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PNNL-22131

Performance Evaluation of Externally JSATS-Tagged Subyearling Chinook Salmon

Final Report

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Prepared for
the U.S. Army Corps of Engineers, Walla Walla District
Walla Walla, Washington
under Contract Number W912EF-08-D-0004

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Summary

Fish passing through hydro turbines are exposed to a rapid decrease in pressure that may lead to injuries referred to as barotrauma. Barotrauma includes injuries such as swim bladder rupture, exopthalmia (eye pop), emboli, and hemorrhaging. Recent research indicates that the presence of a telemetry tag implanted inside the coelom of a juvenile salmon could increase the likelihood that it will be injured or die when exposed to rapid decompression characteristic of turbine passage. The excess mass (the weight in water of an object) of an implanted tag has been shown to lead to an increased swim bladder volume. This increased volume of gas in the swim bladder leads to a higher likelihood that fish will be mortally injured during the rapid decompression. Thus, turbine passage survival estimates conducted using telemetry tags implanted into the coelom of fish may be inaccurate.

The Pacific Northwest National Laboratory (PNNL) developed an externally attached neutrally buoyant acoustic transmitter (based on a JSATS [Juvenile Salmon Acoustic Telemetry System] transmitter) for the U.S. Army Corps of Engineers (USACE) to be used to accurately estimate turbine passage survival. The external attachment and neutral buoyancy of the tag eliminates added mass and organ crowding associated with internally implanted tags. Extensive laboratory research indicated that the external tag could be a valuable tool for estimating survival of turbine passed fish. Following laboratory testing, the USACE, Walla Walla District, contracted Battelle–Pacific Northwest Division (Battelle) to perform a field evaluation of the external tag's performance. Field testing was conducted to verify that under riverine conditions the presence of the external transmitter would not reduce survival due to high predation rates and would demonstrate detection efficiency and tag retention similar to that of internally implanted acoustic transmitters.

To determine how use of the external tag would influence seaward-migrating juvenile salmon under field conditions, survival estimates and travel times were compared between externally and internally JSATS tagged hatchery-reared subyearling Chinook salmon *Oncorhynchus tshawytscha*. Fish with both tag types were released in the tailrace of Ice Harbor Dam and approximately half of the fish from both tag groups were exposed to simulated turbine passage (STP) prior to release. Exposures to STP were conducted to replicate the likely mild pressure change scenarios expected to be present in newly designed turbines intended to replace existing turbines at Ice Harbor Dam. Survival and travel time to a detection array near the mouth of the Snake River (Burbank array; 12 km below Ice Harbor Dam) and the forebay of McNary Dam were compared. These river reaches provided a high predation area to test the hypothesis that external tags would lead to higher predation relative to internal tags.

In addition to the above comparisons of survival and travel time, a separate group of fish was tagged with dummy neutrally buoyant external tags and internally injected with passive integrated transponder (PIT) tags. These fish were released in the Ice Harbor Dam forebay and recaptured at the McNary Dam juvenile bypass facility following PIT detection, where they were examined for tag retention and tissue response. A high occurrence of tag loss or major injury due to the presence of an external tag would also bias survival estimates and would consequently compromise any benefit of eliminating bias due to the tag burden present in internally tagged fish.

Survival to Burbank Array

There were no significant differences in survival (mean [%] ± standard error [SE]) estimates to the array at the mouth of the Snake River near Burbank (internal-unexposed: 93.0 ± 1.6; external-unexposed: 90.5 ± 1.9; internal-exposed: 87.2 ± 2.4; external-exposed: 86.1 ± 2.3). Thus, no effect of either tag type or exposure to STP was observed. Despite the high level of predation in this study reach, the survival of externally tagged fish was not different from that of internally implanted fish. This finding indicates that the external transmitter is a viable option for examining turbine survival, even in areas with high predation levels.

Although there were no differences in survival due to tag type among fish exposed to STP, we predicted that survival would be higher for externally tagged fish than for internally tagged fish. The limited sample sizes that were used in this pilot-scale effort may have compromised our ability to detect a significant difference if one did exist. In addition, the target pressure changes of the experiments were relatively mild, which, combined with small sample sizes, may have made identifying differences in survival difficult.

Tag Retention to McNary Dam

Of the external dummy tagged fish recovered by the McNary Dam separation-by-code system (SbyC), 10% were recovered without their external transmitters attached. These fish were recovered between 9 and 17 d after release. These results along with those of laboratory studies (1 fish lost its tag 13 d after attachment) suggest that any analysis or results relying on external transmitter detections after about 9 d post-tagging may be compromised and negatively biased due to tag loss.

Survival to McNary Dam Forebay Array

Survival estimates to the array in the McNary Dam forebay were considerably lower than to Burbank. There were also significant differences among groups, characterized by effects of tag type and STP. Probability of survival (mean [%] ± SE) to the McNary forebay array was higher for internally tagged fish than for externally tagged fish (internal-unexposed: 72.1 ± 2.9; external unexposed: 55.6 ± 3.2; internal exposed: 66.8 ± 3.4; external exposed: 48.2 ± 3.3). Survival estimates from Ice Harbor to the McNary Dam forebay suggest that survival is considerably lower for externally tagged fish than for internally tagged fish. However, it was clear from the loss of external tags among fish recaptured in the McNary Dam SbyC, that tag retention compromised results of survival estimates to the forebay of McNary Dam. Thus, comparisons of survival between internally and externally tagged fish likely do not reflect true survival or provide insight on possible susceptibility to predation in the reach between the mouth of the Snake River and McNary Dam.

Travel Time

Travel times of subyearling Chinook salmon migrating through the lower Snake River and McNary pool were highly variable and much slower than those observed by a concurrent study. Within this reach, travel time of seaward-migrating run-of-river (ROR) subyearling Chinook salmon implanted with JSATS tags was nearly three times faster than mean travel times for the hatchery-reared fish examined for this study. Travel times to both the Burbank and McNary Dam forebay were significantly different. Differences between the groups were significant, with an effect of tag type but not STP exposure. To

Burbank, although travel times were statistically different, there is likely no biological significance because median travel times for all treatment groups were approximately 0.2 d. Conversely, there were large differences in travel times to the forebay of McNary Dam, where travel time estimates of internally tagged fish were much slower than those of externally tagged fish. These differences could be driven by the loss of external tags because migrating fish with lost tags would not be detected, leaving only detections of fish arriving to the array before tag loss occurred. Therefore, travel time estimates of externally tagged fish to McNary Dam forebay may not be accurate.

Conclusions

Several years of laboratory research indicate that given the tag burden of internally tagged fish traveling through turbines, survival estimates for this route of passage may be biased; survival may possibly be higher than estimated. This study, in combination with laboratory work, suggests that the use of a neutrally buoyant externally attached tag may alleviate this bias in short-term (≤9-d) survival studies. The USACE plans to replace aging turbines in dams throughout the Columbia River basin with turbines designed for safer fish passage. An existing turbine at Ice Harbor Dam is scheduled to be the first replaced with a new turbine design. This new tagging technology would be appropriate to use when only turbine-passage survival is of interest, such as when comparing older turbines to their replacements. Without accurate knowledge of baseline turbine survival, determining the benefits of new turbine designs may not be possible.

We recommend further research using a smaller external transmitter and ROR fish (unlike the hatchery-sourced fish used for this research). Research is currently under way at PNNL to produce a smaller JSATS transmitter than was used as the base for the external transmitters tested in this research. This could reduce the volume of the external transmitter by approximately 40%. Part of this volume reduction could be attained by using a smaller battery with a reduced life (7–10 d). In addition, because the use of hatchery-reared fish for this effort compromised longer-term survival and travel time estimates, use of ROR fish would provide a more robust ability to examine turbine-passed fish between Ice Harbor Dam and McNary Dam, improving upon this initial pilot-scale effort.

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Acronyms and Abbreviations

Battelle	Battelle–Pacific Northwest Division
°C	degree(s) Celsius or centigrade
CJS model	Cormack–Jolly–Seber single-release model
cm^3	cubic centimeter(s)
d	day(s)
EXT-EXP	externally attached tag-exposed to simulated turbine passage
EXT-UNX	externally attached tag-unexposed to simulated turbine passage
FCRPS	Federal Columbia River Power System
FL	fork length
ft	foot, feet
g	gram(s)
gpm	gallon(s) per minute
h	hour(s)
in.	inch(es)
INT-EXP	internally attached tag-exposed to simulated turbine passage
INT-UNX	internally attached tag-unexposed to simulated turbine passage
JFF	juvenile fish facility
JSATS	Juvenile Salmon Acoustic Telemetry System
km	kilometer(s)
L	liter(s)
ln	natural log-transformation
LRP	natural log of the ratio (acclimation pressure/exposure [nadir] pressure) of pressure change
M	meter(s)
MABL	Mobile Aquatic Barotrauma Laboratory
mg	milligram(s)
mg/L	milligrams(s) per liter
min	minute(s)
mL	milliliter(s)
mm	millimeter(s)
MS-222	tricaine methanesulfonate
nadir	the lowest pressures fish experience when passing a turbine
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
psia	pounds per square inch-absolute
RKM	river kilometer(s)

ROR	run-of-river
RPC	ratio of pressure change
s	second(s)
SbyC	separation-by-code system
SE	standard error
SMP	smolt monitoring program
STP	simulated turbine passage
U_{crit}	critical swimming speed
USACE	U.S. Army Corps of Engineers

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1.0 Introduction

Survival of juvenile salmonids passing through hydroturbines can vary depending on several factors. The stresses experienced by fish when passing through turbines vary depending on the type of turbine, the ways in which turbines are operated, the route the fish take when passing through the turbine, the discharge rate, and the head differential (forebay and tailrace elevation differential; Deng et al. 2007, 2010). Regardless of these variable factors, all turbine-passed fish are exposed to a rapid decrease in pressure. These rapid decreases in pressure result in injuries such as swim bladder rupture, exophthalmia, and emboli and hemorrhaging in the fins and tissues (Brown et al. 2009, 2012b, 2012d). These types of injuries are known as barotrauma.

Researchers typically use implanted telemetry tags (e.g., acoustic, radio, inductive) as a tool to track movements and estimate survival of fish following turbine passage. However, recent research indicates that the presence of a telemetry tag implanted inside the coelom of a juvenile salmon could increase the likelihood that it will be injured or die when exposed to rapid decompression characteristic of turbine passage (Carlson et al. 2012). Using experimental pressure scenarios that simulate turbine passage, Carlson et al. (2012) determined that the probability of mortal injury (mortality or injury highly associated with mortality) varies with the fish's tag burden (i.e., the weight of a transmitter relative to the weight of a fish). Fish implanted with larger transmitters, or having a higher tag burden, have a higher probability of mortal injury that increases with the ratio of pressure change (RPC), the ratio of acclimation pressure to the lowest exposure pressure. Acclimation pressure represents the pressure (or depth equivalent) where fish are neutrally buoyant upstream approaching the hydroturbine. The lowest exposure pressure fish experience when passing a hydroturbine is typically called the nadir.

Among fish bearing transmitters, the excess mass (the weight in water of an object) of an implanted tag has been shown to lead to an increased swim bladder volume; that is, they increase their displacement to balance the increased mass (Gallepp and Magnuson 1972). This increased volume of gas in the swim bladder leads to a higher likelihood that fish will be mortally injured during the rapid decompression associated with turbine passage (Stephenson et al. 2010). In addition, the volume of the transmitter present in the coelom likely leads to a higher incidence of barotrauma when fish are rapidly decompressed. The swim bladder may be more likely to rupture, and there may be a higher likelihood of compression-related injuries (such as damage to internal organs or vasculature caused by the increased size of the swim bladder). Both the expansion and rupture of the swim bladder appear to be the main causes of barotrauma in fish (Brown et al. 2012d).

Thus, turbine passage survival estimates conducted using telemetry tags implanted into the coelom of fish may be inaccurate. Accurate and precise assessments of turbine survival are critical for evaluating turbine operations, dam passage survival, and for assessment prior to and after turbine replacement, to determine the effect of operation and design on survival. This is especially important because a large proportion of the existing turbines in the Columbia River basin are nearing the end of their functional lifespan and need replacement. A new tool was developed to provide unbiased estimates of survival for turbine-passed fish. Deng et al. (2012) developed a neutrally buoyant externally attached acoustic transmitter (based on the Juvenile Salmon Acoustic Telemetry System [JSATS; McMichael et al. 2010]) to eliminate pressure related bias in turbine survival estimates. This neutrally buoyant externally attached acoustic transmitter should reduce bias in survival studies since it eliminates additional mass and occupied space within the coelom, and thus has an effective tag burden of zero.

