# Whooshh Transport Survival Efficacy is Reproducible Across a Three-Year Viability Assessment Study

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***Abstract***

The Whooshh Fish Transport System (WFTS), a novel, innovative ecotechnology has been developed to facilitate fish transfer and fish passage. Is the efficacy of fish transport via the WFTS comparable and reproducible to traditional transport methods? A hatchery fish transport setting was selected as the evaluation site. Salmon hatchery programs have been a vital component of the fisheries industry and salmon conservation and recovery efforts in the Pacific Northwest. Salmon selected for hatchery programs typically require handling and transport after capture to enable condition assessment, sampling, measurements and relocation to hatchery facilities. Traditionally such activities are labor intensive. Efficiencies are often dictated by the location. The means of trapping the fish and transporting by hand carriage, boot or net presents potential risk to both fish and handler. Once in the hatchery, the fish are monitored and data on adult survival rates, productive spawning and egg viability are collected. Implementing the use of new technologies on valuable, natural resources requires robust evaluation to ensure the benefits of the technology are sound and that there are no negative impacts on the natural resource attributable to the use and function of the new technology. A three-year comparative study, run by the Yakama Nation Fisheries in the Columbia basin of Washington state, assessed the hatchery monitored outcomes of Spring Chinook salmon that were either transported through a 40 ft WFTS to the hatchery truck or were hand walked to the hatchery truck revealed reproducible results indicating no measurable impact of WFTS transport on subsequent adult survival, productive spawning and egg viability. The WFTS was found to provide safe, efficient, effective and rapid fish transport with the added benefit of removing hand walking safety concerns for the fish and fisheries personnel. In addition, in the last year of the study a feasibility, viability assessment was included to evaluate the adaptability and efficacy of employing a WFTS to safely transport live Chinook salmon across a distance (1100 ft) and elevation (100 ft) that models a high head dam passage distance. The answer to the question of whether the WFTS safely, efficiently, effectively and rapidly (in ~35 seconds) transports fish 1100 ft, with no impact on hatchery monitored outcomes, is YES. Appreciable gains in transfer safety, delivery location flexibility and time-saving were additional benefits.

***Introduction***

The Cle Elum Supplementation and Research Facility (CESRF) in the Washington Yakima River basin has an integrated spring Chinook Salmon hatchery program designed to increase natural production. The program has been in place since the late 1990's and has proven to be successful at increasing salmon returns to the basin and reducing the risks of repopulation genetic effects. The program involves a long-term comprehensive monitoring program tied together with the hatchery propagation program which are controlled and designed to accommodate additional arms of research investigation (Fast, 2015). The third consecutive year of evaluating the WFTS in terms of transport-associated adult survival, production spawning and egg viability is complete. The study was conducted by the Yakama Nation Fisheries engaging their operations and expertise at the Roza Adult Monitoring Facility (RAMF) and CESRF.

It has been reported that dams impact anadromous fish species in a number of ways with a domino of ecosystem impacts (Harrison, 2008). The most obvious impediment however is that dams block anadromous fish passage. The spawning migrations of Pacific salmon are fueled by energy stores acquired during ocean residency prior to entering freshwater rivers and streams (Nadeau, 2010). Because salmon populations have genetic adaptations optimized for migration efficiency for specific river conditions, it is expected that the stresses encountered in travel through man-made passage facilities could have negative implications regarding spawning success. Man-made passage impediments often require additional travel time and energy expenditures for the fish. Traditional ladder passage may cause fish to tap into energy reserves as they are forced to swim through a series of high gradient cascades to pass the barrier. This output of energy may deplete a portion of the population inhibiting them from reaching the spawning grounds or having adequate energy remaining for spawning. In addition, there is growing evidence that dam-associated increases in water temperature, which often feed the upper section of ladders by gravity, is contributing to downstream fallback and represents a significant migration obstacle concern (Crozier, 2013 and Caudill, 2013).

