Comparative Performance of Sham Radio-Tagged and PIT-Tagged Juvenile Salmon

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EXECUTIVE SUMMARY

Various fish marking methods are being used to estimate juvenile salmon survival in the Columbia River Basin, including PIT tags (passive integrated transponder tags) and balloon tags. In some locations, methods are limited because of lack of sampling and detection capabilities downstream or availability of adequate numbers of fish. In these situations, radiotelemetry has been proposed because high detection rates allow the use of smaller sample sizes, and because radiotelemetry monitors are easily deployed. To ensure that the presence of the radio transmitter and antenna do not compromise the performance of smolts, and thus do not provide biased estimates of survival, the National Marine Fisheries Service and the U.S. Geological Survey compared migration rates, detection probabilities, and survival of hatchery yearling chinook salmon (*O. tshawytscha*) tagged with either gastrically or surgically implanted sham radio tags to those of their cohorts tagged only with PIT-tags.

From 23 to 28 April 1999, we released 1,113 fish with gastrically implanted sham radio tags, 1,113 fish with surgically implanted sham radio tags, and 1,071 PIT-tagged fish into the tailrace of Lower Granite Dam. Sham radio tags were similar in size and weight to commercially manufactured coded radio tags for juvenile salmonids. A PIT tag was embedded in each sham-tag casing by the manufacturer. Migration rates, detection probabilities, and survival were estimated from PIT-tag detections of individual fish at Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dams. Differences among migration rates, detection probabilities, and survival relative to the PIT-tagged groups were evaluated by analysis of variance (ANOVA).

Hatchery yearling chinook salmon with gastrically implanted radio tags had shorter travel times (higher migration rates) than either surgically implanted or PIT-tagged fish; however, these differences were small overall and consisted of 3 km/day or less between dams on the Snake and Columbia Rivers. Among tagging methods, PIT-tag detection probabilities at downstream dams varied by less than 5%, and differences were not statistically significant. Estimated survival was not statistically different among tagging methods between the tailraces of Lower Granite and Lower Monumental Dams (106 km), although fish with gastrically implanted radio tags had slightly higher relative survival than those with surgical implants.

Survival estimates were lower for both gastrically and surgically implanted fish relative to PIT-tagged fish for a longer reach, between the tailraces of Lower Granite and McNary Dams (225 km), although the difference was not significant ($P = 0.062$). Based on the results of this study, we concluded that the performance of yearling chinook salmon with gastrically or surgically implanted radio tags was not adversely affected by the radio tag. However, survival estimates over longer reaches for fish with either gastrically or surgically implanted radio tags were slightly lower than those of fish tagged only with PIT-tags. Nevertheless, juvenile salmonids with either gastrically or surgically implanted radio tags would be expected to have survival estimates similar to those of PIT-tagged fish over short reaches.

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INTRODUCTION

The National Marine Fisheries Service (NMFS) and the Northwest Power Planning Council have set an interim performance standard of 95% juvenile passage survival at each dam on the lower Snake and Columbia Rivers in order to recover threatened and endangered anadromous salmonids. Various research methods to estimate survival and fish passage are being used to determine whether this standard is being met. Among these are PIT tags (passive integrated transponder tags), balloon tags, hydroacoustic evaluations, and radiotelemetry. Each research method has its advantages and disadvantages, but the choice of method is limited in certain situations where downstream sampling or detection capabilities do not exist or when adequate numbers of target fish are unavailable. In these situations, radiotelemetry has been proposed as a potential method for evaluating passage behavior and estimating survival.

Radiotelemetry is often the only effective method available to investigate biological problems (Winter 1983). Studies using telemetry to describe the behavior and movements of fish have increased since first reported by Trefethen (1956). Early studies were restricted to small sample sizes and large fish due to limitations of monitoring systems and the large size of the transmitters. However, recent advances in radiotelemetry techniques and equipment include coded transmitters (Stuehrenberg et al. 1990), which allow monitoring of larger sample sizes, and the miniaturization of electronic components, which provide transmitters small enough to tag juvenile salmonids.

A requisite assumption in telemetry studies is that tagged fish are representative of the entire population, with the tag and/or tagging procedure not altering growth, survival, or behavior of the test animal (Mellas and Haynes 1985). Numerous studies have been conducted to evaluate the effects of gastrically or surgically implanted transmitters on physiological response, swimming performance, growth, feeding behavior, predator avoidance, and survival of juvenile salmonids (Fried et al. 1976; Moore et al. 1990; Moser et al. 1990; Adams et al. 1998a,b; Martinelli et al. 1998; Brown et al. 1999). However, most of these evaluations were conducted in laboratory tanks, and those conducted in the field did not compare radio-tagged fish performance to that of non-radio-tagged fish. The performance of radio-tagged fish in the field may differ from performance in a laboratory setting since conditions that fish face in the wild are less forgiving (e.g. feeding and predator avoidance).

Furthermore, a consensus on the preferred attachment method for radio-tagging juvenile salmonids has not been reached (Adams et al. 1998a). To address the effects of the radio tag on juvenile salmonid performance, as well as the lack of consensus on a preferred tagging method, we compared migration rates, detection probabilities, and survival among hatchery yearling chinook salmon (*Oncorhynchus tshawytscha*) tagged with either gastrically or surgically implanted sham radio tags to those tagged with PIT tags in the Snake and Columbia Rivers during 1999.

