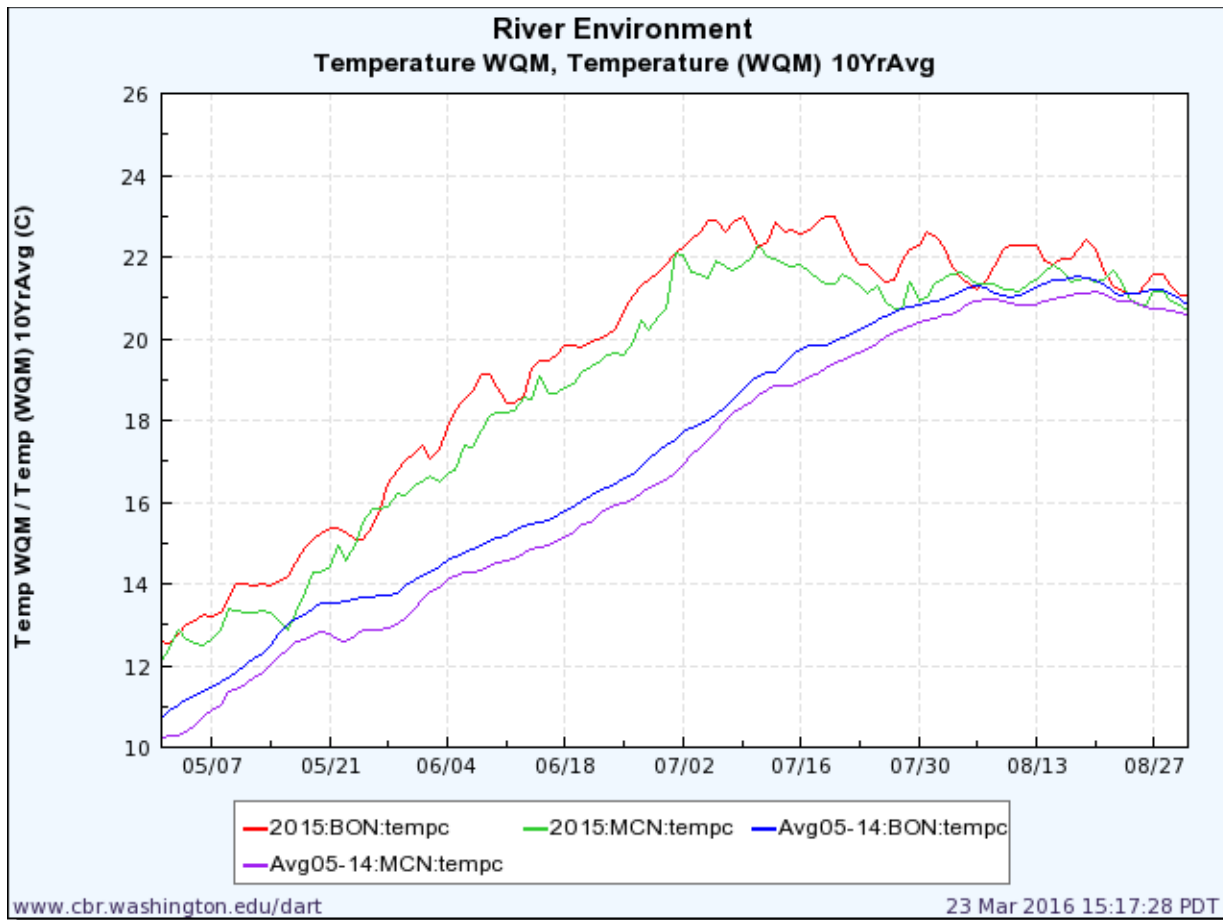
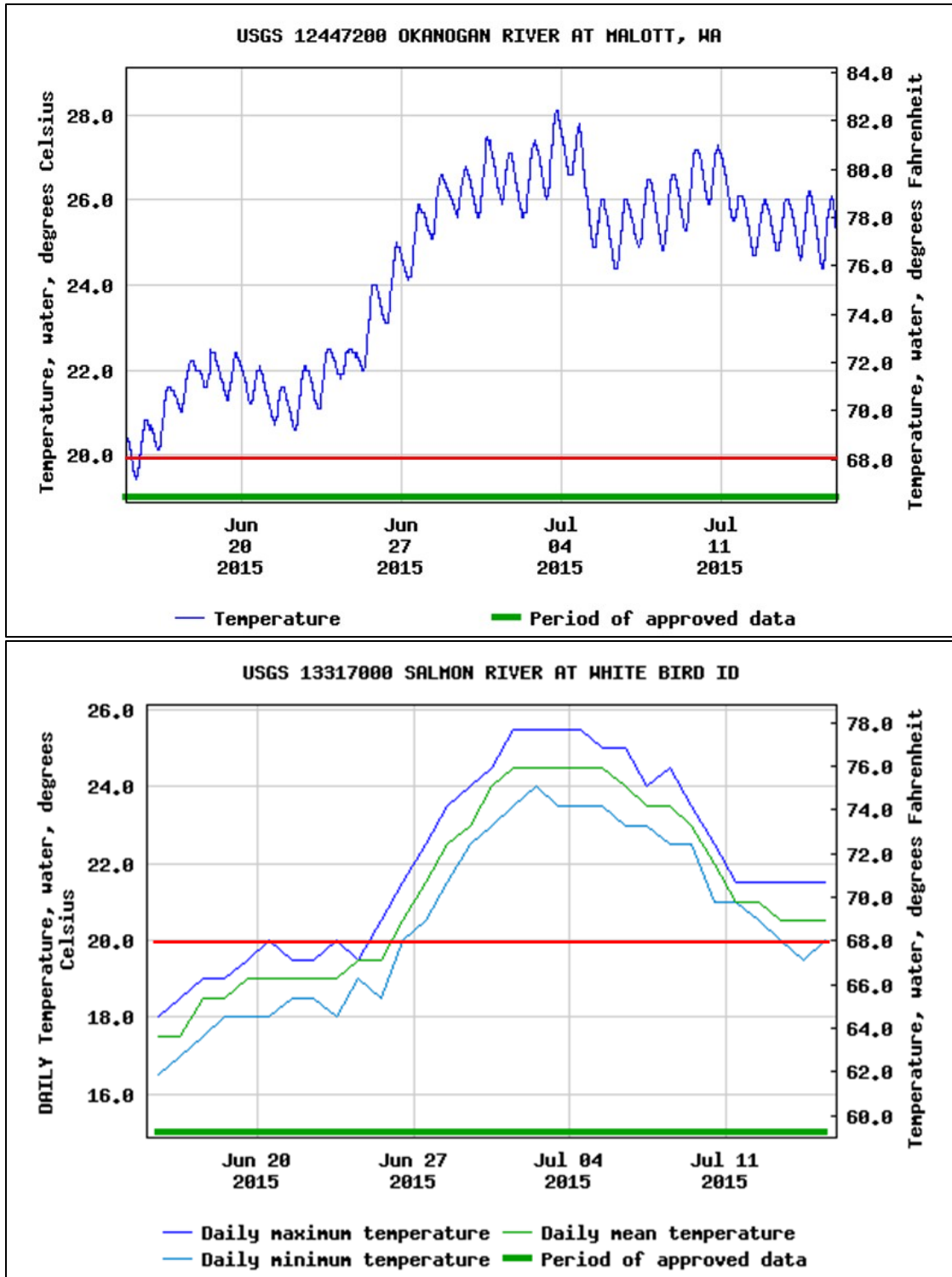


Figure 2. Columbia River temperature at Bonneville Dam and McNary Dam (forebays) in 2015 relative to the prior 10-year average.



Figures 3a and 3b. Temperatures in the Okanogan (a) and Salmon (b) rivers during 2015. “Approved data” were subjected to quality assurance review before publication. Source: USGS

2.2 Mainstem Reservoir Environment and Thermal Stratification

The following sections describe the general effects of reservoirs and flow augmentation in the lower Snake and Columbia rivers on temperatures including thermal stratification and the potential to create temperature gradients in adult fish ladders. Specific operations for adult sockeye salmon migration during 2015 are discussed in Section 4.

2.2.1 Thermal Effects of Upstream Storage Reservoirs

Little information is available on historical temperatures in the lower Snake River basin. Peery and Bjornn (2002) provided temperature information near the mouth of the Snake River from 1955 to 1958, prior to the construction of the lower Snake River dams or the Hells Canyon Complex, showing that temperatures in the free-flowing lower Snake River often exceeded 20°C in July and August during this period and occasionally exceeded 25°C (Figure 4).

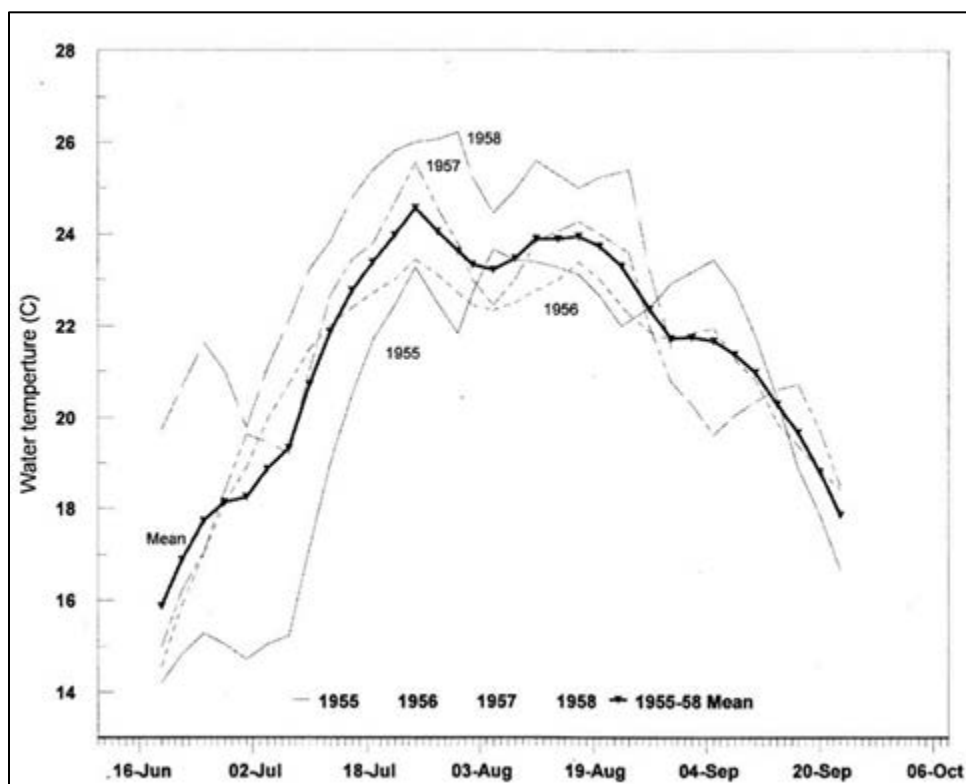


Figure 4. Water temperatures recorded at the mouth of the Snake River (Sacajawea, WA) during 1955-58, and mean water temperatures for the four years. Source: Eldridge (1963) and Peery and Bjorn 2002.

Idaho Power Company began to operate the Hells Canyon project in 1959 and Reclamation began to operate the Grand Coulee project in the upper Columbia in 1942. One might expect that the greater surface area and low velocity of water in the large storage reservoirs would result in more solar exposure and heat gain, and thus higher downstream water temperatures than in a river without dams. However, Moore (1969, cited in EPA 2002), found that both projects released water that was cooler than inflow during spring through mid-August (Figures 5a and 5b) and warmer than inflow during fall and winter. This is possible because these reservoirs become

thermally stratified and the cooler water released from depth buffers peak summer temperatures in downstream river segments. Thus, water management at the large storage reservoirs in the Hells Canyon reach and upper Columbia basin likely did not contribute substantially to the warm water conditions that adult sockeye salmon experienced during the June-July, 2015, migration.⁶

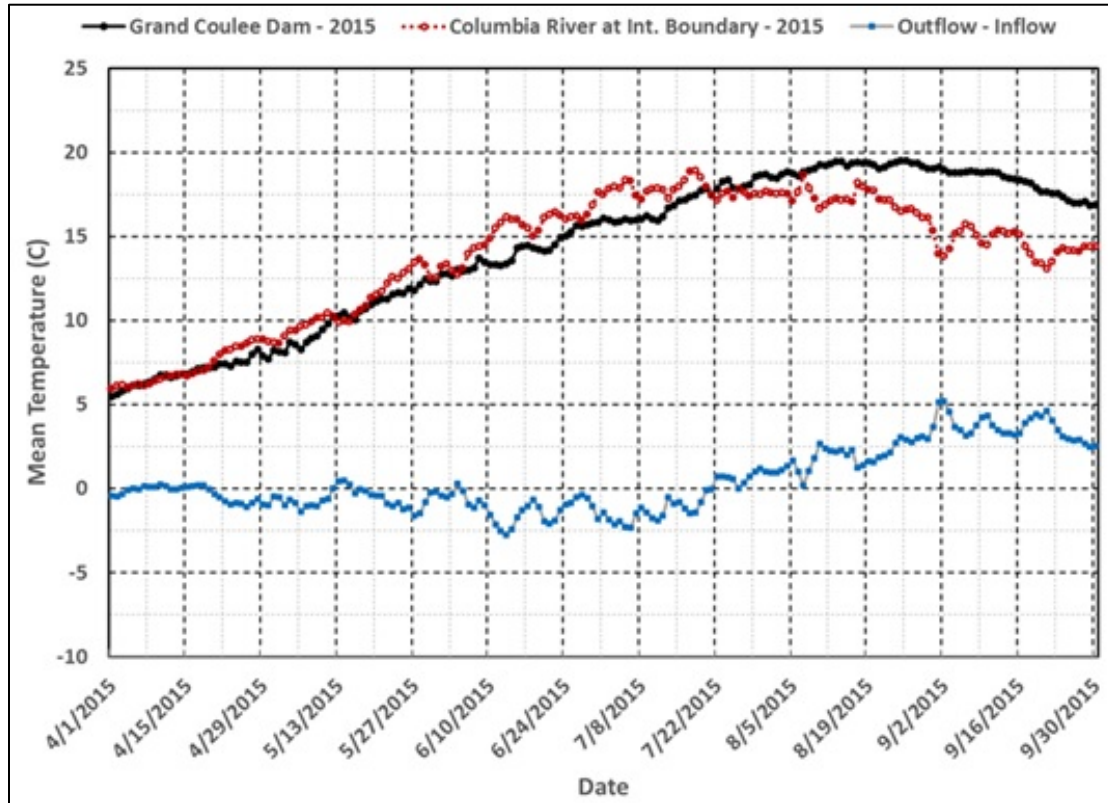


Figure 5a. Outflow temperatures at Grand Coulee Dam compared to upstream Columbia River temperatures at the international boundary. Blue line indicates the difference (inflow – outflow) in temperature. Source: USBR Hydromet Data.

⁶ Moore (1969) had similar findings for Grand Coulee Dam in the upper Columbia basin where the large mass of cold water at depth in Lake Roosevelt dampens the effect of elevated inflow temperatures. Outflow during late spring and early summer 2015, when most adult sockeye salmon from the Okanogan and Lake Wenatchee populations were in the mainstem, was cooler than inflow. This effect dissipated in the mid-Columbia reach, which is affected by the privately-owned hydropower projects.

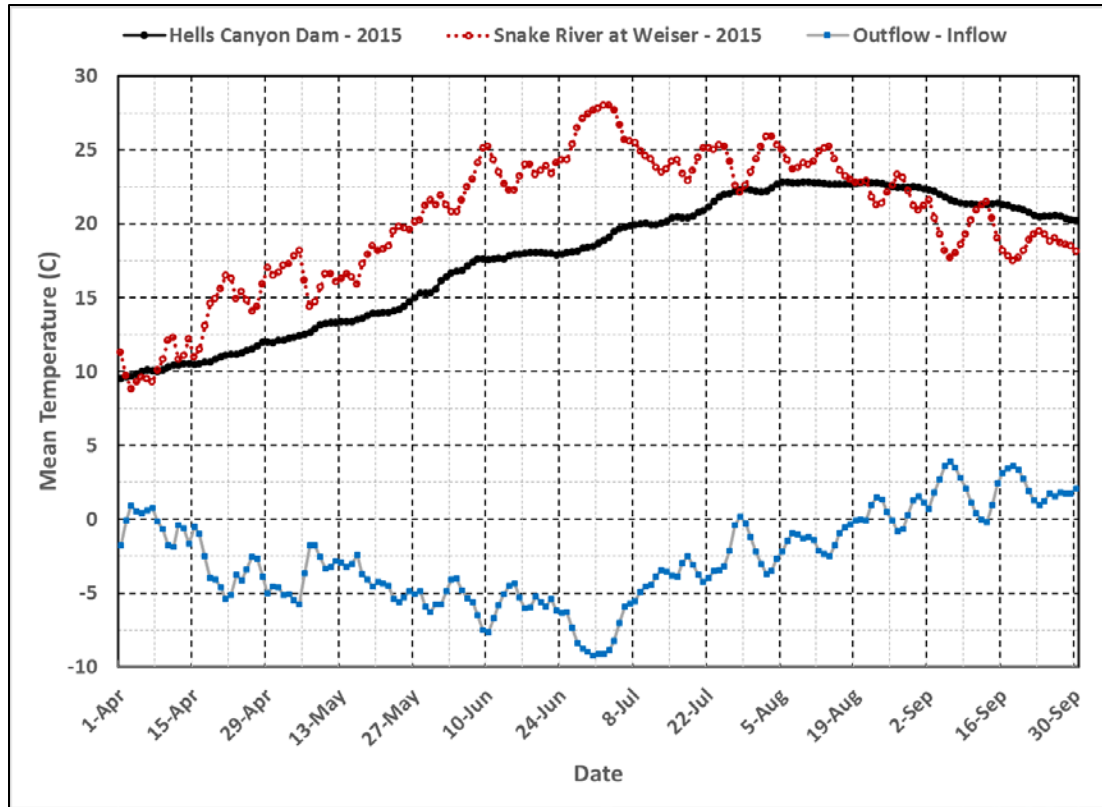


Figure 5b. Outflow temperatures at Hells Canyon Dam compared to upstream Snake River temperatures near Weiser, Idaho. Blue line indicates the difference (inflow – outflow) in temperatures. Sources: Idaho Power Company and USGS data.