The above-mentioned research suggests that this neutrally buoyant externally attached transmitter could improve the ability to accurately estimate survival of turbine-passed fish. Considerable laboratory testing of the efficacy of a neutrally buoyant externally attached transmitter indicates that the manufacturing process does not affect the acoustic properties of the transmitter (Deng et al. 2012) and that the presence of the tag does not affect fish performance compared to untagged individuals. For example, compared to untagged fish, there were no differences in growth or mortality over a 14-d holding period, or in predator avoidance (Deng et al. 2012; Janak et al. 2012). When evaluating swimming performance, fish tagged with the neutrally buoyant external transmitters had a lower critical swimming speed (U_{crit}) than untagged individuals. However, when compared to fish internally implanted with an acoustic transmitter and a passive integrated transponder (PIT) tag (a combined mass of 0.53 g), there was no difference in U_{crit} (Janak et al. 2012). Further, no mortalities or tag loss were observed during exposure to shear forces (Deng et al. 2012) and the presence of the tag did not increase the fish's susceptibility to barotrauma compared to untagged fish (Brown et al. 2012c). A field-based comparison of survival and behavior among fish tagged with a neutrally buoyant external transmitter and those implanted internally with JSATS transmitters was needed to ensure that under field conditions, the presence of an external transmitter will not reduce survival. If in-river predation is elevated due to the presence of an external transmitter or the transmitter is not retained, any reduction in barotrauma related survival bias could be offset by biases specific to the external tag.

To determine if the neutrally buoyant externally attached transmitter would be an effective tool for estimating turbine passage survival, survival and travel time were compared between externally and internally tagged fish. Fish of both tag types were released in the tailrace of Ice Harbor Dam and examined while migrating downstream to detection arrays at the mouth of the Snake River (at Burbank) and at the forebay of McNary Dam for differences in survival and travel time. Among these fish, we hypothesized that tag type would not influence survival or travel time.

A comparison was also made between internally and externally tagged fish following simulated turbine passage (STP). Thus, prior to release, half of the fish from each tag-type were exposed to STP. As there is no tag burden associated with the external tag, we hypothesized that tag type would influence survival probability and predicted that survival would be higher in externally tagged fish compared to those internally implanted with a JSATS tag if they were exposed to STP.

In addition to the above comparisons of survival and travel time, a separate group of fish was tagged with dummy neutrally buoyant external tags and internally injected with PIT tags. These fish were released in the Ice Harbor Dam forebay and recaptured at the McNary Dam juvenile bypass facility following PIT detection where they were examined for tag retention and injury. A high occurrence of tag loss or major injury due to the presence of an external tag would also bias survival estimates and would consequently compromise any benefit of eliminating bias due to the tag burden present in internally tagged fish.

2.0 Methods

2.1 Fish Acquisition and Holding

Subyearling fall Chinook salmon *Oncorhynchus tshawytscha* were obtained from Lyon's Ferry Fish Hatchery and transported to Lower Monumental Dam on May 29, 2012. Subyearling fish were used as they are the smallest class of out-migrating juvenile salmonids and thus represent the class of fish that is most likely to be susceptible to the negative effects of tag presence. During the study period, all fish were held at the juvenile fish facility (JFF) of Lower Monumental Dam in three 650-L circular tanks and were supplied with 13.9–17.7°C flow-through river water. Fish were fed an ad libitum ration of 1.5-mm Bio Vita Fry (Bio-Oregon, Longview, Washington) every second day. Fish selected for tagging were restricted from feeding for 24 h prior to tagging.

2.2 Surgery

During surgery, an 80-mg/L solution of tricaine methanesulfonate (MS-222) buffered with an 80-mg/L solution of sodium bicarbonate was used to anesthetize the fish until they reached stage 4 anesthesia (as described by Summerfelt and Smith 1990). The fork length (FL; mm) and mass (g) of each fish were measured before being randomly assigned to a treatment. There were four treatments: internally tagged and exposed to STP (INT-EXP; n = 244), internally tagged and not exposed to STP (INT-UNX; n = 244), externally tagged and exposed to STP (EXT-EXP; n = 244) and externally tagged and unexposed (EXT-UNX; n = 243; Figure 2.1).

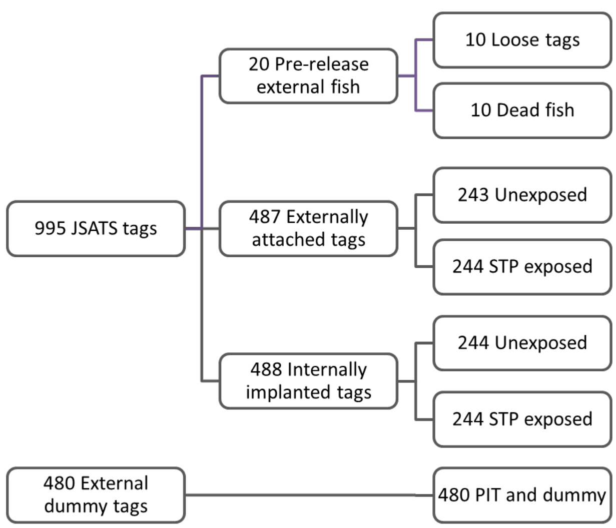

Figure 2.1. Experimental design for the field evaluation of a neutrally buoyant externally attached tag. Subyearling Chinook salmon were tagged with JSATS tags and released (n = 975 plus 20 pre-release tags) into the Snake River, Washington. There were two tagging groups (internally implanted vs. externally attached); within each tag type, fish were either exposed to simulated turbine passage (STP) or released without exposure. An additional 480 fish were affixed with dummy external tags and injected with a PIT tag. These fish were recovered downstream at McNary Dam following PIT detection using the separation-by-code system and examined for tag retention and injury due to the presence of the external tag.

For external attachment of tags, fish were placed on a foam rubber pad and were oriented dorsal side up (for detailed methods, see Deng et al. 2012). Neutrally buoyant externally attached acoustic transmitters were attached to the dorsal musculature anterior to the dorsal fin and secured by two sutures (Monocryl 5-0 absorbable monofilament) using 2 × 2 × 2 × 2 reinforced square knots (similar to Deters et al. 2012). The sutures rested in two grooves on the top of the transmitter. For internal implantation of tags, fish were placed ventral side up on a foam rubber pad. Internal transmitters were surgically implanted by making a 5- to 6-mm incision on the linea alba, inserting a JSATS tag, and closing the incision with two simple interrupted sutures (Monocryl 5-0 absorbable monofilament) using 1 × 1 × 1 × 1 reinforced square knots (similar to Panther et al. 2011; Deters et al. 2012). A small tube was inserted into the fish's mouth during tagging to provide a constant maintenance flow of 40-mg/L MS-222 buffered with a 40-mg/L solution of sodium bicarbonate. When tagging was completed, researchers placed the fish in 20-L perforated buckets. Once a bucket contained 10 tagged fish, it was transferred to a 680-L Bonar double-wall insulated box with flow-through water.

External and internal tagging occurred simultaneously, and fish were assigned with alternating tag-types. One surgeon performed all external surgeries to eliminate a surgeon bias (Deters et al. 2012). However, because internal implantation of a transmitter takes more time than externally attaching tags (see Deng et al. 2012 for examples of tagging time differences), two surgeons were required in one tagging session for internal implantation of tags. Surgeons worked in teams of two while alternating days; thus, four expert surgeons conducted internal surgeries due to the large number of fish to be tagged each day. Transmitters used for surgical implantation were the JSATS micro transmitters designed by Advanced Telemetry Systems (Isanti, Minnesota; third-generation 2012 model). Internal transmitters were 10.79 mm long, 5.26 mm wide, and 3.44 mm thick and weighed 304 mg in air and 186 mg in water. External tags (type A; Figure 2.2) were comprised of the same JSATS transmitter that was used for the internally tagged fish but were encased in a positively buoyant substance to make them slightly negatively buoyant. The external tags were manufactured using the protocols described in Deng et al. (2012) except that this study used an epoxy mixture density of 0.72 g/cm^3 instead of the 0.68 g/cm^3 density used by Deng et al. (2012), resulting in a wet weight of 28 mg for the external tags in this study. Both internal and external tags had a single model 337 battery that pulsed every 3 s, yielding a tag life of approximately 24 d.

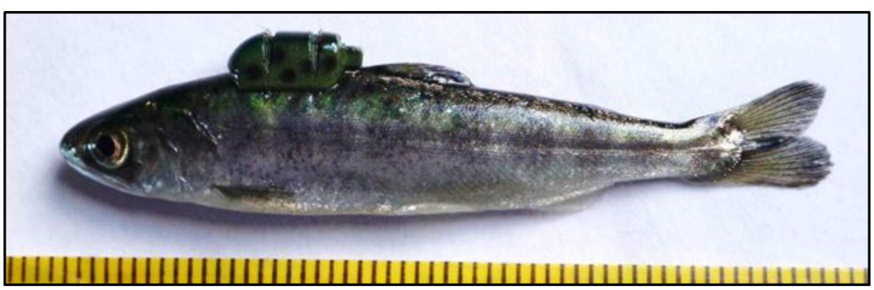

Figure 2.2. A juvenile Chinook salmon with an externally attached neutrally buoyant acoustic transmitter.

Fish were tagged over 13 d from June 10 through 25, 2012. On the first 12 tagging days, 80 fish were tagged per day. Each bucket contained 5 fish with external tags and 5 fish internally implanted with a JSATS tag. Each day, half (n = 4) of the buckets were exposed to STP and the other half were not. On the last day of tagging (June 25), only 30 fish were tagged. Two buckets of 10 fish were exposed to STP while one was not. These fish were released to account for mortalities or fish that had to be excluded (see Section 2.3).

2.3 Exposures and Releases

Prior to beginning the study, 10 dead fish with active external tags and 10 unattached active external tags were released in the tailrace of Ice Harbor Dam. These releases were done to ensure that if a fish died or lost a tag, a detection would not occur at the first array 12 river kilometers (RKM) downstream (Burbank) of Ice Harbor Dam. Because none of the tag codes from these initial releases were detected downstream, the study continued as planned. For the survival and behavior aspects of this study, 975 hatchery juvenile Chinook salmon were tagged and released. Only fish 95 mm or greater were tagged; thus, fish size ranged from 95 to 122 mm fork length (FL; mean ± standard error [SE] = 101.3 ± 0.1 mm) and weighed 4.6 to 18.4 g (mean ± SE = 10.1 ± 0.06 g). Fish size is noteworthy because the study fish were considerably smaller than run-of-river (ROR) fish collected by smolt monitoring programs (SMPs). For example, taggable fish (i.e., ≥ 95 mm FL) collected by the Lower Monumental SMP ranged from 95 to 142 mm FL (mean ± SE = 106.7 ± 0.2 mm; Figure 2.3).

Immediately upon completion of tagging, fish were transported to Ice Harbor Dam by truck in an aerated 680-L Bonar double-wall insulated transport tank. Buckets containing fish that were not going to be exposed to STP were held at the Ice Harbor Dam JFF in one of two 650-L circular tanks with flow-through river water overnight prior to release. The four buckets containing fish designated for exposure to STP were placed into separate hyper/hypobaric chambers in the Mobile Aquatic Barotrauma Laboratory (MABL; detailed in Stephenson et al. 2010) immediately after transport from Lower Monumental Dam.

In preparation for STP, all fish were acclimated to a pressure of 21.2 psia (simulating a depth of 15 ft) with 2 gpm of flow through river water for approximately 16 hours. An air pocket was maintained at the top of the chambers to allow fish to gulp and fill their swim bladders in order to attain neutral buoyancy. Over the season, water that flowed through the test chambers ranged from 14.0 to 16.8°C (mean = 15.2°C) and total dissolved gas levels ranged from 102% to 107% (mean = 105%).

After the acclimation period, each fish was visually assessed to determine if it had achieved neutral buoyancy (using methods described by Stephenson et al. 2010). Any fish that was negatively buoyant following the acclimation period would have a higher probability of survival and thus was excluded from analyses (similar to Brown et al. 2012b and Carlson et al. 2012). Fish were exposed to pressure scenarios with nadir pressures ranging from 5.4 to 14.9 psia (mean ± SE = 11.3 ± 0.09; Table 2.1; Figure 2.4). Given the acclimation depth of 21.2 psia used in this study, this translates to a RPC ranging from 1.4 to 3.9 (mean ± SE = 1.9 ± 0.02; LRP [natural log of the ratio of pressure change] range from 0.35 to 1.36; mean of 0.66). Pressure exposures were designed to simulate the entire pressure scenario that a fish passing through the turbines would experience at a hydropower facility; from the pressurization associated with the intake, rapid decompression occurring at the turbine blades, and subsequent return to atmospheric pressure in the tailrace (Stephenson et al. 2010). Target nadir pressures were 10.5 to 12.8 psia (mean of 11.6 psia) and were determined based on expected nadirs of the new replacement turbines to be installed at Ice Harbor Dam.