METHODS

Tagging and Release Procedures

The sham tags used in this study were similar in size and weight to commercially manufactured juvenile salmonid coded transmitters, with a 7- to 23-day operational life. Each tag (purchased from Lotek Engineering, Inc.[1]) measured 18 mm in length by 7.3 mm in diameter, weighed 1.4 g in air, and had a 30-cm external flexible whip antenna. A PIT tag (Prentice et al. 1990a) was embedded in the sham-tag potting by the radio-tag manufacturer.

Hatchery yearling chinook salmon were collected and tagged at Lower Granite Dam on the Snake River from 16 to 27 April, either as part of the NMFS transportation study sample or the Fish Passage Center daily smolt monitoring sample. Fish collected for tagging were preanesthetized (Matthews et al. 1997) with either benzocaine and alcohol or tricaine methane sulfonate (MS-222) and sorted in a recirculating MS-222 anesthetic system to separate target species from bycatch. Initially, we attempted to tag fish immediately after sorting; however, this resulted in difficulty controlling the amount of time fish were anesthetized.

Therefore, beginning on 21 April, we modified our collection and handling procedures by holding target fish a minimum of 16 hours after sorting in 712-L tanks mounted on trucks to allow recovery from the anesthetic. Holding tanks were supplied with flow-through water and aerated with oxygen during holding and tagging. Holding densities did not exceed 50 g of fish per liter of water. Prior to tagging, fish were transferred from the holding tanks to a tagging facility via sanctuary dip net (Mathews et al. 1986) using water-to-water transfer techniques.

Once inside the tagging facility, fish were anesthetized in a bath containing 70 mg/L MS-222 buffered to pH 7 with sodium bicarbonate and kept in the bath until loss of equilibrium was exhibited. After losing equilibrium, fish were weighed to the nearest tenth of a gram. Fish less than 20 g in weight were not tagged. If the weight was greater than 20 g, they were measured to the nearest millimeter (fork length), and randomly assigned to one of three tagging methods: PIT-tagging, gastric implantation of a sham radio/PIT tag, or surgical implantation of a sham radio/PIT tag (Fig. 1). Tagging method, tagger name, PIT-tag code, fork length, and weight were recorded for each tagged fish using PIT-tagging software.

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service or the U.S. Geological Survey.

PIT-Tagging Procedures

Fish were PIT-tagged by hand (Prentice et al. 1990a,c) using individual syringes with a 12-gauge hypodermic needle. Used syringes were sterilized in ethyl alcohol for a minimum of 10 minutes before reloading with PIT tags.

Gastric Tagging Procedures

Gastric tagging techniques were similar to those described by Adams et al. (1998a). Fish were held ventral side up in an 8-L dishpan containing anesthetic while the transmitter was gently pushed into the stomach using a plexiglass tube (4 mm in diameter, 150 mm long). The transmitter antenna was bent before implantation so that the portion protruding from the mouth pointed posteriorly. Approximately 12 additional fish per day were gastrically tagged and held at a density of 2 fish per 19-L container to offset tagging mortality and regurgitation of tags.

Surgical Tagging Procedures

Surgical tagging was conducted simultaneously at three stations concurrent with PIT- and gastric-tagging in batches of 9 fish (3 fish per tagging method) with fresh anesthetic solutions used with each batch. During an 8-hour day, approximately 200 fish were surgically radio tagged. In order to reduce fatigue to the taggers, five surgeons were rotated among three tagging stations each day.

Procedures for surgical implantation of transmitters were similar to those used by Moore et al. (1990), but were modified for the use of radio transmitters. A soft foam pad with a groove cut in the center was soaked with a commercially available water conditioner (Stress Coat, Aquarium Pharmaceuticals, Inc) and was used to stabilize the fish's body during surgery. Fish were placed ventral side up on the pad, and the gills were continuously flushed with anesthetic (MS-222, 20 mg/L) fed through a tube placed in the fish's mouth. An in-line valve was used to control anesthetic flow and prevent contamination of the incision. The flow rate of the anesthetic varied with the size of the fish but averaged 250 mL/minute. About 1 minute before completion of the surgical procedure, the flow of anesthetic solution was replaced with oxygenated fresh water to start the recovery process. Disinfection and sterilization of surgical equipment followed procedures described by Summerfelt and Smith (1990).

To implant a transmitter in a fish, a 10-mm-long incision was made 3 mm away from and parallel to the mid-ventral line starting about 3 mm anterior to the pelvic girdle. The incision was only deep enough to penetrate the peritoneum (Summerfelt and Smith 1990). A body weight dosage of 50-mg/kg oxytetracycline (100 mg/mL) was pipetted into the incision to minimize infection (Summerfelt and Smith 1990).