2.2.2 Reservoir Environment in the Lower Snake River

Increased water residence times and solar heating, along with inflow from interior basin tributary systems, contribute to warming in the lower Snake River reservoirs. In an effort to moderate this effect, the USACE releases cold water from the hypolimnion of Dworshak Reservoir on the North Fork Clearwater River, Idaho. Temperatures from the Clearwater River are typically 10°C or more cooler than those in the lower Snake during July and August and the colder and denser water from the Clearwater plunges beneath the flow in the lower Snake (Cook et al. 2006). The layering phenomenon is reinforced by the prevailing upstream summer winds, which further slowing the movement of the surface water mass (Caudill et al. 2013).⁷ Among the four lower Snake projects, the strongest stratification is observed in the forebay of Lower Granite Dam during summer, where surface waters are often several degrees warmer than in the tailrace. The warmer surface layer feeds into the top of the fish ladder at Lower Granite Dam, 48 km downstream. In comparison, the water in the tailrace is a combination of warm water from the ladder and surface passage weir plus cold water discharged from the turbines (from deeper in the reservoir) and intermediate temperature water discharged from the regular spill gates (from an

⁷ According to Cook et al. (2006), wind forcing can hold water in the upper layer in place or even move it slightly upstream.

intermediate depth).⁸ Turbulence in the tailrace mixes these sources together and the pattern repeats at the dams farther downstream although with smaller thermal gradients between each forebay and tailrace as the effect of colder water from Dworshak Reservoir diminishes.

The difference in temperature between the warmer water at the top of the ladder (fishway exit) and the cooler water at the bottom (entrance) can block the movement of migrating fish. This was especially true in 2015 when water flowing into the reservoir from the Snake River was much warmer than that released from Dworshak Dam. Water from the tailrace of Lower Granite Dam became thermally stratified once again as it sank to depth in Little Goose Reservoir (although to a lesser degree than in Lower Granite pool), creating the same type of ladder exit and entrance temperature differential at this project.

2.2.3 Water Temperature Control Operations at the Lower Snake River Projects

As described above, the release of cold water from behind Dworshak provides river managers with the ability to influence temperature in the lower Snake River.⁹ Dworshak is operated to reach its full elevation (1,600 feet above Mean Sea Level) by the end of June and then drafted to its lower limit (1,520 feet) by mid-September, an operation that releases a total volume of 1.2 million acre-feet. The USACE uses a water quality and hydrodynamic model (CEQUALW2) to assess the volume that should be released each week so that temperatures do not exceed 20°C in the Lower Granite tailrace. Inputs to the model include the anticipated volumes of water flowing into Lower Granite Reservoir from the Snake and Clearwater rivers, water temperatures in the Snake and Clearwater rivers, water temperature and discharge volume from Dworshak Reservoir, wind, forecasted air temperature, and an index of solar radiation. The regional Technical Management Team reviews these results on a weekly basis throughout the summer months to ensure that the 1.2 million acre-feet of water is released from Dworshak Reservoir as efficiently as possible to meet the temperature objective. Dworshak operations and outflow temperatures in 2015 are summarized in Figure 6.

⁸ When the removable spillway weir (RSW) is in operation, it releases warmer water taken from the surface of the reservoir.

⁹ The ability to moderate mainstem temperatures dissipates below Little Goose Dam (USACE 2013).

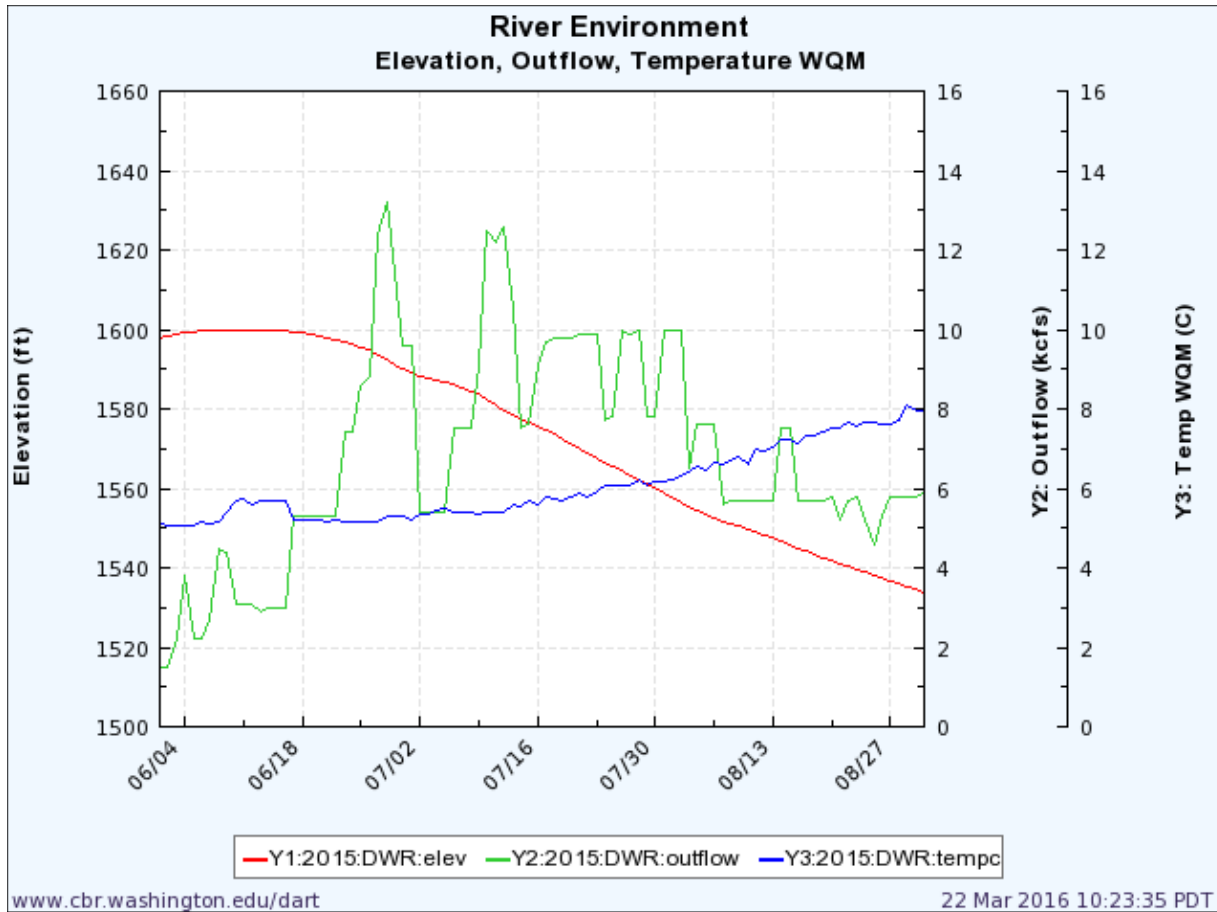


Figure 6. Dworshak Dam reservoir elevations, outflows, and water temperature releases, June 1 to August 31, 2015.

In addition, the USACE (2002) examined the potential to reduce heat gain and thus mainstem temperatures by breaching mainstem dams for its Lower Snake River Juvenile Salmon Migration Feasibility Report and Environmental Impact Statement. The study used EPA’s RBM-10 model, which had been developed to support a total maximum daily load (TMDL) for temperature as required under Section 303(d) of the Clean Water Act (Yearsley 1999, as cited in USACE 2002). The EPA provided their temperature modeling expertise and resources to assist the USACE in evaluating the effects of the dams and impoundments on lower Snake River temperature. The USACE found that the RBM-10 model was an effective tool for modeling temperature effects and relied primarily on the RBM-10 modeling results in the temperature analysis for its Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement. When the RBM-10 simulations assumed Dworshak flow augmentation in average flow years, average temperatures at Snake RM 107 exceeded 20°C for 64 days with dams in place compared to 59 days for the near-natural condition (USACE 2002). Historical data showed that the 20°C benchmark has been exceeded less frequently in years with flow augmentation from Dworshak, confirming these modeling results.

However, RBM 10 is a one-dimensional model that assumes the reservoirs are well mixed, not stratified or layered. Thus, although the RBM 10 results were useful for examining the likely

effects of dam breaching on average temperatures in the lower Snake River, they do not address the current problem of the effects of the stratified reservoir on ladder temperatures and adult migration. The stratified reservoirs in the lower Snake River created a problem in 2015, when the surface water feeding the adult ladder exit was much warmer than that at the entrance, but the existence of colder water at depth that can be pumped into the top of the ladder provided an opportunity to reduce the thermal gradient (Caudill et al. 2013; see also Section 4).

2.2.4 Reservoir Environment in the Lower Columbia River

As discussed earlier, the federal operators took many actions (especially cool water releases from upstream storage reservoirs and additional summer flows from U.S. and Canadian storage projects) to reduce temperatures in the mainstem upper Columbia and lower Snake rivers in an otherwise warm, low runoff year. However, that cooling effect did not prevent the lower Columbia River from becoming substantially warmer in 2015 compared to the previous 10 years (see Figure 2, page 13). Between mid-June and mid-July when most sockeye salmon were passing Bonneville Dam, temperatures were often 4 or 5°C warmer than average, exceeding 20°C five or more weeks earlier than under average conditions. The heat gain within the McNary to Bonneville reach was about 1°C, similar to the recent 10-year average.

The ability to influence temperatures even in the upper reaches of the mainstem Columbia River using water released from Grand Coulee Dam is limited. Grand Coulee Dam has three powerhouses; the older left and right powerhouses draw water from about 60 m in Lake Roosevelt and a newer power plant that draws water from around 27 m. Selective water withdrawals for temperature control are limited to the amount of water that can be passed through the older powerhouses (90,000 cfs), which is below the amount needed to meet the fisheries flow objectives. As a result, the newer powerhouse must also be operated, reducing the efficiency of this operation for temperature management. Furthermore, the effect attenuates with distance downstream and does not moderate temperatures in the lower Columbia reach.

2.3 Effects of Elevated Temperatures on the Survival of Adult Salmon

Elevated temperatures in the mainstem migration corridor have the potential to reduce the survival and productivity of adult salmon, including sockeye. These effects occur via several mechanisms: direct lethality to adults and smolts under high temperature conditions; delay in migration and spawning; depletion of energy stores through heightened respiration; deformation of eggs and decreased viability of gametes; and increased incidence of disease (McCullough et al. 2001). Each of these effects is briefly discussed in the following sections.

1. Direct Lethality

Survival rates based on the amount of time exposed and temperature of exposure in laboratory studies are described in the scientific literature. The standard index for effects reporting is the “upper incipient lethal temperature,” which represents the exposure temperature (given previous acclimation at a constant temperature) that 50% of the experimental fish can tolerate for 7 days

(Elliott 1981, cited in McCullough et al. 2001). Upper incipient lethal temperatures for adult salmonids range from 21-22°C for fish acclimated at 19°C before testing.

2. Delay in Migration and Spawning

Adult sockeye can continue to migrate when water temperatures exceed 20°C, but a sustained exposure to higher temperatures will slow migration (McCullough et al. 2001). Swimming speed and migration rates can be impaired if oxygen concentrations are also low; fish may refuse to migrate, migrate back downstream, or seek shelter in tributaries or other cold-water refuges if these are available (Keefer et al. 2008). Under these conditions, net upstream movement may be reduced or delayed.

During periods of high water temperatures, flow from the forebay of a mainstem dam into the fish ladder can expose migrating adults to high temperatures and thermal stress. In addition, ladders fed by warm surface waters, but with the fish entrance in a cooler tailrace will have a thermal gradient or differential. At temperature differentials of greater than 1°C, Chinook and steelhead have a higher likelihood of entering the ladder multiple times followed by exits back into the tailrace. This movement in the ladder can significantly delay migration, increase thermal exposure, consume energy, and decrease migration success (Keefer and Caudill 2015).

3. Depletion of Energy Stores through Heightened Respiration

An organism expends more energy on metabolic processes such as respiration near the upper end of its thermal tolerance, reducing its capacity to carry out activities such as swimming. Prolonged exposure to elevated temperatures during migration has been related to prespawning mortality. Increased metabolic costs can deplete energy reserves before adults reach their spawning grounds, reducing the size and number of viable eggs even in fish that survive the journey (Sauter et al. 2001). Farrell et al. (2009) describe a potential “death spiral” due to cardiac insufficiency when individuals are exposed to water temperatures above optimal (15-20°C) for sustained periods (Farrell et al. 2008; Eliason et al. 2013).

4. Deformation of Eggs and Decreased Viability of Gametes

Hatchery managers have long known that highest survival of Chinook adults occurs when fish are held at water temperatures less than 14°C and that when adults hold in higher temperature water, egg survival declines (McCullough et al. 2001). Laboratory and field studies show that when adult fish are exposed to constant or average temperatures above 13-15.6°C during the final part of their upstream migration or during holding prior to spawning, the size, number, and/or fertility of eggs are reduced.

5. Increased Incidence of Disease

The bacterial infection *columnaris* has been observed throughout the mainstem Columbia River and in numerous tributaries: the Okanogan, Wenatchee, John Day, Umatilla, Yakima, Snake, and Similkameen rivers. It is carried by all species of Pacific salmon and also by carp, sucker, chub, bass, northern pikeminnow, chiselmouth, and catfish (Colgrove and Wood 1966, as cited in

Materna 2001). Ordal and Pacha (1963; as cited in Materna 2001) considered temperature-induced *columnaris* a major factor responsible for declines of Columbia River Chinook salmon. Other diseases associated with warm water also can produce significant mortalities. *Aeromonas salmonicida* and *A. hydrophila* are common bacterial pathogens linked to high water temperatures (Groberg et al. 1978). These organisms are the infective agent for *furunculosis*, a pathogen affecting all Pacific salmon. Resistance to this disease varies with fish strain, but expression of the disease is also related to water temperature. There also are variations in resistance to *Ceratomyxa shasta*, with the effects of the parasite enhanced by warm water.

6. Summary: Effects of Elevated Temperatures

There are a number of pathways by which warm temperatures can influence the survival and productivity of upstream migrating salmon including Snake River sockeye. In addition to the specific mechanisms discussed above, several of these can interact to reduce survival to the spawning grounds (Keefer et al. 2008). For example, fish that encountered a thermal gradient in the ladders at the lower Snake River dams could already have been weakened by disease. Or the increased metabolic demand for respiration in warm water could have made them less likely to press on past a thermal gradient. Although the actual mechanism of loss is unknown for most of the fish that did not return to spawning area in the Sawtooth Valley, Lake Wenatchee or Okanogan River, there is sufficient evidence that the problem was exacerbated, if not caused, by elevated mainstem temperatures.

3. Adult Sockeye Salmon Migration Timing and Survival in 2015

The migration timing of adult Columbia Basin sockeye salmon at Bonneville Dam in 2015 was consistent with the pattern seen during the previous 10-year period. Fish began to arrive at Bonneville in early June and passage peaked near the last week of June, ending in July (Figure 7). However, unlike the previous years, water temperatures at Bonneville Dam were as much as 4°C warmer during June and July 2015 (see Figure 2, page 13). These high temperatures appear to have taken a toll on adult sockeye survival¹⁰ as described below.

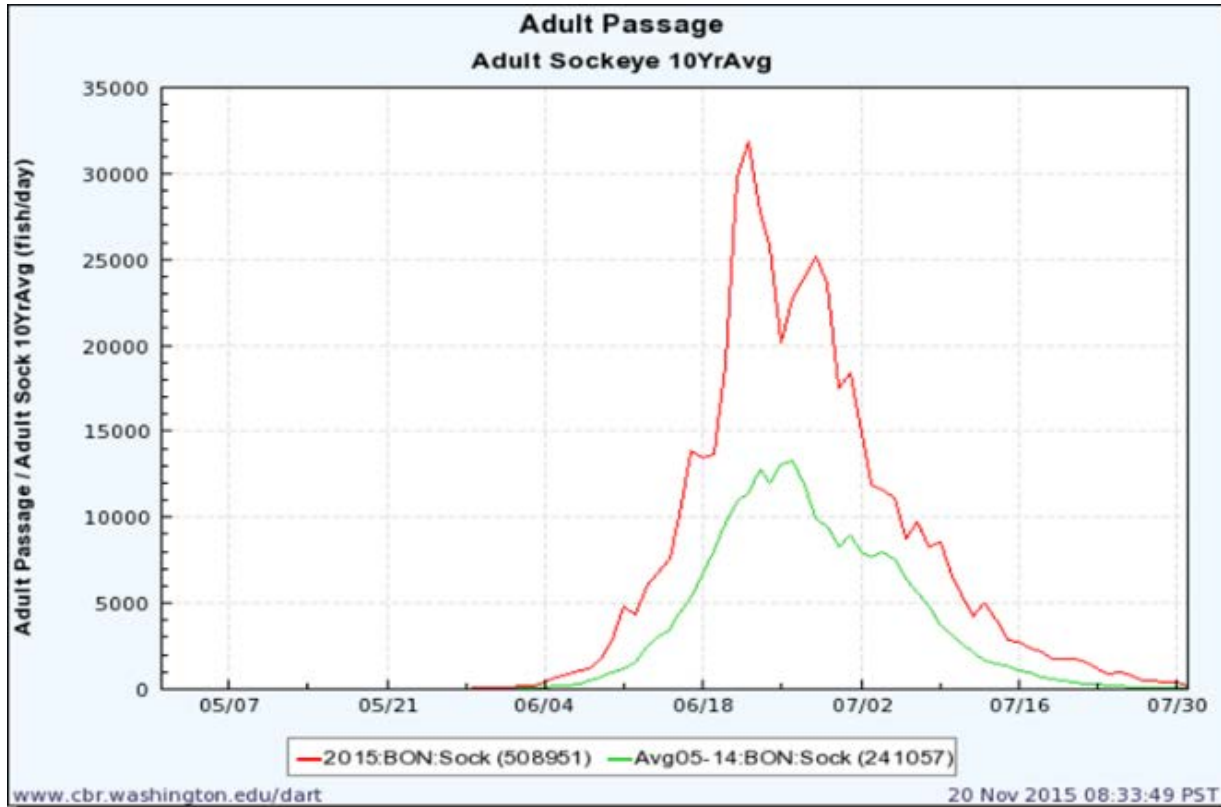


Figure 7. Adult sockeye salmon ladder counts at Bonneville Dam in 2015 compared to the 2005-2014 average.

3.1 Survival Rates in the Bonneville to McNary Reach

Weekly survival estimates for Upper Columbia River (UCR) stocks of sockeye and Snake River sockeye that were either migrated inriver or were transported as juveniles are shown in Figure 8.