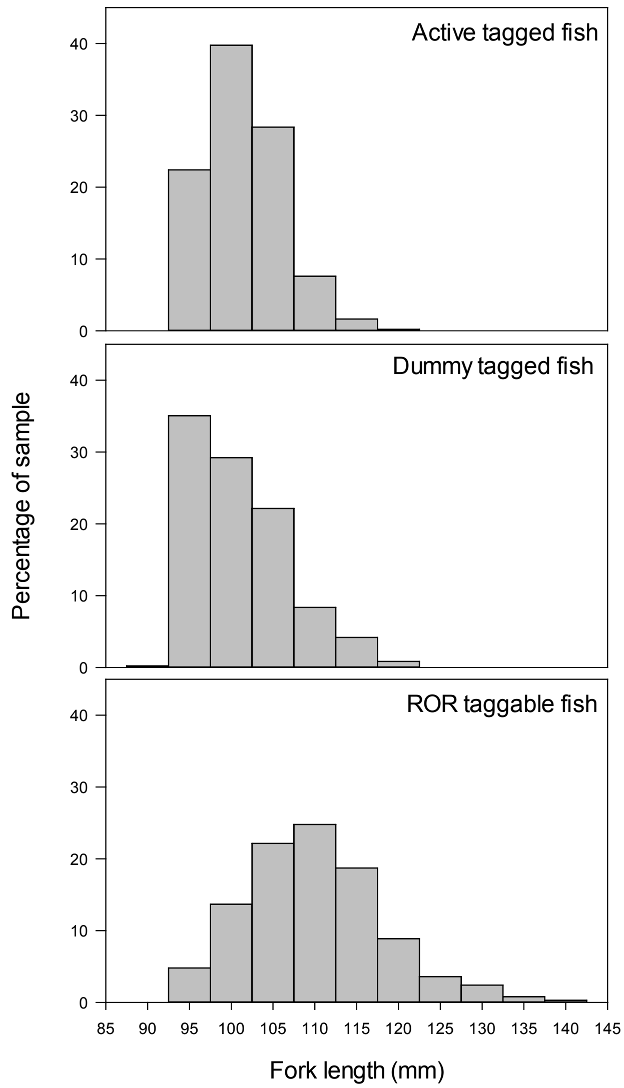

Figure 2.3. Comparison of size distributions of subyearling Chinook salmon tagged during this research and those sampled at the Lower Monumental Dam smolt monitoring system. Two panels show the size frequency distributions of fish tagged with active (top) and dummy (middle) tags for this study that were obtained from the Lyon's Ferry Fish Hatchery. The bottom panel shows run-of-river (ROR) fish sampled at the Lower Monumental Dam smolt monitoring system throughout the season and contains a mix of hatchery and wild origin fish.

Immediately prior to release, all buckets (each containing 10 fish; four buckets exposed to STP and four buckets not exposed to STP) were checked to ensure all transmitters were operational and all codes were assigned to the appropriate bucket. Buckets were then placed in the transport tote and transported from the JFF to the powerhouse tailrace at Ice Harbor Dam (approximately 5 min). After an examination for any overnight mortalities of unexposed fish, all fish were released into the tailrace through a PVC flex hose (40 ft long and 2 in. in diameter) with an attached receiver funnel comprised of PVC reducing couplers from 12 in. to 2 in. Fish were released in front of unit 1 in the powerhouse tailrace. Depending on operations of this unit at the time of release, the location was changed slightly to ensure fish were able to proceed in an outward direction downstream away from the powerhouse. The two different release locations were used depending on the flow patterns, to reduce the possibility of fish becoming entrained in a backroll (Figure 2.5).

Table 2.1. The number of juvenile Chinook salmon that were exposed to simulated turbine passage during June 2012. The number of fish that were neutrally buoyant is shown as well as the lowest pressures (nadir) to which fish were exposed and the ratio of pressure change (the acclimation pressure, 21.2 psia, divided by the nadir pressure).

Exposure Date	Test #	*N* External	*N* internal	*N* external neutrally buoyant	*N* Internal neutrally buoyant	Nadir	Ratio pressure change
6/11/12	1	5	5	5	5	11.09	1.91
6/11/12	2	5	5	5	4	11.82	1.79
6/11/12	3	5	5	5	5	9.77	2.16
6/11/12	4	5	5	5	5	13.43	1.57
6/13/12	5	5	5	4	4	14.9	1.42
6/13/12	6	5	5	5	3	13.14	1.61
6/13/12	7	5	5	4	4	9.82	2.15
6/13/12	8	5	5	5	4	5.42	3.90
6/14/12	9	4	5	4	4	11.23	1.88
6/14/12	10	5	5	5	4	11.18	1.89
6/14/12	11	5	5	4	3	10.6	2.00
6/14/12	12	5	4	4	4	13.33	1.59
6/15/12	13	5	5	5	5	11.58	1.83
6/15/12	14	5	5	5	4	11.62	1.82
6/15/12	15	5	5	5	5	10.6	2.00
6/15/12	16	5	5	5	5	11.14	1.90
6/17/12	18	5	5	5	3	11.18	1.89
6/17/12	19	5	5	5	4	10.6	2.00
6/17/12	20	5	5	5	2	8.11	2.61
6/18/12	21	5	5	5	3	14.46	1.46
6/18/12	22	5	5	5	5	11.09	1.91
6/18/12	23	5	5	5	4	12.26	1.73
6/18/12	24	5	5	5	5	11.48	1.84
6/19/12	25	5	5	5	5	7.47	2.83
6/19/12	26	5	5	5	4	14.07	1.50
6/19/12	27	5	5	5	4	10.94	1.93
6/19/12	28	5	5	5	5	10.5	2.01
6/20/12	29	5	5	5	5	7.96	2.66
6/20/12	30	5	5	5	3	10.65	1.99
6/20/12	31	5	5	5	4	12.89	1.64
6/20/12	32	5	5	5	4	8.69	2.43
6/21/12	33	5	5	0	0	9.23	2.29
6/21/12	34	5	5	5	4	11.09	1.91
6/21/12	35	5	5	5	5	11.14	1.90
6/21/12	36	5	5	5	4	7.77	2.72
6/22/12	37	5	5	5	5	10.45	2.02
6/22/12	38	5	5	5	5	11.53	1.83
6/22/12	39	5	5	5	4	11.77	1.80
6/22/12	40	5	5	5	5	11.28	1.88
6/23/12	41	5	5	4	3	13.43	1.57
6/23/12	42	5	5	5	5	13.28	1.59
6/23/12	43	5	5	5	3	12.7	1.67
6/23/12	44	5	5	5	5	14.51	1.46
6/24/12	45	5	5	5	5	11.62	1.82
6/24/12	46	5	5	5	3	12.41	1.70
6/24/12	47	5	5	4	4	11.28	1.88
6/24/12	48	5	5	5	5	13.97	1.51
6/26/12	49	5	5	5	0	12.21	1.73
6/26/12	50	5	5	4	1	12.45	1.70

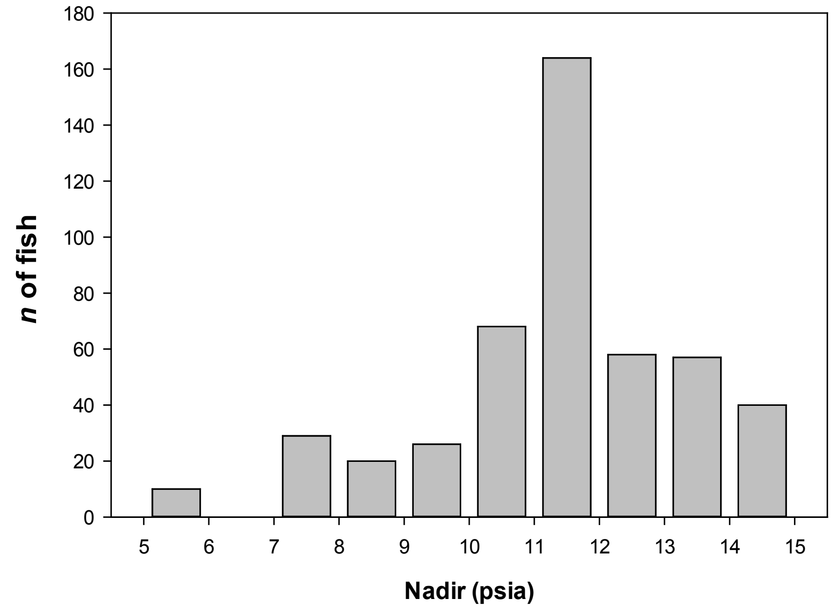

Figure 2.4. Frequency distribution of the lowest (nadir) pressures to which subyearling Chinook salmon were exposed during simulated turbine passage in June 2012 prior to release in the tailrace of Ice Harbor Dam.

2.4 Acoustic Telemetry Receivers

Acoustic transmissions from tagged fish were detected and decoded by JSATS autonomous receivers (Model N201; Sonic Concepts, Inc., Bothell, Washington), which were deployed using the methods described by Titzler et al. (2010). Receivers were deployed in lines (referred to as "arrays") that ran approximately perpendicular to shore. Arrays were located near the confluence of the Snake and Columbia rivers (12 RKM from Ice Harbor Dam; Columbia River RKM 525; called the Burbank array), in the forebay of McNary Dam (Columbia River RKM 472) and at Crow Butte (Columbia River RKM 422; Figure 2.6). McNary Dam also had a cabled array and a tailrace array (Columbia River RKM 470 and RKM 468, respectively) but these were not used for survival analysis due to the concern of not knowing how far dead fish with retained transmitters can float downstream.

2.5 Evaluation of Retention of the External Transmitter

To evaluate the retention of the external transmitters, an additional 480 juvenile Chinook salmon were tagged with PIT tags and dummy external transmitters on June 28 and 29, 2012. Although the size cutoff for this study was 95 mm, the fish obtained from the hatchery were of such a small size that after tagging all the fish for the survival study, the size cutoff had to be reduced to 92 mm in order to have enough fish for the tag retention task (Figure 2.3). Fish used ranged from 92 to 122 mm in fork length (mean ± SE = 100.9 ± 0.3 mm) and weighed 6.4 to 20.5 g (mean ± SE = 10.7 ± 0.1 g). Fish were tagged with an externally attached neutrally buoyant dummy transmitter and an internally injected PIT tag (Destron Technologies, St. Paul, Minnesota). The coating material, dimensions and weight of the dummy tags were the same as the functional external tags. PIT tags were 12.5 × 2.1 mm and 0.10 g in air, 0.06 g in water, and had a volume of 0.04 mL.

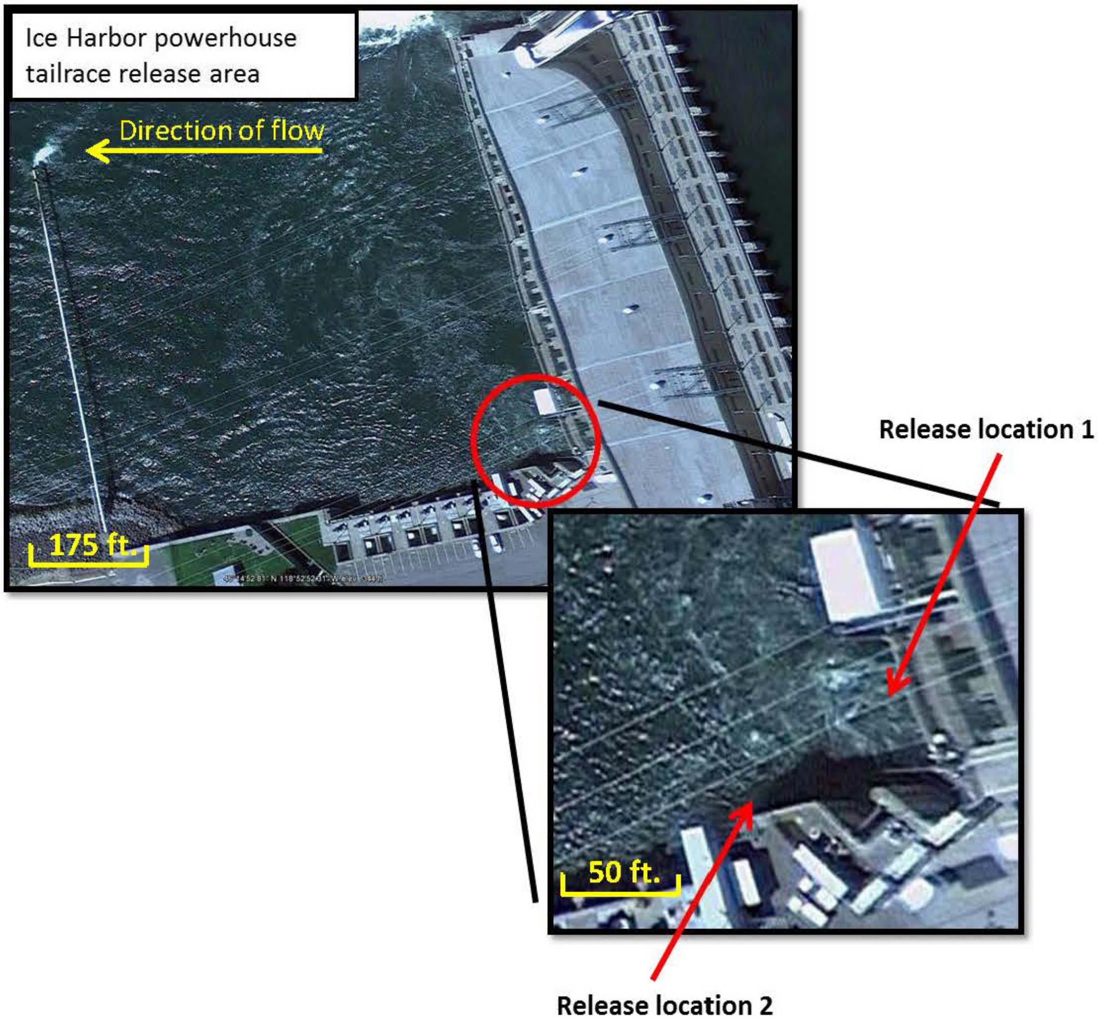

Figure 2.5. Overhead image of the Ice Harbor Dam tailrace release locations for all JSATS-tagged subyearling Chinook salmon. Depending on flows resulting from powerhouse operation, two different release locations were used to ensure fish were released in current most likely to take them downstream out of the tailrace. Release locations were less than 100 ft. apart.

