Results of a PIT tag study at Priest Rapids Dam to assess the impact of the Whooshh Fish Transport System on upstream migrating Sockeye Salmon

Conducted for Whooshh Innovations, LLC

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Abstract

Between June 29 and July 22, 2016, 897 Sockeye Salmon (Oncorhynchus nerka) were PIT tagged at the Priest Rapids Dam Off Ladder Adult Fish Trap and released as part of a study to assess the impact of the Whooshh Fish Transport System (WFTS) on migrating salmon. During the first three weeks of the study, alternate groups of five Sockeye Salmon were sent via the WFTS or hand carried to the recovery area. Study fish were tracked upstream by PIT tag detections downloaded from www.ptagis.org. On July 22, WFTS tagged Sockeye Salmon were transported directly over the dam as opposed to going into the recovery area and continuing up the ladder, thereby missing detection at the top of Priest Rapids Dam. Wenatchee stock Sockeye Salmon were subsequently detected at Priest Rapids, Rock Island and Tumwater dams, while Okanogan stock Sockeye Salmon were subsequently detected at Priest Rapids, Rock Island, Rocky Reach, Wells, and Zosel dams.

This study found no difference in survival between the WFTS and non-WFTS groups to either Wells or Tumwater dams combined over the entire study, however there were significant differences between the WFTS and non-WFTS groups in the distribution of Sockeye detected at individual dams that were likely attributable to differences in stock composition. There was no significant difference in median or mean passage times at dams between WFTS and non-WFTS Sockeye Salmon or between migration travel time of WFTS and non-WFTS Sockeye Salmon. The sole exception was when release to site travel time data were analyzed for July 22, the only day sampled in Week 30, which compared Sockeye Salmon sent via the WFTS to the Priest Rapids Dam forebay to the ladder passage and migration of the Week 30 non-WFTS Sockeye. As calculated by the Mann-Whitney U test comparing the test group population means, the Week 30 WFTS Sockeye had significantly lower travel times to Rock Island Dam ($p<0.01$) and Rocky Reach Dam ($p=0.03$) than did non-WFTS Sockeye.

In terms of group composition, the WFTS and non-WFTS groups were very similar in age and size. There was no significant difference in fallback rates at any upstream dam.

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Introduction

Salmon in the Columbia Basin are currently restricted to about one third of their historic habitat, primarily due to high dams without fish passage built 50 or more years ago (Columbia Basin Tribes and First Nations 2015,Northwest Power Planning Council 2014). In recent years, there has been increasing interest in restoring salmon to these areas. Some smaller dams, such as Marmot Dam on the Sandy River and Condit Dam on the Little White Salmon, have been removed to allow salmon to pass freely up to headwaters. However, in many cases, it is not possible to remove dams due to their value for hydropower, flood control, water storage, recreation, and other reasons. Therefore, if salmon are to be restored to these areas, a way must be found to get these fish around these dams. Fish ladders have been very successful in the Columbia Basin at passing returning adult salmonids over dams; however construction of fish ladders is very expensive in costs of construction, maintenance, water use, and land access. In addition, for high dams such as Grand Coulee, Chief Joseph, Dworshak, or Brownlee, conventional fish ladders would be so long that successful salmon passage and upstream survival to spawning is uncertain.

A possible solution to passing returning adult salmonids around dams is a fish passage system developed by Whooshh Innovations, designed to decrease passage time with the benefit of requiring minimal energy expenditure during passage. The Whooshh Fish Transport System (WFTS) utilizes a novel differential pressure system that facilitates movement of individual fish through a soft tube structure in a matter of seconds. The tube is made of a flexible material which is highly adaptable to location needs and challenges, and provides the ability to direct entry and exit at desired locations (Whooshh, 2016). Proof of concept of the ability to utilize the WFTS system to transport fish through a tube of 330 m has been demonstrated on live Pacific salmon (Whooshh, 2016).

The WFTS has been shown to safely move salmon in laboratory tests, and from river to hatchery trucks and raceways (Geist et al., 2016). However, there has not been a study to address the question of whether WFTS salmon transport on actively migrating salmon will affect their subsequent migration. The National Marine Fisheries Service (NMFS) requested such a study prior to allowing more widespread use of WFTS where ESA-listed species are present.

The Columbia River Inter-Tribal Fish Commission (CRITFC) has conducted yearly migration studies on the Columbia River to monitor the up-river migration of salmonids (Fryer et al, 2016a, Fryer et al., 2016b). These studies have focused fish tagging at

Bonneville Dam, although CRITFC has also tagged Sockeye at Wells and Priest Rapids dams on the Columbia River. At these sites, salmon are trapped, anesthetized, measured and assessed, PIT tagged, and allowed to recover prior to their release. These fish can then be tracked through the Columbia Basin as they pass through fish ladders at dams, most of which have PIT tag antennas, and often into tributaries and hatcheries as many of these sites also have PIT tag antennas. These studies offer a good opportunity to conduct tests on the impact of different treatments on these fish, allowing comparisons in terms of survival and migration time to upstream dams.

The study described herein is a migration study in which migration time, survival and passage time were directly assessed. By the nature of the study design, indirect assessment of three other attributes are also possible. If WFTS negatively affected fish behavior, homing or disease transmission, the outcomes of migration time, survival and/or passage time would be expected to be impacted relative to the non-WFTS tagged comparator fish group.

Methods

Study Area

To test the WFTS on migrating salmon, we determined that Sockeye at Priest Rapids Dam would be the best species and site for this work. Sockeye upstream of the Snake River are not listed under the Endangered Species Act, thus easing permitting requirements and yet enabling testing on a sensitive species as a potential ESA-listed surrogate. Tagging at Priest Rapids means that after release, all Sockeye have the potential to be detected at Rock Island Dam. The Okanogan stock Sockeye which typically comprise the majority of the run, can be subsequently detected at Rocky Reach, Wells, and Zosel dams in addition to instream arrays, one of which (OKC) is located in the lower reaches of the spawning area and has a high detection rate (Figure 1). Wenatchee stock Sockeye Salmon migrate past Rock Island Dam then enter the Wenatchee River, a tributary of the Columbia River, and are subsequently detected upstream at Tumwater Dam. At each of these sites, PIT-tag data is uploaded to www.ptagis.org, allowing survival rates and migration times to be calculated for Sockeye tagged at Priest Rapids Dam.