¹⁰ In this report, we estimate survival using data obtained from PIT tags and dam counts. PIT tags provide the most accurate measure of fish passage and survival through the system, allowing us to calculate fallback and reascension rates, to partition mortality between specific river reaches, and to estimate rates of straying into non-native spawning areas. Because PIT tags allow fish of known geographic origin to be tracked through the hydrosystem, we can estimate survival for specific populations. A total of 679 PIT-tagged Snake River sockeye salmon were detected passing Bonneville Dam in 2015, compared to a much smaller number (425) of sockeye from the Upper Columbia population (i.e., because far fewer were PIT-tagged). Dam counts are also an important indicator of passage success in a mainstem reach, but lack the detail provided by PIT-tagged fish and by themselves cannot account for adult fallback and reascension or straying rates.

Survival of Snake River Sockeye through the Bonneville to McNary reach was extremely low in 2015. This coincided with a period of unseasonably warm water temperatures in the lower Columbia River. Whereas temperatures are usually about 14°C in early June and increase to 20°C by late July, they reached nearly 18°C in early June and increased to almost 23°C by early July, 2015 (see Figure 2, page 13). Fish that passed Bonneville Dam early in the season when water temperatures were still less than 18°C had the highest survival, approaching 90% for upper Columbia sockeye and 70% for Snake River fish. Survival rates of adult sockeye salmon passing Bonneville declined substantially once water temperatures exceeded 20°C.

Based on PIT-tag detections,¹¹ the relatively low upstream survival of Snake River sockeye salmon that were transported as juveniles appears to have contributed to the low overall return rate of adults from this ESU (Figure 8). Transported fish have higher straying, wandering, and fallback rates as adults than those that are not transported (Keefer and Caudill 2012). Fish that exhibited any of these behaviors moved upstream more slowly and therefore were more likely to experience mainstem temperatures above 20°C during 2015.

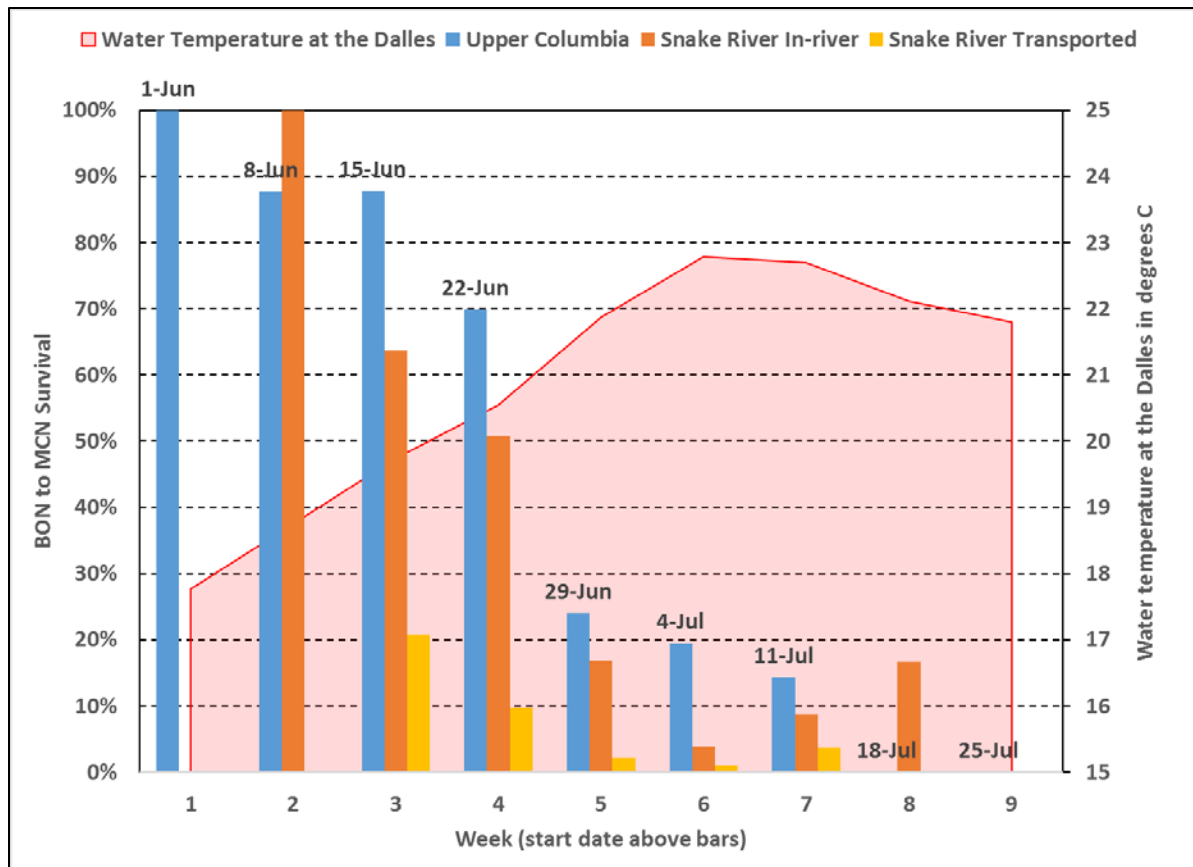


Figure 8. Weekly adult sockeye survival estimates from Bonneville to McNary dam in 2015 for Upper Columbia River sockeye salmon (blue bars), Snake River sockeye salmon that migrated inriver as juveniles (orange bars), and Snake River sockeye that were transported as juveniles (yellow-orange bars) with water temperatures (red line) at The Dalles Dam. Source: PITAGIS data and Columbia River DART.

¹¹ Idaho Fish and Game estimates that 16.7% of adult Snake River Sockeye returning in 2015 were PIT tagged.

One example of the effects of the delayed sockeye run was captured in a video clip made in the vicinity of Drano Lake, near the confluence of the Little White Salmon and Columbia rivers, in July, 2015 (Figure 9). Adult salmon are attracted to this area because it is often cooler than the mainstem Columbia River, but symptoms of disease were clearly visible on many of the fish observed in this video.

Figure 9. Video capture of an adult sockeye near Drano Lake during mid-July, 2015. The white areas on the surface of the fish appear to be a fungus, possibly *Saprolegnia* sp., which is known to affect fish subjected to thermal stress (Roberts 2012).



Annual estimates of survival (2010-2015) from Bonneville to McNary dams for upper Columbia River (UCR) stocks and Snake River sockeye that migrated inriver as juveniles or were transported are shown in Figure 10. Beginning in 2012, survival rates of UCR sockeye salmon have been substantially higher than estimates for Snake River sockeye salmon. During 2013-2015, the survival rates for adults that migrated inriver as juveniles were significantly higher than for adults that had been transported. Tailrace temperatures at The Dalles Dam during June and July were highest in 2015, followed by 2013-14 (Figure 11).

The survival differences between UCR and Snake River sockeye salmon are consistent with their respective passage timing at Bonneville Dam. In general, based on PIT tag detections of known origin fish, adult Snake River sockeye begin passing Bonneville about a week later than the UCR stocks. Thus, Snake River fish are exposed to higher (cumulative) temperatures than UCR sockeye stocks, which was likely responsible, either directly or indirectly (or both), for their lower survival rates in 2013-15. There was no difference in migration timing at Bonneville Dam between adult sockeye that had been transported or migrated inriver as juveniles. However, it appears that Snake River sockeye salmon that had been transported as juveniles had an impaired homing ability, which delayed their upstream progress and increased their exposure to elevated mainstem temperatures.

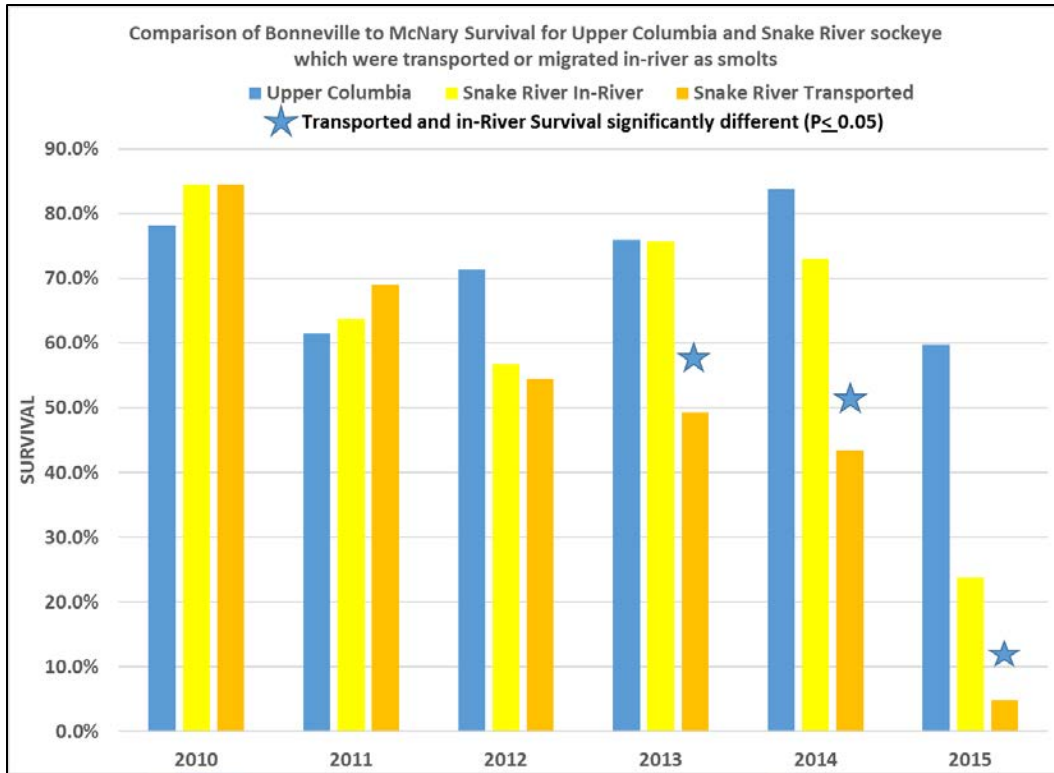


Figure 10. Annual adult survival estimates from Bonneville to McNary dams for upper Columbia River sockeye stocks (blue bars) and Snake River sockeye salmon that migrated inriver (yellow bars) or were transported as juveniles (orange bars). Source: PTAGIS data

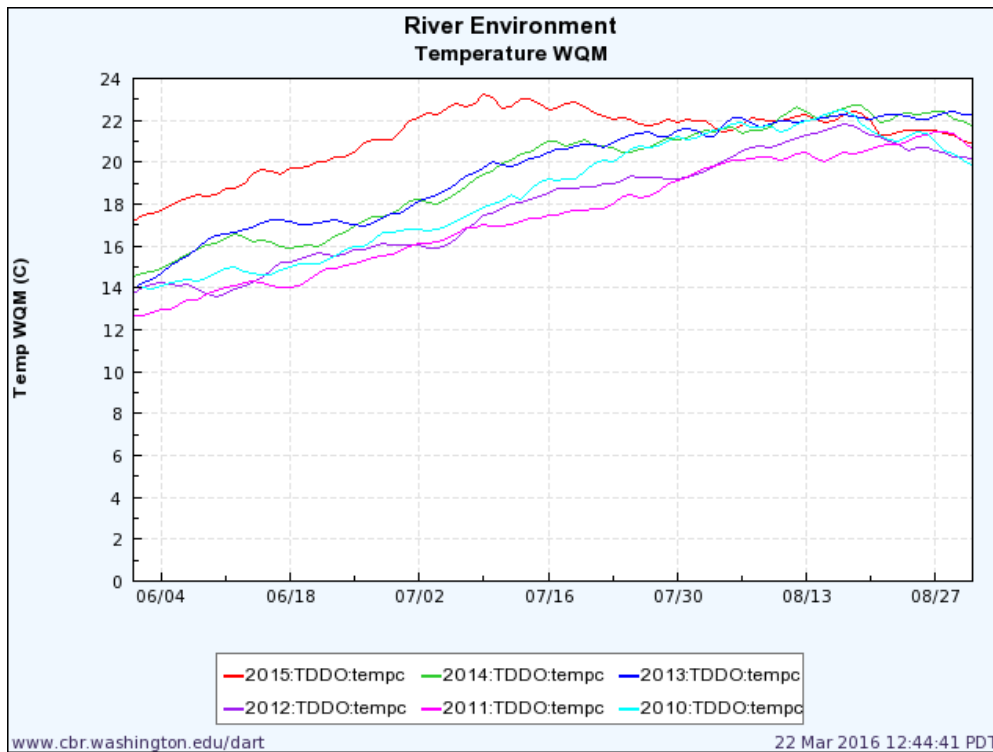


Figure 11. Tailrace temperatures at The Dalles Dam from June 1 to August 31 (2010-2015).

3.2 Survival Rates in the McNary to Rock Island / Wells Reach and the Okanogan River

Although adult survival from Bonneville to McNary Dam was higher for upper Columbia than Snake River sockeye salmon during 2015, survival to the spawning grounds was poor for both groups. About 47% of the adults bound for the upper Columbia basin survived passage from Bonneville to Wells Dam, but only 6% passed Zosel Dam on the Okanogan River and about 2% ultimately survived to Lake Osoyoos, just upstream (Fryer 2016). A total of 37,624 sockeye passed upstream through the underwater video at Zosel in 2015 (Schaller 2016). These are total observed counts (upstream minus downstream) and have not been adjusted for fallback. An unknown percent of those fish successfully spawned. This was far below survival observed during the past 5 years, during which survival rates ranged from about 25-50% from Bonneville Dam to spawning (Fryer 2016).

3.3 Survival Rates in the McNary to Lower Granite Reach and the Mainstem Salmon River

Only 14% of the PIT-tagged population that passed Bonneville Dam in 2015 were detected at McNary, 9% at Ice Harbor, and 4% at Lower Granite. One percent of the Snake River sockeye salmon detected at Bonneville reached Idaho's Sawtooth Valley, and another 0.5% were collected at Lower Granite Dam and transported directly to Eagle Fish Hatchery (Figure 12).¹² Of the 8% detected at Ice Harbor Dam, less than about 44% were detected at Lower Granite Dam, compared to an average of 90.6% between Ice Harbor and Lower Granite Dam during the preceding five years (range = 70.6% to 97.4% from 2010 to 2014). Though ameliorated by releases of stored water from Dworshak Dam and reduced temperatures (relative to inflow) from the Hells Canyon Complex, adult sockeye salmon were still exposed to unusually high June and July water temperatures in the lower Snake (Figure 13) in addition to their exposure in the lower Columbia River during 2015. As described in Section II.A (Flow and Temperature Conditions), temperatures in the Salmon River reached 25°C during early July. Of the 27 detected PIT-tagged adult sockeye at Lower Granite Dam, three were collected and transported directly to Eagle Fish Hatchery. Of the remaining 24 migrating in-river, less than one third (seven) were detected in the Sawtooth Valley.

¹² Of the 98 adult Snake River Sockeye salmon that were detected at McNary Dam, nine strayed up the Columbia River (were detected at or above Priest Rapids Dam). Six of these fish were transported as juveniles, three migrated inriver as juveniles (one of which fell back at Ice Harbor Dam before migrating up the Columbia River. All nine of these fish that strayed survived to pass Rock Island Dam, seven were detected at Wells Dam, but none of these fish were detected at Zosel Dam in the Okanogan River.

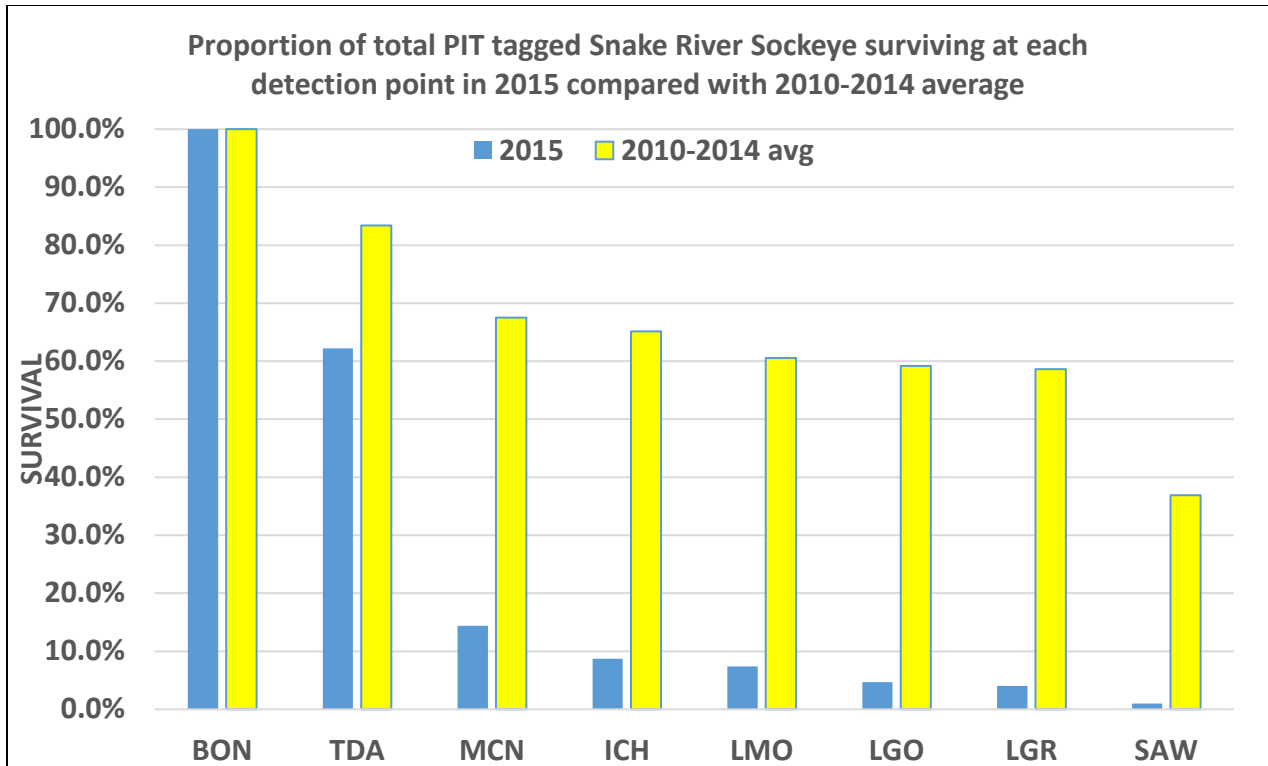


Figure 12. Proportion of total PIT-tagged Snake River sockeye salmon detected at Bonneville Dam that survived to each subsequent detection point (The Dalles, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams and the Sawtooth Hatchery weir) in 2015 compared to average for 2010-2014. Source: PTAGIS data