Surgical methods (e.g., anesthesia time, equipment, attachment methods) were the same as for the survival study, and surgeries were conducted by the same surgeon. All PIT tagging occurred prior to affixing the external dummy tag and was completed by one tagger. PIT tags were implanted using a 12-gauge hypodermic needle and syringe just posterior to where the tip of the pectoral fin lies against the body and slightly dorsal of the linea alba. The needle was inserted at an angle of about 30° pointing toward the posterior of the fish. PIT tags were used so that fish could be later detected by the separation-by-code system (SbyC) at the McNary Dam JFF for examination. Similar to the survival study, fish were placed in buckets for surgery, recovery, and transport. Fifteen fish were placed in each bucket due to the large number of fish needing to be transported at once.

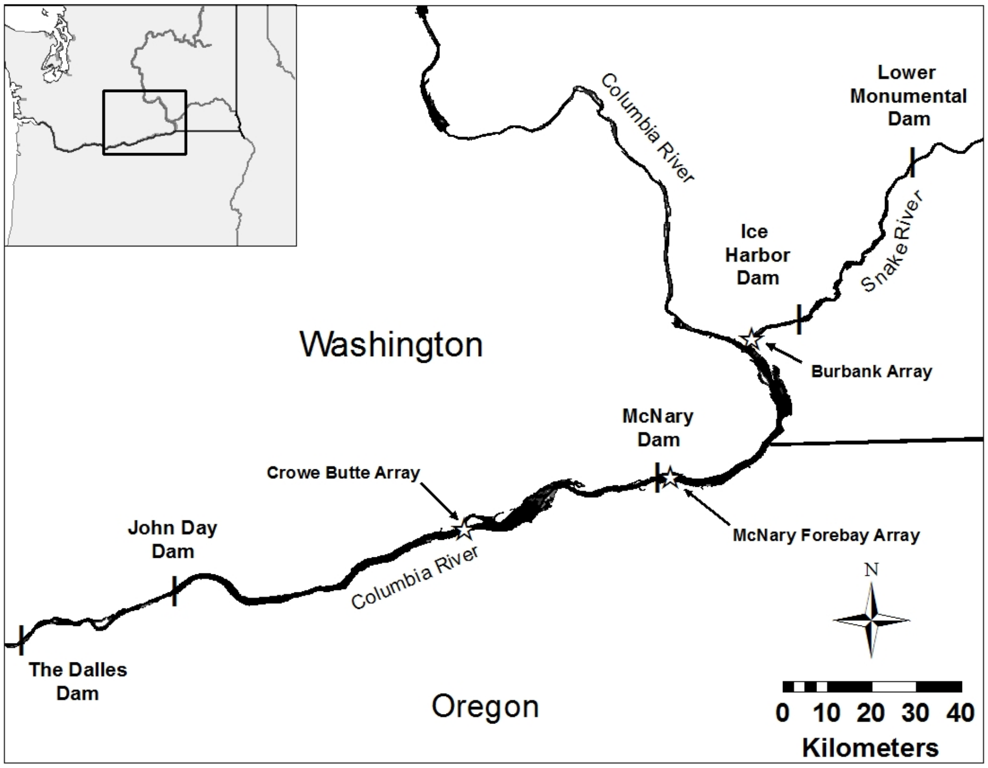

Figure 2.6. Eight locks and dams located on the Columbia and Snake rivers. Fish were tagged at Lower Monumental Dam and released in either the tailrace or the forebay of Ice Harbor Dam. Dummy tagged fish were recaptured using the separation-by-code system at the McNary Dam juvenile fish facility.

After surgery, buckets were placed in 650-L circular tanks with flow-through river water (eight buckets per tank) for 16–24 h at Lower Monumental Dam. After this recovery period, buckets were transported to the Ice Harbor Dam forebay boat launch in the North Shore Recreation Area by truck in the same way as the survival study fish. Buckets were then loaded into a boat and transported to the forebay of Ice Harbor Dam where the fish were released approximately 500 m upstream of the dam (Figure 2.7) in two groups of 240 fish on June 29 and 30, 2012. Fish were released upstream of Ice Harbor Dam to allow for dam passage prior to recapture and evaluation. Including dam passage in the tag retention evaluation exposed fish to environmental conditions that externally tagged fish may experience during a turbine passage survival study.

Fish that entered the juvenile fish facility at McNary Dam (Figure 2.8) were collected on odd-numbered days July 1 through August 15, 2012, using the SbyC. All fish that entered the bypass were detected, but because fish collection at McNary Dam occurs only every second day, not all detected fish were routed into examination tanks. Fish detected on collection days were routed to a holding tank (Figure 2.8D) and examined the following day. Fish were evaluated on six criteria—presence of the external tag; whether sutures were loose, untied, or lost; the extent of tissue tearing (measured in millimeters); tag indentation; percentage of tissue laceration; and percentage of discoloration, similar to Deng et al. (2012).

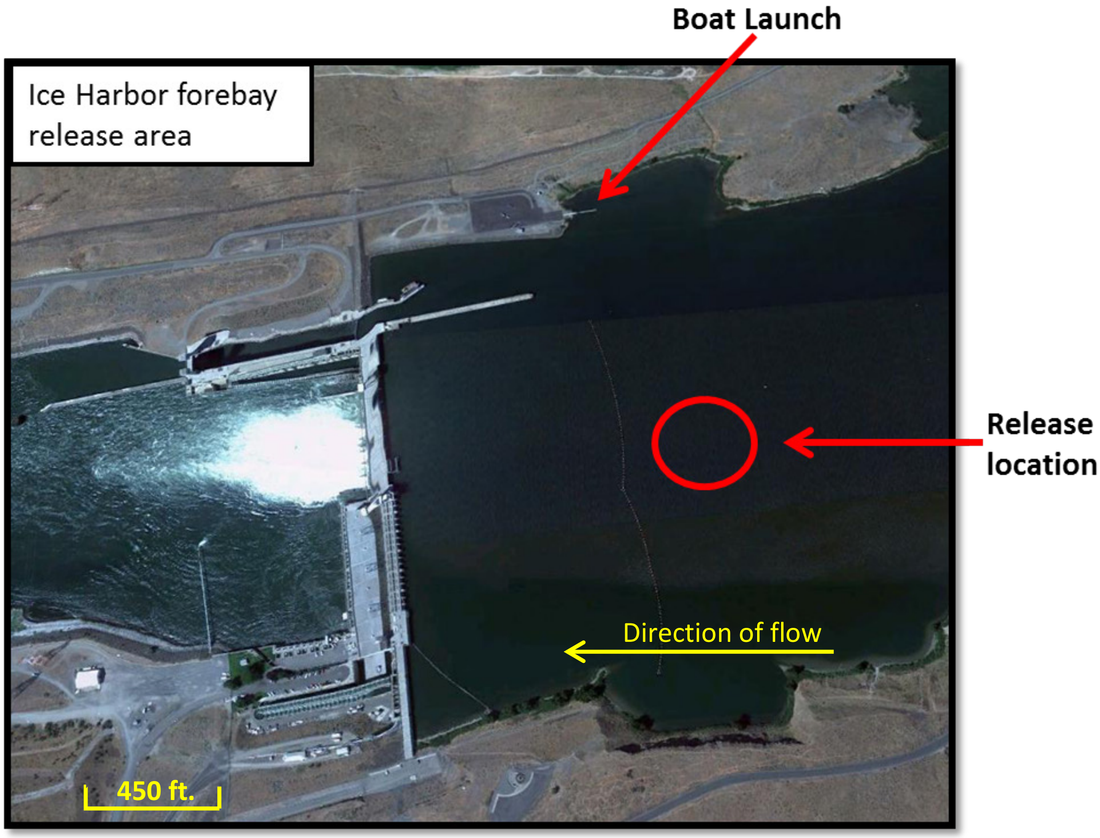

Figure 2.7. Overhead image of the forebay release location at Ice Harbor Dam for subyearling Chinook salmon affixed with dummy neutrally buoyant external tags. Fish released in this location were later collected at the McNary Dam juvenile fish facility for examination of tag retention and injury.

2.6 Statistical Analyses

Differences in survival and travel time between groups from release to the array near the confluence of the Snake and Columbia rivers (Burbank) as well as from release to the McNary Dam forebay array were determined. Because there was concern that the external tags may have compromised detection efficiency due to the modifications required to achieve neutral buoyancy, detection probabilities were also compared at the arrays where survival was estimated. For fish exposed to STP, all non-neutrally buoyant fish following the acclimation period were excluded from analyses. All videos of exposures were later examined to confirm categorization of each fish's state of buoyancy. The data were initially explored for any bias caused by the experimental design. For example, differences in fish distributions among groups were tested as well as differences in survival with surgeon, release site, and with release date.

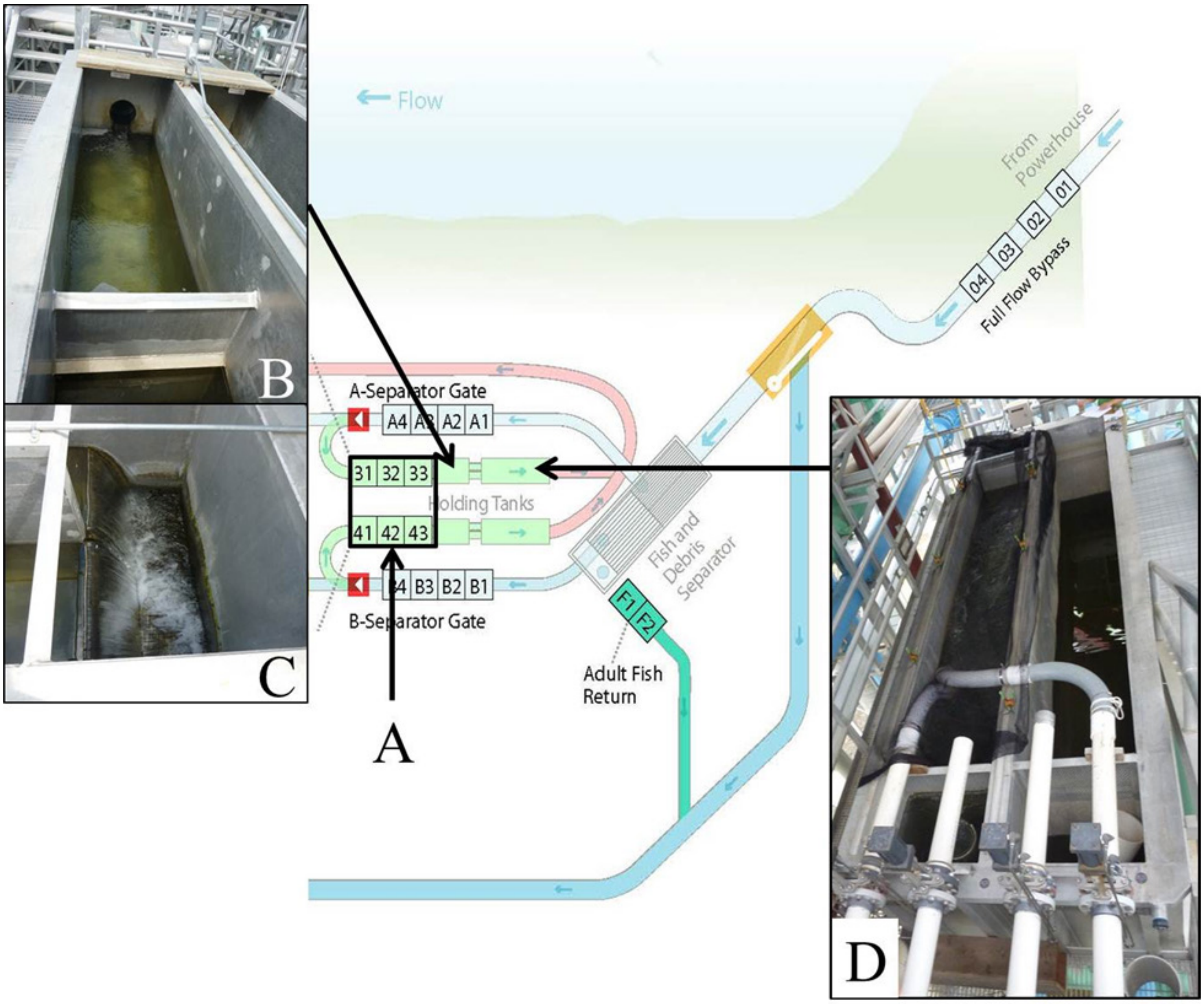

Figure 2.8. McNary Dam juvenile fish facility where dummy-tagged fish were collected with final PIT tag detectors (A) prior to entering tanks in the holding zone (B, C, and D). Panel C depicts the downstream end of tank B. Separation-by-code system fish were recovered from tank (D).