WFTS is an innovative fish passage system developed by Whooshh Innovations, LLC (Whooshh) that utilizes a novel differential pressure system to facilitate 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 Innovations, 2016a). A number of successful studies and applications have been conducted employing 40 and 250 ft tubes to transfer fish from holding tanks and traps in rivers to haul trucks and raceways. In a comparative study conducted by PNNL, evaluating fish well-being of net capture and haul, to a 40 or 250 ft WFTS tube transfer yielded favorable results with the WFTS transported fish, (both 40 ft and 250 ft transport) demonstrating equal to or better outcomes in health, survival and reproduction measures (PNNL, 2014). Proof of concept of the ability to utilize the Whooshh system to transport a fish through a tube of a 500 ft length was demonstrated as far back as 2014 on non-live fish. The transport time through a 500 ft Whooshh tube ranged from 20-22 seconds. With the ability to alter the pressure, the system is designed such that deceleration at exit can be achieved to NMFS standards of exit impact velocity ($\leq$ 25 ft/sec). The current study has modeled the distance from a sited location of attraction flow to the dam crest of the Cle Elum dam which encompasses an approximate 1100 ft distance and an elevation increase of approximately 100 ft and live Chinook salmon were transported.

The current study results compare three consecutive years of adult survival, production spawning and egg viability data of standard hand carriage verses WFTS 40 ft transport of spring Chinook taken at the RAMF and monitored as part of the CESRF. In addition, this year included an additional study arm comparing hand carriage verses 1,100 ft WFTS passage evaluation applying the same study parameters; adult survival, spawning and egg viability.

***Methods***

Typically, a total of ~400-600 adult spring Chinook salmon are transported from the RAMF to the CESRF via established protocols and trained Yakama Nation Fisheries (YN) personnel (Fast, 2015). Transported Chinook were hauled to Cle Elum hatchery and housed in raceways for weeks to months until they were ready to spawn. The adult survival rates are indicative of the percent of Chinook that survive until spawning. In the past three years, after measurements and tagging, a percentage of fish have been hand carried to a haul truck and the remaining WFTS transported directly into the truck. The WFTS 40 represents ~40 ft of tube through which the fish were transported from the RAMF into the haul truck. The 2016 addition of the WFTS 1100 represents ~1100 ft of tube through which the fish were transported from the RAMF into the haul truck (Bureau of Reclamation, 2016, Whooshh Innovations, 2016b). In 2014 and 2015 nearly 14% of the daily sampled Chinook were randomly selected for WFTS 40 transport verses hand carriage. The total of transported WFTS 40 and hand carry Chinook together encompass the necessary fish numbers required for the hatchery CESRF program. In 2016 between May and June 9th nearly 18% of the daily sampled Chinook were randomly selected for WFTS 40 transport verses hand carriage. From June 10th through the end of the run the WFTS 40 was not used, however the WFTS 1100 was employed. Just under 10% of the fish sampled during that time-period were transported through the WFTS 1100. As there are some differences in the sizes and condition of the fish during the length of the run, WFTS comparisons to hand carriage were conducted as a group set and broken out such that comparable fish relative to sample date were evaluated.

Trained YN personnel manage the fish trafficking, monitoring, measuring, tagging and transport methods. Measuring and tagging were conducted after the fish were mildly sedated in a MS-222 solution. Hand carriage fish are carried while in the sedated state as the calm state helps to prevent dropping or damaging the fish. The WFTS selected fish were allowed to partially recover from MS-222 treatment prior to loading into the system. The behavior of the fish after they enter the haul truck tanks was visually observed. Standard behavior of swimming in a righted position, collecting near the bottom of the tank, and typical fish to fish interactions were considered.

Once in the fishery haul truck, all fish, regardless of study group, were treated in an identical manner. They were hauled to the Cle Elum hatchery by truck in chilled, oxygenated water tanks at which point the fish were moved into holding raceways until spawning. Standard hatchery practices were employed with regard to feeding, water flow etc. At spawning 3x3 crosses were performed to allow for viability assessment without single pairing incompatibility confounders. The fertilized eggs were handled per CESRF protocol, physically shocked, sorted and counted.

