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Effects of surgically implanted acoustic transmitters >2% of body mass on the swimming performance, survival and growth of juvenile sockeye and Chinook salmon

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The influence of surgical implantation of an acoustic transmitter on the swimming performance, growth and survival of juvenile sockeye salmon *Oncorhynchus nerka* and Chinook salmon *Oncorhynchus tshawytscha* was examined. The transmitter had a mass of 0·7 g in air while sockeye salmon had a mass of 7·0–16·0 g and Chinook salmon had a mass of 6·7–23·1 g (a transmitter burden of 4·5–10·3% for sockeye salmon and 3·1–10·7% for Chinook salmon). Mean critical swimming speeds (U_{crit}) for Chinook salmon ranged from 47·5 to 51·2 cm s^{-1} [4·34–4·69 body lengths (fork length, L_F) s^{-1}] and did not differ among tagged, untagged and sham-tagged groups. Tagged sockeye salmon, however, did have lower U_{crit} than control or sham fish. The mean U_{crit} for tagged sockeye salmon was 46·1 cm s^{-1} (4·1 L_F s^{-1}), which was *c.* 5% less than the mean U_{crit} for control and sham fish (both groups were 48·6 cm s^{-1} or 4·3 L_F s^{-1}). A laboratory evaluation determined that there was no difference in L_F or mass among treatments (control, sham or tag) either at the start or at the end of the test period, suggesting that implantation did not negatively influence the growth of either species. None of the sockeye salmon held under laboratory conditions died from the influence of surgical implantation of transmitters. In contrast, this study found that the 21 day survival differed between tagged and control groups of Chinook salmon, although this result may have been confounded by the poor health of Chinook salmon treatment groups.

Key words: growth; survival; swimming performance; transmitter.

INTRODUCTION

As ocean-bound juvenile Pacific salmon *Oncorhynchus* spp. migrate down the Columbia River, U.S.A., they pass hydroelectric dams. Comprehensive monitoring programmes, including studies using acoustic telemetry, are undertaken to examine the influence of these dams on fish passage, behaviour and survival. In order that the experimental procedures properly reflect the population at large, it is important that the effects of transmitters are not disproportionate

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to the tagged fishes. Several aspects of transmitter implantation could influence the behaviour, survival or growth of migrating juvenile salmonids. Swimming performance of juvenile salmonids could be influenced either by the excess burden of a transmitter, or by the process of implanting the transmitter. Typically, the critical swimming speed (U_{crit}, an index of prolonged swimming performance; Beamish, 1978; Webb, 1995) is compared among test groups [*e.g.* tagged, sham (*i.e.* surgery, but no transmitter)] and a control group to determine if swimming performance is influenced by tag implantation.

Several researchers have used swimming performance studies to examine how implantation of transmitters influences fishes of varying size (Adams *et al.*, 1998*a*; Brown *et al.*, 1999; Anglea *et al.*, 2004). Adams *et al.* (1998*a*) found that juvenile Chinook salmon *Oncorhynchus tshawytscha* (Walbaum) (10–46 g) implanted with radio transmitters (with a 31 cm long antenna) had lower U_{crit} when they were surgically or gastrically implanted with a radio transmitter that had a mass of 1 g (2·2–10·4% of the fish's body mass). This was true when fish recovered from implantation for 1 day; however, if fish were allowed to recover for 21 days, the larger of the fish (120–160 mm fork length, L_F) had U_{crit} similar to control fish. The smaller of the tagged fish (95–120 mm L_F) still had lower U_{crit} than control fish. The presence of an antenna, however, adds the variable of drag to the possible negative influence of these transmitters. As such, an antenna two to three times the L_F of the fish may negatively influence the swimming performance of tagged fish (Murchie *et al.*, 2004). Results may be different, however, for fish that are implanted with transmitters, which do not have external antennas such as acoustic transmitters.

Other studies have examined the influence on fishes of transmitters with very short or no antennas. Anglea *et al.* (2004) determined that the U_{crit} of juvenile spring Chinook salmon with a mass of 23–45 g was not influenced by the presence of an acoustic transmitter between 3 and 6·5% of the fish's mass in air (tag 1·5 g in air, 1·0 g in water). Fish were allowed to recover 1 and 21 days following surgical implantation. Brown *et al.* (1999) determined that the U_{crit} of juvenile rainbow trout *Oncorhynchus mykiss* (Walbaum) (5–10 g) was not negatively influenced by surgical implantation of a radio transmitter. They implanted fish with radio transmitters (0·6 g in air, 0·4 g in water), which had a mass between 6 and 12% of the fish's mass in air and had their antenna shortened to 2·5 cm.

The presence of a transmitter, or the surgical procedure, may decrease the growth of fishes or even lead to mortality. If growth is decreased, then the implanted fishes may not behave similar to untagged fishes, or may be more likely to die. Adams *et al.* (1998*b*) noted that juvenile Chinook salmon with a mean mass of 28·0 g had decreased growth 21 days after being implanted with a radio transmitter with a mass of 1·0 g in air (0·7 g in water). The authors found that mortality was not influenced by the implantation of the radio transmitter. Unfortunately there has not been any research on how the growth of smaller salmonids (*e.g.* 6 g) would be influenced by a transmitter with a mass of up to 10% of their body mass in air.