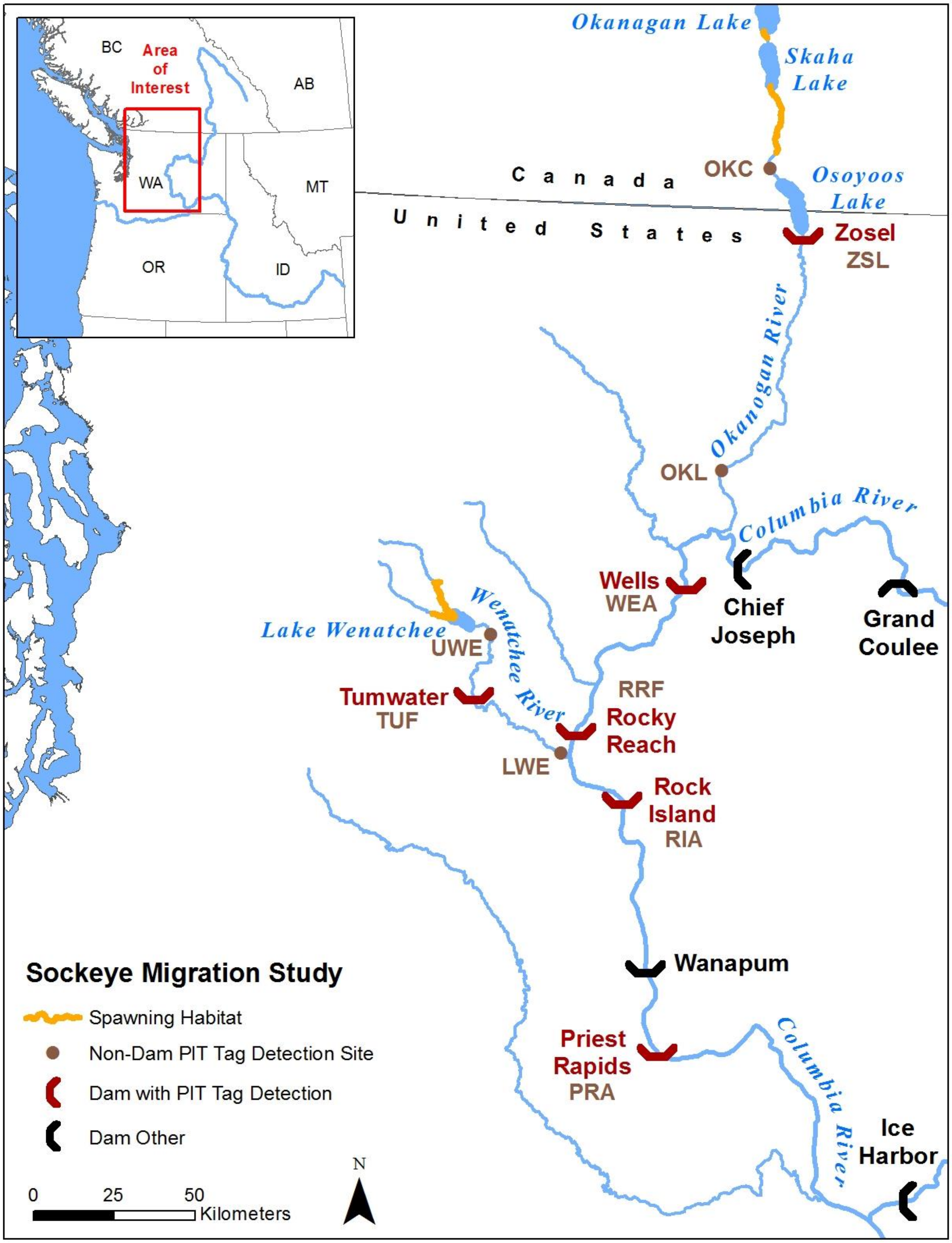

Figure *1*. Map showing PIT tag detection sites and spawning areas for adult Sockeye Salmon PIT tagged at Priest Rapids Dam in 2016.

Sampling

Sockeye Salmon were sampled weekly for the four weeks between June 29, 2016 and July 22, 2016, which, based on historical run timing, comprise the period when the bulk of the Sockeye migration pass Priest Rapids Dam. The goal was to tag between 700 and 900 Sockeye salmon, half of which were to be transported to the recovery area by the WFTS with the other half being hand-carried to the recovery area (non-WFTS group). The sampling crew consisted of staff from CRITFC, the Yakama Nation, and Whooshh Innovations, LLC.

Sockeye Salmon trapped at the Priest Rapids Dam left bank ladder fish trap were diverted by a barrier gate into the Off Ladder Adult Fish Trap (OLAFT). An attraction flow of approximately 9 cfs was provided over the steeppass wherein the fish volitionally entered the steeppass and slid down a sorting chute. The trap operator regulating fish collection diverted a group of Sockeye into a large holding area for sampling. Additional Sockeye passing up the steeppass were automatically diverted back to a channel returning them to the ladder upstream of the barrier gate. As Sockeye were required for sampling, they were crowded in the holding tank and four or five netted into a 380-liter stock tank filled with 300 liters of water and 24 mg Aqui-S/l. They were held in the Aqui-S solution until they lost equilibrium and their opercular rate was slow but regular. Sockeye were examined for existing tags, fin clips, wounds, and condition. Fork lengths were measured and five scales were removed and placed on scale cards for later age analysis. Caudal punches were collected for possible future genetics analysis. Sockeye were also scanned for PIT tags and, if none found, they were tagged in the body cavity.