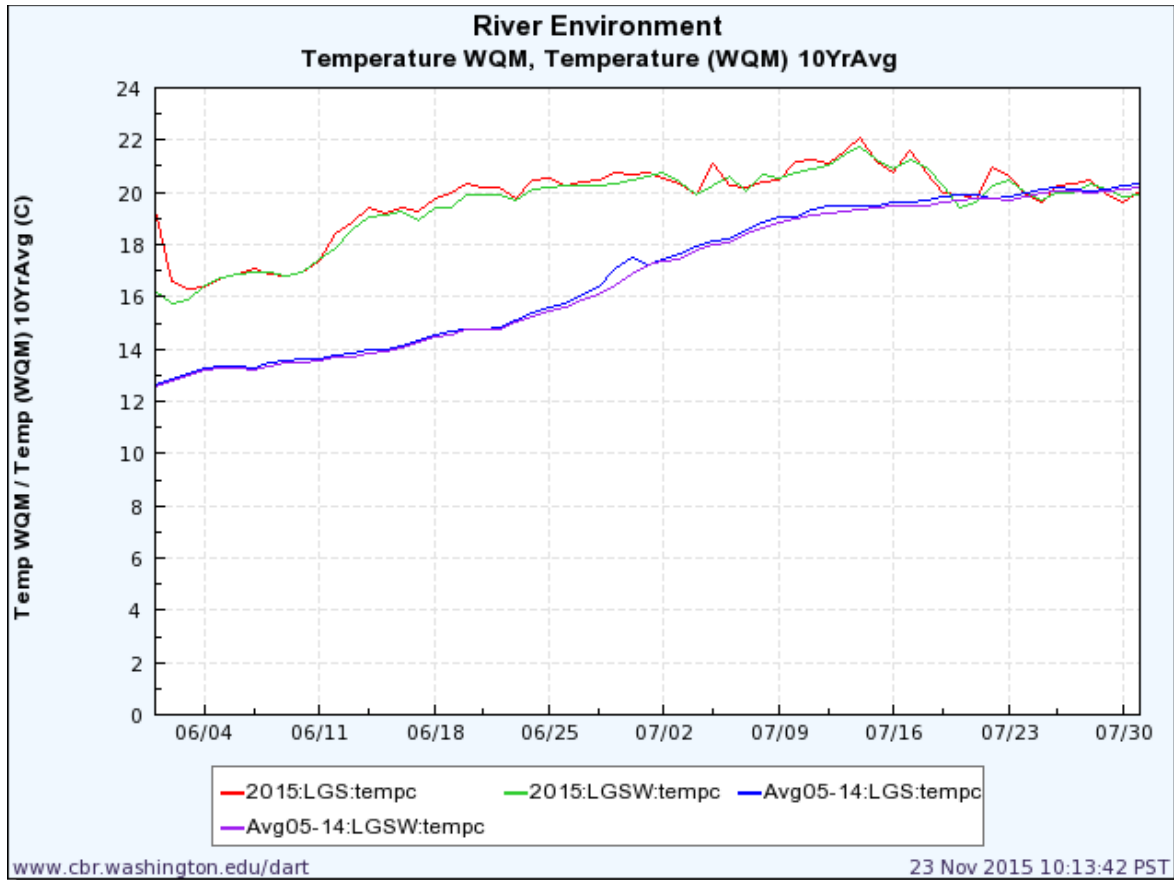


Figure 13. Water temperatures measured in the forebay (red line) and tailrace (green line) at Little Goose Dam during June and July, 2015, and 10-year average temperatures at these locations (blue and purple lines), respectively.

3.4 Summary of Mainstem and Tributary Survival and Detection Histories

Survival rates of Snake River and upper Columbia River sockeye salmon in key reaches of the adult migration corridor are shown in Tables 4 and 5, respectively.

Table 4. Estimated annual survival rates of adult Snake River sockeye salmon by adult migration year and juvenile migration history from Bonneville Dam to the Sawtooth Valley (yellow shaded cells) indicate statistically significant differences, $P < 0.05$. Source: PTAGIS data

Adult Migration Year	Juvenile Migration History	# at BON	Survival Estimates (%)			
			BON to MCN	MCN to LGR	BON to LGR*	LGR to Sawtooth Valley
2010	Inriver	32	84	96	81	77
	Transported	8	88	74	63	80
2011	Inriver	307	64	97	62	75
	Transported	209	69	95	66	77
2012	Inriver	111	57	94	53	64
	Transported	11	55	67	36	50
2013	Inriver	136	76	76	57	33
	Transported	69	49	38	19	31
2014	Inriver	216	71	93	66	56
	Transported	129	43	95	41	55
2015	Inriver	320	26	33	8	29 [^]
	Transported	357	5	0	0	0

* The survival estimate for the BON to LGR reach is the product of survival from (BON to MCN) x (MCN to LGR). For example, $(0.84) \times (0.96) = 0.81$ or 81%.

[^] There were 27 detections of PIT tagged adults at Lower Granite Dam in 2015 (transported and inriver juvenile migrants combined). Three of the 27 were transported to the hatchery for spawning and 24 migrated instream. Of these 24, only seven (i.e., 29%) were detected in the Sawtooth Valley.

Table 5. Estimated annual survival rates of adult upper Columbia River sockeye salmon by migration year from Bonneville Dam to Rock Island Dam (both UCR ESUs) and Rock Island to Zosel Dam (Okanogan River sockeye salmon only). Source: CRITFC.

Adult Migration Year	Juvenile Migration History	# at BON	Survival Estimates (%)			
			BON to MCN	MCN to RIS	RIS to WEL (Okanogan River Only)	WEL to Zosel (Okanogan River Only)^
2010	Inriver	957	82	95	88	77
2011	Inriver	651	69	86	78	75
2012	Inriver	572	74	91	63	39
2013	Inriver	157	77	88	85	70
2014	Inriver	323	88	88	80	69
2015*	Inriver	425	60	78	100	12

* Estimated escapement of Wenatchee River and Okanogan River sockeye in 2015 was 10-15% and 3-4.5%, respectively.

^ Prior to 2014, >5% of PIT tagged fish were detected at Zosel Dam. Beginning in 2014, additional detectors were deployed and as a result, detection probabilities have greatly improved.

Detection histories of adult sockeye migrating through the mainstem dams (to Rock Island Dam for UCR stocks of sockeye salmon and to LGR for Snake River sockeye salmon) in 2015 are depicted in Figure 14. Several conclusions can be drawn from this figure about the behavior of adult sockeye groups discussed in this paper:

- UCR sockeye adult salmon passed Bonneville Dam earlier than Snake River inriver adults, which resulted in differential exposures to increasing temperatures in June and July.
- Early migrating adults (those that passed Bonneville Dam before temperatures exceeded 20°C) migrated quickly (similar to past years) and survived through the mainstem migration corridor at relatively high rates.
- Few adults from any group that migrated past Bonneville Dam after temperatures reached about 22°C at The Dalles ultimately survived to the uppermost dams.
- Later arriving PIT tagged fish from all groups were detected in the mouth of the Deschutes River – a known thermal refuge – and there is visual evidence of adults resting near Drano Lake (see Figure 2, page 13), a known thermal refuge in Bonneville pool.
- Later arriving fish exposed to temperatures in excess of 21 or 22°C were far more likely to “fall back” at The Dalles Dam. Some of the Snake River inriver migrants subsequently fell back at Bonneville Dam before moving upstream again. A much larger number (and proportion) of transported Snake River sockeye salmon which were exposed to the

highest temperatures engaged in these behaviors (falling back at The Dalles and Bonneville Dams and being detected at the mouth of The Deschutes River).

- Some Snake River sockeye were apparently able to survive for several months in the Little Goose reservoir – a thermal refugia resulting from Dworshak water releases – migrating past Lower Granite Dam in late September or October. However, none of these fish are known to have survived to the Sawtooth Valley.
- Adult Snake River sockeye salmon that were transported as juveniles appeared to have an impaired homing ability compared to those that migrated inriver. This resulted in delays in upstream passage and increased exposure to elevated temperatures. This likely contributed to the large disparity in estimated survival between Bonneville and Lower Granite dams for smolts that were transported (0% survival) and those that migrated inriver as juveniles (8%).

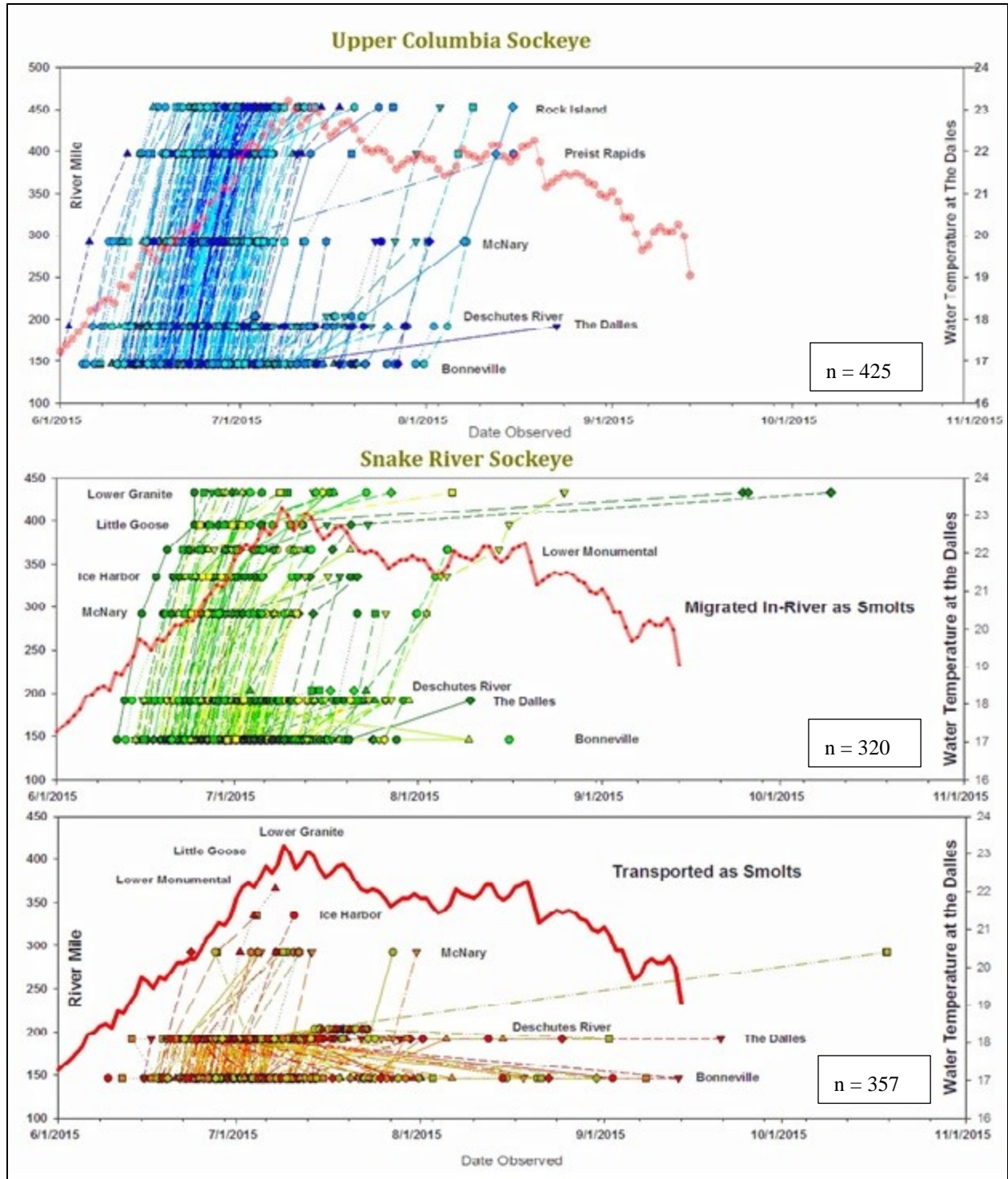


Figure 14. 2015 PIT tag detection histories for adult UCR sockeye salmon stocks (upper panel – with temperatures at The Dalles Dam) and Snake River sockeye salmon that migrated inriver (middle panel) or were transported as juveniles (lower panel). Source: PTAGIS data.

4. In-Season Management Decisions and Actions

Based on in-season observations of dam counts and PIT-tag conversion rates¹³ it was evident to regional salmon managers by early July that the sockeye run was not performing well. In 2015, the salmon managers focused their attention on management actions in the lower Snake River where there were some ability to manage temperatures by releasing cold water from Dworshak Dam,¹⁴ some of the facilities needed for a successful trap-and-haul operation were present at Lower Granite Dam, and there was some potential to draw cooler water from the project forebays. In contrast, few in-season actions could be taken to improve conditions on the lower Columbia River because there are no large storage reservoirs that can be used to regulate temperature in that reach and the run-of-the-river reservoirs are not well stratified (i.e., no cooler layer at depth that can be pumped up to cool the fish ladders).

The salmon managers set a target temperature of 19.2°C in the tailrace of Lower Granite Dam to provide some assurance that 20°C was not exceeded during the sockeye migration period. However, two of the solar radiation monitoring sensors near Lewiston Idaho, malfunctioned just before the July 4th weekend so that incorrect data were used in the USACE's water quality model. Based on flawed modeling results, the Technical Management Team (TMT)¹⁵ agreed to reduce discharge from Dworshak Dam while temperatures in the lower Snake River were increasing rapidly, exceeding 21°C in the tailrace of Lower Granite for several days during the peak of the sockeye migration. Temperatures as high as 22°C were observed in the tailrace at Little Goose Dam by mid-July, the next project downstream (see Figure 13, page 30). Temperatures as high as 25°C were measured near the surface in the forebay.

Passage of sockeye at the Little Goose project slowed dramatically during mid-July when temperatures reached these levels, but the reason was not clear to the fisheries managers at the time. The three reasons postulated as likely for the passage delay were:

- Adults were exhausted from stress and disease due to prolonged exposure to the high temperatures they had already encountered in the lower Columbia and Snake rivers
- The ladder was drawing water, at times exceeding 25°C, from a shallow depth in the forebay, creating a temperature differential that adults perceived as a passage barrier
- Adults had difficulty finding the entrance to the fish ladder at this project because back eddies in the tailrace interfered with attraction flows.

¹³ Conversion rates measure the minimum survival of adult fish passing from one dam to the next upstream dam of interest. This number can be adjusted (upwards) to account for harvest and background stray rates.

¹⁴ Cold water released from Dworshak Dam on the north fork of the Clearwater River exerts the greatest control on temperature at Lower Granite Dam; the quantity of water released from Dworshak is generally regulated to target a 20°C temperature in the Lower Granite Dam (LWG) tailrace after mixing first with warmer waters of the mainstem Clearwater River and later, the Snake River. Its effect decreases downstream as it mixes with water in the lower Snake River to the point where there it has little effect on temperature (below Ice Harbor Dam).

¹⁵ The Technical Management Team, composed of federal, state, and tribal agency representatives, is a forum for advising federal operators on adaptively managing inseason operations of the Federal Columbia River Power System in accordance with the 2008 FCRPS BiOp (as amended in 2010 and 2014).

It is likely that all of these factors were responsible to some degree. Following discovery of the malfunctioning solar radiation monitoring stations, Dworshak releases were increased to achieve the Lower Granite tailrace target. The remaining management choices were primarily focused on project operations at the each of the lower Snake River dams.

4.1 Project-Specific Operations

NOAA Fisheries declared a passage emergency on July 13, 2015, which allowed USACE to operate the adult trap at Lower Granite Dam outside the range of previously established maximum temperatures (which were developed to provide safe conditions for fish handled in the trapping facility). The Idaho Department of Fish and Game (IDFG) hauled trapped adults to Eagle Hatchery in insulated trucks, circumventing a 400-mile migration in unusually warm water (see Section IV.B, Adult Sockeye Salmon Transportation). The TMT also discussed changing spill and turbine operations at Lower Granite and Little Goose dams to improve hydraulic tailrace conditions and make the fish ladders more attractive to adults. NOAA Fisheries proposed operating only Unit 1 at Lower Granite Dam and spilling the remaining volume of water. Turbine Unit 1 is a “fixed blade unit,” which requires a greater volume of water to operate than Unit 2. That is, a lesser volume of water would be available to spill, an important consideration during the 2015 low runoff year when the volume of water spilled at Lower Granite was already below the planned BiOp level of 18 kcfs. The fisheries managers made a similar decision to operate Unit 1 during the summer of 2013 (another warmer than average year) and this appeared to result in higher hourly adult ladder counts of fall Chinook salmon (Table 6).¹⁶ Also, USACE had reported that hydraulic conditions in the tailrace of Lower Granite appeared much better (visual observations) under Unit 1 operation (Figure 15).

¹⁶ Modified operations were conducted in 2013 at Lower Granite Dam when high temperatures and confusing tailrace hydraulics had established during both the sockeye and fall Chinook passage seasons. Based on tailrace observations and count data, the operation of the fixed blade Unit 1 at a higher unit flow reversed the tailrace eddy (Figure 15) and increased fall Chinook salmon counts over the Fish Passage Plan operation (Table 6). Temporary alterations to operations outside of the Fish Passage Plan are infrequent, but may be warranted when an adult passage issue outweighs the risk to juvenile salmonids, especially if very few juveniles are passing at a particular project during low flow and high temperature conditions. In-season alterations to project operations may range from spill pattern changes, removing spillway weirs, change in priority units, or changes in spill pattern or volume to temporarily improve attraction for adults during emergency situations.