2.6.1 Survival Estimates

Probabilities of survival and detection (i.e., the probability of survival, migration, and tag function and retention) were analyzed with R (version 2.15.1) using the single release-recapture model (hereafter referred to as the CJS model) developed by Cormack (1964), Jolly (1965), and Seber (1965). Assumptions associated with this single-release CJS model according to Skalski et al. (1998) are as follows:

- The test fish are representative of the population of inference.
- Test conditions are representative of the conditions of interest.
- The number of fish released is exactly known.

- Tag codes are accurately recorded at the time of tagging and at all detection sites.
- The fate of each individual fish is independent of the fates of all other fish.
- All fish in a release group have equal survival and detection probabilities.
- Prior detection history has no effect on subsequent survival and detection probabilities.

The CJS model requires detections at the point of interest as well as at one downstream site. Although we were interested only in survival to Burbank and the McNary Dam forebay arrays, the CJS model required the use of the Crow Butte array downstream of McNary Dam as well. The CJS model was used to calculate survival and detection probabilities and associated variability for each treatment group overall as well as independently for each release group of each treatment. This allowed for point estimates of survival for comparison between treatment groups and also for an evaluation of how survival changed throughout the duration of the project. *F*-tests were used to compare survival by treatment to both the Burbank and the McNary Dam forebay arrays. More specifically, an *F*-test tested for homogeneous reach survivals between the four treatment groups. Given a significant *F*-statistic, it was concluded that reach survival was heterogeneous, and linear contrasts were constructed to test for differences between tag types (internal vs. external) and pressure exposure (exposed vs. unexposed).

2.6.2 Travel Time

Travel time was calculated as the difference between release and first detection at the Burbank array as well as between release and first detection at the McNary Dam forebay array. Travel time rate (km/day) was then determined by dividing the distance traveled by the travel time (in d). Because travel times typically have a right-skewed distribution, all data were transformed using the natural log-transformation (ln) prior to analysis. Histograms of ln(travel time) appeared roughly normally distributed and therefore an analysis of variance was used to compare travel times by treatment to both the Burbank and McNary Dam forebay arrays. When there was a significant difference in ln(travel time) between treatments, contrasts were used to test for differences between tag types (internal vs. external) and pressure exposure (exposed vs. unexposed). A lack of an effect of exposure allowed for exposure treatments to be combined within each tag type. Because study fish were much smaller than seaward-migrating fish (a mix of wild fish and hatchery fish not recently released; also referred to as ROR; Figure 2.3) and consequently may have been more likely to be subject to tag effects, data were explored for a length effect. Regression analyses were used to determine relationships between length and travel time to the McNary Dam forebay array. For internally tagged fish, the same analyses were repeated but with tag burden instead of length.

2.6.3 Detection Probability

Detection probability was estimated using the CJS model. Detection probability was calculated by comparing the number of detections at a point of interest (Burbank and the McNary Dam forebay arrays) to those of a downstream array (McNary Dam forebay and Crow Butte arrays, respectively). Because our interest was in only the effect of tag type on detection probability (i.e., if modifications to the JSATS tag effect detectability of external tags), exposure groups were combined and differences in detection probability were compared using a *t*-test.

3.0 Results

Distributions of fish size did not differ significantly among treatment groups (P = 0.41). Across release dates, there were significant differences in survival to both the Burbank (P = 0.048) and the McNary Dam forebay arrays (P = 0.0032). Generally this indicates a seasonality effect. Indeed, fish released later in the season had higher survival rates but as fish from all four treatments were released evenly throughout release days, this seasonality effect does not compromise further analyses. There were no significant differences in survival among the five surgeons (four surgeons for internal tags and one for external tagging) to the McNary Dam forebay array, the last detection point of interest (P = 0.063). There were also no significant differences in survival between the two release locations (P = 0.28). Detection probability was 100 % among all groups at both the Burbank and McNary Dam forebay arrays.

3.1 Survival Estimates

3.1.1 To Burbank

There were no significant differences (P = 0.07) in survival (mean [%] ± SE) estimates to the array at the mouth of the Snake River near Burbank (INT-UNX: 93.0 ± 1.6; EXT-UNX: 90.5 ± 1.9; INT-EXP: 87.2 ± 2.4; EXT-EXP: 86.1 ± 2.3). Thus, no significant differences due to tag type or exposure to STP were observed. However, although the p-value revealed non-significance ($\alpha = 0.05$), planned contrasts were conducted given the importance of this result to the conclusions. Planned contrasts revealed a significant effect of STP (exposed fish having lower survival than unexposed; P = 0.01) but no effect of tag type (P = 0.4). Therefore, some large but non-significant differences (e.g. 86% survival for external exposed fish and 93% survival for internal unexposed fish) are explained by exposure treatment and not tag type.

3.1.2 To McNary Dam Forebay

Compared to Burbank, survival estimates to the array in McNary Dam forebay were considerably lower. There were also significant differences among groups (P < 0.0001; Figure 3.1) with a significant effect of tag type (P < 0.0001) and STP (P = 0.048). Probability of survival (mean [%] ± SE) to the McNary forebay array was higher for internally tagged fish (INT-UNX: 72.1 ± 2.9; INT-EXP: 66.8 ± 3.4) than for externally tagged fish (EXT-UNX: 55.6 ± 3.2; EXT-EXP: 48.2 ± 3.3) and survival was higher for unexposed compared to exposed fish.

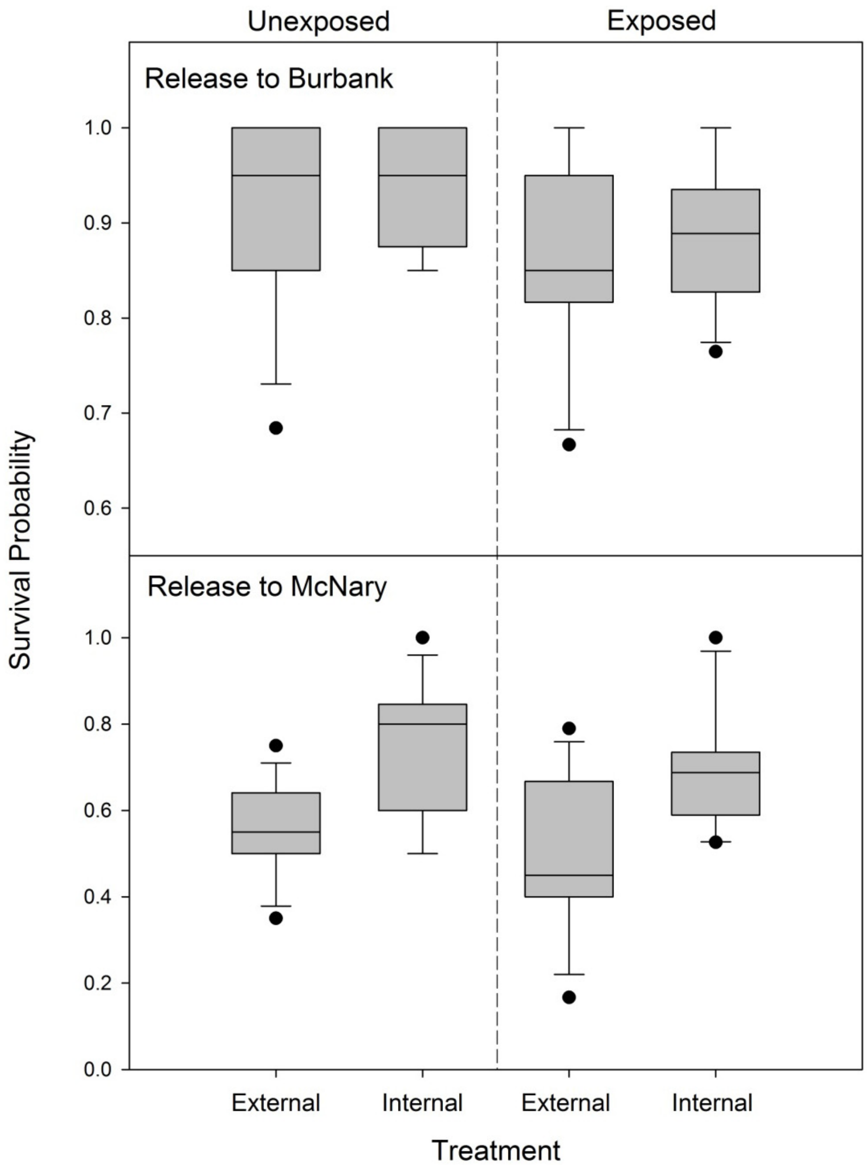

Figure 3.1. Survival probability to the mouth of the Snake River (Burbank) and to the McNary Dam forebay for subyearling Chinook salmon with two different tag types (internally implanted JSATS tag and externally attached neutrally buoyant JSATS tag) released in the tailrace of Ice Harbor Dam in the Snake River, Washington, in June 2012. Prior to release, half of the fish of each tag type were exposed to simulated turbine passage (Exposed) and the other half were released without exposure to simulated turbine passage (Unexposed). Boxes show the variance in survival probabilities across releases (line within box = median; lower and upper edges of boxes = 25th and 75th percentiles, respectively; ends of whiskers = 1.5 × inter-quartile range; dots = outliers).

Table 3.1. Survival probability by release day to the mouth of the Snake River (Burbank) and to the McNary Dam forebay for subyearling Chinook salmon with two different tag types (internally implanted JSATS tag and externally attached neutrally buoyant JSATS tag) released in the tailrace of Ice Harbor Dam in the Snake River, Washington, in June 2012. Prior to release, half of the fish of each tag type were exposed to simulated turbine passage (Exposed) and the other half were released without exposure to simulated turbine passage (Unexposed).

	Survival (% ± SE)							
	Burbank				McNary			
	Exposed		Unexposed		Exposed		Unexposed	
Release day	Internal	External	Internal	External	Internal	External	Internal	External
6/11/2012	89.5 ± 7.0	90.0 ± 6.7	85.0 ± 8.0	95.0 ± 4.9	57.9 ± 11.3	50.0 ± 11.2	50.0 ± 11.2	50.0 ± 11.2
6/13/2012	86.7 ± 8.8	83.3 ± 8.8	90.0 ± 6.7	95.0 ± 4.9	60.0 ± 12.6	16.7 ± 8.8	60.0 ± 11.0	65.0 ± 10.7
6/14/2012	93.3 ± 6.4	70.6 ± 11.1	85.0 ± 8.0	85.0 ± 8.0	73.3 ± 11.4	41.8 ± 12.0	50.0 ± 11.2	35.0 ± 10.7
6/15/2012	79.0 ± 9.4	85.0 ± 8.0	90.0 ± 6.7	68.4 ± 10.7	52.6 ± 11.5	50.0 ± 11.2	60.0 ± 11.0	42.1 ± 11.3
6/17/2012	88.9 ± 10.5	100 ± 0.0	95.0 ± 4.9	90.0 ± 6.7	66.7 ± 15.7	40.0 ± 12.6	65.0 ± 10.7	55.0 ± 11.1
6/18/2012	76.5 ± 10.3	85.0 ± 8.0	95.0 ± 4.9	85.0 ± 8.0	52.9 ± 12.1	40.0 ± 11.0	80.0 ± 8.9	55.0 ± 11.1
6/19/2012	88.9 ± 7.4	85.0 ± 8.0	100 ± 0	100 ± 0.0	72.2 ± 10.6	65.0 ± 10.7	80.0 ± 8.9	63.2 ± 11.1
6/20/2012	93.8 ± 6.1	90.0 ± 6.7	85.0 ± 8.0	80.0 ± 8.9	68.8 ± 11.6	30.0 ± 10.2	85.0 ± 8.0	60.0 ± 11.0
6/21/2012	100 ± 0.0	66.7 ± 12.2	95.0 ± 4.9	100 ± 0.0	92.3 ± 7.4	40.0 ± 12.6	90.0 ± 6.7	75.0 ± 9.7
6/22/2012	84.2 ± 8.4	80.0 ± 8.9	95.0 ± 4.9	100 ± 0.0	73.7 ± 10.1	45.0 ± 11.1	75.0 ± 9.7	50.0 ± 11.2
6/23/2012	81.2 ± 9.8	89.5 ± 7.0	100 ± 0.0	95.0 ± 4.9	62.5 ± 12.1	79.0 ± 9.4	84.2 ± 8.4	50.0 ± 11.2
6/24/2012	88.2 ± 7.8	100 ± 0.0	100 ± 0.0	90.0 ± 6.7	70.6 ± 11.1	68.4 ± 10.7	80.0 ± 8.9	65.0 ± 10.7
6/26/2012	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0	71.4 ± 17.1	100 ± 0.0	60.0 ± 21.9
Overall	87.2 ± 2.4	86.1 ± 2.3	93.0 ± 1.6	90.5 ± 1.9	66.8 ± 3.4	48.2 ± 3.3	72.1 ± 2.9	55.6 ± 3.2

3.2 Travel Time

3.2.1 To Burbank

There was a large amount of variability in the time it took fish to travel the 12 km from the release location to the array near the mouth of the Snake River. Travel times ranged from 0.06 d to over 2 weeks while individual travel rates ranged from 202 km/day to 0.7 km/day (Figure 3.2A). Differences between the groups were significant ($P = 0.0048$) with an effect of tag type ($P < 0.0001$) but not exposure ($P = 0.35$). However, these differences appeared largely driven by the many outliers and are likely not biologically relevant as median travel times (± SE) were very similar across groups (internal unexposed: 0.21 ± 0.1; external unexposed: 0.20 ± 0.06; internal exposed: 0.20 ± 0.14; external exposed: 0.19 ± 0.07; Figure 3.2B). There was considerably more variability among travel time data for internally tagged fish than externally tagged fish (i.e., more instances of lingering in internally compared to externally tagged fish).