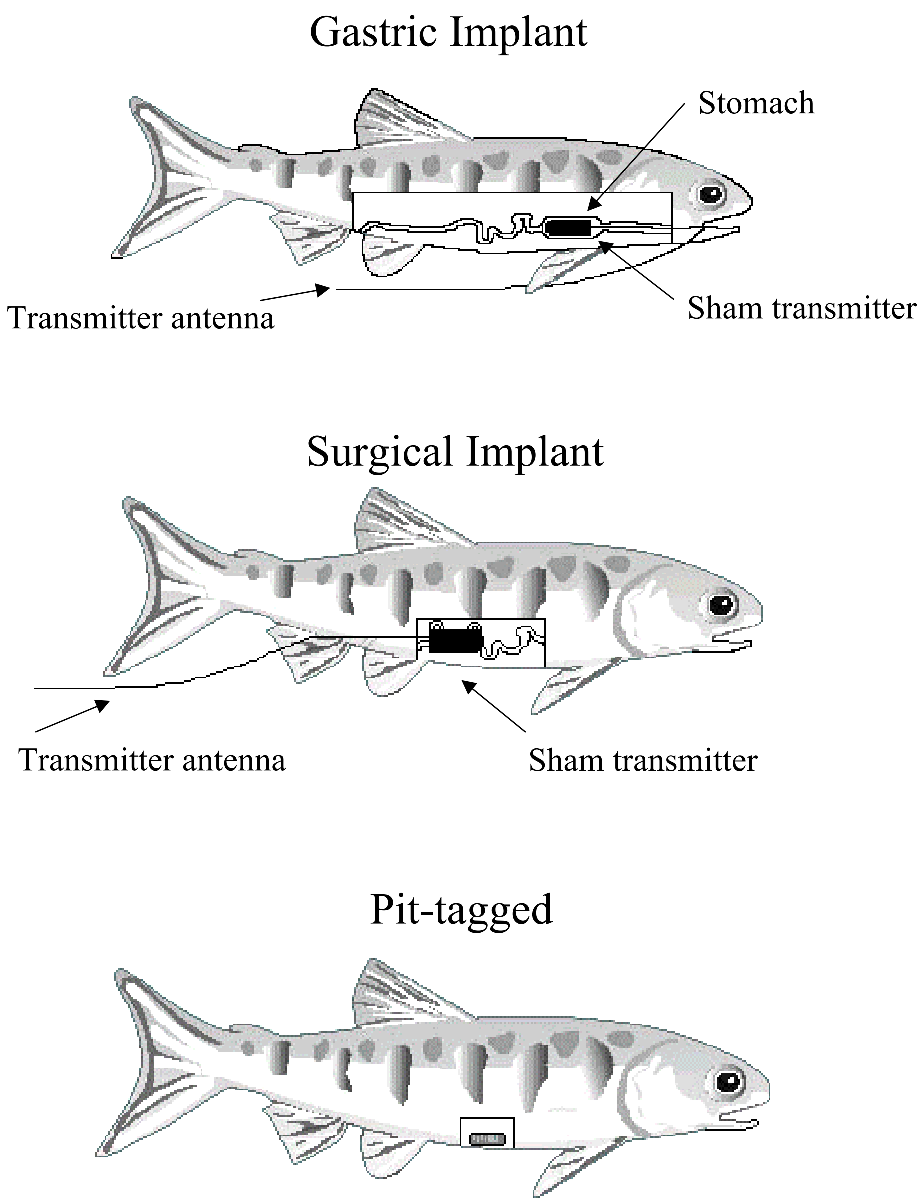

Figure 1. Tagging methods for comparison of travel time, migration rate, detection probability, and survival.

To provide an outlet in the body wall for the antenna, we used a shielded-needle technique similar to that described by Ross and Kleiner (1982). An intravenous catheter and needle (Abbocath-T No. G714, 16G x 51 mm), with the hard plastic base of the catheter removed, was used to guide the antenna through the body wall of the fish. The catheter-covered needle was inserted through the incision to a point 5 to 10 mm posterior and slightly ventral to the origin of the pelvic fins. The point of the needle was exposed by pulling the catheter back onto the needle and applying pressure until both the needle and catheter pierced the skin of the fish. The needle was then pulled back out of the incision, leaving the catheter in position to guide the transmitter's antenna through the body wall.

The transmitter was inserted into the abdominal cavity by first threading the antenna through the incision end of the catheter. Both the antenna and catheter were gently pulled posteriorly while the transmitter was simultaneously inserted into the body cavity. The position of the transmitter inside the fish was adjusted by gently pulling on the antenna until the transmitter was horizontal and directly under the incision.

The incision was closed with three simple, interrupted absorbable sutures (Ethicon braided-vicryl, 5-0 taper RB-1 needle) evenly spaced across the incision. The antenna was attached to the side of the fish with a single suture at the caudal peduncle, about 5-6 mm posterior to the exit site. To prevent infection, a small amount of antibacterial ophthalmic ointment (Bacitracin) was applied to all incisions (Summerfelt and Smith 1990). Approximately 9 additional fish per day were surgically tagged and held at a density of 2 fish per 19-L container to offset losses from tagging mortality.

Post-Tagging Recovery

Immediately after tagging, fish were transferred to a 19-L holding container with oxygenated freshwater. Each holding container contained three fish (one of each tagging method). The holding containers had numerous 1.3-cm-diameter holes in the top 18-cm for water exchange and a 35.6-cm by 5.4-cm bicycle inner tube inflated around the top to provide stability and floatation. Floating the holding containers provided tagged fish access to the air for buoyancy compensation (Fried et al. 1976). Once fish regained equilibrium, the container was covered with a lid and placed into an oxygenated freshwater recovery bath with flow-through river water for a minimum of 10 minutes. After the post-tagging recovery period, the holding containers were transferred to a raceway (1.2 m wide x 24.7 m long x 1.5 m deep) supplied with flow-through river water and held for 16 to 24 hours (Moser et al. 1990, Stuehrenberg et al. 1990).