***Results***

The total number of spring Chinook transported included wild/natural, supplemental and hatchery stocks. In terms of tracking counts within a given stock, Jacks were differentiated from the males and the females. For the purposes of the comparative study, the total count number included only the Chinook with confirmed gender assignment and excluded all Jacks. Thus in 2014 466 spring Chinook transported from RAMF to CESRF were evaluated whereas in 2015 562 and in 2016 550 spring Chinook were assessed. In 2014 and 2015 13.9% of the total fish were transported to the fishery haul truck via the WFTS 40. In 2016 17.9% of the total fish were transported to the fishery haul truck via the WFTS 40, 9.5% of the total fish were transported to the fishery haul truck via the 1100 ft/100 ft vertical climb WFTS 1000 tube and the remaining were hand carried (H&H) to the fishery haul truck. The gender composition of the groups had some variability across the years which is most readily viewed by comparing the female to male ratios. The ratios between the study groups were closer in 2015 at 1.64 to 1 for the H&H group verses 1.89 to 1 for the WFTS 40 group (Table 1). In combining all WFTS (WFTS 40 plus WFTS 1100), the 2016 female to male ratios were nearly identical to 2014. Separating WFTS 40 and WFTS 1100 it is apparent that the WFTS 40 group contained considerably more females than males, 2.24 to 1 (Table 1). In all cases, across study groups and years, the sample set was predominantly female (Table 2). Examination of the female to male ratio was conducted to determine if there was any apparent gender bias related to adult survival. No consistent reproducible trend was observed across transport groups or years.

*Table 1. Comparison of the hand and haul (H&H) and Whooshh transported groups of fish. Gender and female/male ratio data are captured here. 2016 Whooshh data is further separated to indicated WFTS 40 and WFTS 1100 group composition. 2014 data are in green, 2015 blue and 2016 tan. (* = Acct'd w/known/true sex, ** Hand & Haul (H&H) = Non-Whooshh transport)*

| Chinook Sampled* | H&H** | WFTS 40 |
|---|---|---|
| **2014 TOTAL= 468** | | |
| Females | 219 | 43 |
| Males | 184 | 22 |
| Ratio female/male | 1.19/1 | 1.95/1 |
| **2015 TOTAL = 562** | | |
| Females | 301 | 51 |
| Males | 103 | 27 |
| Ratio femalel/male | 1.64/1 | 1.89/1 |
| *Acct'd w/ known/ true sex | | |
| ** Hand & Haul = Non-Whooshh | | |

| | H&H** | WFTS40+1100 |
|---|---|---|
| **2016 TOTAL = 550** | | |
| Females | 208 | 111 |
| Males | 174 | 57 |
| Ratio female/male | 1.20/1 | 1.95/1 |
| **2016 WHOOSHH TOTAL = 168** | | |
| | WFTS40 | WFTS1100 |
| Females | 76 | 35 |
| Males | 34 | 23 |
| Ratio female/male | 2.24/1 | 1.52/1 |

*Table 2. Recorded measurements of the 2014-2016 Whooshh transported fish. 2014 data are in shades of green and 2015 data in shades of blue. 40ft and 1100 ft WFTS groups from 2016 are represented in light and darker shades of tan.*

| | 2014 40 ft WFTS | | 2015 40 ft WFTS | | 2016 40 ft WFTS | | 2016 1100 ft WFTS | |
|---|---|---|---|---|---|---|---|---|
| **Female** | **Forklength** | **Weight** | **Forklength** | **Weight** | **Forklength** | **Weight** | **Forklength** | **Weight** |
| Mean | 70.2 | 4.7 | 70.8 | 4.2 | 71.2 | 5.7 | 73.0 | 6.2 |
| Max | 80 | 6.8 | 78 | 5.3 | 77 | 7 | 79 | 7 |
| Min | 64 | 3.4 | 62 | 3 | 66 | 4.2 | 68 | 4.7 |
| Count | 43 | 43 | 51 | 51 | 76 | 76 | 35 | 58 |
| **Male** | | | | | | | | |
| Mean | 71.2 | 4.8 | 71.4 | 4.1 | 70.3 | 5.4 | 73.4 | 6.1 |
| Max | 78 | 5.9 | 77 | 5.4 | 75 | 6.4 | 78 | 6.9 |
| Min | 63 | 3 | 62 | 3 | 63 | 3.9 | 68 | 5 |
| Count | 22 | 22 | 27 | 27 | 34 | 34 | 23 | 23 |
| **Total** | | | | | | | | |
| Mean | 70.6 | 4.7 | 71.0 | 4.2 | 70.9 | 5.6 | 73.2 | 6.1 |
| Max | 80 | 6.8 | 78 | 5.4 | 77 | 7 | 79 | 7 |
| Min | 63 | 3 | 62 | 3 | 63 | 3.9 | 68 | 4.7 |
| Count | 65 | 65 | 78 | 78 | 110 | 110 | 58 | 58 |