Table 6. Adult Chinook counts in the ladders at Lower Granite Dam during July 25–August 10, 2013, when emergency pumps were in operation and Turbine Unit 1 alternated with Unit 2. The operation was designed to enhance tailrace conditions while spilling water up to the Total Dissolved Gas cap (120% of saturation) as measured in the tailrace at each project. Source: USACE data

Number of Adults	Unit 2	Unit 1
Ascending Ladder	260	2,021
Descending Ladder	232	1,337
Net Ascending	28	684
Hours Operated	88	239
Net Ascending / Hour	0.3	2.9

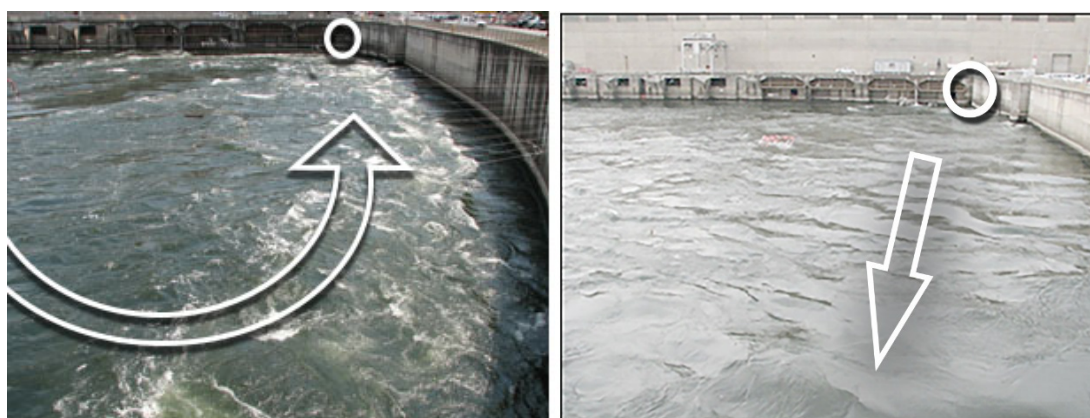


Figure 15. Tailrace conditions at Lower Granite Dam in July 2013 showing the reverse eddies with Turbine Unit 2 operating (left) and improved downstream flow with Unit 1 operating (right). Circles show ladder entrances. Arrow on the left shows the direction of the back eddies, which can confuse adults trying to orient into the current to move upstream. Arrows on the right show the direction of flow (away from the ladder entrance) without the reverse eddies. Photo courtesy of Darren Ogden (Northwest Fisheries Science Center).

4.1.1 Operations at Lower Granite Dam

Since 2013, USACE has used auxiliary and emergency pumps to draw deep, cool forebay water at Lower Granite Dam to cool and reduce the thermal temperature gradient within the fish ladder. In 2015, rented emergency pumps were operated from June 25 - Sept 30, 2015 to reduce temperatures in the upper exit section of the ladder. The auxiliary pump was operated from June 23 - Sept 30 to cool the middle section of the ladder. Even with these actions, substantial differences in temperature were observed between the entrance (bottom) and exit (top) of the adult fish ladder (Figure 16).

Sockeye counts at Lower Granite Dam were increasing at the beginning of July with ladder exit temperatures remaining under 21.1°C (Figure 16). After July 3rd, ladder exit temperatures increased beyond 21.7°C as a warming trend began in the lower Snake River. Counts declined with only two adult sockeye counted on July 7th. Twelve sockeye were counted on July 8th, after the USACE closed the removable spillway weir and implemented a uniform spill pattern, even though the daily ladder exit temperature averaged 23.3°C. The daily count again increased

slightly (to 17 fish) on the 9th (ladder exit temperature averaging 23.4°C). The temperature increased slightly to 23.6°C on the 10th and sockeye passage declined. On the 13th, the turbine unit priority was switched to Unit 1 with a uniform spill pattern (Figure 16). Counts increased steadily for four days after the change in priority, which corresponded with a brief decrease in ladder exit temperatures. Passage rates dropped rapidly to two fish per day on the 18th and 19th as ladder exit temperatures again increased to above 21.7°C. Passage remained minimal until exit temperatures fell below 21.1°C on the 21st and the remaining sockeye exited the ladder in a pattern that is characteristic of counts at the tail end of a fish run.

The return to Turbine Unit 2 operation on the afternoon of July 31st did not correspond with an observable passage response, although it did coincide with the tail end of the run and ladder exit temperatures above 21.1°C. However, this behavior is typical: fish counts at Lower Granite Dam have consistently shown a stronger initial response to a change to Unit 1 operations than a change to Unit 2 operations. As a side note, none of the fish that passed Lower Granite after July 16th are known to have survived migration to the Sawtooth Valley.

In summary, it appears that the emergency operations at Lower Granite Dam did not have a detrimental impact and may have benefited adult passage through improved adult attraction conditions. The poor condition of the fish by the time they reached Lower Granite and the elevated ladder temperatures were likely the main drivers of the low passage counts in 2015. The day-to-day variability in ladder counts may have been related to the ladder exit temperatures and/or the turbine unit priority/spill operations, but the data sets are too small and variable for statistical comparisons.

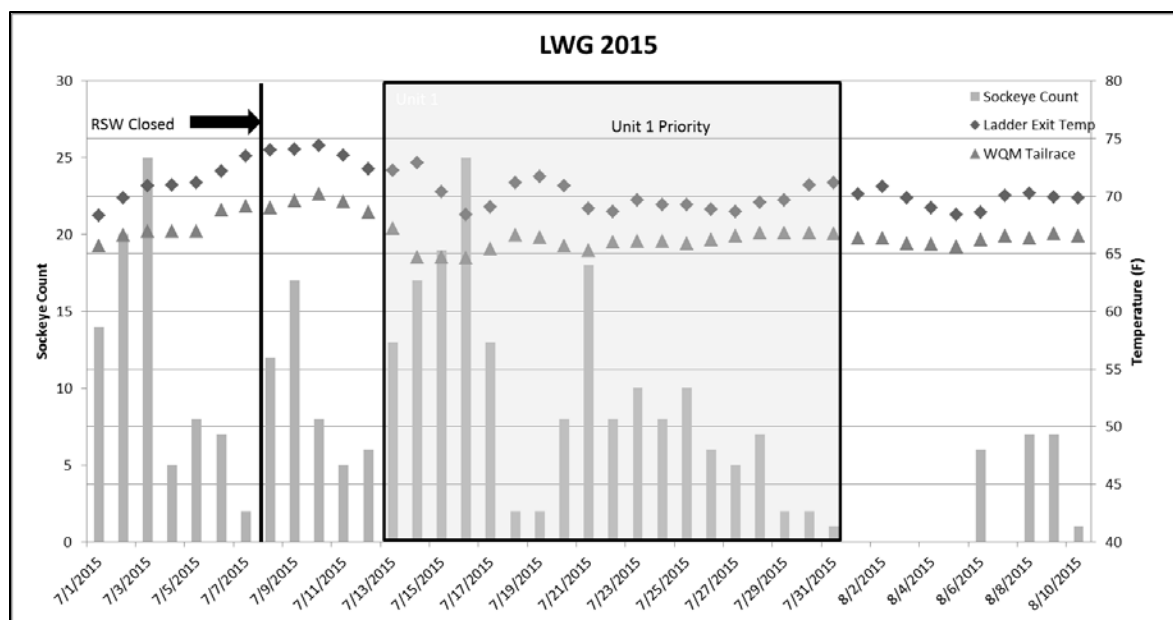


Figure 16. Sockeye salmon ladder counts, ladder exit pool temperature, and tailrace temperature (WQM Tailrace) at Lower Granite Dam during 2015. Source: USACE data

4.1.2 Operations at Little Goose Dam

Figure 17 summarizes adult sockeye ladder counts and ladder exit temperatures at Little Goose Dam during summer 2015. Passage was clearly affected on at least two occasions when temperatures exceeded about 23°C (June 27-28 and July 8-9).

The USACE removed the temporary spillway weir for the season on June 18, 2015. As counts and conversion rates through Little Goose Dam remained low, NOAA Fisheries proposed that USACE pass all water through the turbines during daytime (i.e., provide no spill) at this project. This action was expected to reduce the potential for eddies to form, making it easier for adults to locate the fish ladder, and reducing temperatures in the tailrace. The temperature at 30 m in the Little Goose forebay, where the turbine intakes are located, was approximately 19°C, several degrees cooler than at 20 m where the spillways draw water. Therefore, operating only the turbines had the potential to provide cooler water to adults holding below the project.

The TMT did not reach consensus on implementing these operations when they were discussed on July 22nd. The State of Oregon and the Nez Perce Tribe objected, citing more confidence that they would reduce the survival of migrating Snake River fall Chinook salmon smolts than that they would provide any benefit to adult sockeye salmon. Taking the co-managers' comments into account, NOAA Fisheries recommended a block design schedule for spill operations at Little Goose Dam (i.e., blocks of two days each with spill off, on, and off). NOAA Fisheries analyzed the potential negative effect on the juvenile fall Chinook population prior to implementation, and identified little or no negative effect (Appendix A).

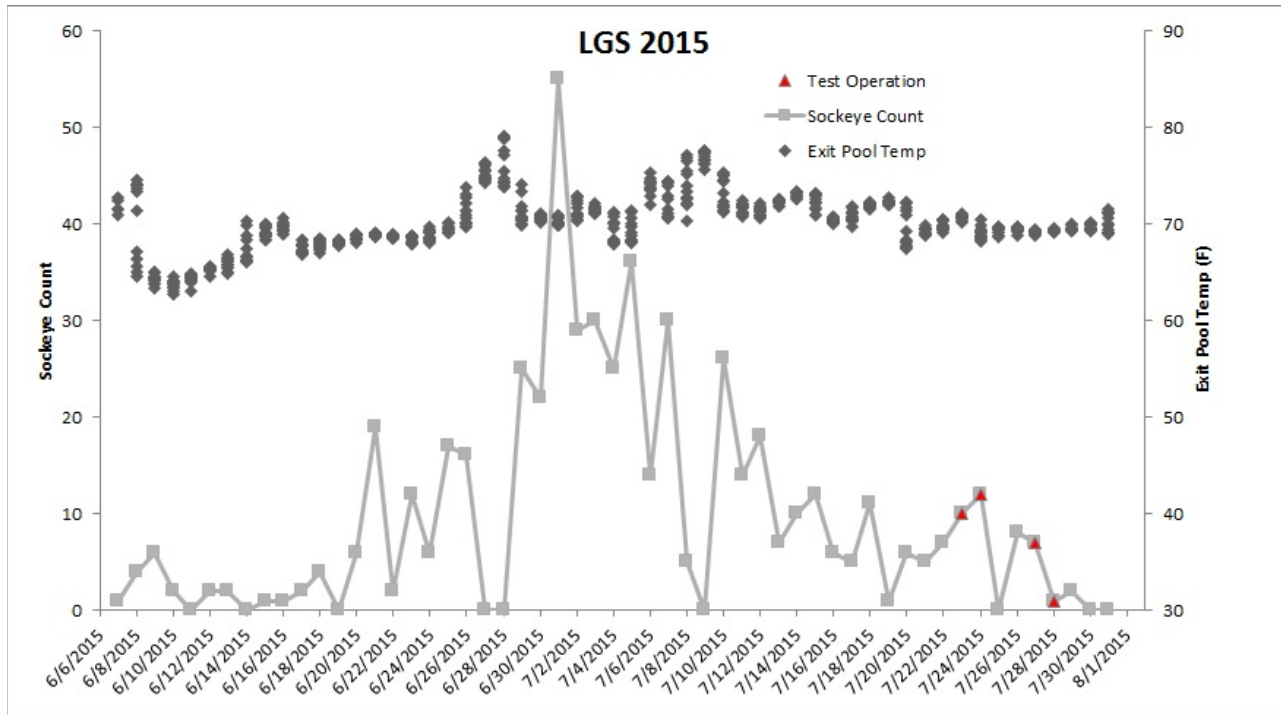


Figure 17. Adult sockeye passage counts and hourly ladder exit temperatures at Little Goose Dam in 2015 (red triangles denote counts during days when spill was turned off in an effort to provide better hydraulic conditions at the Little Goose ladder entrance). Source: USACE data

The 6-day blocked spill operation began at Little Goose on July 23rd with agreement that any additional days without spill would be contingent on the results. Initially, adult passage increased at Little Goose (Table 7), but the adult count was also similar on one of the no-spill days. And the second block of two days, with spill, produced similar results as the preceding block of no-spill days.

A best case result would have been an increase in adult passage of several hundred fish, the cumulative difference between the ladder counts at Lower Monumental and Little Goose dams. However, only 40 fish passed the Little Goose ladder after July 23rd. Therefore, no additional no-spill days were proposed after July 28th.

Table 7. Adult sockeye salmon passage at Lower Monumental and Little Goose dams during the blocked spill operations at Little Goose Dam. Daytime spill was not provided on days marked “Test.” Source: USACE data

Date	Test Days	Adults Ascending Lower Monumental ^a	Adults Ascending Little Goose
7/20/2015		12	6
7/21/2015		3	5
7/22/2015		1	7
7/23/2015	x	0	10
7/24/2015	x	9	12
7/25/2015		0	0
7/26/2015		4	8
7/27/2015	x	3	7
7/28/2015	x	1	1
7/29/2015		1	2
7/30/2015		0	0
7/31/2015		0	0

^a The numbers of adult sockeye ascending Lower Monumental Dam are shown in this table as a gage of the numbers available to ascend the ladders at Little Goose Dam. However, the cumulative adult count at Lower Monumental was several hundred fish greater than at Little Goose Dam, indicating several hundred fish may have been lost between Lower Monumental Dam and Little Goose Dam.

The fate of the fish that did not pass Little Goose Dam is unknown. Most likely, these fish either died in Lower Monumental Reservoir (water temperatures in the tailrace of Little Goose Dam, at the upper end of Lower Monumental Reservoir, approached 22°C, see Figure 13, page 30) or fell back past Lower Monumental and Ice Harbor dams and ascended the upper Columbia River. Similar to what was observed in Drano Lake and the Deschutes River in the lower Columbia River, compromised fish may have held and died in the cool water outflow from Lyon’s Ferry Hatchery, which is located midway between Lower Monumental and Little Goose dams. Support for the latter possibility is based on the observation that about 30% of the adult sockeye that were trapped at Lower Granite Dam originated in the upper Columbia basin. If the proportion of out-of-basin fish was also this high (or higher) at Little Goose, and if many of these fish fell back, it would account for most of the ladder count differential. The relative influence of each factor (mortality due to high temperature exposure versus fallback) is unknown.

On July 23, 2013, the regional Fish Passage Advisory Committee submitted System Operation Request 2013-4 to the USACE, suggesting measures with the potential to increase adult passage. These included cycling (opening and closing) the navigation locks as often as practical. This suggestion was also proposed during a Fish Passage Operations and Maintenance (FPOM) conference call on July 24th, where the USFWS also requested cycling of the locks as an alternate route of passage upstream (Fish Passage Center 2015). The parties debated the question of how effective more frequent lock operation would be in passing adults with little consensus on the benefits. The following review of the available information indicates that some additional

fish could be passed through the locks if they were operated more frequently, but the benefit is likely to be small and there is little information to evaluate the potential for negative effects.

Based on PIT tag detections and migration studies, adult salmonids do use the navigation locks at the lower Columbia and Snake River dams for upstream passage, but the frequency of use is very low. More than 99% of the PIT-tagged adults known to pass Snake River dams had migrated through and were detected in the fish ladders (PSMFC 2014). The rest of the undetected adults (<1%) could have passed through the locks or have passed through the adult ladder undetected due to tag “collisions” (interference). Keefer et al. (2004) found that adult salmonids “only occasionally pass navigation locks.” Bjornn and Peery (1992) reported that 0.86% of sockeye salmon, 1.1% steelhead, and 1.3% of Chinook salmon passed through the Bonneville Lock during the 1969 season. Only 7 out of 801 (0.8%) radio tagged Chinook salmon passed through the locks at Bonneville Dam in 1996 (Keefer et al. 1996). Less than 2% of adults with radio-telemetry tags migrated through the locks at John Day and The Dalles dams (Boggs et al. 2004).

This information indicates that under current operations, small numbers of adults pass through the navigation locks. Although the locks should not be considered a primary passage route, more frequent operation could be considered as a strategy to pass a small number of additional fish during low flow, high temperature conditions. If implemented, the fate of these fish should be monitored to determine whether there are negative effects associated with this passage route. However, other alternatives aimed at improving conditions within the adult fishways during periods of high temperatures appear to be more promising and effective (see Section 5).

4.2 Adult Sockeye Salmon Transportation

In this section, we describe the “trap-and-haul” operation for adult sockeye at Lower Granite Dam during 2015. In June, the Idaho Department of Fish and Game (IDFG) and NOAA Fisheries became increasingly concerned that environmental conditions (extremely low flows, above average water temperatures, and the projected forecast for continued sunny and very hot temperatures) could lead to major problems for migrating adult salmon in the Columbia River, especially endangered Snake River sockeye salmon. They closely monitored and reported water temperatures and conversion rates through the FCRPS on a weekly basis as PIT-tagged fish began to arrive at Bonneville Dam. By July 6th the monitoring showed: 1) water temperatures continuing to increase into the lethal range for salmonids, 2) significant declines in adult sockeye conversion rates between dams and increasing fallback rates, and 3) large numbers of adult sockeye found dead or dying in cool water refuges throughout the lower Columbia (e.g., near Drano Lake, as described above). They therefore agreed to declare an adult Snake River sockeye salmon passage emergency and to implement trap and haul at Lower Granite Dam beginning July 13, 2015. Plans were made to trap adult sockeye from the ladder and transport them to the Eagle Fish Hatchery (EFH) for holding until their final disposition could be determined (e.g., spawned in the hatchery or released into the natal lakes in the Sawtooth Valley for natural spawning). NOAA Fisheries permitted this activity as direct take under the IDFG’s Endangered

Species Act Section 10(a)(1)(a) 1454 permit and as incidental take under the 2014 FCRPS Supplemental Biological Opinion.¹⁷

1. Trap and Haul Operations

Staff from USACE, NOAA Fisheries, and IDFG trapped adult sockeye for transport to the Eagle Fish Hatchery between July 13 and August 5, 2015.¹⁸ The trap was operated from about 7:00 am to 11:30 am each day, before temperatures rose to potentially lethal levels. Occasionally, the period of operation would be extended (e.g., to capture an adult sockeye observed passing the viewing window). On other days, operations did not begin until sockeye were observed in the viewing window, reducing the likelihood of handling other species of salmon and steelhead. The duration of trapping was extended until 2:00 pm on July 28th to increase captures of sockeye while water temperatures in the ladder were cooler. Staff from the Nez Pierce Tribe's Department of Fisheries Resources Management provided additional help beginning on July 28th so that the emergency trap and haul operation could be extended. Trapping hours were based on transport logistics and reducing fish stress, but PIT-tag and window count data also indicated that sockeye salmon were actively moving in the ladder between the hours of 7 and 11 am. Prior PIT-tag data indicated a probability of capturing about 30% of the run during this 4-hr time frame (Figure 18). The fisheries agencies began emergency trapping when water temperatures in the fish ladder exceeded 21°C. They discontinued the effort to trap sockeye salmon on August 5, 2015, when fewer than five fish were observed in the counting window and few or no adults were likely to enter the trap. However, four more fish were captured and transported to Eagle Fish Hatchery between August 5–13, 2015, during routine biosampling (fork length, weight, sex, hatchery marks, tag numbers, and fish condition) for Chinook salmon and steelhead.