At the OLAFT, Whooshh Innovations set up a WFTS near the sampling area with the tube running approximately 30.5 m in a sweeping curve with an incline of 1.5m over its length, exiting into the recovery area (see https://1drv.ms/v/s!Ak8mNDpAR2geinsYc-bdQ9EzyrPo). With the exception of the final day of sampling on July 22, Sockeye were sampled in groups of five. The five Sockeye were sequentially sampled, tagged and placed in a 380-liter stock tank with freshwater and allowed to recover from the Aqui-S anesthetic. Prior to transporting a group of fish, wet sponges were run through the WFTS to make sure the tube walls remained lubricated. This was followed by the five Sockeye run sequentially through the WFTS to a calm water area with a channel leading to the fish ladder upstream of the barrier gate. These comprised the WFTS treatment group.

Sockeye that were not put through the WFTS were, as with the WFTS fish, sampled in groups of five. After each fish was sampled, it was placed in a rubber boot and hand carried approximately 15 meters and placed into the same calm water site to which the WFTS fish were transported. After recovery, these fish, as with the WFTS fish, could swim up the channel leading to the fish ladder upstream of the in-ladder barrier gate. These Sockeye comprised the non-WFTS treatment group (Figure 2).

On July 22 (the only sampling day in Week 30), there was the opportunity to use the WFTS to transport Sockeye over Priest Rapids Dam to the forebay above the dam rather than the calm water site leading to the fish ladder. The one day WFTS setup, use and breakdown requirement presented a number of challenges. Recovery of sponges used to lubricate the tube prior to fish passage from the Priest Rapids forebay was difficult so the decision was made to continuously pass WFTS sockeye through the tube after an initial run through of wet sponges. To do so, rather than separating the subject Sockeye into groups of five, approximately two-thirds of the non-WFTS Sockeye were sampled while the WFTS was being set up, followed by sampling the complete set of WFTS fish and then completing the day of sampling with the remaining one-third of the non-WFTS Sockeye sample set of the day. The WFTS fish were transported by WFTS 50.9 m up a 12.2 m (24%) incline into the Priest Rapids Dam headwater immediately above the OLAFT and near the Priest Rapids ladder exit.

Figure 2. Images from the 2016 Priest Rapids Sockeye migration study. Left: remaining ladder climb after sampling at OLAFT. Top Left: CRITFC and Yakama Nation crew sampling and PIT tagging Sockeye at OLAFT. Top Right: Hand feeding Sockeye into the WFTS. Right: Week 30 WFTS fish transporting to top of the dam. Bottom: Week 30 WFTS spanning the dam crest.

Analysis

Age Determination

Five scales were collected for each Sockeye Salmon sampled from a preferred area approximately two to three scales above the lateral line along a line from the posterior dorsal fin to the anterior of the anal fin. Scales were mounted and pressed according to methods described by Clutter and Whitesel (1956) and the International North Pacific Fisheries Commission (1963). Individual samples were visually examined and categorized using well-established scale age-estimation methods (Gilbert 1912, Rich and Holmes 1928).

The European method for fish age description (Koo 1962) is used in this report. The number of winters a fish spent in freshwater (not including the winter of egg incubation) is described by an Arabic numeral followed by a period. The number following the period indicates the number of winters a fish spent in saltwater. Total age, therefore, is equal to one plus the sum of both numerals. For example, the most common age class for Sockeye in our study was 1.2, where 2016 returns would be from 2012 spawners, that outmigrated in 2014 (one freshwater), and return after two years in the ocean as four-year olds.

If the scale quality from a particular fish was deemed poor such that it prevented age determination in all scales collected, no age was assigned to that fish.

Upstream Conversion Rates

Daily and weekly conversion rates were calculated for Sockeye to upstream dams with PIT tag detection as:

$$S_i = \frac{D_i}{N_i}$$

where i is the date or week tagged, D_i is the number of Sockeye detected at or above the dam or site in question, and N_i is the number of Sockeye Salmon tagged.

Total conversion rates, S_T were calculated as

$$S_T = \frac{D}{N}$$

A chi-square (χ^2) test was used to compare WFTS with non-WFTS conversion rates. A p value $\leq$ 0.05 is considered statistically significant.

Detection Rate

The PTAGIS recorded data of PIT tag detections corresponding to the PIT tag signatures of our study fish was used to determine the detection rate at the fish ladders at dams. PIT tag antennas in fish ladders are placed such that all fish must go through them. PIT tagged fish going through PIT tag antennas can still be missed due to rare antenna outages, possible faulty tags or tag orientation, tag collision from two tagged fish passing through antennas simultaneously, or problems with antennas. The detection rate is calculated as the ratio of the number of fish detected upstream but missed at the site in question, divided by the total number of fish detected upstream. For example, the percentage missed at Rock Island Dam was calculated as:

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

where R_m was the number of fish missed at Rock Island Dam but detected at sites upstream of Rock Island Dam divided by R_d, the number of fish detected upstream of Rock Island Dam. A chi square (χ^2) test was used to compare WFTS with non-WFTS detection rates. A p value $\leq$ 0.05 is considered statistically significant.

Migration Time, Passage Time, and Release to Site Travel Time

Migration timing was calculated using the date and time of PIT tag detection at the different dam sites. Migration times were defined as the travel time between site pairs, specifically, as the time between the last detection at a downstream site and the first detection at an upstream site. The amount of time required to pass through each site (or dam), passage time, was estimated as the difference between the first detection time at a site and the last detection time at the same site. In addition, release to site time was calculated. Release time is the time at which the fish was PIT tagged and scanned during sampling at OLAFT. For all non-WFTS Sockeye, release to site time includes swim passage up the remaining Priest Rapids ladder to the forebay plus the time to the site in question. Release to site time for weeks 27-29 WFTS included WFTS tube transport 30.5 m to the recovery area followed by swim passage up the remaining Priest Rapids ladder to the site in question, and for Week 30 WFTS, WFTS tube direct transport 50.9 m over Priest Rapids Dam into the Priest Rapids forebay to the site in question. A Mann Whitney U test was used to compare the treatment population means of passage times at dams as well as travel times to, and between, upstream sites. A p value $\leq$ 0.05 is considered statistically significant.