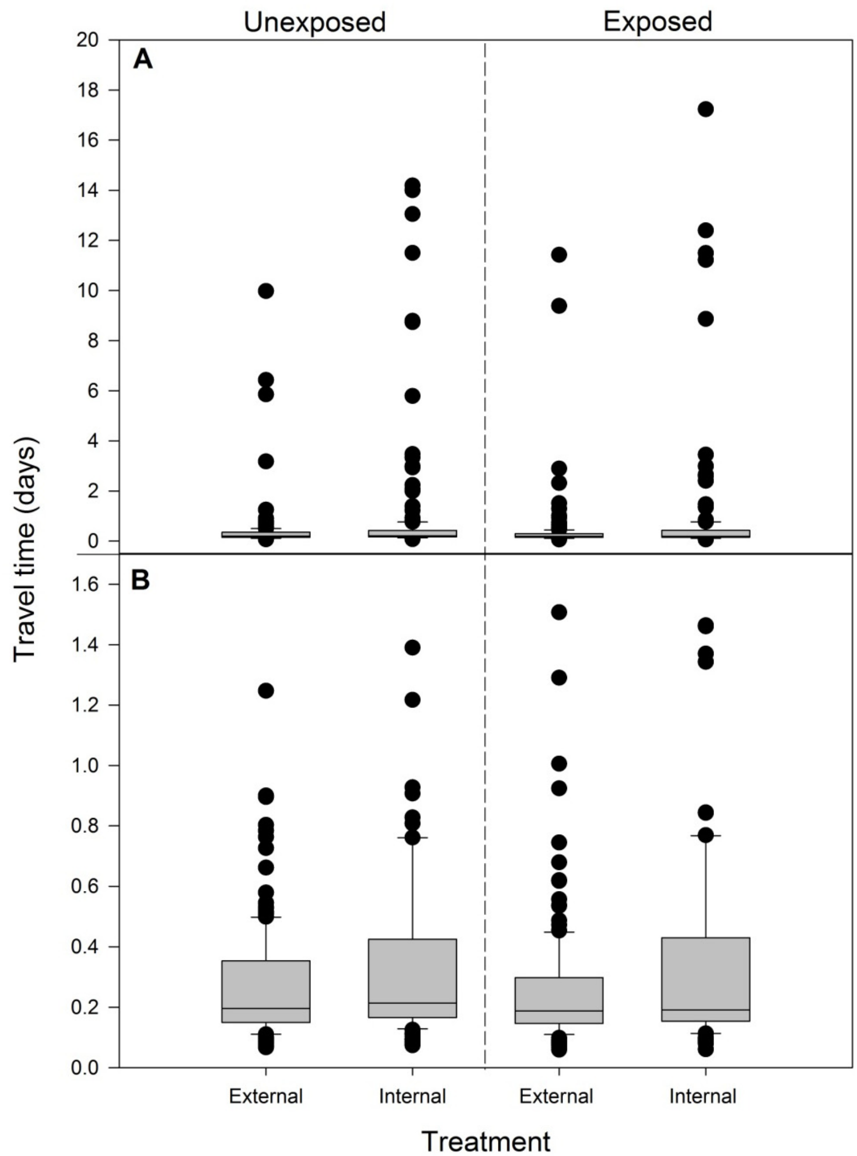

Figure 3.2. Travel time (days) to Burbank of subyearling Chinook salmon with two different tag types (internally implanted JSATS tag and externally attached neutrally buoyant JSATS tag) released in the tailrace of Ice Harbor Dam in the Snake River, Washington, in June 2012. Prior to release, half of the fish of each tag type were exposed to simulated turbine passage (Exposed) and the other half were released without exposure to simulated turbine passage (Unexposed). Fish were detected on the array of autonomous receivers near the mouth of the Snake River (Burbank), 12 river kilometers downstream from release. Travel time was very right-skewed with many outliers (A), but when data in the lower 1.7 days were magnified (in the lower two panels; B), it can be seen that there are minimal differences between medians (line within box = median; lower and upper edges of boxes = 25th and 75th percentiles, respectively; ends of whiskers = 1.5 × interquartile range; points = outliers).

3.2.2 To McNary Dam Forebay

Similar to the trends observed to Burbank, travel time to McNary Dam forebay, 65 RKM downstream, was highly variable among individuals. Travel times ranged from 1 d to almost 3 weeks while travel rates ranged from 3.1 km/d to 62.2 km/d. There were also significant differences among groups ($P < 0.0001$) with an effect of tag type ($P < 0.0001$) but not exposure ($P = 0.73$). However, unlike to Burbank, there were large differences in travel time estimates (days ± SE) among treatments; estimates for externally tagged fish were more than twice as fast as those for internally tagged fish (INT-UNX: 9.3 ± 0.4; EXT-UNX: 4.1 ± 0.3; INT-EXP: 9.6 ± 0.4; EXT-EXP: 4.0 ± 0.3; Figure 3.3).

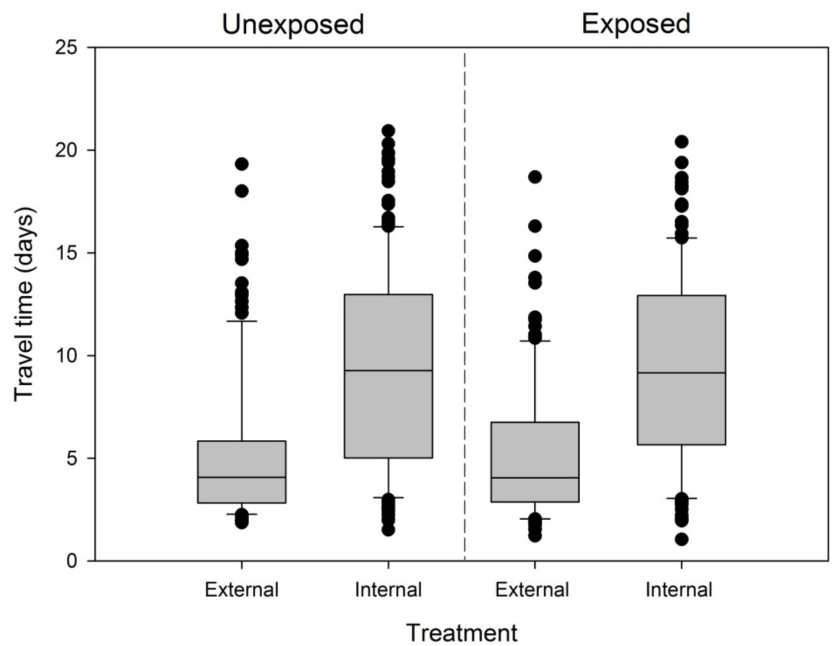

Figure 3.3. Travel time (days) to McNary Dam forebay of subyearling Chinook salmon with two different tag types (internally implanted JSATS tag and externally attached neutrally buoyant JSATS tag) released in the tailrace of Ice Harbor Dam in the Snake River, Washington, in June 2012. Prior to release, half of the fish of each tag type were exposed to simulated turbine passage (Exposed) and the other half were released without exposure to simulated turbine passage (Unexposed). Fish were detected on the array of autonomous receivers in the forebay of McNary Dam (line within box = median; lower and upper edges of boxes = 25th and 75th percentile, respectively; ends of whiskers = 1.5 × interquartile range; points = outliers).

Table 3.2. Travel time (days) by release day to McNary Dam forebay of subyearling Chinook salmon with two different tag types (internally implanted JSATS tag and externally attached neutrally buoyant JSATS tag) released in the tailrace of Ice Harbor Dam in the Snake River, Washington, in June 2012. Prior to release, half of the fish of each tag type were exposed to simulated turbine passage (Exposed) and the other half were released without exposure to simulated turbine passage (Unexposed).

	Travel time (mean days ± SE)							
	Burbank				McNary			
	Exposed		Unexposed		Exposed		Unexposed	
Release day	Internal	External	Internal	External	Internal	External	Internal	External
6/11/2012	0.25 ± 0.0	0.24 ± 0.0	0.23 ± 0.0	0.23 ± 0.0	12.90 ± 1.1	6.71 ± 1.0	11.74 ± 0.9	7.07 ± 1.1
6/13/2012	1.95 ± 1.0	0.30 ± 0.0	0.39 ± 0.1	0.60 ± 0.3	10.64 ± 1.5	8.96 ± 1.7	11.91 ± 0.8	7.12 ± 1.3
6/14/2012	0.55 ± 0.2	0.17 ± 0.0	0.47 ± 0.2	0.19 ± 0.0	11.07 ± 0.9	5.53 ± 1.2	9.66 ± 2.0	4.18 ± 1.4
6/15/2012	1.23 ± 0.7	0.27 ± 0.1	0.35 ± 0.1	0.30 ± 0.1	9.33 ± 1.2	7.09 ± 1.8	12.60 ± 1.5	8.00 ± 2.1
6/17/2012	0.36 ± 0.1	0.44 ± 0.2	1.24 ± 0.5	0.31 ± 0.0	8.45 ± 0.9	6.77 ± 1.9	10.88 ± 1.3	5.78 ± 1.1
6/18/2012	1.75 ± 1.3	0.39 ± 0.1	1.10 ± 0.7	0.28 ± 0.0	10.39 ± 1.8	4.86 ± 1.1	8.53 ± 1.1	4.29 ± 0.7
6/19/2012	0.10 ± 0.0	0.094 ± 0.0	0.76 ± 0.7	0.10 ± 0.0	8.89 ± 1.3	5.17 ± 0.6	8.15 ± 0.9	4.63 ± 0.6
6/20/2012	0.23 ± 0.0	0.20 ± 0.0	0.29 ± 0.0	0.63 ± 0.4	10.06 ± 1.9	5.09 ± 1.5	8.98 ± 1.4	5.66 ± 0.8
6/21/2012	0.30 ± 0.1	0.25 ± 0.1	0.70 ± 0.4	0.25 ± 0.0	11.81 ± 1.1	6.98 ± 1.3	9.448 ± 1.2	4.75 ± 0.5
6/22/2012	0.54 ± 0.2	1.68 ± 0.9	1.37 ± 0.7	0.81 ± 0.1	4.78 ± 0.6	4.70 ± 0.9	6.68 ± 1.3	3.01 ± 0.2
6/23/2012	0.31 ± 0.0	0.27 ± 0.0	0.35 ± 0.1	0.33 ± 0.1	10.76 ± 1.0	5.20 ± 0.8	9.34 ± 1.2	5.83 ± 1.9
6/24/2012	1.22 ± 0.8	0.21 ± 0.0	1.04 ± 0.6	0.40 ± 0.2	7.82 ± 1.6	2.96 ± 0.4	8.50 ± 1.2	4.36 ± 1.0
6/26/2012	1.22 ± 0.8	0.20 ± 0.0	0.34 ± 0.06	0.14 ± 0.0	3.85 ± 1.8	2.57 ± 0.4	6.44 ± 1.4	3.37 ± 0.4
Overall	0.20 ± 0.14	0.19 ± 0.07	0.21 ± 0.1	0.20 ± 0.06	9.6 ± 0.4	4.0 ± 0.3	9.3 ± 0.4	4.1 ± 0.3

Table 3.3. Statistical outputs from tests of differences in travel time and survival from release in the Ice Harbor Dam tailrace to two downstream arrays (Burbank and McNary dam forebay) between four different treatment groups of tagged fish (internally tagged and exposed to simulated turbine passage, externally tagged and exposed, internally tagged and unexposed and externally tagged and unexposed). Fish were tagged by five different surgeons. Post-hoc tests were conducted on analyses of survival to Burbank given the importance of this data regardless of the non-significant overall P-value.

			Post-hoc contrasts					
			Tag type		Pressure exposure		Interaction	
Test	Test Statistic	P-value	Test Statistic	P-value	Test Statistic	P-value	Test Statistic	P-value
Differences with surgeon	$F_{4,\infty} = 2.2308$	0.063	*Not conducted*					
Survival to Burbank	$F_{3,\infty} = 2.3415$	0.0711	Z = 0.8838	P = 0.3768	Z = 2.4772	P = 0.0132	Z = 0.3269	P = 0.7437
Survival to McNary	$F_{3,\infty} = 11.4992$	P < 0.0001	Z = 5.5215	P < 0.0001	Z = 1.9777	P = 0.0480	Z = 0.3157	P = 0.7522
Travel time to Burbank	$F = 5.9974$	P = 0.0048	$F = 17.0878$	P < 0.0001	$F = 0.8918$	P = 0.3453	$F = 0.124$	P = 0.9112
Travel time to McNary	$F = 45.129$	P < 0.0001	$F = 135.2522$	P < 0.0001	$F = 0.1182$	P = 0.7311	$F = 0.0160$	P = 0.8993

3.2.3 Relationships Between Travel Time and Fish Size/Tag Burden

Among travel time data to the McNary Dam forebay array, there was a significant correlation between fish length and travel time among internally tagged fish (P = 0.0007; r^2 = 0.037; Figure 3.4B) but not among externally tagged fish (P = 0.63; Figure 3.4A). Fish tagged with the neutrally buoyant external tag had essentially no tag burden but tag burdens among internally tagged fish ranged from 1.7 % to 6.6% (mean ± SE = 3.1 ± 0.03%). However, among internally tagged fish, the relationship between tag burden and travel time was stronger (P < 0.001, r^2 = 0.066; Figure 3.4C) than the relationship between travel time and length with a correlation coefficient almost twice as large. Smaller fish with higher tag burdens traveled slower than larger fish with smaller tag burdens.