¹⁷ NOAA Fisheries authorized additional incidental take of adult sockeye salmon, Chinook salmon and steelhead to support the sockeye transportation effort, beyond that originally anticipated in the 2008 FCRPS Biological Opinion (as amended in 2010 and 2014), on July 10, 2015. The permit included up to 10% mortality of Snake River sockeye salmon, handling of about 1,000 Chinook salmon and 3,800 steelhead, and the incidental mortality of up to 38 listed Chinook salmon and 33 steelhead. (See Appendix B)

¹⁸ In addition, some of the adult sockeye falling back over the dam were collected from the juvenile fish separator (Table 8).

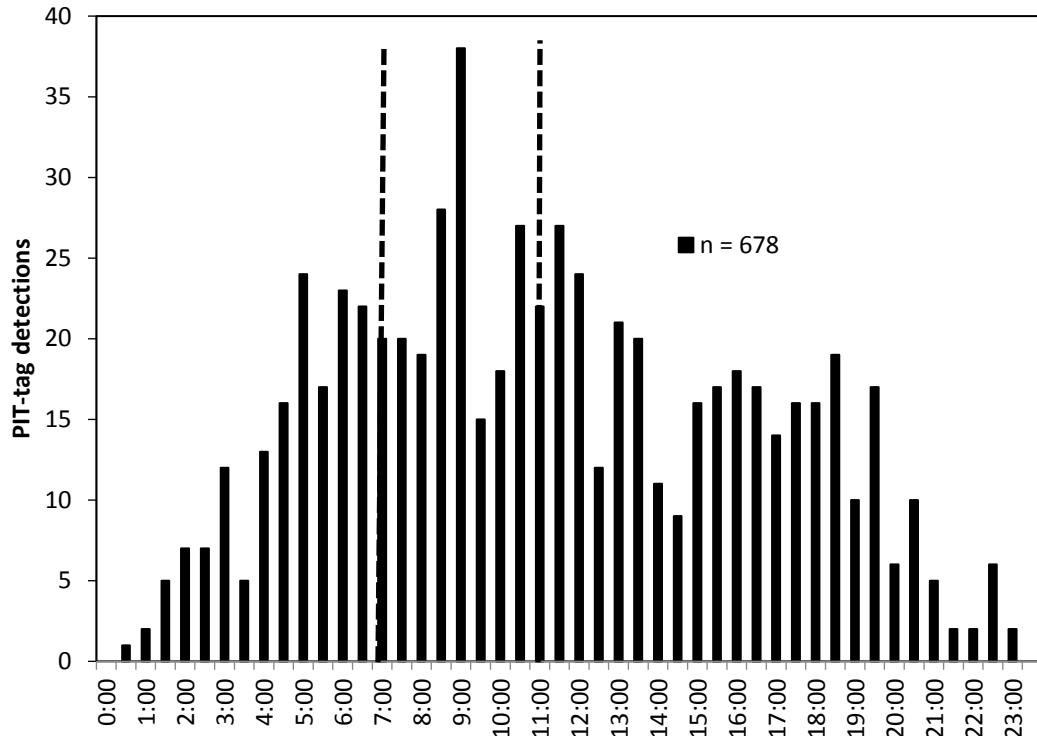


Figure 18. Cumulative number of PIT tag detections per hour near the counting window in the fish ladder at Lower Granite Dam during 2011-2014. Trapping at Lower Granite Dam occurred from 7–11 am to avoid additional temperature stress during the afternoon period. Source: PTAGIS data

Initially, all fish were transported to Eagle Fish Hatchery the day they were trapped.¹⁹ Later in the season, fish were held up to 26 hours before transport. The transport vehicle was a truck fitted with two 250-gallon insulated fiberglass tanks with continuous oxygen delivery (45 to 50 psi in a flow adjusted to 1.0 to 1.5 ppm).²⁰ Transport times from Lower Granite Dam to the hatchery averaged 8.3 hours (range = 7.8 to 8.9 hours) and fish were visually monitored about every two hours for signs of stress or unusual activity during transport.²¹

¹⁹ Sockeye collected at the juvenile separator or collected during bio-sampling activities for Chinook salmon or steelhead were held in the steelhead kelt tank at Lower Granite Dam for one night before being transported to Eagle Fish Hatchery.

²⁰ Each transport tank was fitted with one recirculating water pump and “air scoops” (aerators) to help with gas exchange. The tanks were filled with 13.3°C water at the hatchery, but the water gradually warmed during transit to Lower Granite Dam. By the time the fish were loaded into the tanks, temperatures averaged 17°C, ranging from 16-17.8°C. Sockeye were held in the transport tanks from a few minutes to 3.5 hours before the vehicle left for the hatchery and during this time, the oxygen systems and aerators were in operation and fish were monitored closely for signs of stress. Fifty pounds of cubed ice was added to each tank about three hours into the trip to begin tempering the water to match the hatchery’s water temperature of 13°C.

²¹ After arrival at Eagle Fish Hatchery, water in the transport tanks was further tempered to within 2.2°C of the temperatures in hatchery’s holding tanks 13.3°C. Due to arrival late in the day at Eagle Fish Hatchery, the adults were transferred from the transport tanks to 3-m circular holding tanks. The next morning fish were examined and the following metrics were recorded: fork length, weight, sex. Marks, tag number, and fish condition were also noted. Genetic samples were taken from all of the fish and scale samples were collected from the unmarked returns. Fish were injected with the antibiotic Erythromycin and treated with formalin.

A total of 51 sockeye salmon were collected at Lower Granite Dam during the 2015 fish passage emergency (Figure 19). Of these, 19 were unmarked, indicating they had emigrated from a natural spawning area (although their parents could have been hatchery-origin fish that were outplanted to spawn). Another 32 were marked, indicating they were raised in a hatchery facility. The number of fish collected each day at Lower Granite ranged from zero to six. A total of five were collected from the juvenile separator (Table 8). There were no mortalities during trapping or transport.

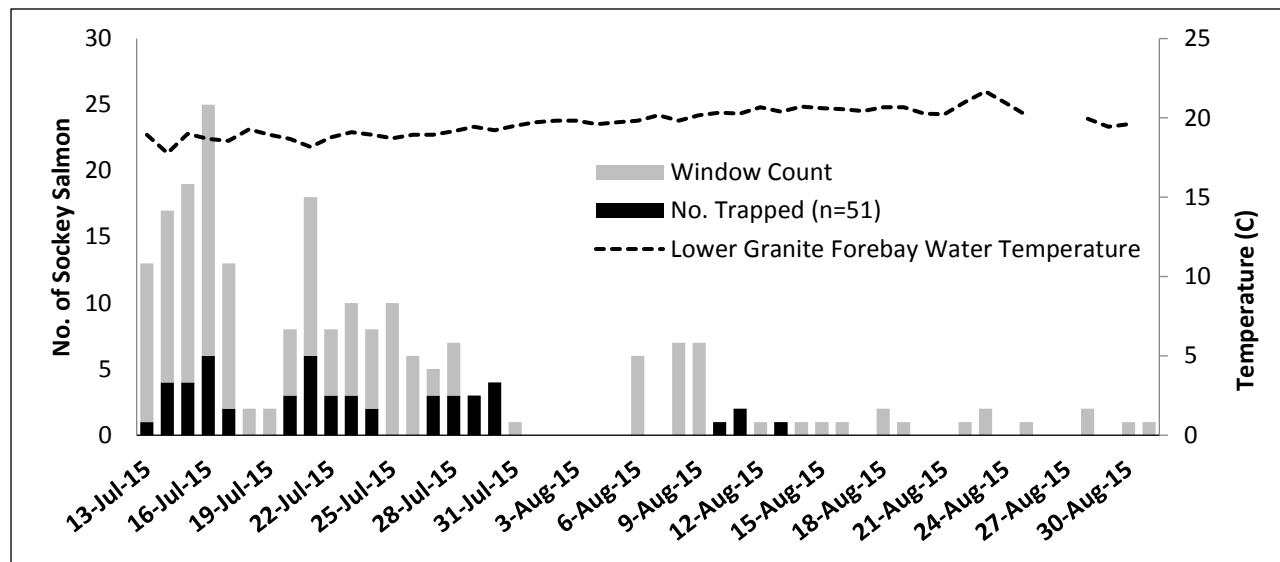


Figure 19. Number of adult sockeye salmon trapped and transported from Lower Granite Dam to Eagle Fish Hatchery (black bars) and the daily window counts (grey bars). Water temperatures in the Lower Granite forebay are also plotted (broken line). Source: IDFG data

2. Genetic Analysis and Identification of Out-of-Basin Sockeye Salmon

The IDFG takes fin clips from all anadromous and captive sockeye salmon each year and based on a suite of 13-16 microsatellite markers, determines relatedness in the population. This allows them to prioritize fish to be used for spawning at the hatchery and for release into natural spawning areas. The initial genetic analyses indicated that some of the adults trapped at Lower Granite had alleles not present in the captive broodstock; thus IDFG performed a genetic assignment test using the program GeneClass2 (Piry et al. 2004) to ascertain population membership. The IDFG maintains a baseline for microsatellite data for the Sawtooth Valley basin, but a larger baseline was needed to ascertain out-of-basin membership. Geneticists from the Columbia River Intertribal Fish Commission (CRITFC) provided a baseline for *O. nerka* throughout the Columbia River Basin. The fish collected at Lower Granite Dam were then screened with 96 Single Nucleotide Polymorphisms (SNPS) to compare to this larger baseline. Of the 51 adults collected at Lower Granite Dam, 35 (69%) were assigned to the Snake River sockeye salmon genetic stock group and of these, three were natural origin fish. The remaining 16 (31%) were determined to be from the Lake Wenatchee or Lake Osoyoos (Okanogan) genetic stocks and were subsequently culled from the potential broodstock. Of the fish identified as out-of-basin, as many as three could have been collected from the juvenile bypass system and if so,

may have been trying to fall back downstream.²² We observed no discernable difference in run timing distribution at Lower Granite Dam between the Snake River and out-of-basin adults (Figure 20).

Table 8. Date of collection, total number of fish collected (N), number of fish collected on the juvenile bypass separator (N_{SEP}) and in the adult trap (N_{TRAP}) at Lower Granite Dam in 2015, number of fish genetically assigned to the Snake River sockeye broodstock (N_{SRS}), and number of fish assigned to an out-of-basin genetic stock and culled (N_{CULLED}). Source: IDFG data

Collection Date	N	N_{SEP}	N_{TRAP}	N_{SRS}	N_{CULLED}
7/13/2015	1	0	1	1	0
7/14/2015	4	0	4	3	1
7/15/2015	4	0	4	3	1
7/16/2015	6	1	5	6	0
7/17/2015	2	1	1	1	1
7/20/2015	3	0	3	1	2
7/21/2015	6	0	6	3	3
7/22/2015	3	1	2	2	1
7/23/2015	3	0	3	2	1
7/24/2015	2	1	1	2	0
7/27/2015	3	0	3	3	0
7/28/2015	3	0	3	3	0
7/29/2015	3	0	3	3	0
7/30/2015	2	1	1	0	2
7/31/2015	2	0	2	0	2
8/10/2015	1	0	1	1	0
8/11/2015	2	0	2	1	1
8/13/2015	1	0	1	0	1
	51	5	46	35	16

²² The fish collected in the juvenile separator were not differentially marked from those collected in the trap so geneticists could not determine if these adults were more likely to have originated outside of the Snake River basin.

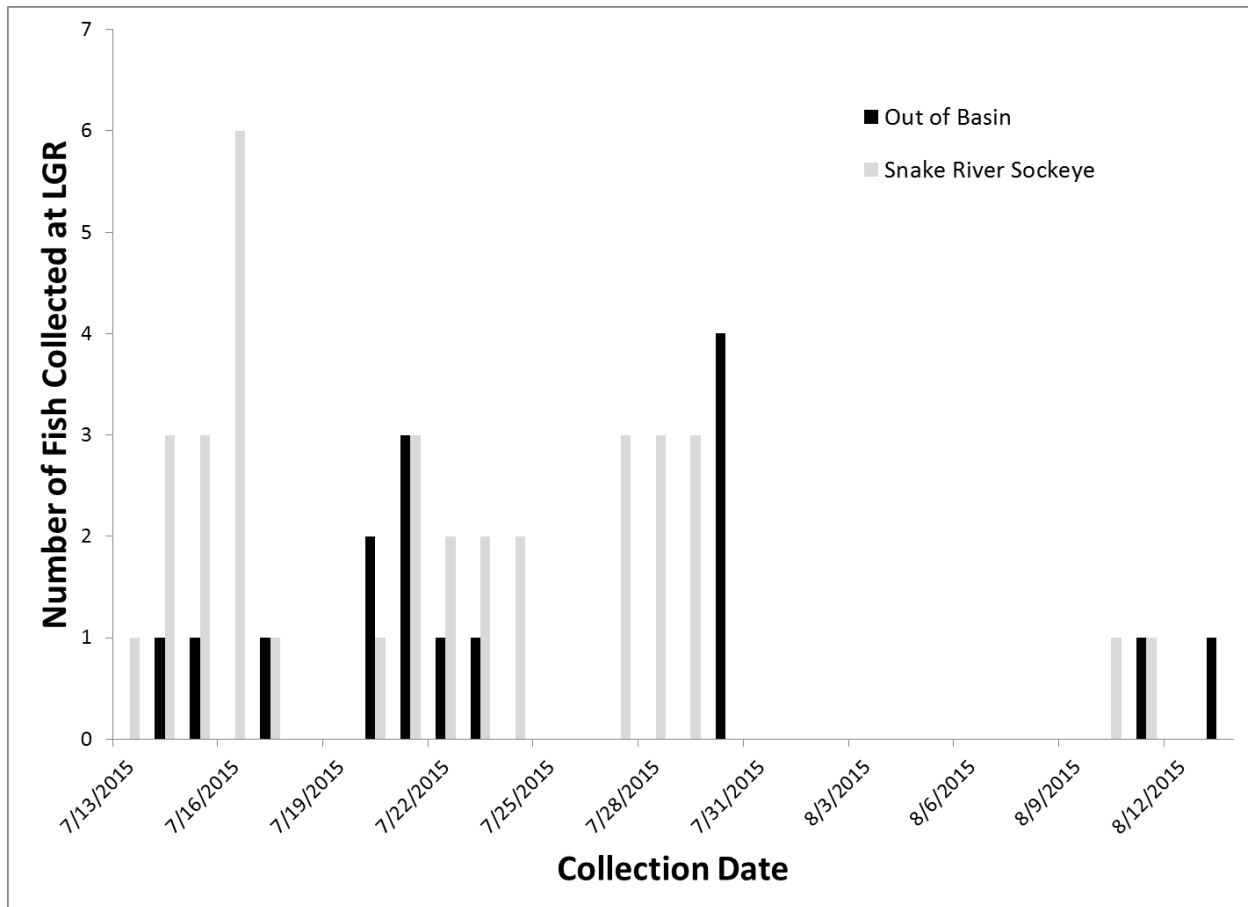


Figure 20. Run timing of Snake River sockeye salmon and fish assigned to an out-of-basin genetic stock collected at Lower Granite Dam from July 13, 2015, to August 13, 2015. Source: IDFG data

3. Hatchery Spawning

Of the 35 Snake River sockeye salmon that were trapped at Lower Granite and transported to Eagle Fish Hatchery for incorporation into the captive broodstock program, only one died during holding period at the hatchery. The remaining 34 (17 females and 17 males) were spawned. One of the females was non-productive, leaving 16 females from the trap and haul program that contributed to brood year 2015 production (Table 9). Fish collected at the Redfish Lake Creek weir (25 females, 25 males) were also prioritized for spawning at Eagle Fish Hatchery whereas the fish collected at the Sawtooth Hatchery weir (4 females, 1 male) were released into Pettit Lake for volitional spawning along with some of the captive broodstock adults. The anadromous fish had experienced high temperatures during their migration and it was presumed that they would contribute more fitness benefits to the population by being spawned in the hatchery rather than released for natural spawning. The IDFG was also concerned that the egg quality/viability of these fish had been compromised due to the stress that these fish had undergone during their migration. Given the uncertainty of the egg quality of the anadromous adults, production targets were instead based upon the number of maturing fish in the captive broodstock. The eggs from the anadromous spawners could be used to bring production levels above target. Anadromous fish were spawned with other anadromous or captive broodstock adults.

After spawning, female fecundity, egg quality, and spawn timing were compared for adults collected from the Lower Granite trap with those trapped at Red Fish Lake Creek. The survival of eggs from the “green” to “eyed” stage was significantly higher for fish collected at Lower Granite (84%) compared to those from the Red Fish Lake Creek trap (67%; $t = 2.1$, $df = 35$, $P = 0.04$; Table 9), indicating a loss of egg viability for those that migrated in-river from Lower Granite to the Sawtooth Valley. In terms of spawn timing, the median spawning date for the females trapped at Lower Granite was November 3, 2015, compared to October 16, 2015, for the females trapped at Redfish Lake Creek (Figure 21). These differences could have been mediated by temperature: the fish collected at Lower Granite were placed on cooler water when they arrived at Eagle Fish Hatchery, which may have delayed spawn timing compared to fish exposed to warm water for their entire migration.

Table 9. Spawning results for females collected at Lower Granite Dam (LGR) and transported to Eagle Fish Hatchery (EFH) and for females collected at the Redfish Lake Creek (RFLC) trap. Source: IDFG data

	<i>LGR Trap and Haul</i>	<i>Returning to RFLC trap</i>
Number of Females	16*	21*
First Spawn Date	9 October	22 September
Last Spawn Date	12 November	12 November
Total Eggs (green)	33,288	55,596
Average Fecundity	2,081	2,647
Total Eyed Eggs	28,074	38,843
Survival to Eyed Stage	84%	67%
Average Eggs per gram	15 (larger eggs)	21 (smaller eggs)

*One of the females collected at Lower Granite Dam and four of the females collected at Red Fish Lake Creek were non-productive.