Fallback

Three methods were used to estimate fallback, which is defined as a fish that ascends a fish ladder into the reservoir above the dam, then “falls back” to the downstream side of the dam either over the spillway, or through the navigation locks, juvenile bypass systems, or turbines. The first method was to check if a PIT tagged adult Sockeye Salmon was detected in the juvenile bypass system. However, upstream of Priest Rapids dam, only Rocky Reach dam has juvenile bypass system PIT detection. Furthermore, there is no detection at any dam for fish falling back over the spillway or through the navigation locks or turbines. Therefore, a second method of estimating fallback was to look at each dam for fish detected at the uppermost antenna in the adult fish ladder followed by detection more than two hours later at an antenna located downstream in the same ladder (or another ladder for multiple ladder dams). Finally, a third method of defining fallback was ascertained by fish that passed an upstream PIT tag detector at a given dam, then were next observed at a site downstream of the dam in question. Thus, if a fish was detected at the upper antenna at Wells Dam and then subsequently detected at Tumwater Dam, it would be considered a fallback at both Wells and Rocky Reach dams. Similarly, if a fish was last detected at the Wells Dam upper antenna and then detected at the Rocky Reach juvenile bypass, it would also be considered a fallback at Wells and Rocky Reach dams.

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

A chi-square test was used to determine whether there was a difference in fallback rates between WFTS and non-WTFS groups at each upstream dam. A p value $\leq$ 0.05 is considered statistically significant.

Results

Sockeye Salmon were sampled and tagged at the Priest Rapids Dam OLAFT over four weeks between June 29, 2016 and July 22, 2016 (Table 1). A total of 906 Sockeye were sampled and 897 PIT tagged Sockeye released. Between June 29 and July 12, a total of 394 non-WFTS PIT tagged Sockeye were hand carried to the recovery area where as 393 Sockeye were transported by WFTS to the recovery area (Table 1). On the final date of sampling, July 22, 2016, 56 Sockeye were hand carried to the recovery area and 54 Sockeye transported by WFTS above Priest Rapids Dam and into the forebay (Table 1).

Table 1. Number of Sockeye Salmon tagged listed by date and week and by treatment at OLAFT at Priest Rapids Dam in 2016.

		Non-WFTS Sockeye					WFTS Sockeye				
Sampling Date	**Week**	**Sampled**	**Tagged**	**Prev. Tagged**	**Sampling Mortality**	**Total Tags**	**Sampled**	**Tagged**	**Prev. Tagged**	**Sampling Mortality**	**Total Tags**
6/29/2016	27	30	30	0	0	30	30	30	0	0	30
6/30/2016	27	50	49	0	0	49	50	49	0	0	49
7/1/2016	27	70	70	0	0	70	70	70	0	0	70
7/6/2016	28	100	98	2	0	100	100	100	0	0	100
7/7/2016	28	70	70	0	0	70	70	69	1	0	70
7/12/2016	29	75	75	0	0	75	75	74	0	0	74
7/22/2016	30	56	54	2	0	56	60	59	0	5	54
Total		451	446	4	0	450	455	451	1	5	447
Weekly Totals											
	27	150	149	0	0	149	150	149	0	0	149
	28	170	168	2	0	170	170	169	1	0	170
	29	75	75	0	0	75	75	74	0	0	74
	30	56	54	2	0	56	60	59	0	5	54
Total		451	446	4	0	450	455	451	1	5	447

There were five mortalities among sampled Sockeye Salmon on July 22 of fish that were designated for transport by WFTS over Priest Rapids Dam. These fish did not recover after sampling and likely died due to an overdose of Aqui-S. They were not transported through the WFTS. This occurred during a period when our project lead for the day was at the top of the dam evaluating fish exiting the WFTS, placing personnel trained but less experienced with the use of Aqui-S to do the tagging. It is possible that additional fish did not fully recover and were sent through the WFTS during this same period. Among a group of 16 Sockeye sampled during this period by the less experienced personnel, there were the five mortalities noted above plus an additional six Sockeye that were transported through the WFTS into the Priest Rapids forebay but not subsequently detected, suggesting they succumbed to sampling complications or fallen prey to predators. Among the WFTS Sockeye in Week 30 other than this group of 16, only 4 out of 44 were not subsequently detected. Only the five known mortalities were removed from further analysis as they were not transported through the WFTS, but no effort was made to adjust for any additional possible mortalities.

We also had an additional four Sockeye sampled on July 7, two WFTS and two non-WFTS, which were recovered dead in the recovery area the day following sampling. These fish were not observed in the recovery area at the end of the day so were either missed or swam upstream, died, and drifted back to where they were recovered. These fish were included in analysis of survival to upstream sites.

Age Composition

Based on scale age assessment, over 90% of the WFTS and non-WFTS Sockeye were Age 1.2, with the remainder of Age 1.1 and 1.3 (Table 2). Mean fork lengths by age for the two groups varied by 0.6 cm or less. With scale age assessment and mean fork lengths showing only small differences between the WFTS and non-WFTS groups, the group compositions are considered equivalent with respect to age and size parameters.

Table 2. Age composition of Sockeye tagged at OLAFT at Priest Rapids Dam by week and treatment group in 2016

		Non-WFTS Sockeye			WFTS Sockeye			All Sockeye		
Week	**% of run passing Priest Rapids Dam**	**1.1**	**1.2**	**1.3**	**1.1**	**1.2**	**1.3**	**1.1**	**1.2**	**1.3**
≤27	65.5%	0.0%	94.4%	5.6%	2.7%	91.8%	5.4%	1.4%	93.1%	5.5%
28	22.2%	1.2%	91.5%	7.3%	0.6%	89.8%	9.6%	0.9%	90.6%	8.5%
29	8.5%	1.4%	90.4%	8.2%	0.0%	93.3%	6.7%	0.7%	91.9%	7.4%
≥30	3.8%	0.0%	91.8%	8.2%	0.0%	87.5%	12.5%	0.0%	89.5%	10.5%
Weighted by Week		0.4%	93.4%	6.3%	1.9%	91.3%	6.7%	1.2%	92.3%	6.5%
Mean Length (cm)		42.7	49.6	56.5	41.7	49.6	57.0	42.1	49.6	56.8
SE (cm)		3.3	2.8	1.7	1.5	2.4	2.4	2.1	2.6	2.1

Upstream Detections

Sockeye traveling upstream through fish ladders at dams rarely escaped detection (Table 3). The highest percentages of fish missed by PIT detection at a dam were at Rock Island Dam, which is known to have a lower detection rate than is typically observed at other dams although changes to the facility in 2015 have improved detection (Fryer et al. 2016a). PIT-tagged Sockeye were also missed at Zosel Dam which can, under certain operating conditions, pass Sockeye upstream through the spill gates (Fryer et al. 2016b).