Release Procedures

The morning after tagging, holding containers were removed from the raceway, and lost tags and mortalities were counted for each tagging method. The beginning and ending release times and water temperature were also recorded. Fish were released into the tailrace of Lower Granite Dam (RKm 695 from mouth of Columbia River) by pouring the contents of the container into a release funnel connected to a 10.2-cm-diameter flexible hose attached to a 15-cm-diameter water-filled pipe that paralleled the existing juvenile bypass pipe. The release hose and pipe were supplied continuously with river water throughout the release. PIT-tag data files for each release group were uploaded to the PIT Tag Information System (PTAGIS) maintained by the Pacific States Marine Fisheries Commission.[2]

Monitoring

The PIT tags of released fish were passively interrogated by automatic PIT-tag detectors (Prentice et al. 1990a,b,c) within the bypass/detection systems at Little Goose (RKm 635), Lower Monumental (RKm 589), McNary (RKm 470), John Day (RKm 347), and Bonneville Dams (RKm 235; Fig. 2). The majority of detected PIT-tagged fish were diverted back to the river by slide gates (rather than being barged or trucked downstream), which provided the potential for detection of individual fish at multiple sites downstream from release (Marsh et al. 1999).

Statistical Analysis

Travel Times and Migration Rates

Travel times and migration rates were calculated for the following reaches: release (Lower Granite Dam tailrace) to Little Goose Dam (60 km), release to Lower Monumental Dam (106 km), release to McNary Dam (225 km), release to John Day Dam (348 km), and release to Bonneville Dam (460 km). Migration rate through a reach was calculated as the length of reach (km) divided by the travel time (days) and included both delays associated with residence time in forebays before passing dams and those within the bypass system.

The true travel times and migration rates for a release group included travel times and migration rates of both detected and nondetected fish. However, travel times and migration rates could not be determined for fish that traversed a river section but were not detected at one or both ends of the reach. Thus, travel-time and migration-rate statistics were estimated from travel time rates for detected fish only, with computations representing a sub-sample of the complete release group.

Travel times and migration rates for each tagging method between release and each downstream detection location were compared using a two-factor Analysis of

[2] Pacific States Marine Fisheries Commission, PIT Tag Operations Center, 45 SE 82nd Drive, Suite 100, Gladstone, OR 97207.

Variance (ANOVA) with release day as a random (blocking) factor and the treatment as a fixed factor. Residuals were examined to assess the performance of the analysis.

Detection and Survival Probabilities

PIT-tag detection data for all release groups were retrieved from PTAGIS and checked for errors. The "complete capture history" protocol (Burnham et al. 1987) was used to estimate survival and detection probabilities by applying the Single-Release Model (SR) (Smith et al. 1994, Skalski et al. 1998a) independently to each release group. The release-recapture data were analyzed by use of the Survival with Proportional Hazards (SURPH) statistical model developed at the University of Washington (Smith et al. 1994). This model extends the Single-Release Models (Cormack 1964, Jolly 1965, Seber 1965) by simultaneously analyzing release-recapture data from multiple release groups.

Estimated survival and detection probabilities were weighted averages of daily estimates. Weights were inversely proportional to the respective estimated relative variances (coefficient of variation squared). The variance of estimated survival and detection probabilities from the SR Model are a function of the estimates themselves; that is, lower survival and detection probability estimates tend to have smaller estimated variance. Consequently, when estimated absolute variances are used in weighting, lower survival and detection probability estimates tend to have disproportionate influence on the weighted mean. Estimates of survival probabilities under the SR model are random variables, subject to sampling variability. When true survival probabilities are close to 1.0 and/or when sampling variability is high, it is possible for estimates of survival probabilities to exceed 1.0.

Mixing of the release groups at downstream dams was evaluated using contingency table tests for differences between distributions of daily detections at each detector dam. Chi-square goodness-of-fit was used to test equal probability of detection over time. Estimated survival and detection probabilities for each tagging method were compared using a weighted two-factor ANOVA with release day as a random (blocking) factor and the treatment as a fixed factor. The weights were the inverses of the respective sample variances. The analysis was done on the natural log scale to normalize the relative survival estimates and the log-scale means were back transformed. Residuals were examined to assess the performance of the analysis. No formal analysis of adult returns of tagged fish used in this study is anticipated.