The objective of this study was to determine if implantation of an acoustic transmitter with a mass in air of 0·7 g would influence the swimming performance, growth or survival of juvenile sockeye *Oncorhynchus nerka* (Walbaum)

and Chinook salmon with a mass of 6·7–23·1 g. This research is important in that it will inform managers about the effects of transmitters and transmitter implantation on small juvenile salmonids. As far as is known, no other research that has examined the influence of transmitters on Pacific salmon in this size range, in addition, very little telemetry work has been done on juvenile sockeye salmon. Some authors suggest that transmitter burden generally should not exceed 2% (Winter, 1996), however, it was hypothesized that being tagged with transmitters, which had a mass of up to 10% of the fishes body mass would not negatively influence their critical swimming speeds, growth or survival.

MATERIALS AND METHODS

FISH HANDLING AND TAGGING

Run-of-the-river sub-yearling juvenile sockeye and Chinook salmon were used for this study. Fishes were acquired at the Rocky Reach Dam, Washington, U.S.A., juvenile sampling facility, located at river kilometre 761 on the Columbia River. Sockeye salmon were transported to the Pacific Northwest National Laboratory (PNNL) on 17 May 2004, while Chinook salmon were transported on 12 July 2004. Fish maintenance, handling and testing procedures were reviewed and approved by PNNL's Animal Care Committee. During the study period, the test populations were held in two outdoor circular tanks (each tank was 1·83 m diameter and 0·53 m deep and held 1394 l of water). All sockeye salmon holding tanks and test chambers were supplied with 10–13° C well water, while Chinook salmon holding tanks and test chambers were supplied with 13–16° C well water. Sockeye salmon were fed primarily frozen brine shrimp *Artemia* sp., but their diet was supplemented with Biodiet™ moist pellets. Chinook salmon were fed frozen brine shrimp when they first arrived in the laboratory but quickly converted over to Biodiet™ moist pellets. Fishes selected for a given test were not fed 24 h before and 48 h after surgery. Tested juvenile sockeye salmon ranged from 101 to 133 mm L_F and in mass from 7·0 to 16·0 g. Tested juvenile Chinook salmon ranged from 91 to 125 mm L_F and in mass from 6·7 to 23·1 g.

Treatment fishes were implanted with model 795 m acoustic tags (Hydroacoustic Technology, Inc., Seattle, WA, U.S.A.). Test tags measured *c.* 6·8 mm in diameter, 16·5 mm in L_F and 0·7 g in air. Transmitters made up 4·6–8·4% of the body mass in air for sockeye salmon and 3·2–10·0% for Chinook salmon. Tags had a volume of 0·32 ml and mass of 0·41 g in water.

Surgical procedures followed those used by Anglea *et al.* (2004). All surgeries were conducted by a single, experienced surgeon. Each fish was anaesthetized with an 80 mg l^{-1} (Chinook salmon) or 100 mg l^{-1} (sockeye salmon) solution of MS-222. The L_F (nearest mm) and mass (g) for all treatment groups, including controls, were measured after fishes were anaesthetized. While still anaesthetized, the fish was placed ventral side up in a groove within a piece of wet foam that was saturated with a solution of PolyAqua® (Kordon Aquarium Products, Hayward, CA, U.S.A.). A small tube inserted in the fish's mouth during surgery provided a continuous solution of 40 mg l^{-1} MS-222. A 10 mm incision was made 3 mm from the midventral line, anterior to either of the pelvic fins, and the transmitter was inserted into the peritoneal cavity. Sham fishes were incised but no tag was inserted. Incisions were closed with two simple, interrupted sutures for all fishes that underwent surgery (Ethicon absorbable 5-0 coated vicryl violet braided sutures). Neobacimyx antibiotic ointment was placed on the closed incision. Following surgery, fishes recovered in a circular tank for a minimum of 48 h before they were used in a test. Fishes designated as controls were handled (*i.e.* netted from tanks) but did not experience anaesthesia or surgery. All fishes were allowed to recover from surgery in a common tank. Lights inside the tank room were automatically controlled to follow the natural photoperiod (46°16′ N). Following recovery,

fishes were designated into either the swimming performance experiments or growth experiments.

SWIMMING PERFORMANCE

For the swimming performance tests, sub-yearling Chinook salmon and sockeye salmon were randomly assigned to one of three treatment groups: tag, sham (surgery, but no transmitter) and control (Table I). There was no significant difference in mass or L_F among groups for Chinook or for sockeye salmon (ANOVA, Chinook mass and L_F: $F_{2,186}$, $P > 0{\cdot}05$ and $F_{2,186}$, $P > 0{\cdot}05$, respectively; sockeye salmon mass and L_F: $F_{2,193}$, $P > 0{\cdot}05$ and $F_{2,193}$, $P > 0{\cdot}05$, respectively).