The overall composition of the fish in the study groups and across the three years, 2014, 2015 and 2016, were very similar. It was observed that there was a slight decline in 2015 in body weight compared to 2014 and a slight increase in body weight in 2016 compared to 2014 (Table 2). It is interesting to note that in 2016 all the WFTS 40 Chinook came in the early part of the run from May-June 9$^{th}$ and all the WFTS 1100 Chinook came in the late part of the run June 10-July. The WFTS 1100 Chinook were on average slightly larger than the early run WFTS 40 2016 Chinook.

2015 has been referred to as a drought year, with excessive temperatures dominating a considerable length of time during the spring, summer and fall seasons. This temperature excess impacted water temperatures and resulted in an increase in adult mortality numbers across the board.

In all three years, the adult survival rate of the WFTS 40 transported fish group appeared to be slightly better than the hand carriage group (Table 3). The H&H 95% confidence limit was calculated to determine the significance of the WFTS 40 survival rate observation. The 95% confidence limit was calculated and included for the H&H group as it was the largest group and therefore provided the most data for a representative population sampling and correspondingly the tightest confidence limit interval. The 2014 and 2015 WFTS 40 survival rates were just above the H&H 95% confidence limit indicating a significant difference in survival rates. The 2016 data was distributed across three transport groups and the WFTS 40 and the WFTS 1100 survival rates fell within the H&H 95% confidence limit interval. Therefore, the WFTS 40, WFTS 1100 and

H&H survival rates are considered statistically similar (Table 3).

*Table 3. Adult Survival Rates in percentages of total Chinook regardless of origin: wild/natural, supplementation or hatchery. Any adult survival rate that falls within the 95% confidence limit is statistically indistinguishable from the H&H adult survival rate. Those that are above the 95% confidence limit are significant; statistically better than the H&H adult survival rate.*

**Adult Survival**

| Chinook | H&H | WFTS 40 | WFTS 1100 | H&H 95% Confidence Limit |
|---|---|---|---|---|
| 2014 | 90.3% | 93.8% | | (87.0%-93.0%) |
| 2015 | 72.5% | 76.9% | | (68.3%-76.5%) |
| 2016 | 84.9% | 85.7% | 81.80% | (81.2%-88.1%) |

For the CESRF program there were a predetermined number of surviving females that would be needed to produce the required number of progeny to support the hatchery program. Selected females and males underwent hatchery harvest and spawning. As the wild/natural stock constituted the majority of the sample set, the largest percentage of females harvested were of the wild/natural group followed by hatchery fish and supplemental fish. Whooshh transported fish made up 14.8% of the wild/natural subpopulation sample set in both 2014 and 2015. In 2016 WFTS 40 made up 22.3% and WFTS 1100 made up 8% of the wild/natural subpopulation sample set. In 2014 and 2015 the supplemental fish were not used in the spawning harvest. In 2016 15.1% of the production spawners were obtained from the supplemental population (Table 4). The distribution of production spawners in 2014 and 2015 were similar across the transport groups. In 2016 the distribution was spread across three transport groups and overall a higher percentage of WFTS 40 transported fish (22.9%) were used to contribute eggs to the hatchery efforts compared to the previous years (Table 5A).