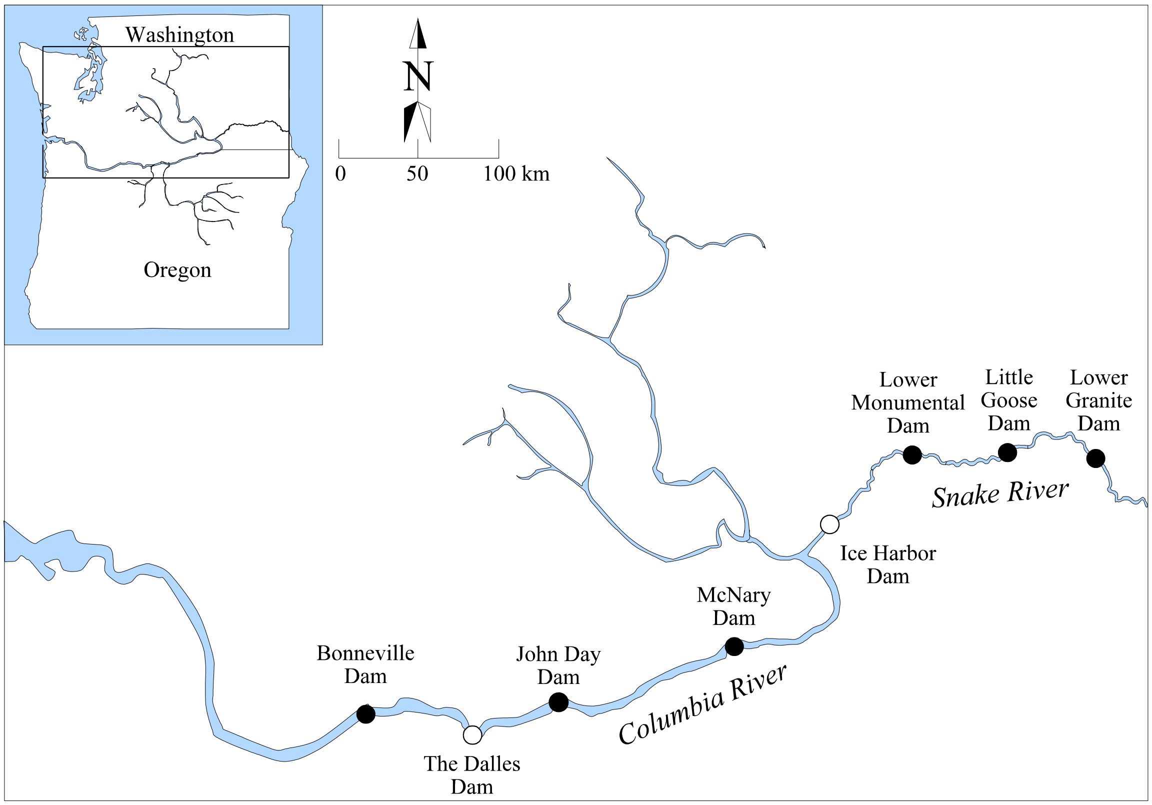

Figure 2. Study area showing release site (Lower Granite Dam), and hydroelectric dams with (●), and without (○) PIT-tag detection facilities.

RESULTS

Fish Collection, Tagging, and Release

Only fish released from 23-28 April were used in the analysis. Fish tagged prior to this period were eliminated because of modifications to fish collection and handling protocols. We released 1,113 surgically tagged, 1,113 gastric tagged, and 1,071 PIT-tagged hatchery yearling chinook salmon over 6 consecutive days at Lower Granite Dam (Table 1). Handling and tagging mortality averaged 1.5% and tag loss averaged 0.6% overall. The minimum, maximum, and average fish sizes were similar among tagging methods (Table 2). The sham transmitters weighed an average of 3.9% of the fish's weight (range 1.3 to 7.0%).

Statistical Analysis

Migration Rates and Travel Times

For detected fish, hatchery yearling chinook salmon with gastrically implanted sham radio tags had shorter travel times (higher migration rates) than either surgically implanted or PIT-tagged fish for all reaches between release and detection at downstream dams (Tables 3 and 4). Migration rates were significantly higher for fish with gastrically implanted sham radio tags ($\alpha = 0.05$) compared to PIT-tagged fish in all reaches between release and McNary Dam (Table 5). Fish with gastrically implanted radio tags also had significantly ($\alpha = 0.05$) higher migration rates than fish with surgically implanted radio tags in all reaches between release and detection at downstream dams except from release to John Day Dam. Migration rates and travel times of fish with surgically implanted radio tags were not significantly different from those of PIT-tagged fish.

Detection Probability

Of the 3,297 tagged fish released into the tailrace of Lower Granite Dam, 2,668 unique PIT-tag detections occurred at downstream dams on the Snake and Columbia Rivers (Table 6). PIT-tag detection probabilities at downstream sites varied among treatments and detection location; however, these differences were less than 5% and were not statistically significant between tagging methods at each detection site (Table 7). The sample sizes used in this study did not provide reasonably precise detection probability estimates downstream from McNary Dam due to very low numbers of fish detected at John Day and Bonneville Dams (Table 6).

Table 1. Numbers of hatchery yearling chinook salmon tagged by surgical implant, gastric implant, or PIT tag and released at Lower Granite Dam for comparison of fish performance during 1999. Tag loss and tagging mortality are also shown.

	Surgical implant				Gastric implant				PIT-tagged			
Tagging date	Number tagged	Tag loss	Tagging mortality	Number released	Number tagged	Tag loss	Tagging mortality	Number released	Number tagged	Tag loss	Tagging mortality	Number released
22 April	155	0	0	155	153	1	0	152	148	0	0	148
23 April	194	0	7	187	201	5	7	189	188	0	1	187
24 April	195	0	2	193	199	1	4	194	185	2	0	183
25 April	195	0	8	187	201	4	9	188	187	1	0	186
26 April	197	0	2	195	203	2	3	198	186	0	2	184
27 April	197	0	1	196	199	2	5	192	184	1	0	183
Total	1,133	0	20	1,113	1,156	15	28	1,113	1,078	4	3	1,071

Table 2. Fork length and weight at tagging for hatchery yearling chinook salmon with surgically implanted sham radio tags, gastrically implanted sham radio tags, or PIT tags released into the tailrace of Lower Granite Dam, 1999. Abbreviations: Min-minimum, Max-maximum.