There were no significant differences in detection rates between WFTS and non-WFTS groups at any dam (Table 3).

Table 3. Number of WFTS and non-WFTS Sockeye Salmon PIT tagged at Priest Rapids Dam detected at upstream fish ladders and the percentage not detected at associated PIT tag arrays in 2016

	Non-WFTS		WFTS		
Dam	**Number of Sockeye detected upstream**	**% Missed by PIT array**	**Number of Sockeye detected upstream**	**% Missed by PIT array**	**Chi-Square test p-value for difference in detection rates**
Priest Rapids	373	0.3%	329[1]	0.0%	0.29
Rock Island	357	2.5%	361	1.9%	0.50
Rocky Reach	243	0.0%	233	0.0%	1.00
Wells	189	0.0%	192	0.0%	1.00
Zosel	105	1.9%	111	1.8%	0.62
Tumwater	73	0.0%	82	0.0%	1.00

Survival to upstream sites was highest during Week 27 with survival generally declining later in the run (Tables 4 and 5) as has commonly been observed with Sockeye tagged at Bonneville Dam (Fryer et al. 2016). Summary data is presented for weeks 27-29 as well as Week 30. Special attention is called to Week 30 as the WFTS treatment was different. WFTS Sockeye were transported to the Priest Rapids Dam forebay rather than back into the fish ladder, as was the case in the three prior weeks.

Table 4. Survival: Percentage of non-WFTS Sockeye Salmon released at Priest Rapids Dam detected at, or upstream of upstream dams in 2016.

Week	**Priest Rapids**	**Rock Island**	**Rocky Reach**	**Wells**	**Tumwater**	**Zosel**	**Tumwater or Wells**	**OKC**
27	96.0%	91.3%	75.2%	71.8%	20.1%	64.4%	84.6%	34.9%
28	90.6%	76.5%	52.9%	50.0%	20.0%	33.5%	53.5%	20.0%
29	94.7%	80.0%	49.3%	46.7%	26.7%	26.7%	53.3%	16.0%
30	92.9%	83.9%	37.5%	28.6%	37.5%	16.1%	53.6%	12.5%
All Weeks	93.3%	82.9%	57.8%	54.0%	23.3%	40.4%	63.8%	23.3%

[1] This excludes the 54 Sockeye transported over Priest Rapids Dam on July 22, thus bypassing detection at the Priest Rapids fish ladder.

Weeks 27-29	93.4%	82.7%	60.7%	57.6%	21.3%	43.9%	65.2%	24.9%

Table 5. Survival: Percentage of WFTS Sockeye Salmon released at Priest Rapids Dam detected at or upstream of upstream dams in 2016.

Week	**Priest Rapids**	**Rock Island**	**Rocky Reach**	**Wells**	**Tumwater**	**Zosel**	**Tumwater or Wells**	**OKC**
27	96.6%	89.3%	59.7%	58.4%	28.9%	54.4%	83.2%	31.5%
28	90.6%	77.6%	51.2%	46.5%	24.1%	39.4%	63.5%	20.0%
29	94.6%	86.5%	58.1%	56.8%	23.0%	36.5%	59.5%	25.7%
30	NA[2]	83.3%	61.1%	46.3%	24.1%	29.6%	53.7%	20.4%
All Weeks	NA	83.7%	56.4%	52.1%	25.5%	42.7%	68.2%	24.8%
Weeks 27-29	93.6%	83.7%	55.7%	52.9%	25.7%	44.5%	70.2%	25.4%

A χ^2 test found no significant difference (α=0.05) for the percentage of WFTS and non-WFTS Sockeye that passed PIT tag detection arrays at either Tumwater or Wells dams combined for all weeks (p=0.765), weeks 27-29 (p=0.955) or Week 30 (p=0.609) (Table 6). When weeks 27-30 were combined, there were also no significant differences in the percentage of WFTS and non-WFTS Sockeye that passed PIT tag detection arrays at Priest Rapids, Rock Island, Rocky Reach, Wells, Tumwater or Zosel dams. However, there were significant survival differences when examining weeks 27-29 at Rocky Reach (p=0.048) and Tumwater (p=0.046) (when WFTS fish were released into the fish ladder). More substantial significant survival differences measured by PIT tag detection percentage, were identified in Week 30 at Rocky Reach (p=0.001), Wells (p=0.010) and Tumwater (p=0.014) (when WFTS fish were released into the Priest Rapids forebay and non-WFTS passaged up the ladder) (Table 6). In all cases, the significant differences in PIT tag detection percentage were at terminal locations passed by only one Sockeye stock (Rocky Reach, Wells, and/or Tumwater dams).

Table 6. Percentage of WFTS and non-WFTS Sockeye passing upstream dams with a p-value from a chi square test for differences between treatments for weeks 27-30, 27-29, and Week 30 in 2016. Shaded p values indicate significant results at α=0.05.

		Percentage of released Sockeye detected at or above							
Week	**Treatment**	**Priest Rapids**	**Rock Island**	**Rocky Reach**	**Wells**	**Tum-water**	**Zosel**	**Tumwater or Wells**	**OKC**
All Weeks	Non-WFTS	93.3%	82.9%	57.8%	54.0%	23.3%	40.4%	76.9%	23.3%
	WFTS	92.4%	83.7%	56.4%	52.1%	25.5%	42.7%	77.4%	24.8%
	X^2 test p-value	0.443	0.638	0.536	0.417	0.285	0.433	0.765	0.452

[2] These fish were not detected at Priest Rapids Dam as they were released in the Priest Rapids Dam forebay.