The sample set distribution in Table 5B indicates the distribution of the sampled Chinook within a given year and how they were transported: WFTS 40, H&H or WFTS 1100. The selected transport group distribution of production spawners (Table 5A) roughly mirrors the sample set distribution (Table 5B). Because there was significant adult mortality across the study groups in 2015, the impact of the elevated temperatures, plus a few cases noted in the data in which fish were not tested or released back into the river, the percentage of production spawners shifted slightly from the sample set percentages, although the shift was not significant (Table 5A compared to 5B). The 2016 sample set and production spawner distributions were quite different than the previous years in that there were three transport groups with wild/natural, supplemental and hatchery fish selected for production spawning, however the 2016 production spawning distributions roughly reflect the overall 2016 sample set distribution.

*Table 4. Production Spawners (female)Populations: The wild/ natural, supplemental and hatchery spawner (female) counts and percentage of the total year spawner (female) populations are recorded. 2014 data in green, 2015 data in blue and 2016 in tan.*

**Production Spawners Populations**

| | Wild/Natural Count (Percent) | Supplemental Count (Percent) | Hatchery Count (Percent) | **Total Count (Percent)** |
|---|---|---|---|---|
| **2014** | 188 (86.6%) | | 29 (13.4%) | 217 (100%) |
| **2015** | 181 (89.2%) | | 22 (10.8%) | 203 (100%) |
| **2016** | 173 (70.6%) | 37 (15.1%) | 35 (14.3%) | 245 (100%) |

At harvest eggs and milt were collected and 3x3 crosses conducted. The fertilized eggs were treated as per hatchery protocol. After several months, the fertilized eggs underwent physical shock, sorting and counting. It was observed that, (as is consistently observed at CESRF) very high egg survival rates (>92%) were achieved across all groups and years (Table 6). The total number of WFTS 1100 eggs is a small number due to the sample size. Greater than 50% of the WFTS 1100 production spawners were from the Supplemental subpopulation and egg data for those was not reported and therefore not captured here. The viable egg percentage differences between the study groups are not significant. Nearly identical egg survival rates were reproducibly achieved across all groups and across the three years of study.

*Table 5. A. Spawner (female) Distribution Across Transport Groups: The transport group WFTS40, H&H and WFTS 1100 female spawner counts and percentages are recorded. B. Sample Set Distribution Across Transport Groups: Distribution of Chinook sampled at RAMF and transported to Cle Elum hatchery.*

**A. Spawner Distribution Across Transport Groups**

| | **2014 Spawners** | **2015 Spawners** | **2016 Spawners** |
|---|---|---|---|
| WFTS 40 | 34 (15.7%) | 26 (12.8%) | 56 (22.9%) |
| H&H | 183 (84.35) | 177 (87.2%) | 165 (67.3%) |
| WFTS 1100 | | | 24 (9.8%) |
| Total | 217 (100%) | 203 (100%) | 245 (100%) |

**B. Sample Set Distribution Across Transport Groups**

| | **2014 Sampled** | **2015 Sampled** | **2016 Sampled** |
|---|---|---|---|
| WFTS 40 | 65 (13.9%) | 78 (13.9%) | 110 (20%) |
| H&H | 403 (86.1%) | 484 (86.1%) | 382 (69.5%) |
| WFTS 1100 | | | 58 (10.5%) |
| Total | 468 (100%) | 562 (100%) | 550 (100%) |

*Table 6. Egg Viability. Total fertilized egg count and percent transport group distribution of the whole are captured in the top of the table for each transport group and year. Egg viability post shock counts and survival percentage of transport group total egg count are captured in the bottom of the table for each transport group and year. 2014 data in green, 2015 data in blue and 2016 in tan. * Egg count data was not available from YN for the Supplemental spawner group; all data below is the sum of Wild/Natural and Hatchery spawning egg counts.*