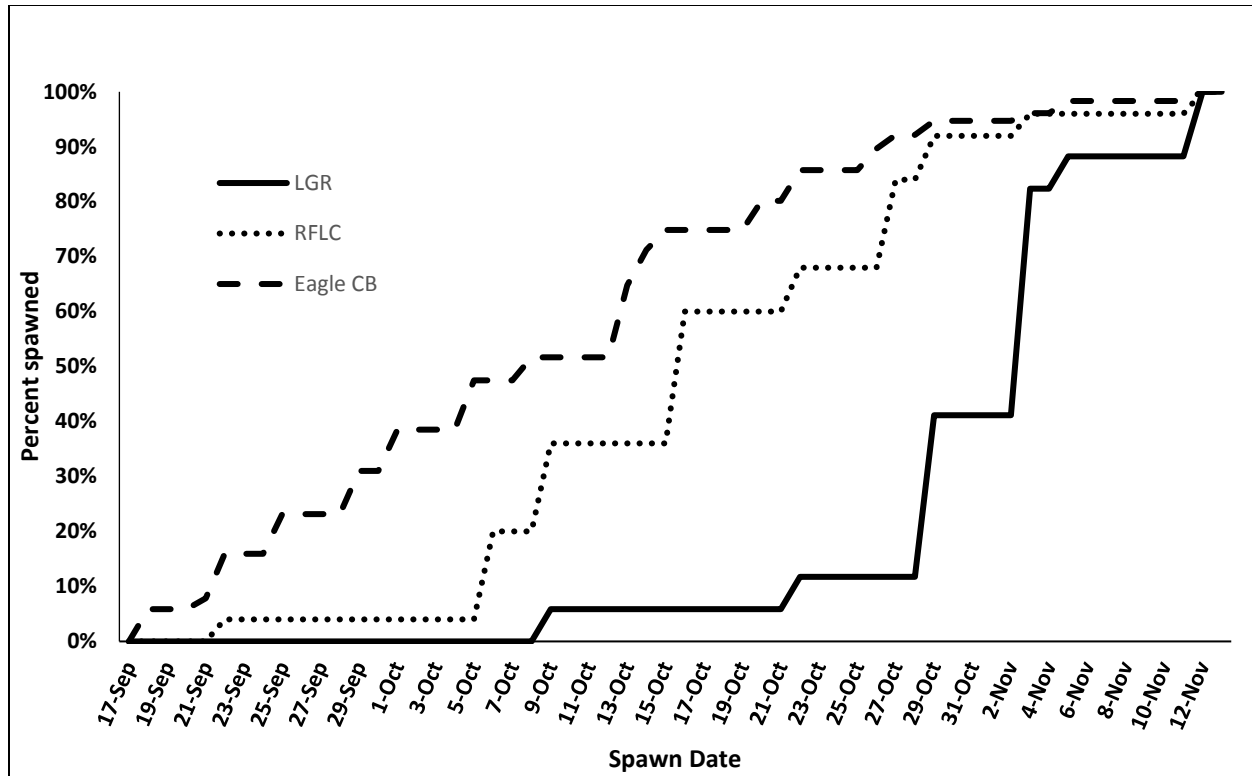


Figure 21. Spawn timing for female sockeye salmon collected at Lower Granite Dam and transported to Eagle Fish Hatchery, females collected at the Red Fish Lake Creek trap and transported to the hatchery, and captive broodstock females reared at the hatchery. Source: IDFG data

4. Outcomes

A total of 56 adults (30 females, 26 males) successfully migrated back to the basin in-river and seven of these fish had PIT tags. The total included 11 natural-origin and 45 hatchery-origin adults. PIT-tag data informed migration timing and survival from Lower Granite to the basin for in-river migrants (Figure 22). Migration from Lower Granite to the basin averaged 46 days (range = 38-58 days). Of the 27 PIT-tagged fish detected at Lower Granite Dam, three were collected and transported to the Eagle Fish Hatchery.

The Snake River fish collected at Lower Granite accounted for 38% of the overall return and almost doubled the number of sockeye collected in the Snake River basin in 2015. The lack of an accurate assessment of population sizes at Lower Granite and limited numbers of PIT-tagged fish present a significant challenge when estimating the relative benefit of the trap-and-haul effort. For example, based on PIT-tag detections, survival estimates from Lower Granite to the basin was about 29% (see Table 4). Survival estimates using window count data were significantly lower (about 15%).²³ Regardless of which method is used to estimate the survival benefits,

²³ Window counts may also be used to estimate conversion rates. However, there is some uncertainty in the number of adults passing over Lower Granite given that some fish fallback over the dam and may be counted multiple times, and this uncertainty is compounded by an unknown proportion of fish from out-of-basin genetic stock groups that were enumerated in the counting window this year. The 2015 fallback estimate at Lower Granite was 7.7% and the proportion of out-of-basin fish collected during this operation was 31%, so it is likely that the window count was

without the trap-and-haul operation it is likely that none of the Snake River sockeye salmon adults that passed over Lower Granite after July 16th would have survived their migration to the Sawtooth Valley. This emergency action provided a mechanism to include a larger and more representative sample of adults with anadromous experience (and the likely fitness benefit of that experience) in the genetic resources of the captive broodstock program.

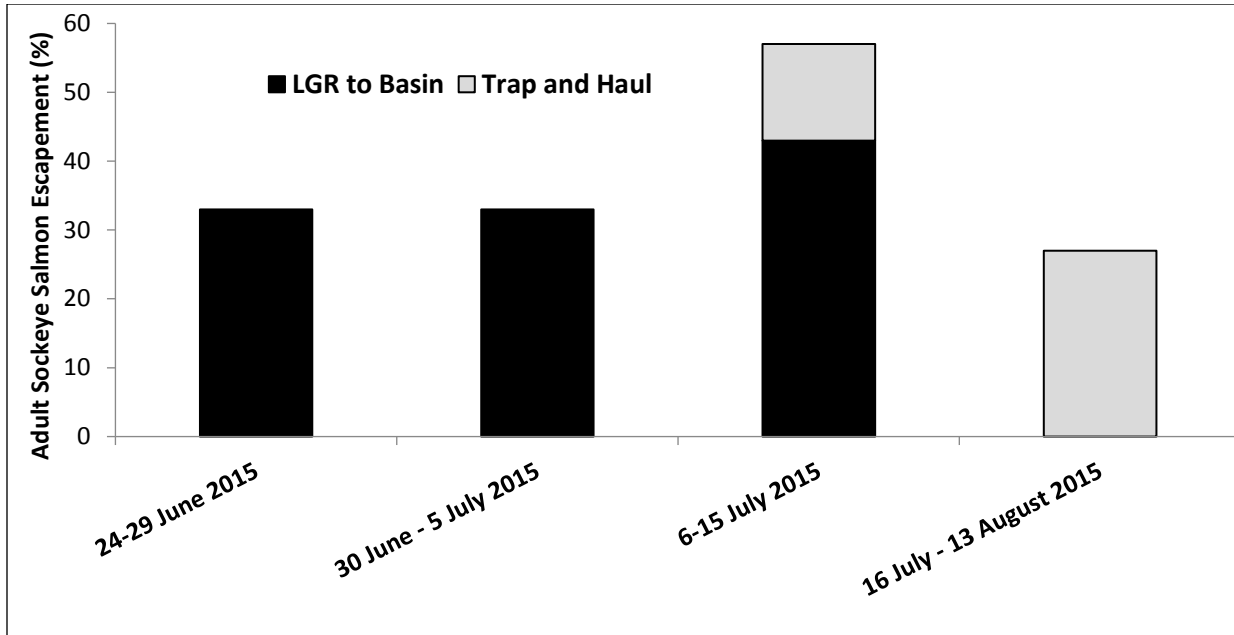


Figure 22. Adult sockeye salmon survival from Lower Granite to the Sawtooth Valley by time period and in-river migration versus transport strategy based on PIT-tag data. Source: IDFG data

high and led to an underestimate of the survival rate from Lower Granite to the basin. Therefore, the in-river survival and trap-and-haul benefits estimates based upon PIT-tag data are likely more accurate.

5. Discussion

The June and July 2015 temperatures experienced in the mainstem and tributaries of the Columbia River basin were unprecedented. Although this condition has not been observed in the recent historical record (i.e., temperature data from Bonneville Dam and McNary dams are available since 1949 and 1956, respectively) it is reasonable to expect that similar events could occur more often in the future. Rare events are unlikely to have large or lasting impacts to sockeye salmon populations because their complex life histories provide resiliency against cataclysmic events. However, if this type of event occurs more frequently, the impact on sockeye salmon populations in the Columbia River basin could be substantial.

Sockeye losses and aberrant behaviors indicative of stress appear to have begun in the lower Columbia River when temperatures at The Dalles Dam exceeded 21 or 22°C. UCR sockeye salmon stocks were least affected, probably because a higher proportion of these stocks passed Bonneville Dam prior to these conditions. There was no difference in passage timing at Bonneville Dam of adult Snake River sockeye salmon that migrated inriver or that were transported as juveniles. However, far fewer adults that had been transported as juveniles survived to McNary Dam and none survived to Lower Granite Dam. It is unclear why this difference was so large in 2015 but it was likely due to an interaction between high temperatures and altered behavior (e.g., homing ability) that increased the exposure of adults from the transport group.²⁴ The high sockeye mortalities in 2015 warrant a review of actions that have been taken and consideration of additional actions that might avoid or lessen some of these effects in the future.

5.1 System Operations

Tributary river temperatures were abnormally high throughout the Columbia River basin. Outflows from large water storage facilities (Brownlee Dam, Grand Coulee Dam, and Dworshak Dam) are cooler in June and July than project inflows. However, even temperature reductions in the range of 5°C as observed through the Hells Canyon Complex, though beneficial, were insufficient to counteract inflows from tributaries and heating throughout the downstream reaches. Releases of cool water from Dworshak Dam were effective at reducing temperatures in the lower Clearwater River and lower Snake River, though the effect dampened at each successive downstream project. However, inaccurate information from key temperature gages fostered management decisions that allowed temperatures to exceed targets for a short time before it was discovered and corrective operations were taken. Releases of stored water from the upstream projects (which accounted for up to 30% of river flows at The Dalles Dam in July) to increase flows also likely benefited adult migrants by preventing temperatures from increasing as much as they might have otherwise. Although temperatures in the lower Columbia River were

²⁴ Although adult survival has not previously varied with juvenile migration history except in the McNary to Ice Harbor reach, during 2013, adult migrants that had been transported as juveniles were twice as likely to fall back over Bonneville, The Dalles, or McNary Dam as those that were inriver juvenile migrants (Crozier et al. 2014).

warm, the heat gain in the reach between Bonneville and McNary dams was about 1°C in 2015, similar to the previous 10-year average.

5.2 Lower Granite Dam Operations

During 2014, the USACE installed temporary pumps to draw 25-50 cfs of cooler water from a depth of 60 feet in the forebay for discharge into the top of the adult fishway. This cooler water mixes with 25 cfs from a depth of 30 feet that is provided by the existing pumps. This action appears to have been successful as temperatures measured at the adult fish trap were generally kept below 21°C and fish continued to ascend the ladder throughout the migration season. A permanent structure was completed in 2016, which enhances the USACE's ability to provide better temperature conditions in the upper section of the adult fishway and the adult trap.

Prioritizing turbine unit 1 (over turbine unit 2) and taking the removable spillway weir out of service during periods of low flow appear to have also contributed to improved hydraulic conditions and likely assisted adult migrants attempting to find the ladder entrance.²⁵ There is still uncertainty regarding the effect of surface and intermediate depth spill on forebay and downstream temperatures at Lower Granite Dam and this uncertainty is likely to persist until enhanced models are developed or physical tests are conducted. In August, 2016, the Regional System Configuration Team assigned a high priority for the USACE to develop a model that more accurately predicts temperature effects in project forebays and tailraces with changes in spill and turbine operations.

5.3 Little Goose Dam Operations

On July 23-24 and July 27-28, spillways were turned off during the daytime, when adult fish predominantly pass through the ladders, to assess whether this action could improve hydraulic conditions near the fishway entrance and entice fish to pass upstream where they could reside in somewhat cooler waters in Little Goose Reservoir. If passage were successful, these fish would also potentially move upstream and pass Lower Granite Dam where they would be available for capture and transportation which was ongoing. Although adult ladder counts did increase at Little Goose Dam on July 23-24, too few fish (only 40 adults passed through the Little Goose ladder after July 23) were counted on subsequent days to prove definitively the efficacy of this action. It seems clear that this action did not negatively affect adult passage (counts at Little Goose did increase independently of Lower Monumental Dam counts). Also, given the relative strength of threatened Snake River fall Chinook salmon (and the relatively few migrating smolts in the Snake River reservoirs at this time) compared to the value of endangered adult Snake

²⁵ Use of the Removable Spillway Weir (RSW) causes more turbulence in the tailrace near the adult ladder entrance relative to a deeper spill gate operation with a more uniform pattern. The use of the RSW can also pass warmer water downstream. Some individuals contend that this warm water release is beneficial because it can decrease temperature conditions in the Lower Granite forebay. Others that that operating the RSW has little effect on forebay temperatures at Lower Granite, but should be avoided to keep the water in the downstream reservoir as cool as possible.

River sockeye salmon and the circumstances faced by managers in 2015, erring on the side of adult sockeye salmon passage in the midst of uncertainty seemed warranted and prudent.

5.4 Adult Sockeye Transportation

A total of 56 adult Snake River sockeye salmon (30 females and 26 males) returned to the Sawtooth Valley in 2015. IDFG, in cooperation with the Nez Perce Tribe, NOAA Fisheries, and USACE successfully trapped and transported 51 adult sockeye salmon from Lower Granite Dam to the Eagle Fish Hatchery. No mortalities occurred as a result of these activities. Of these fish, 35 (69%) were Snake River sockeye salmon (17 females and 17 males – one died during holding at the hatchery) and 16 (31%) were from the unlisted Lake Wenatchee or Okanogan River populations. This high proportion of strays was unexpected and the implications will need to be carefully considered in the future. The fecundity of the transported females compared favorably to those that migrated to the Redfish Lake Creek Trap: they had larger eggs and the eggs had a higher survival rate to the eyed stage. The trap and transport efforts increased the number of spawners in 2015 by about 38%, indicating that it is an effective, if limited, tool for increasing the survival of these valuable fish during periods of extreme temperatures.

5.5 New Actions at Lower Granite Dam

Permanent intake structures and pumps were installed at Lower Granite Dam in February 2016. These are being used in the summer months to draw water up from a 60-foot depth in the forebay to cool the exit section of the adult ladder. These structures should provide a permanent solution for the differential temperatures that have been observed in the adult ladder at Lower Granite Dam, especially in 2015.

Turbine Unit 1 is being rebuilt as a fully functional Kaplan unit with the same operational range as Unit 2. This refurbishment is scheduled for completion by April 2017. Turbine Unit 1 was used in 2013 and 2015 as a potential means of increasing adult sockeye passage (see previous discussion). A controversy arose because Unit 1 (with blades fixed) requires a greater volume of flow to operate than Unit 2, and consequently less flow goes over the spillway. Returning Unit 1 to its status as fully functional Kaplan unit will allow it the same operating range as Unit 2.

6. Recommendations

This report has described numerous effects of the high temperatures experienced by adult sockeye salmon returning to their natal lakes in 2015. It has also described several actions that were taken by federal hydropower operators and co-managers, to minimize or reduce these impacts in some fashion. Based on our consideration of information summarized in this report, NOAA Fisheries recommends that the following measures (by federal operators, other hydro and water storage facility operators, and regional co-managers) as means of improving management decision making and reducing, to the extent practicable, the negative impacts of high summer temperatures on adult sockeye salmon. NOAA Fisheries expects that some of these actions will take several years to accomplish and that others will continue indefinitely. Although these actions focus on the impounded reaches of the Snake and Columbia River, NOAA Fisheries recommends that agencies with land management, water management, or Clean Water Act authorities (or other governmental or private organizations involved in the preservation, conservation, or restoration of habitat) prioritize actions that would reduce summer temperatures in tributaries and reservoirs throughout the interior Columbia River Basin.

1. Improve monitoring and reporting of all mainstem fish ladder temperatures and identify ladders with substantial temperature differentials ($\geq 1.0^{\circ}\text{C}$).

- Monitor temperatures in adult ladders near the entrances and exits (downstream of diffusers) at each mainstem dam. Also monitor temperatures in the forebay (using temperature strings) and tailrace adjacent to the fishway entrances and exits of each mainstem dam. This data should be made accessible online and in near real time. (NOTE: some dams already have sensor strings that might serve this purpose.)
- Rationale: Both excessive river temperatures and ladder temperature differentials appeared to contribute to adult sockeye passage issues in 2015. Timely knowledge of real time temperature conditions would help identify a looming potential problem and help inform the effectiveness of management actions targeted to address ladder and reservoir temperature issues.

2. NOAA Fisheries, co-managers, and federal operators will develop triggers to indicate when summer temperatures are likely to exceed critical thresholds.

- The trigger should consider some probability that river or ladder temperatures would likely exceed an agreed upon critical threshold (e.g., ladder differential, tailrace temperature, flow, and thermal exposure) that would alert hydro operators and co-managers as early as possible, that measures should be taken to minimize the impacts of high temperatures on migrating adult salmon and steelhead. Specifically, a triggering event would:
 - 1) cause the TMT to meet the following day to discuss and recommend actions; and
 - 2) cause USACE and BPA to ready and implement actions.

- Rationale: Cumulative thermal exposure has been highly correlated with adult sockeye migration success through the FCRPS and should be considered in the development of management triggers (Crozier et al. 2014). Developing triggers indicative of likely high temperatures weeks in advance would allow more time to consider alternative measures and enhance the region's ability to ready and implement proactive measures to maintain, to the extent practicable, passage through adult fish ladders.

3. NOAA Fisheries, co-managers, and federal operators should develop a trap and transport contingency plan for Snake River sockeye salmon.

- The Plan should consider temperature and tailrace conditions in the lower Columbia River as well as the Snake and Salmon rivers and the likelihood that adult Snake River sockeye salmon will survive to the targeted fish trap. IDFG and other co-managers involved in further development of sockeye salmon recovery planning should develop goals and objectives for trap and transport operations.
- Rationale: The trap and transport contingency plan should allow managers to act quickly, and in concert, to implement necessary measures to attain objectives. Quicker implementation of pre-planned actions should increase the likelihood that targeted adults will be trapped successfully and used to complement and further recovery goals and objectives.

4. Evaluate, and install if feasible and effective, pumps in the Little Goose Dam forebay to bring cool water from depth into the adult ladder.

- Evaluate the feasibility of, and install permanent pumps to bring deeper water up into the ladder exit at Little Goose Dam, if likely to be effective at reducing temperature differentials in the single fish ladder at Little Goose Dam.
- Rationale: Temporary (rental) pumps have been used at Little Goose Dam during 2016 and thus far have been effective in reducing ladder temperatures and the potential for a temperature gradient. If this operation proves successful as temperatures warm through late summer, the Plan should consider installing permanent pumps at this project, as well.

5. Investigate methods to reduce maximum temperatures and temperature differentials in adult fish ladders at mainstem lower Snake and Columbia dams identified (either through reviews of existing data or through monitoring – see #1 above) as having these problems, and implement if feasible.