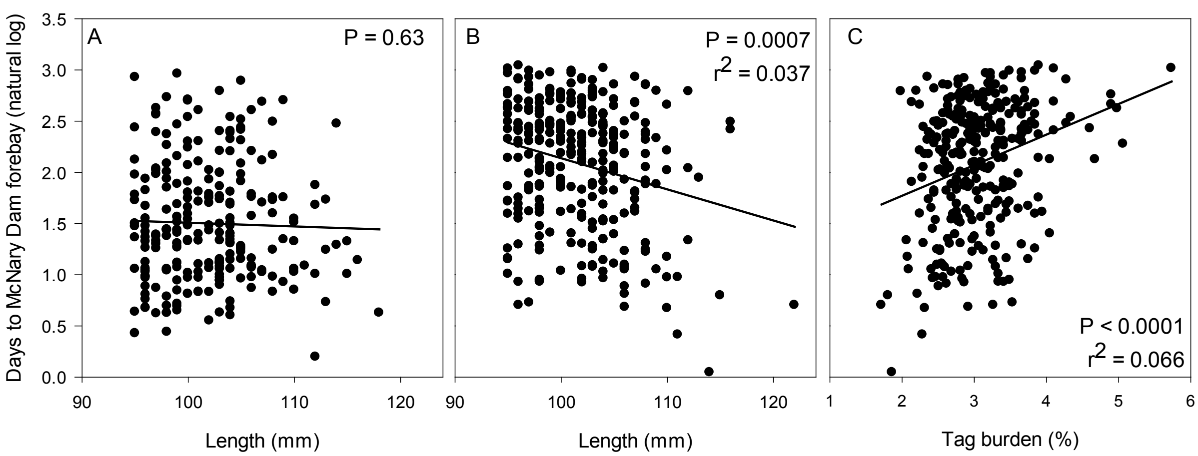

Figure 3.4. Relationships between size and travel time (natural log) to the array in the McNary Dam forebay for subyearling Chinook salmon tagged with either an externally attached neutrally buoyant JSATS tag (A) or an internally implanted JSATS tag (B). The external tags had no tag burden (ratio of tag weight to body weight), but for internally tagged fish, tag burden was related to travel time (C).

3.3 Tag Retention to McNary Dam

Thirty (6.3%) of the 480 dummy tagged fish were recovered using the SbyC at McNary Dam. Fish were recovered between 3 and 17 d post release, three of which (10% of those recaptured) were recovered without their external transmitters attached (Figure 3.5). The first of three fish was recovered 9 *d* after release, and although the tag was missing, the posterior suture was retained. The second fish was recovered 14 *d* after release. This fish was dead and was missing both sutures. The third fish was recovered 17 *d* after release and was missing both sutures. The same day on which the third fish without a tag was found, two of the missing tags were recovered in the holding tank. One externally tagged fish was found dead 6 *d* after release with the external tag still attached.

Within the JFF, although most fish covered the distance between initial detection and the holding tank in a small amount of time (approximately 10 min.), fish that lost their tags spent considerably more time in the system. One fish was in the separator of the bypass for about a day and a half where it could have possibly shed its tag. The other two of these fish spent an extended amount of time in the tanks downstream of the last separator gate (Figures 2.8B–D)—one of which was found dead. It is possible that these two fish spent an unusual amount of time in the farthest downstream tank and were missed during collection. However, it is also possible that they spent an extended time in the tank downstream of the last separator gate but upstream of the tank where we netted them.

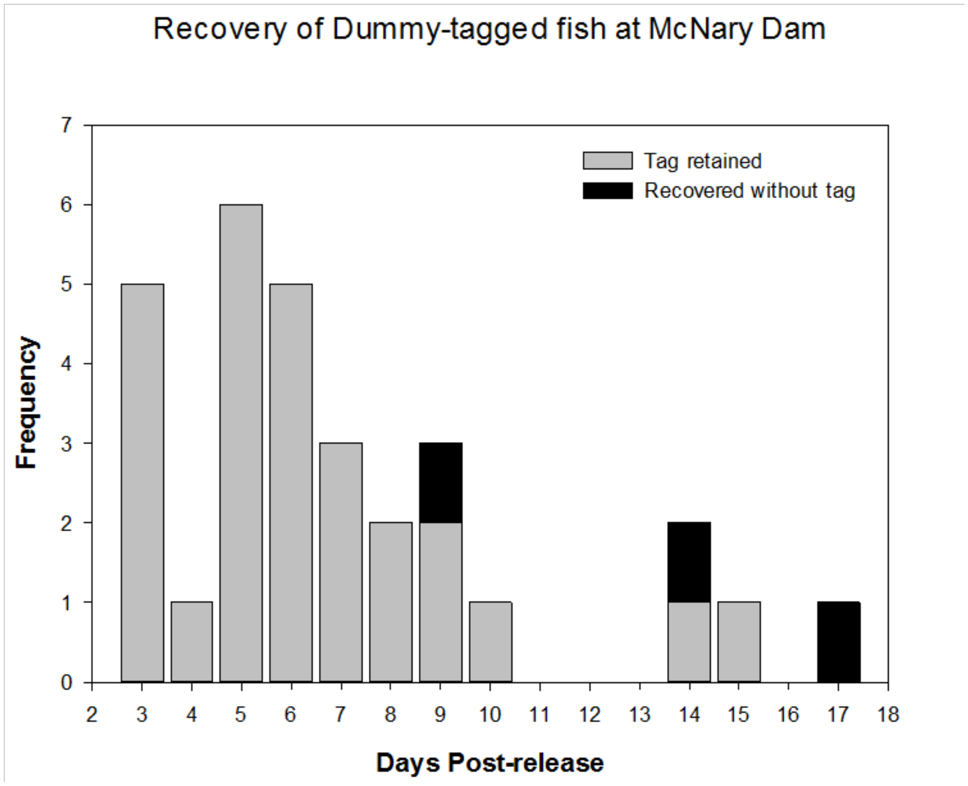

Figure 3.5. Frequency of subyearling Chinook salmon affixed with dummy neutrally buoyant external tags and implanted with PIT tags recovered using the separation-by-code system at the McNary Dam juvenile fish facility. Fish were released across two days in June 2012 in the forebay of Ice Harbor Dam in the Snake River, Washington.

Although most recovered fish retained their tags, many tags were loose upon recovery (19% of fish recovered with tags). In two cases, both the anterior and posterior sutures were loose. In one case only the anterior suture was loose and in two other fish the posterior sutures were so loose that they slipped off of the tag. Tags were often loose and tearing at the suture insertion point was common. The longest tear measured on individual fish ranged from 1 mm to 10 mm with a mean ± SE of 2.8 ± 0.41 mm. All fish had some degree of tearing. The only two fish with tears of 10 mm were found without tags; therefore, the measurement was made across the fish where the suture tore the flesh off. In fish with retained tags, the longest tear was 5 mm. Fish condition upon recovery was highly variable (Figure 3.6). Most fish had discoloration (the color being lighter under the tag) at the tag site; 46.7% of fish recovered had discoloration on less than 50% of the area under the tag while 36.7% of fish had discoloration on more than 50% of the area under the tag (Table 3.4). Only 16.7% of fish recovered had no discoloration. Tissue laceration, caused by the tag rubbing against the tissue, was present in 80% of fish (63.3% with less than 50% tissue laceration and 16.7% with greater than 50% tissue laceration; Table 3.4). Tag indentation, where the tag leaves an imprint on the fish's back, was not as common. Half of the fish observed had no tag indentation, 46.7% of fish had mild tag indentation, and tag indentation was classified as severe in only 3.3% of fish (Table 3.4).

Figure 3.6. Examples of the condition of subyearling Chinook salmon affixed with dummy neutrally buoyant external tags and implanted with PIT tags recovered by the separation-by-code system at the McNary Dam juvenile fish facility. Fish were released across two days in June 2012 in the forebay of Ice Harbor Dam in the Snake River, Washington. Good condition fish showed minimal tearing, and little fungal growth or discoloration under the tag (left two photos). Bad condition fish were often recovered with loose tags, substantial tissue tearing and has fungal growth, evidence of tag indentation and discoloration under the tag site (right two photos)

Table 3.4. Injuries observed in 30 subyearling Chinook salmon affixed with dummy neutrally buoyant external tags and implanted with PIT tags recovered by the separation-by-code system at the McNary Dam juvenile fish facility. Fish were released across two days in June 2012 in the forebay of Ice Harbor Dam in the Snake River, Washington.

	Percentage of sample (%)		
Injury	None	Mild	Severe
Discoloration	16.7	46.7	36.7
Tissue Laceration	20.0	63.3	16.7
Tag Indentation	50.0	46.7	3.3

4.0 Discussion

This field study evaluated the efficacy of a neutrally buoyant externally attached transmitter to provide reliable survival estimates in turbine-passed subyearling Chinook salmon. We evaluated detection probability, survival, travel time, and tag retention.

4.1 Survival

4.1.1 Differences Between Internally and Externally Tagged Fish

Survival between fish internally and externally tagged that were not exposed to STP did not differ from their release in the tailrace of Ice Harbor Dam to the detection array, 12 km downstream near the mouth of the Snake River. A major concern of fisheries managers with the possible use of this externally attached transmitter is that high predation rates would make it less useful than internally implanted transmitters. A protruding tag may attract predators more than a tag that is internally implanted. Therefore, fish were released below Ice Harbor Dam primarily because this area is known to have high predation.

Within the Columbia River, a short distance (4–12 km) downstream of its confluence with the Snake River, are three islands: Foundation, Badger, and Crescent. These islands are known breeding sites for large colonies of double-crested cormorants *Phalacrocorax auritus*, American white pelicans *Pelecanus erythrorhynchos*, and Caspian terns *Hydroprogne caspia*. Evans et al. (2011) determined that the double-crested cormorant colony of Foundation Island and the Caspian tern colony of Crescent Island consumed approximately one million juvenile salmonids annually from 2004 to 2009. The Caspian terns nesting on Crescent Island are estimated to have the highest per capita predation rate on PIT-tagged juvenile salmonids of all studied bird colonies during 2007 to 2010 (Evans et al. 2012).

Further indication that the reach upstream of McNary Dam has high predation was the relatively low survival (28%–30%) noted by McMichael et al. (2006) for subyearling Chinook salmon from the location of their PIT tagging and release in the Hanford Reach downstream to McNary Dam. They indicated that this is possibly due to exposure to abundant levels of smallmouth bass *Micropterus dolomieu* and Caspian terns. Other researchers have also determined that not only are populations of smallmouth bass in the lower Snake River relatively large compared to populations in the Columbia River (Zimmerman and Parker 1995), but smallmouth bass tend to prey more upon smaller subyearling Chinook over yearling size salmonids (Poe et al. 1991; Tabor et al. 1993; Naughton et al. 2004).

Despite this high level of predation, the survival of externally tagged fish was not different from that of internally implanted fish. This indicates that the external transmitter is a viable option for examining turbine survival, even in areas with high predation levels. However, as results from McNary Dam indicate, the tag is not likely useful for longer-term (≥9-day) projects.

Survival estimates from Ice Harbor to the McNary Dam forebay suggest that survival is considerably lower for externally tagged fish than for internally tagged fish. However, it was clear from the loss of external tags among fish recaptured in the McNary SbyC that tag retention compromised results of survival estimates to the forebay of McNary Dam and farther downstream. Unfortunately, the few lost tags in both this field study (n = 3) and in a previous laboratory study (n = 1) preclude the ability to account (or correct) for tag loss in survival modeling. Thus, comparisons of survival between internally and externally tagged fish likely do not reflect true survival or provide insight on possible susceptibility to predation in the reach between the mouth of the Snake River and McNary Dam.

4.1.2 Differences Between STP-Exposed and Unexposed Fish

Among fish exposed to STP, there was no difference due to tag type in survival estimates to Burbank. Our prediction is based on the results of laboratory research by Carlson et al. (2012) in which the probability of mortal injury was determined based on specific ratios of pressure change and tag burdens. Using the equation of Carlson et al. (2012) and the targeted nadir of this study (11.6 psia), one would expect to see a 13.1% difference between internally tagged fish (median tag burden 3.1%; expected mortal injury rate of 16.8%) and fish without a tag burden (tagged with an externally attached neutrally buoyant tag; expected mortal injury rate of 3.7%). During field STP exposures, the actual mean of nadirs was slightly lower at 11.3 psia than the target of 11.6 psia. For this exposure, we would expect to see 4.1% mortal injury for externally tagged fish and 18.2% for internally tagged fish, with a difference of 14.1%. However, no significant difference was seen between internally tagged and externally tagged fish exposed to STP.