Weeks 27-29	Non-WFTS	93.4%	82.7%	60.7%	57.6%	21.3%	43.9%	78.4%	24.9%
	WFTS	93.6%	83.7%	55.7%	52.9%	25.7%	44.5%	78.4%	25.4%
	X^2 test p-value	0.841	0.598	0.048	0.062	0.046	0.623	0.955	0.790
Week 30	Non-WFTS	92.9%	83.9%	37.5%	28.6%	37.5%	16.1%	66.1%	12.5%
	WFTS	NA	83.3%	61.1%	46.3%	24.1%	29.6%	70.4%	20.4%
	X^2 test p-value	NA	0.664	0.001	0.010	0.014	0.550	0.609	0.155

Passage Time at Dams

There were no significant differences in the mean passage time at dams between WFTS and non-WFTS Sockeye (Table 7). Passage times at Wells and Tumwater dams are likely inflated by delays due to operation of fish traps for sampling and broodstock collection at these dams. Wells Dam also has an antenna low in the fish ladder as well as antennas at the upper end of the ladder which would lead to greater passage times. In comparison, other dams listed in Table 7 upstream of Priest Rapids have antennas closely spaced at the upper end of the ladder.

Table 7. Passage time at dams in minutes as measured from time of first detection to time of last detection for WFTS and non-WFTS Sockeye tagged at Priest Rapids Dam in 2016.

	Non-WFTS Sockeye				**WFTS Sockeye**				**P value for Mann Whitney-U test to compare treatment population means**
Site	**Median**	**Mean**	**Standard Deviation**	**% over 12 hours**	**Median**	**Mean**	**Standard Deviation**	**% over 12 hours**	
Priest Rapids	8.8	98.0	505.8	2.4%	9.8	69.8	287.9	1.9%	0.96
Rock Island	0.2	14.1	98.4	1.1%	0.2	9.2	57.0	0.3%	0.97
Rocky Reach	6.6	60.8	457.8	1.9%	6.9	20.8	98.5	0.8%	0.93
Wells	5.5	303.1	1340.3	5.4%	6.7	428.5	1899.7	6.9%	0.96
Zosel	0.4	8.8	51.4	0.0%	0.4	17.7	164.3	0.5%	0.96
Tumwater	7.0	170.4	1084.7	3.9%	6.4	153.3	1003.9	3.5%	0.99

Fallback

A total of 16 WFTS Sockeye and 25 non-WFTS Sockeye were estimated to fall back over dams. Not included in these totals are any Sockeye that may have fallen back over a dam but were not subsequently detected. Two WFTS and four non-WFTS Sockeye fell back over two dams (Wells and Rocky Reach) and were last detected in the Wenatchee River.

Fallback rates ranged from 0% at Tumwater and Zosel dams to 5.0% for non-WFTS Sockeye at Rocky Reach Dam, however at 3.2%, Rocky Reach was the location of highest WFTS fallback as well. At four of the five Columbia River dams, non-WFTS Sockeye were estimated to have a higher fallback rate than WFTS Sockeye; the sole exception being at Wells Dam, however, in no cases did these differences in fallback rates reach statistical significance (Table 8).

Table 8. Number of fallbacks and fallback rates for WFTS and non-WFTS Sockeye at upstream dams.

	Non-WFTS		WFTS		Chi-Square Test p value
	Fallback (n)	Fallback (%)	Fallback (n)	Fallback (%)	
Priest Rapids	5	1.2%	1	0.2%	>0.99
Rock Island	2	0.5%	1	0.3%	>0.99
Rocky Reach	13	5.0%	8	3.2%	0.90
Wells	5	2.1%	6	2.6%	0.60
Zosel	0	0.0%	0	0.0%	>0.99
Tumwater	0	0.0%	0	0.0%	>0.99
Total	25		16		

Migration Travel Time

There were no significant differences in migration times between the WFTS and non-WFTS groups (Table 9). The median migration travel time for WFTS and non-WFTS Sockeye over all weeks combined (weeks 27-30) varied by less than 10%.

Table 9. Median and mean migration travel times between upstream dams for WFTS and non-WFTS Sockeye PIT tagged at OLAFT at Priest Rapids Dam are recorded in days.

			All Weeks			Mann Whitney-U P value
Between Sites	Treatment	N	Median	Mean	StdDev	
Priest Rapids-Rock Island	WFTS	323	3.73	3.97	1.60	0.31
	Non-WFTS	363	3.60	3.97	1.94	
Priest Rapids-Rocky Reach	WFTS	219	4.69	4.91	1.60	0.93
	Non-WFTS	259	4.67	4.97	1.85	
Priest Rapids-Wells	WFTS	208	6.63	6.92	1.96	0.73
	Non-WFTS	242	6.61	7.03	2.37	

Priest Rapids-OKL	WFTS	83	8.69	12.07	11.53	0.08
	Non-WFTS	97	8.94	16.41	16.00	
Priest Rapids-Zosel	WFTS	175	10.55	13.26	10.73	0.67
	Non-WFTS	186	10.46	14.40	13.31	
Priest Rapids-OKC	WFTS	100	91.09	83.59	26.68	0.98
	Non-WFTS	104	91.32	83.90	25.69	
Priest Rapids-LWE	WFTS	45	5.31	5.71	2.29	0.20
	Non-WFTS	53	5.73	7.97	6.84	
Priest Rapids-Tumwater	WFTS	101	13.89	14.74	4.38	0.31
	Non-WFTS	105	14.18	15.16	4.12	
Rock Island-Rocky Reach	WFTS	247	1.05	1.26	0.84	0.41
	Non-WFTS	253	1.05	1.33	0.97	
Rock Island-Tumwater	WFTS	112	9.43	10.49	4.03	0.24
	Non-WFTS	103	10.02	10.76	3.56	
Rocky Reach-Wells	WFTS	233	1.86	2.08	1.05	0.38
	Non-WFTS	243	1.80	2.04	1.19	

Release to Site Travel Time

In considering all weeks sampled (weeks 27-30), there were no significant differences in travel times from release to any upstream sites between the WFTS and non-WFTS groups (Table 10). The median release to site travel time for WFTS and non-WFTS Sockeye over all weeks varied by less than 10%, with the exception of release to LWE in the Lower Wenatchee River. The median and mean time from release to LWE for the WFTS group was substantially shorter than the non-WFTS time but this difference was not statistically significant.