	Fork Length (mm)				Weight (g)		
Tagging method	N	Min	Max	Mean	Min	Max	Mean
Surgical implant	1,113	127	285	156.7	20.1	110.9	36.5
Gastric implant	1,113	127	264	156.3	20.1	104.0	35.8
PIT tag	1,071	128	284	155.2	20.1	104.3	35.2

Table 3. Travel times (days) for hatchery yearling chinook salmon with surgically implanted sham radio tags, gastrically implanted sham radio tags, or PIT tags released into the tailrace of Lower Granite Dam, 1999. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam; JDD-John Day Dam; BON-Bonneville Dam; N-Number of fish on which statistics are based; 20%-percentile passage; 80%-percentile passage; Med.-Median.

	LGR to LGO				LGR to LMO				LGR to MCN				LGR to JDD				LGR to BON			
	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%
Surgical implant	610	2.7	3.9	6.0	474	4.7	6.4	8.6	253	9.3	11.5	14.3	150	13.0	15.3	18.2	93	14.9	18.3	20.6
Gastric implant	601	2.7	3.6	5.3	493	4.5	5.6	7.8	280	8.2	9.9	12.8	228	11.7	13.7	17.5	134	13.3	15.4	19.6
PIT-tag	585	3.3	4.2	5.9	439	5.1	6.4	8.5	295	8.7	10.8	13.9	138	12.5	14.2	17.9	115	14.3	16.0	18.8

Table 4. Migration rates (km/day) for hatchery yearling chinook salmon with surgically implanted sham radio tags, gastrically implanted sham radio tags, or PIT tags released into the tailrace of Lower Granite Dam, 1999. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam; JDD-John Day Dam; BON-Bonneville Dam; N-Number of fish on which statistics are based; 20%-percentile passage; 80%-percentile passage; Med.-Median.

	LGR to LGO				LGR to LMO				LGR to MCN				LGR to JDD				LGR to BON			
	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%
Surgical implant	610	10.0	15.3	22.1	474	12.3	16.6	22.4	253	15.8	19.6	24.3	150	19.1	22.8	26.8	93	22.3	25.2	30.8
Gastric implant	601	11.3	16.8	22.1	493	13.6	19.0	23.5	280	17.6	22.8	27.3	228	19.9	25.4	29.8	134	23.4	29.9	34.6
PIT-tag	585	10.2	14.1	18.3	439	12.4	16.5	20.6	295	16.1	20.8	26.0	138	19.4	24.5	27.9	115	24.5	28.7	32.1

Table 5. Comparison of migration rates for hatchery yearling chinook salmon with gastrically implanted sham radio tags, surgically implanted sham radio tags, and PIT tags between release into the tailrace of Lower Granite Dam and detection at downstream dams, 1999. Shaded cells indicate significant differences in migration rates determined from ANOVA ($\alpha = 0.05$). Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam; JDD-John Day Dam; BON-Bonneville Dam.

	LGR to LGO	LGR to LMO	LGR to MCN	LGR to JDD	LGR to BON
Gastric vs. PIT	faster $P = 0.001$	faster $P = 0.011$	faster $P = 0.029$	faster $P = 0.800$	faster $P = 0.434$
Gastric vs. Surgical	faster $P = 0.045$	faster $P = 0.016$	faster $P = 0.001$	faster $P = 0.252$	faster $P = 0.047$
Surgical vs. PIT	faster $P = 0.102$	similar $P = 0.972$	slower $P = 0.167$	slower $P = 0.559$	slower $P = 0.336$

Table 6. Numbers of first-time PIT-tag detections at hydroelectric dams on the Snake and Columbia Rivers for hatchery yearling chinook salmon tagged with either surgically implanted sham radio tags, gastrically implanted sham radio tags, or PIT tags released into the tailrace of Lower Granite Dam, 1999. Percentages of numbers released in parentheses. See Table 1 for numbers released.

	Surgical implant	Gastric implant	PIT tag	All fish
Little Goose Dam	610 (54.8%)	601 (54.0%)	585 (54.6%)	1,796 (54.5%)
Lower Monumental Dam	188 (16.9%)	231 (20.8%)	184 (17.2%)	603 (18.3%)
McNary Dam	54 (4.9%)	56 (5.0%)	70 (6.5%)	180 (5.5%)
John Day Dam	13 (1.2%)	23 (2.1%)	19 (1.8%)	55 (1.7%)
Bonneville Dam	8 (0.7%)	13 (1.2%)	13 (1.2%)	34 (1.0%)
Total	873 (78.4%)	924 (83.0%)	871 (81.3%)	2,668 (81.0%)

Table 7. Estimated detection probabilities for hatchery yearling chinook salmon tagged with either surgically implanted sham radio tags, gastrically implanted sham radio tags, or PIT tags released into the tailrace of Lower Granite Dam, 1999. The estimated detection probabilities (provided by the Single-Release Model) were compared using ANOVA ($\alpha = 0.05$). Standard errors in parentheses. See Table 1 for numbers released.