The lack of a difference could be due to several factors. The limited sample sizes used in this pilot-scale effort may have compromised our ability to detect a significant difference if one did exist. In addition, the target pressure nadirs of the experiments were relatively mild, which, combined with small sample sizes, may have made identifying a significant difference difficult.

Survival estimates of STP exposed fish to McNary Dam indicate that there was lower survival among externally tagged fish compared to internally tagged fish and fish exposed to STP had lower survival than those that were not. Although we predicted that fish exposed to STP would have a lower survival, we did not expect survival to be higher for internally tagged fish than externally tagged fish. Tag loss is likely a contributing factor for failing to observe these expected differences to McNary Dam. Tag loss may also have had a small influence on survival estimates to Burbank. However, few fish (1.2% of all released fish) took more than 9 d (when tag loss was first noted at McNary Dam) to travel the distance from release to Burbank. There were more internally tagged fish (1.8%) observed taking long periods to travel this distance than externally tagged fish (0.6%), as might be expected if externally tagged fish were losing tags. However, the small percentage of fish having these delayed travel times likely had little influence on the survival estimates.

4.2 Tag Retention

Analyses of survival and travel time led to the appearance that tag loss compromised results. Indeed, 10% of the fish recovered at McNary Dam shed their external transmitter. These fish were recovered in the SbyC between 9 and 17 d after release, indicating that tag loss compromised all analyses to McNary Dam and, possibly to a lesser extent, to the mouth of the Snake River. However, given low sample sizes of recovered fish and the unusual circumstances of fish with shed tags spending an abnormally long time within the SbyC, it is difficult to make firm conclusions about the retention of the external transmitters.

The loss of tags observed in this field trial was not surprising, considering results of the laboratory evaluation of this tag (Deng et al. 2012) and other laboratory studies of suture retention (e.g., Panther et al. 2011 and Deters at al. 2012). Deng et al. (2012) found that loss of external tags among fish held in circular tanks in water at about 17°C began 13 d after tagging. One fish, or 4.8% of test fish, shed its tag during the 14-d holding experiment. However, losses may happen sooner in a more dynamic river environment and when passing hydro facilities or the juvenile bypass systems.

All tags in this field evaluation were sutured to the fish using 5-0 Monocryl absorbable monofilament sutures. Deters et al. (2012) suggest that these absorbable sutures are not necessarily absorbed but are instead actively expelled by the fish (physiologically) or passively expelled due to drag on the suture. They found that the sutures, through physiological processes, typically moved closer to the incision while the suture and knot remained intact. Such a migration of the sutures would cause loosening of external transmitters over time, leading to eventual loss. Panther et al. (2011) also documented the eventual loss of sutures over a 98-d holding period. They found that fish held in warmer water (20°C) had faster loss of sutures than fish held in 12°C water. This may equate to higher tag retention when research is done during periods with colder water than during this study (14–16°C). Similar temperature-dependent suture loss was found in juvenile Chinook salmon by Deters et al. (2010) and in white bass by Walsh et al. (2000). Although we cannot exactly quantify a percentage of tag loss, our data in combination with laboratory results suggest that tag loss is a concern for these external tags after about 7 d. Furthermore, the external tags were not designed to stay on the fish long term but just long enough to conduct a single dam turbine survival study, which would typically be less than 7 d. Because fish known to have lost their tags were recovered at McNary Dam 9, 14, and 17 d after their release, this does not disregard the viability of the tags for the types of studies for which they were intended.

4.3 Injuries Due to External Tag

Of fish recovered at McNary Dam with the tag still affixed, sutures were commonly loose upon recovery. This could be due to natural dissolving of the sutures, suture stretching, tissue tearing at the point of insertion, or natural migration of sutures out of the fish's body. Tissue tearing was the most common injury observed (tears ≥ 1.5 mm seen in 83% of fish) among recovered fish. As sutures loosen, the tag separates from the body. Swimming with this loosened tag would likely accelerate tissue tearing as the tag moves away from the body. Therefore, not only is there the possibility of sutures dissolving, the observed injuries suggest that as tags loosen, they could be pulled away from the body. Of the two fish recovered alive without tags, the wounds looked fairly fresh and there were large tears in the tissue. Only one fish with a lost tag had retained one of the two sutures used to attach the tag. Although tissue tearing is a concern, other injuries were generally minor. Discoloration at the tag site was also common—the skin was lighter under the tag—but this likely did not have large negative effects to overall fish health or condition. Our observations suggest that injury due to tag presence likely did not affect fish performance within the first week.

4.4 Travel Time

Overall, travel times of fish tagged for this study were relatively slow. The 65-km distance from Burbank to McNary Dam was covered in a median of 5.7 *d* by the hatchery-origin fish used in this study compared to a median of approximately 2 *d* (Geoff McMichael, PNNL, unpublished data. 2012) for concurrent studies on ROR wild subyearling Chinook salmon in the Columbia River basin.

Slower travel times in fish recently released from hatcheries are common (Monzyk et al. 2009; Muir et al. 1994; Plumb et al. 2006). For example, travel rates of wild juvenile steelhead were found to be twice as fast as hatchery steelhead, especially during periods of low flow, as the hatchery fish were observed moving upstream, delaying their seaward migration (Plumb et al. 2006). Behavioral and physiological changes occur in juvenile salmonids during the smoltification period cueing migration to begin. These cues are regulated by environmental conditions (Muir et al. 1994). Due to the unnatural rearing conditions of hatcheries, hatchery-sourced fish are often not physiologically cued for migration upon release (Wedemeyer et al. 1980; Folmar and Dickhoff 1981). However, even upon release, some in-river migrational experience may be required to initiate physiological changes accompanying smoltification (Muir et al. 1994; Zaugg et al. 1985). By using hatchery fish in this study, travel times were much slower and therefore tag loss more common than would have been likely if the study were conducted on ROR fish.

There was large variability in travel times that differed significantly among groups as soon as detection at Burbank. To Burbank, differences in travel time were driven by lingering individuals; travel times ranged from 0.06 d to 17 d, but median travel times for all groups were approximately 0.2 d. It is likely that the observed differences were not biologically significant between internally and externally tagged fish. To the forebay of McNary Dam, however, large differences in travel time were apparent; estimates of travel time for externally tagged fish were more than twice as fast as those of internally tagged fish.

Reasons for this difference in travel time with tag type are ambiguous. Tag loss is a factor to consider. It is possible that externally tagged fish lingered as much as internally tagged fish but were not detected at later dates as their tags were shed. In addition, the relationship between tag burden and travel time in internally tagged fish suggests the presence of length-specific tag effects. It is common for smaller fish to have slower rates of travel (Giorgi et al. 1997; Monzyk et al. 2009); consequently, those fish have reduced survival (Connor et al. 2004). However, the lack of a correlation between length and travel time in externally tagged fish suggests that the presence of the internal tag may be a factor in the slower migration rates in the small fish, not just that slower travel times are normal for small fish. Although slower travel times may not have been observed in externally tagged fish due to tag loss, the higher correlation coefficient when conducting the analyses with tag burden instead of length suggests that length-specific tag effects are possibly a result of tag burden. Among fish of the smallest size class of internally tagged fish (95–99 mm; 20% of sample), the mean tag burden was 3.5%, ranging from 2.7% to 6.6%. These results may highlight one possible benefit of the external tag: the lack of a tag burden may reduce or eliminate any travel time related tag effects associated with burden.

4.5 Ideal Conditions for Use of an External Transmitter

The benefits of the neutrally buoyant transmitter are greatest when the combination of fish tag burden and ratio pressure change is likely to create the greatest bias in survival estimates for internally tagged fish. At very high RPCs, there is little difference in mortal injury attributed to differences in tag burden because most fish, irrespective of tag burden, are mortally injured (Figure 4.1). In contrast, when pressure changes are slight and tag burdens are low, there is very little bias due to carrying an internal transmitter. For fish in the size range and tag burden (3.1%) used in the study, the greatest bias, an expected increase in mortality of 43%, would occur at RPC 3.4 (LRP of 1.2). Given the acclimation pressure (21.2 psia, equivalent to 15 ft of depth) used in this study, an RPC of 3.4 would be achieved with a nadir of 6.2 psia. Although the pressures to which fish could be exposed during turbine passage vary, it would not be uncommon for them to be exposed to nadirs as low as about 6 psia (Carlson et al. 2008). In this research, target nadirs were close to surface pressure, so the resulting RPCs were quite low. Although the pressures used in this study did not represent the highest bias to survival estimates expected of fish tagged with internal tags, 14.1% higher mortal injury was expected among these internally tagged fish than externally tagged fish. These target exposures were chosen not only based on pressures that were expected to affect survival estimates but also to simulate the pressures expected of new turbines being designed to replace existing turbines. However, using exposures other than those that provide the greatest bias between internal and external fish, along with a pilot-scale sample size, could have reduced our ability to detect significant differences in survival between groups if one existed.

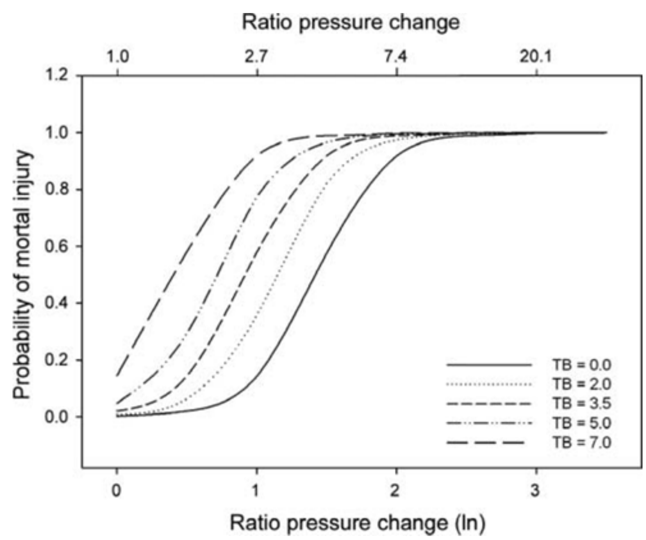

Figure 4.1. Logistic regression curves showing the probability of mortal injury with varying ratio pressure changes in juvenile Chinook salmon with tag burdens (TB; the weight of a transmitted relative to the weight of the fish) ranging from 0 to 7.0%. Figure extracted from Carlson et al. (2012).

4.6 Efficacy of the Neutrally Buoyant External Tag

Use of a neutrally buoyant externally attached transmitter is likely to be more beneficial under some conditions than others. Results from this study reveal that the externally attached neutrally buoyant JSATS transmitter could be appropriate for short-term turbine passage studies when survival estimates can be obtained in 7 d or less. To the mouth of the Snake River, we saw no statistical differences between survival and similar travel times among tagging treatments. In addition, dummy tag recoveries revealed tag retention to be 100% within the first week of the study, and only minor external tag-related injuries were observed during this period.

Although the tag may be appropriate for research over relatively short reaches, we did observe large differences in travel time over a longer term. There are confounding factors to consider, such as a known tag loss that we are unable to quantify and length-specific tag effects in internally tagged fish but not externally tagged fish. Further, the target nadirs of this work were near surface pressure and therefore correspond to a relatively large amount of variation in the probability of mortal injury among individuals. Despite this, the results to McNary Dam could also indicate that, contrary to our predictions, external tags actually negatively influence fish performance compared to that of internally tagged fish.

5.0 Conclusions

Several years of laboratory research indicate that given the tag burden of internally tagged fish traveling through turbines, survival estimates for this route of passage may be biased; survival might possibly be higher than estimated (Carlson et al. 2012). This study, in combination with laboratory work, suggests that the use of a neutrally buoyant externally attached tag may alleviate this bias. The USACE has plans to replace aging turbines in Lower Snake and Columbia river dams with turbines designed for safer fish passage. A test turbine runner is scheduled to be installed at Ice Harbor Dam and will be the first of its kind designed with an innovative process for improved fish passage (Brown et al. 2012a). An appropriate application of this new tagging technology would be when only turbine-passage survival is of interest for a study, such as when comparing older turbines to their replacements. Without appropriate knowledge of baseline turbine survival, determining the benefits of new turbine designs may not be possible with accuracy.

We recommend further research using a smaller external transmitter and ROR fish. Research is currently under way at PNNL to produce a smaller JSATS transmitter than was used as the base for the external transmitters tested in this research. This could reduce the volume of the external transmitter by approximately 40%. Part of this volume reduction could be attained by using a smaller battery with a reduced life (7–10 d). This could also enhance tag retention because drag or the likelihood of snagging on debris may be reduced when using a smaller external tag. In addition, because the use of hatchery-reared fish for this effort compromised longer-term survival and travel time estimates, use of ROR fish would provide a more robust ability to examine turbine-passed fish between Ice Harbor Dam and McNary Dam, improving upon this initial pilot-scale effort.

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