Table 10. Median and mean release to site travel times across all weeks: from OLAFT release to upstream sites for WFTS and non-WFTS Sockeye PIT tagged at OLAFT at Priest Rapids Dam, recorded in days.

			All Weeks			Mann Whitney-U P value
Release to Site Travel Time	**Treatment**	**N**	**Median**	**Mean**	**StdDev**	
Release-Priest Rapids	WFTS	362	0.08	0.59	1.21	0.34
	Non-WFTS	413	0.09	0.75	1.56	
Release-Rock Island	WFTS	367	4.04	4.49	2.11	0.26
	Non-WFTS	364	4.03	4.77	2.56	
Release-Rocky Reach	WFTS	252	4.99	5.47	2.07	0.64
	Non-WFTS	260	4.98	5.76	2.59	
Release-Wells	WFTS	233	7.11	7.44	2.37	0.98

	Non-WFTS	243	6.92	7.79	3.15	
Release- OKL	WFTS	97	9.12	14.58	12.71	0.65
	Non-WFTS	98	9.47	17.66	17.21	
Release-Zosel	WFTS	190	11.44	15.47	13.14	0.13
	Non-WFTS	187	10.73	15.07	14.04	
Release-OKC	WFTS	111	90.36	83.57	25.78	0.43
	Non-WFTS	105	93.16	84.72	25.61	
Release-LWE	WFTS	45	5.58	6.54	3.02	0.09
	Non-WFTS	42	7.02	8.98	6.95	
Release-Tumwater	WFTS	112	14.14	15.41	4.95	0.24
	Non-WFTS	103	14.98	15.91	4.46	

On Week 30, WFTS Sockeye were directly passed over the dam through a 50.9 m WFTS, rather than the 30.5 m WFTS transport to the recovery area and swim passage up the ladder from the OLAFT to the Priest Rapids forebay which was the passage route for the weeks 27-29 WFTS group. For the non-WFTS group, passage was the same across all weeks, with hand carriage after sampling to the recovery area and then swim passage up the ladder from the OLAFT to the Priest Rapids forebay. The vertical distance of ladder passage from OLAFT recovery area to the forebay, based on the architectural drawings of the Priest Rapids Dam ladder, is ~15.5 feet. The release to site travel times for Week 30 enable a direct head-to-head evaluation of the impact of WFTS passage on travel time. The sample size (N) of the Week 30 WFTS and non-WFTS groups were small and Sockeye detection numbers typically decrease as they pass up-river (Table 11). There was no statistically significant difference in travel times from release to upstream sites between the WFTS and non-WFTS groups except for release to Rock Island Dam ($p \leq 0.01$) and release to Rocky Reach Dam ($p=0.03$) (Table 11). The WFTS group migrated significantly faster to these sites than the non-WFTS group. The mean and median times from release to Wells, OKL, Zosel, LWE and Tumwater were also less for the WFTS group than the non-WFTS group, however the differences did not reach statistical significance. Because of the limited group sample sizes at the various upstream sites, differentiation of statically significant differences were not expected, however the overall trend of faster travel by the WFTS Week 30 group is noteworthy.

Table 11. Median and mean release to dam travel times for week 30 from OLAFT release to upstream dams for WFTS and non-WFTS Sockeye PIT tagged at OLAFT at Priest Rapids Dam, recorded in days.

Release to Site Travel Time	Treatment	N	Week 30			Mann Whitney-U P value
			Median	Mean	StdDev	
Release-Priest Rapids	WFTS	0	N/A	#DIV/0!	N/A	N/A
	Non-WFTS	50	0.12	0.96	1.70	
Release-Rock Island	WFTS	44	3.48	3.89	1.45	<0.01
	Non-WFTS	46	4.07	5.39	2.64	
Release-Rocky Reach	WFTS	33	4.82	5.36	2.36	0.03
	Non-WFTS	21	5.61	6.58	2.64	
Release-Wells	WFTS	25	6.85	7.08	2.04	0.11
	Non-WFTS	16	7.92	9.42	5.00	
Release- OKL	WFTS	14	19.18	25.69	12.70	0.68
	Non-WFTS	8	25.94	27.96	14.99	
Release-Zosel	WFTS	15	22.68	36.20	20.51	0.53
	Non-WFTS	9	23.80	32.51	18.16	
Release-OKC	WFTS	11	77.52	78.57	12.03	0.39
	Non-WFTS	7	76.21	75.41	5.86	
Release-LWE	WFTS	10	5.35	6.36	2.76	0.24
	Non-WFTS	7	7.57	8.54	3.44	
Release-Tumwater	WFTS	13	13.82	15.37	5.87	0.66
	Non-WFTS	21	14.05	78.57	5.12	

Discussion

This study was conducted to assess whether the WFTS had any impact on the subsequent migration of salmonids upstream. This study found no difference in combined survival, as measured by PIT tag detections, to Tumwater or Wells dams, however, differences were noted in PIT tag detection and in survival to individual dams. The most likely interpretation for this is that the WFTS sample in weeks 27-29 was weighted more heavily with Wenatchee stock Sockeye Salmon than the non-WFTS sample, thus resulting in higher percentages of WFTS Sockeye at Tumwater Dam than non-WFTS Sockeye. Conversely, the non-WFTS sample was weighted more heavily with Okanogan stock Sockeye Salmon than the WFTS sample and had a higher percentage of Sockeye at Rocky Reach, and Wells dams. This weighted stock trend reversed in Week 30, resulting in no significant survival differences at all locations over all weeks.

This study found no significant difference between passage times at mainstem dams for WFTS and non-WFTS Sockeye. There also was no significant difference in fallback between WFTS and non-WFTS Sockeye. There was no statistically significant difference in migration travel times between WFTS and non-WFTS Sockeye with the exception of Week 30 where direct passage of the WFTS Sockeye into the forebay rather than the fish ladder resulted in a statistically significant difference in release-to-Rock Island Dam and release to Rocky Reach Dam travel time with the WFTS group migrating faster.