	Surgical implant	Gastric implant	PIT tag	*P*
Little Goose Dam	0.620 (0.018)	0.578 (0.019)	0.598 (0.019)	0.309
Lower Monumental Dam	0.554 (0.034)	0.515 (0.034)	0.507 (0.035)	0.594
McNary Dam	0.328 (0.023)	0.365 (0.017)	0.343 (0.021)	0.418

Survival Estimates

Estimated survival was not statistically different among tagging methods between release and the tailraces of Little Goose, Lower Monumental, and McNary Dams (Table 8). Estimated survival relative to PIT-tagged fish was slightly higher, but not significantly different for fish tagged via gastric implant vs. fish tagged via surgical implant. Although survival estimates from release to McNary Dam were not significantly lower, the estimates approached statistical significance. The sample sizes used in this study did not provide reasonably precise survival estimates downstream from McNary Dam due to very low numbers of fish detected at Bonneville and John Day Dams (Table 6).

Table 8. Estimated survival probabilities for hatchery yearling chinook salmon tagged with either surgically implanted sham radio tags, gastrically implanted sham radio tags, or PIT tags released into the tailrace of Lower Granite Dam, 1999. The estimates (provided by the Single-Release Model) were compared using ANOVA ($\alpha = 0.05$). Standard errors in parentheses. Abbreviations: LGO-Little Goose Dam; LMO Lower Monumental Dam; MCN-McNary Dam. See Table 1 for numbers released.

	Surgical implant	Gastric implant	PIT tag	*P*
Release to LGO	0.895 (0.019)	0.941 (0.018)	0.915 (0.018)	0.263
Release to LMO	0.800 (0.042)	0.889 (0.043)	0.848 (0.044)	0.379
Release to MCN	0.729 (0.043)	0.743 (0.031)	0.872 (0.045)	0.062

DISCUSSION

The basic premise in telemetry research is that radio-tagged individuals behave and survive like non-tagged individuals. In recent years, radio tags have been miniaturized sufficiently for use in smaller fish such as juvenile salmonids. Radiotelemetry has been used extensively in the Snake and Columbia Rivers to evaluate surface bypass collectors (Adams et al. 1996, 1997; Hensleigh et al. 1997) and spillway efficiency (Eppard et al. 1998).

Recent advances in tagging technology (PIT tags and balloon tags) and statistical models have provided the methodology to calculate precise survival estimates of juvenile salmonids through various routes of passage at Snake and Columbia River Dams (Muir et al. 1994, 1998; Normandeau Associates 1995, 1997; Mathur et al. 1996) as well as reach survival estimates incorporating both dam- and reservoir-related mortality (Iwamoto et al. 1994; Muir et al. 1995, 1996; Smith et al. 1998; Hockersmith et al. 1999). PIT tags have worked well for estimating both route-specific mortality at dams and reach survival estimates.

However, PIT-tag evaluations require large numbers of smolts and adequate detection facilities downstream. Balloon tags have worked well for route-specific survival estimates through dams (i.e., turbine or spillway survival), but have not been used for reach survival estimates because of concerns about the effects of the balloon on fish performance.

As a solution to these obstacles, the use of radiotelemetry to evaluate survival is appealing because of the relatively small sample sizes required compared to other methods (PIT tags, coded-wire tags, or nitrogen freeze brands) and the potential for use in areas without sufficient detection or recapture capabilities downstream. Sample sizes for radiotelemetry studies are smaller than for other methods because detection probabilities for radio tags are usually very high (Skalski et al. 1998b). As more salmonid stocks in the Columbia River Basin have been listed under the Endangered Species Act, radiotelemetry has become an increasingly attractive tool for studies of juvenile salmonids.

Skalski et al. (1998b) recently proposed a pilot study using radiotelemetry to evaluate reach and project survival in the mid-Columbia River through Rocky Reach and Rock Island dams. Normandeau Associates et al. (1998) have proposed a similar study using radiotelemetry to evaluate survival through Priest Rapids Dam. In these studies, the same model used to estimate survival in recent PIT-tag studies (Single-Release Model) or a new model, the Route Specific Survival Model (RSSM) proposed by Skalski et al. (1998b), would be used to estimate survival based on radiotelemetry detections.

As with PIT-tag studies, certain assumptions of these models must be met for valid survival estimation. Two of the stated assumptions from Skalski et al. (1998b) are A1) Individuals marked for the study are a representative sample from the population of interest, and A2) Survival and capture probabilities are not affected by tagging or sampling. That is, tagged animals have the same survival probabilities as untagged animals. Juvenile fish are likely to be more sensitive to the presence of the transmitter and attachment methods than adult fish since the weight of the transmitter is a greater percentage of body weight. Both the weight of the transmitter and the presence of a trailing antenna may reduce swimming performance, foraging ability, predator avoidance, and ultimately survival.

Meeting the first assumption may be difficult in radiotelemetry studies with juvenile chinook salmon because a portion of the population is smaller than the minimum size preferred for radio tagging. However, if the mean size of fish in the radio-tagged sample is similar to that of the population, then the tagged sample should be representative of the majority of the population. Most telemetry studies have tagged only the larger smolts (fork length greater than 120 mm for spring migrants, 110 mm for summer migrants) within the entire population. Winter (1983) recommended that the radio transmitter weight be 2% or less of the fish's weight.

However, Adams et al. (1998a) demonstrated that the growth, feeding behavior, and survival of juvenile chinook salmon were unaffected by implanted radio transmitters that weighed up to 5.5% of the fish's weight. Our transmitters weighed 1.4 g, or an average of 3.9% of the fish's weight (range 1.3 to 7.0%). Although radio transmitters have decreased in both size and weight in recent years, battery technology, tag-life requirements, and transmission capability have precluded the manufacture of smaller coded transmitters.