**Egg Viability***

| | 2014 Total Eggs | | 2015 Total Eggs | | 2016 Total Eggs | |
|---|---|---|---|---|---|---|
| WFTS 40 | 113886 | 14.5% | 93470 | 13.0% | 175912 | 23.8% |
| H&H | 669609 | 85.5% | 627129 | 87.0% | 523570 | 70.9% |
| WFTS 1100 | 0 | | 0 | | 38999 | 5.3% |
| Total | 783495 | | 720599 | | 738481 | |

| | 2014 Viable Eggs | | 2015 Viable Eggs | | 2016 Viable Eggs | |
|---|---|---|---|---|---|---|
| WFTS 40 | 105920 | 93.0% | 86767 | 92.8% | 163369 | 92.9% |
| H&H | 636500 | 95.1% | 593068 | 94.6% | 495064 | 94.6% |
| WFTS 1100 | 0 | | 0 | | 37743 | 96.8% |
| Total | 742420 | | 679835 | | 696176 | |

***Conclusions***

Three consecutive years of adult survival and egg viability data have been collected on the spring Chinook population of the Yakima River transported after treatment at RAMF. The fish were collected, sampled and transported to the hatchery associated with CESRF. Typically, the fish were hand-walked after measurements and tagging and deposited into a transport truck with an air exposure time of 15-20 seconds and risk of dropping. For this study a percentage of the sample set in all three years, 2104-2016, was transported through a 40 ft WFTS into the haul truck in less than 5 seconds. In 2014 and 2015 ~ 14% of the total sample set was transported through the 40 ft WFTS and the remaining hand walked. In 2016 20% of the total run sample set was transported through the 40 ft WFTS, 69.5% of the total sample set was hand-walked and the remaining 10.5% of the sample set was transported 1,100 ft up an incline of 100 ft and into the haul truck; a process that took ~35 seconds. The effects of transport, hand walked verses WFTS 40 or WFTS 1100, on adult survival and productive spawning and egg viability, were measured. The three year 2014-2016 data presented here demonstrates a definite positive trend in data reproducibility across years.

There were small characteristic differences observed in terms of forklengths and weights recorded between the spring Chinook runs of 2014, 2015 and 2016.The 2015 Chinook were considerably lighter likely due to the need to expend additional energy reserves surviving in the unseasonably warm waters of that year. The overall adult survival rates were largely influenced by the prevailing weather. 2015 was an exceptionally warm spring, summer and fall which resulted in considerably increased mortality rates. 2016 was a warm summer however not to the extreme of 2015 and 2014 was comparatively cool. Adult survival rates in 2015 ranged 72.5-76.9%, whereas survival rates were higher in 2016 (81.8-85.7%) and 2014 (90.3-93.8%). The 2014 and 2015 WFTS 40 adult survival rates were greater than the 95% confidence limit of the H&H group suggesting that WFTS 40 transport had a positive association with increased adult survival.

Productive spawning was achieved from H&H and WFTS transported Chinook. Transport did not impact the ability to spawn. In 2015, the excessive temperatures impacted all study groups at the level of adult survival. Mortality rates were elevated in all categories. Of those adults that survived to spawn regardless of the year evaluated, the temperature had no notable impact on the ability to spawn nor on the viability of the fertilized eggs. The total percentage of viable eggs reached by the YN was highly reproducible with 94.8% achieved in 2014, 94.3% achieved in 2015 and 94.3% achieved in 2016. There were no significant differences in egg viability between study groups; no transport associated effect on spawning potential or egg viability were found.

The data support the conclusion that 1) the means of transport may have a slight impact on adult survival with WFTS 40 potentially providing greater survival benefit than hand-walking and 2) the means of transport had no measurable impact on reproduction potential and egg viability.

The outcomes support the conclusion that the WFTS is a reliable, durable, viable alternative to the standard hand-walking transport method from the fish safety perspective and provides a reduced risk benefit to the fish of damage due to accidental dropping. From the fish handler perspective, the WFTS is easy to use, fast, may reduce potential fish injury, and adds a measure of safety for the fish handler. The WFTS 1100 provides additional evidence and support for the versatility and adaptability of the WFTS while maintaining safe, timely, efficient and effective fish passage. The results of this comprehensive comparative study strongly endorse the recommendation of use of the WFTS for safe transport of live fish.

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