Overall, mortality rates for both WFTS and non-WFTS were higher than have been historically observed in similar tagging projects. In 2016, adult Sockeye tagging projects had two mortalities out of 811 Sockeye tagged at Wells Dam and one out of 1706 Sockeye tagged at Bonneville Dam (Fryer et al., *in preparation (b)*). In analyzing results, survival rates for Sockeye Salmon tagged at Priest Rapids Dam to upstream sites were noted to be almost 10 percentage points lower than that of Sockeye tagged at Bonneville Dam and later detected passing Priest Rapids Dam (Table 12). The presumed delayed tagging mortality is higher than has been observed in tagging studies at Wells and Priest Rapids dams in past years which ranged up to 4.9%. (Fryer et al. 2015). Partial explanation may be found in the inexperience of the sampling team relative to those who routinely sample at Bonneville and Wells dams. However, within this Priest Rapids Sockeye study, the WFTS and non-WFTS survival rates were not significantly different. PIT detection rates differing by less than 2.5% between WFTS and non-WFTS across all dam and instream PIT detection sites analyzed (Table 6). The study was designed as a head to head comparative in-river study to account for uncontrollable variables and thus regardless of historical mortality rates, the study findings as they relate to the WFTS and non-WFTS groups are substantiated and sound. In addition, it should be noted that preliminary 2016 results from Wells Dam also suggest lower survival rates to upstream sites relative to those of Bonneville-tagged Sockeye than has been observed in other years (Fryer et al., *in preparation (b)*). This suggests that the higher than normal delayed tagging mortality observed at Priest Rapids Dam in 2016 may be related to some characteristic of the 2016 Sockeye run rather than being attributable to Priest Rapids tagging.

Table 12. Survival from tagging to Rock Island Dam for WFTS and non-WFTS Sockeye Salmon by Statistical Week compared to Bonneville-tagged Sockeye Salmon traveling between Priest Rapids Dam and Rock Island Dam in 2016.

Statistical Week	Estimated Percentage of run at Priest Rapids based on fish count	WFTS Sockeye tagged at Priest Rapids	Non-WFTS Sockeye tagged at Priest Rapids	Bonneville tagged Sockeye
27	65.5%	89.3%	91.3%	96.8%
28	22.2%	77.6%	76.5%	94.1%
29	8.5%	86.5%	80.0%	96.3%
30	3.8%	83.3%	83.9%	94.3%
Weighted mean		86.2%	86.8%	96.1%

The goal of this project was to determine if any adverse migration effects related to sending Sockeye through the WFTS when compared to Sockeye which did not go through the WFTS, keeping all other variables constant, could be distinguished. Survival rates, migration times, dam passage times, and fallback rates were all similar for WFTS and non-WFTS Sockeye. A notable dissimilarity that emerged in these analyses was related to marked differences in the distribution of surviving Sockeye between Okanogan and Wenatchee terminal areas. However, this difference was not consistent across all weeks of the study and seems most likely to have been caused by random variations in the stock composition of Sockeye selected for the WFTS and non-WFTS groups. Genetics samples were collected from Sockeye sampled. Although not part of this study, it would be possible to process and analyze these samples to definitively demonstrate the stock composition for the WFTS and non-WFTS groups.

The opportunity for direct WFTS passage over the dam on July 22nd, the only day sampled in week 30, provided the opportunity to assess migration effects related to the method of dam passage. Fifty-four Sockeye (WFTS group) were passed through the WFTS directly into the Priest Rapids forebay following OLAFT sampling and PIT tagging. Fifty-six Sockeye (non-WFTS group) were returned to a recovery channel to navigate passage up the remaining Priest Rapids fish ladder to reach the Priest Rapids forebay following OLAFT sampling and PIT tagging. Migration was tracked by PIT tag detection and significant travel time differences between the WFTS and non-WFTS week 30 Sockeye were observed. WFTS Sockeye completed passage over Priest Rapids Dam in seconds once they recovered from Aqui-S treatment and were hand fed into the WFTS (Whooshh, 2016b). In comparison, the median passage time for Week 30 non-WFTS Sockeye was 2.88 hrs as measured by PIT tag detection at release to the last PIT tag detection at Priest Rapids dam (0.12 days, see Table 11). The Sockeye subsequently migrated upstream. Median release to Rock Island Dam travel time calculated from PIT tag detection data for week 30 WFTS was significantly faster than that of non-WFTS Sockeye equating to about a half a day and release to Rocky Reach Dam with a faster arrival equating to nearly a full day. As the Sockeye continued up river the median WFTS release to dam travel times remained greater than 10% faster than the non-WFTS, with over a full day faster arrival to Wells Dam as well as at the LWE instream PIT detection array, however these differences were not found to be statistically significant. The limited group sample sizes of Week 30 was a confounding factor in the ability to detect significant differences at travel times to upstream sites however it did allow differential trends to emerge. The trend data with faster travel times gleamed from WFTS passage over the dam verses ladder passage is intriguing. Upstream of these sites in mid-summer the Okanogan Sockeye hold off at the mouth of the Okanogan River until water temperatures drop and the Wenatchee Sockeye hold downstream of the Tumwater Canyon in the Wenatchee River until flows through a partial passage barrier drop, prior to continuing their migration. Likely due to such holds, the subsequent upstream median release to site travel times of the WFTS and non-WFTS Sockeye were similar, with <5% differences calculated. These findings support a recommendation for additional, more robust, WFTS over the dam migration travel benefit assessment.

This comparison study directly assessed in-river Sockeye migration times, survival and passage times and found no significant differences between those that were WFTS transported and return to the river for ladder passage and those that were not transported through the WFTS. Additionally, three fish attributes were indirectly assessed for Sockeye. If WFTS transport caused aberrant homing, increased disease transmission and/or abnormal behavior the outcome of these would contribute to an observed and measured difference in survival, migration and passage times between the WFTS and non-WFTS Sockeye groups. As no significant differences of any of the study parameters were observed between the ladder passage groups, this study provides indirect evidence that the WFTS does not affect homing, does not increase the potential for disease transmission and does not promote abnormal behavior of the transported Sockeye Salmon. Overall the study demonstrated safe, efficient, effective passage of all sampled Sockeye regardless of group and transport/passage method.

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