- Operational and structural means of reducing differential temperatures (ideally, to <math><1.0^{\circ}\text{C}</math> if feasible) in mainstem dam fish ladders should be investigated. These methods might include altered spill levels or spill patterns, altered turbine priorities (and restoring Kaplan status to Unit 1 at Lower Granite Dam), as well as the use of inducers, cooling pumps, and deeper intakes to feed cooler water to the fishway exits.
- Rationale: Impaired adult passage through mainstem fishways due to high summer temperatures can contribute to substantial adult losses (particularly of migrating sockeye and summer Chinook salmon). Investigating, and implementing if feasible, operational or structural methods to reduce these effects will likely be increasingly important in the future given observed and predicted warming trends in the Columbia basin.

6. The federal operators should prepare an alternatives study assessing the potential to trap and haul adult sockeye salmon²⁶ at lower Snake River projects to meet the goal and objectives of a contingency plan developed by NOAA and the Co-managers (see #3 above).

- The alternatives study should assess technical and biological issues associated with developing a facility to trap and haul adult salmon and steelhead. The federal operators should coordinate with IDFG, Nez Perce Tribe, Shoshone-Bannock Tribe, and NOAA Fisheries, in the development of this study.
- Rationale: Trapping adult salmon, though not ideal (see discussion in previous sections), ultimately proved to be a safe and effective means of collecting a portion of the Snake River sockeye salmon migrants and transporting them to the Eagle Hatchery. Trapping adults at locations downstream of Lower Granite Dam has the potential to collect a larger number of adults from this ESU (and potentially Snake River summer Chinook salmon and steelhead) for transport to safe locations during periods of high summer temperatures.

²⁶ Potential effects (either negative or positive) to other species (e.g., summer Chinook salmon, steelhead, or lamprey) that could be caught incidentally in a fish trap should also be considered.

7. Develop water temperature models, or similar tools, to assess the effect of alternative project operations at Lower Granite and Little Goose dams on ladder and tailrace temperatures or implement a study to empirically assess the effect of proposed operations.

- As noted earlier in this document, there remains uncertainty and disagreement regarding the relative effect of turbine and spill operations on forebay and tailrace temperatures at Lower Granite and Little Goose dams. A modeling tool should be designed to reasonably predict the temperature response in the forebay and tailrace of Lower Granite and Little Goose dams. Alternatively, empirical studies could be developed and implemented to test alternative hypotheses regarding these actions. Update: In May of 2016, the System Configuration Team (SCT) requested the USACE prioritize and develop a model to more accurately predict the temperature effects in lower Snake River projects forebays and tailraces with changes in spill and turbine operations.
- Rationale: Disagreement regarding the effects of operations on forebay and tailrace temperatures hampered regional discussions and delayed implementation of potentially beneficial actions in 2015. The existing models are not able to evaluate the likely near-field (ladder, tailrace, and downstream reservoir thermal layering) effects of alternative operations (e.g., surface route spill compared to conventional spill or no spill) at Lower Granite and Little Goose dams. Empirical tests of these actions could provide enough information to address regional concerns. Lacking this capability, the regional managers are likely to continue to disagree over the best course of action to take in these circumstances.

8. NOAA Fisheries and Co-managers and federal and other hydro operators should develop and prioritize locations where additional PIT tag detections could substantially improve our understanding of adult behavior and survival during high temperature events, and cooperate in the development and installation of these detection systems, if practicable.

- PIT tag detections at mainstem fish ladders, river mouths (e.g., the Deschutes River), and other detection systems in tributary habitat near the spawning grounds provided valuable information for assessing the behavior and survival of adult sockeye salmon exposed to high temperatures in 2015. However, many gaps remain. For example, many PIT tagged adult sockeye were not detected again after passing The Dalles Dam. These fish could have moved past John Day Dam, fallen back at the Dalles Dam or found and moved into thermal refuges (e.g., Drano Lake).
- Rationale: Broadly supported, prioritized recommendations of additional detection locations would be valuable for future regional discussions in many planning forums. Unlike active tag studies, once PIT tag detectors are installed, data are available annually and can therefore be relied upon for assessing fish behavior during

unexpected environmental conditions. Knowing the behavior and fate of these fish could lead to additional measures to enhance survival in future years.

9. NOAA Fisheries, hydro operators, and co-managers should continue to evaluate the relative migration success of adult Snake River sockeye salmon that migrated inriver or were transported from lower Snake River collector projects as juveniles and consider this information when developing future transport strategies at the Snake River collector projects.

- Substantial effort has gone into developing transport strategies that consider seasonal and annual patterns in the returns of inriver migrating and transported Snake River steelhead and spring/summer Chinook. Only recently have returns of PIT tagged hatchery Snake River sockeye salmon been sufficient for similar evaluations. NOAA Fisheries should evaluate the potential to make annual assessments for hatchery and naturally produced Snake River sockeye salmon.
- Rationale: This report documents behavioral differences between adult sockeye salmon that were transported as juveniles compared to those that migrated in river. Specifically, losses of fish in the lower Columbia River that were transported as juveniles far exceed losses of fish that were not transported and none of the transported group survived the upstream migration to Lower Granite Dam in 2015. Similar, though less substantial survival differences have occurred in some, but not all previous years. Consistent monitoring and additional analyses of transported and inriver sockeye salmon smolts returning as adults will need to be considered, along with updated information on spring/summer Chinook and steelhead that migrate at the same time, in developing future transportation strategies at the Snake River collector projects. Although findings that altered transportation operations as a result of this effort would not necessarily be responsive to high temperature events, they would contribute to a broader strategy for increasing the returns of adult Snake River sockeye salmon given observed ranges of environmental conditions.

10. Evaluate the Dworshak cold water release program to maintain temperatures in the lower Snake River below 18°C during June and most of July to reduce adult sockeye salmon mortality in the lower Snake River.

- The volume of water needed to maintain temperatures at or below 18°C as well as the volume needed to reduce water temperatures when the target is exceeded should be evaluated and compared to the current water temperature management target of 20°C. Coolwater releases from Dworshak should be used efficiently to substantially benefit multiple salmon and steelhead species. This process should include NOAA Fisheries, other regional fisheries managers, particularly the Nez Perce Tribe, and the State of Idaho.

- Rationale: Sockeye passage generally peaks in early July at Ice Harbor Dam. Maintaining temperatures below 18°C during this time would benefit migrating adult sockeye salmon. However, managing to this target is not without risk as less cool water would be available in August and early September to benefit adult migrants of other species (and rearing juvenile fall Chinook salmon). An evaluation of the trade-offs between species of alternative temperature targets would assist managers to most efficiently use Dworshak Dam cool water releases to benefit multiple anadromous species.

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Appendices

Appendix A – Analysis of Emergency Sockeye Operation at Little Goose Dam

Appendix B – NMFS Take Determination Letter

Appendix A: Analysis of Emergency Sockeye Operation at Little Goose Dam

FILE MEMORANDUM

DATE: 7/22/2015

FROM: Trevor Conder NOAA Fisheries

TO: Ritchie Graves

SUBJECT: Analysis of Emergency Sockeye Operation at Little Goose Dam

This analysis investigates the direct survival impact to migrating subyearling Chinook salmon as a result of a temporary change from a 30% spill operation to a test 0% spill operation at Little Goose Dam (LGO) in an attempt to increase adult sockeye passage. This memo uses regionally available survival and smolt monitoring data to estimate the impacts of this test operation. Based on this analysis, we expect the impacts of this two day full powerhouse operation will likely result in the direct mortality of an additional 29 juvenile migrants, which equates to .01% of the subyearlings passing the project.

Based on smolt monitoring information provided at the Fish passage Center website, the passage index for subyearling Chinook salmon at LGO has been declining over the last five days (7-18-7/22) averaging 1321 and ranging from 1015 to 1802 (Table. 1).

Site	SampleDate	Species	RearDisp	Riverflow	Collcount	Sampcount	PassIndex
LGS	7/18/2015	CHO	Combined	29.11	1197	51	1802
LGS	7/19/2015	CHO	Combined	32.52	882	58	1345
LGS	7/20/2015	CHO	Combined	28.51	772	77	1277
LGS	7/21/2015	CHO	Combined	28.46	706	205	1168
LGS	7/22/2015	CHO	Combined	27.51	617	123	1015

Table 1. Subyearling Smolt Monitoring Data Acquired 7/22 from Fish Passage Center Data site at <http://www.fpc.org/smolt/smoltqueries/smpdailydata2015v1.asp>Passage

Using this information, we estimate a two day 48 hour operation will potentially affect 2642 subyearling Chinook assuming the passage index is an accurate estimate of juvenile salmonid passage at LGO, and this average passage index will continue. Passage index of STH and Yearling Chinook indicate a declining trend and is less than 100 fish per day for both species at LGO.

In 2007, prior to the installation of the LGO TSW, data from (Beeman et al. 2008) indicates that 4.4% of subyearling Chinook used turbines, 25.8% used the bypass route, and 69.8% used a deep spillway route.

Based on this information, and considering the 2007 operation is the most similar to the current operation, we use this past information to assume for this analysis that 4.4% of subyearling Chinook are currently passing through turbines at LGO and 69.8% are using deep spill under the current no TSW operation. If there is a switch to full powerhouse operation as planned, all downstream migrants will be navigating through the LGO powerhouse and we expect the proportion of fish using turbines will increase as a function of FGE observed in recent years.

Year	Measure	Route			
		Deep Spill	Spillway Weir	Turbine	Juvenile Bypass System
2012	Proportion	0.2484	0.4765	0.0493	0.2258
	Survival	0.9421	0.9623	0.8128	0.9807
2013	Proportion	0.1213	0.6470	0.0502	0.1816
	Survival	0.9106	0.9143	0.8402	0.8978

Table 2. Passage proportion and survival probability by route for subyearling Chinook salmon at Little Goose Dam (Harnish et al. 2015).

In 2012 and 2013, the screen system at LGO guided approximately 80% of fish migrating through the powerhouse into the JBS system with 17.9% and 21.7% of powerhouse migrants using turbine routes (Table 2). Using an average of the two years (19.8%) the number of fish expected to arrive during a two day operation based on the two day passage index average of 2642 ($.198 * 2642$) equates to 523 fish going through turbine units. This is compared to 116 fish passing turbines that we can expect under the current deep spill scenario. This is a difference of 407 fish that may experience a lower turbine survival probability. Considering that under a 30% operation these fish would use the spillway, 2013 deep spill survival data to these 407 fish produces an estimated 371 survivors ($.9106 * 407$). Under the test operation, these fish will likely migrate through turbines so applying the same low turbine survival data to these 407 fish produces an estimated 342 survivors ($.8402 * 407$). This is a difference of an additional 29 subyearlings lost to mortality due to this proposed two day operation. Given the high guidance at LGO, the rest of the fish will likely be bypassed to transport barges and are not further considered in this direct survival evaluation.

Harnish RA and Coauthors 2015. Diagnostic analysis of subyearling Chinook Salmon Survival Estimates at Little Goose Dam, 2012 and 2013. Draft Report of research prepared to U.S. Army Corps of Engineers, Walla Walla District.

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Appendix B: NMFS Determination Take Letter



UNITED STATES DEPARTMENT OF COMMERCE
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July 10, 2015

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RE: Emergency trapping and transport of Snake River Sockeye Salmon at Lower Granite

Dear Mr Hassmer:

National Marine Fisheries Service (NMFS) Interior Columbia Basin Office's Columbia Hydropower branch has determined that take associated with your request to initiate a trap and haul operation for Snake River Sockeye as part of an emergency action due to high temperatures in the Snake River Basin is permitted in 2015 under the IDFG Section 10(a)(1)(a) permit for the Snake River Sockeye Salmon Hatchery Program and the 2014 FCRPS Supplemental Biological Opinion (2014 Opinion). The estimated numbers of listed salmonids needed to conduct this activity in 2015 are given in Table 3 below.

Project Justification, Description, and Methods

The State of Idaho plans to transport Snake River Sockeye collected at Lower Granite Dam (LGD) and transport them to the Eagle Fish Hatchery for broodstock collection or release into Redfish Lake. This action is being taken as an emergency measure due to the extreme temperature conditions being experienced throughout the lower Snake River, extending upstream through the Salmon River Basin. During the first week of July temperatures in the forebay of LGD have exceeded 25⁰ C at a 3 meter depth, temperature at the Anatone gauge located upstream of Lower Granite Reservoir have exceeded 24⁰C, and temperature at the Whitebird gauge on the Salmon River has exceeded 25⁰C. These temperatures are extremely stressful to

sockeye and are approaching lethal levels if the fish are exposed to these temperatures for an extended duration. Collection and transport of these fish from the Lower Snake River projects to Sawtooth Valley lakes or artificial propagation facilities is deemed essential to increase the survival rate of individuals from this endangered population. Collection and transport from LGD will facilitate recovery actions described in the Snake River Sockeye Salmon Recovery Plan.

The collection and transport of sockeye is consistent with provisions of NMFS's 2014 Supplemental Biological Opinion (2014 BiOp) on the Federal Columbia River Power System (FCRPS) and the Endangered Species Act (ESA) Section 10(a)(1)(A) permit to Idaho Department of Fish and Game (IDFG) for the Snake River Sockeye salmon hatchery program. The Section 10(a)(1)(A) permit specifically authorizes removal of sockeye salmon from the Lower Granite Dam trap when low-flow or temperature conditions are expected to limit adult survival to the hatchery and the spawning grounds. Allowable mortality was not to exceed 10% of the fish handled during trapping and transport. Due to the extreme temperature conditions this year, IDFG has requested additional take coverage for incidental mortality to Sockeye salmon from 10% to 20%.

NMFS' 2014 BiOp supplemented the actions of the 2008 and 2010 FCRPS BiOps. Reasonable Prudent Alternative (RPA) Action 42 of these opinions addressed the need to investigate the collection and transport of adult sockeye from LGD to Sawtooth Valley lakes or the artificial propagation facilities. NMFS included an effects analysis in section 2.5.1.5 of the 2010 BiOp for operating the LGD trap to collect sockeye for transport. This analysis recognized that some Chinook and steelhead would also be collected and would incur some mortality incidental to the process of collecting and sorting adult sockeye. IDFG has requested an additional, incidental, potential lethal take of 38 Chinook salmon and 33 steelhead as a result of this action. Due to high temperatures in the Snake and Columbia rivers, and at the site of the adult trap at Lower Granite Dam (>70°F) this July, about 2.7°F warmer than in the poor sockeye survival year of 2013 (Crozier et al. 2014), the incidental take of sockeye, Chinook, and steelhead is likely to be higher than NMFS anticipated in 2010.

The trap at LGD is normally not operated when water temperature exceeds 70°F. This criterion will be exceeded. The Corps has tried to cool the temperature of the trap by installing pumps that draw cooler water from a depth of 45 feet in the dam's forebay, but has been unable to achieve the 70°F criterion. Operation of this trap outside of the 70°F temperature criterion is consistent with RPA Action 9, Fish Emergencies, of NMFS's 2014 BiOp, which allows operation of fish facilities outside of criteria during emergency events. NMFS deems the current temperature conditions in the Salmon and lower Snake Rivers to constitute an emergency, and action is needed to reduce its impact on these returning Snake River sockeye salmon adults. The LGD trap will only be operated for a four hour period in morning hours (6:00 am to 12:00 pm) to limit the stress to collected fish. Trapping is also being considered at the Ice Harbor project. The same restriction would be applied at this location i.e. Trapping will be limited to a 4 hour period within the hours 6:00 am to 12:00 pm.

Operational Reporting & Notification Requirements

The following additional measures will be taken to document the condition of all species handled during adult trapping for evaluation and preparation of an adaptive management plan for use in future years if these environmental conditions continue or worsen:

Daily Trap operation records will include:

1. Trap and fish ladder water temperatures
2. Trap operation rate
3. Number of fish trapped and handled by species, and their final disposition (transported, released, etc.)
4. Number of mortalities or injuries by species
5. Relevant observations on fish condition

A daily report will be emailed to NOAA Fisheries with a summary of these items.

Fish transportation records (for sockeye salmon only) will include:

1. Numbers of fish transported each day
2. Time fish were held before transport
3. Transport time to the Sawtooth Valley and temperature at which the fish were transported.
4. Mortalities incurred during transport
5. Survival to spawning at the hatchery of transported fish.

Within 2 months of the completion of sockeye spawning, IDFG will send a report documenting these records and presenting a summary and analysis of the procedures to NOAA Fisheries.

Take Estimates

At present, IDFG Section 10(a)(1)(a) permit for the Snake River Sockeye Salmon Hatchery Program allows a 10% mortality rate and IDFG has requested a 20% rate. Neither this permit, nor the 2014 Supplemental FCRPS BiOp has a mechanism for allowing such an increase. However, we request that you assess the cause of mortality when such occurs. Mortalities resulting from infectious diseases due to the high water temperatures necessitating this action should not count against your take authorization because these individuals would have otherwise died prior to spawning in the migration corridor upstream of the FCRPS. Thus, you are still authorized a 10% incidental mortality rate through the hatchery program permit.

IDFG estimated the number of fish that will be handled during the trapping process are 1,000 listed Chinook and 3,800 steelhead passing during the proposed emergency trapping period (July 13 – July 3, the 19-day estimated period of this operation). NMFS believes these are reasonable estimates. The adult trap will be operated during a four hour period within the hours of 6:00 AM – 12:00 PM.

IDFG has estimated the adult sockeye trapping activity may result in 38 listed Chinook salmon and 33 steelhead incidental mortalities. Table 8-5 of the 2014 Supplemental FCRPS BiOp summarizes estimates of take resulting from all RM&E activities given average abundance

during the 2008-2012 migration years (including operation of the adult traps for routine purposes). NMFS finds that the incidental take requested to implement the sockeye emergency transportation should not exceed the overall take allotted in the 2014 BiOp. Additionally, given the relatively large return of Snake River spring/summer Chinook salmon in 2015, the proportional impacts will likely be smaller than estimated.

Please notify Paul Wagner (503)231-2316, paul.wagner@noaa.gov as soon as possible of any deviation from the terms and conditions in this determination.

Sincerely



Ritchie J. Graves, Chief
Columbia Hydropower Branch
Interior Columbia Basin Office
NOAA Fisheries, West Coast Region

Cc: Rock Peters
Russ Kiefer
Darren Ogden
Bill Hevlin
Paul Wagner

Literature Cited

Crozier, L.G., B.J. Burke, B.P. Sanford, G.A. Axel, and B.L. Sanderson, 2014. Passage and survival of adult Snake River Sockeye salmon within and upstream from the Federal Columbia River Power System. Research report to Walla Walla District, U.S. Army Corps of Engineers.