Assumption A2 requires that the presence of the radio tag and the tagging procedure do not significantly affect the performance of tagged fish. If the behavior of smolts is altered by the radio tag, then estimates of survival or passage behavior from tagged smolts should not be inferred for the untagged population. For example, radio-tagged fish might swim at a different depth than non radio-tagged fish, and could be more or less likely to pass dams via juvenile fish bypass systems, spillways, or surface bypasses, or be more vulnerable to predation.

In our study, detection probabilities and survival were not significantly different among tag types between the release site and Lower Monumental Dam (a distance of 106 km), but survival decreased for surgically and gastrically implanted sham radio-tagged fish compared to PIT-tagged fish farther downstream. Sample sizes and detection probability limited the ability to determine significant differences in survival downstream from Lower Monumental Dam. Jepsen et al. (1998) reported that in the wild, radio-tagged smolts were more susceptible to predation than non-radio-tagged fish. These results are not surprising, since conditions smolts encounter in the wild, such as feeding and predator avoidance, are normally less forgiving than those in a laboratory setting.

Migration rates between release and downstream dams were significantly higher for yearling chinook salmon with gastrically implanted radio tags than for either surgically radio- tagged or PIT-tagged fish. The higher migration rates for fish with gastrically implanted tags may have been due to less time spent feeding because of reduced efficiency in consuming food. In recent evaluations using juvenile chinook salmon, both Martinelli et al. (1998) and Adams et al. (1998a) found that the presence of gastrically implanted radio tags significantly reduced growth over the long-term (21 to 54 days), whereas surgically implanted radio tags had little or no effect on growth rate.

Both studies observed "coughing behavior" in gastrically implanted fish, with 5% of the fish successfully expelling tags in the study by Martinelli et al. (1998). Both studies observed abrasions in the mouth near the antenna exit with gastric implantation, with the severity of abrasions increasing over time. Similar feeding activity was observed when comparing controls and fish with either surgically or gastrically implanted radio tags.

These two studies indicated that the lower growth rates for gastrically tagged fish were probably due to difficulty in consuming food and not the ability to compete for food since fish were fed to satiation. Similarly, McCleave and Stred (1975) showed that after 11 days, juvenile Atlantic salmon (*Salmo salar*) with gastrically implanted tags did not have food in their stomachs, but the majority of control fish did.

Furthermore, Adams et al. (1998b) found reduced swimming performance for both gastrically and surgically implanted chinook salmon less than 120 mm in fork length. For fish greater than 120 mm in fork length, swimming performance in surgically implanted fish was reduced after 1 day but not after 21 days. For gastrically implanted fish the opposite was observed: swimming performance was not affected after 1 day, but was significantly lower after 21 days. Fish with either gastric or surgical implants had significantly reduced predator avoidance capabilities compared to controls. Both Adams et al. (1998a,b) and Martinelli et al. (1998) concluded that surgical implantation was the preferred method for most studies, although gastric implantation might be preferred for studies of short duration.

RECOMMENDATIONS

Based on our study, juvenile yearling chinook salmon may be tagged using either surgical or gastric implantation and have similar survival to PIT-tagged fish in the wild through reaches up to 106 km in length. Since this study analyzed survival based on PIT-tag detections and there are no PIT-tag detection facilities between Lower Monumental and McNary Dams (a distance of 119 km) we were unable to determine where or when survival for fish with gastric or surgical implanted radio tags decreased compared to survival for PIT-tagged fish between these dams.

Although we used the Single Release Model to estimate survival for this study, one could estimate survival for radio-tagged fish by using a Paired-Release Model similar to that described by Burnham et al. (1987). The Paired Release Model estimates survival of a treatment group relative to a reference group based on subsequent recapture or detection. The Paired-Release Model assumes random mixing of both treatment and reference groups. Therefore, if both treatment and reference groups are handled and tagged similarly and the groups are temporally and spatially mixed (thereby experiencing similar conditions during downstream movement) both the tagging and/or tag effects would not influence estimation of survival.

Radiotelemetry can be a useful tool for obtaining survival estimates in situations without good PIT-tag detection probabilities (e.g., lower Columbia River, The Dalles Dam, Ice Harbor Dam), or when there are concerns about the number of fish handled. Researchers can minimize concerns of radio tagging and/or tag effects on survival estimates by utilizing a Paired-Release model study design.

Tagging method considerations should include skill of tagging personnel, handling stress, post-tagging holding and recovery conditions, and duration of the study. Surgical implantation may be more stressful to study fish and requires more experienced personnel, aseptic conditions, and increased handling. Surgical implants cannot be easily removed from recaptured fish, and surgically tagged fish may be more susceptible to infection than gastrically tagged fish.

On the other hand, gastric implantation may affect long-term health and growth due to lower efficiency in consuming food. Fish with gastrically implanted tags may migrate faster because they spend less time foraging. In addition, tag loss for gastrically implanted tags (due to regurgitation) is much higher than for surgically implanted tags. Research design and data interpretation and analysis can be affected by any or all of these factors.

Regardless of tagging method, consideration should be given to fish handling and tagging techniques to minimize stress. Also, post-tagging holding and recovery conditions should provide access to the water surface for buoyancy compensation.

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