The U_{crit} was measured by placing a fish in a clear PVC tube (91 cm long, 10 cm in diameter). A bundle of six tubes was constructed to allow simultaneous testing of six fishes. The bundle was placed in the swimming chamber (1·76 m × 0·54 m × 0·57 m) of a Brett-type respirometer (Brett & Glass, 1973). The respirometer is capable of velocities from 0·07 to >2·1 m s^{-1}. The relationship between water velocity in the respirometer and motor speed was established using a Swoffer Instruments, Model 3000 flowmeter. An electrified grid, containing separate circuits for each tube, was secured to the downstream end of the tube bundle. A section of flow straightener and reducer (0·57 m long) was placed at the upstream end of the tube bundle. A black cover was placed at the upstream end to provide cover and orientation for test fishes.

Swimming performance tests were conducted from 8 to 23 June 2004, for sockeye salmon and from 29 July to 25 August 2004, for Chinook salmon. Surgery and sham-tagged fishes were tested 2 days after surgery. The U_{crit} was calculated using the formula of Brett (1964): $U_{crit} = u_i + t_i (t_{ii}u_{ii})^{-1}$, where u_i is the highest velocity maintained for the prescribed period (cm s^{-1}), u_{ii} is the velocity increment (cm s^{-1}), t_i is the time (min) fish swam at the 'fatigue' velocity and t_{ii} is the prescribed period of swimming (min).

For each trial, two fishes were randomly selected from each of the three treatment groups. Tag and sham fishes were differentiated by scanning with a metal detector to check for the presence of a tag. The fishes were anaesthetized in an 80–100 mg l^{-1} solution of MS-222. After L_F and mass were recorded, fishes were placed in the swimming chamber. Placement was done systematically so that an equal number of fishes from each treatment were tested in each of the six tubes. Fishes were then allowed a 15 min recovery period starting from the time the last fish was placed in its tube. After this recovery from anaesthetization, the trial was initiated.

Fishes were given an acclimation period of 2 h with the respirometer speed set at 0·7 body lengths (L_F) s^{-1} (L_F s^{-1}). The acclimation velocity was determined by taking the average L_F of the fishes. The first increment of the U_{crit} test was performed at 0·8 L_F s^{-1}. Thereafter, the speed was increased by 0·8 L_F s^{-1} every 30 min.

TABLE I. Mean ± S.D. and range of fork length and mass for each treatment group tested for critical swimming speed

			L_F (mm)		Mass (g)	
Species	Treatment	n	Mean ± S.D.	Range	Mean ± S.D.	Range
Sockeye salmon	Control	65	113 ± 1	102–123	11·4 ± 1·2	7·6–14·6
	Tag	66	114 ± 4	106–133	11·5 ± 0·9	9·1–13·0
	Sham	65	113 ± 3	101–118	11·2 ± 1·0	8·5–13·3
Chinook salmon	Control	63	110 ± 7	95–125	13·8 ± 2·9	8·7–22·0
	Tag	63	108 ± 6	95–125	13·1 ± 2·8	7·5–23·1
	Sham	63	109 ± 7	94–125	13·5 ± 2·9	7·2–21·0

If a fish stopped swimming and fell back to the downstream end of the tube, that segment of the shocking grid was activated to emit a mild electrical shock. Three mild shocks spaced 3 s apart were administered if a fish remained on the grid, and the fish was considered fatigued if it did not resume swimming following the third shock. The U_{crit} for that fish was then determined using the speed at which the fish fatigued and the number of minutes (out of 30) the fish swam at that speed. The trial was complete when the last fish swimming would not leave the shocking grid.

Data analysis was conducted by first examining which factors [*i.e.* treatment, swim tube (one of six), water velocity, L_F and mass] had an important influence on U_{crit}. This was done in a preliminary univariate regression model to assess the individual correlation of each predictor variable with the response variable (U_{crit}) and to establish the order of entry into the subsequent multivariate model building process. Multivariate analysis was performed by sequentially adding predictor variables in descending order of variance (deviance). This sequential model building process was based on likelihood ratio tests that screen for the smallest set of significant variables while controlling for correlations between predictor variables. This allowed for a final model including the smallest set of factors that increased model predictive power and yielded the smallest mean squared error (MSE) or dispersion parameter. The MSE was used to compute the statistical power curves for the experiment. A model with more predictive power will yield a smaller MSE and increase the statistical power of the experiment to detect changes in mean U_{crit} between treatment groups.

SURVIVAL AND GROWTH

Survival and growth were determined for both juvenile sockeye and Chinook salmon. Fishes were divided into three groups (control, sham and tagged) consisting of 50 fish each (Table II). Prior to testing, each group was uniquely freeze-branded for identification. Surgery and implantation of transmitters was conducted as described above including measurement of mass and L_F. Transmitters accounted for 4·6–7·2% of the mass of sockeye salmon in air, and 4·3–9·7% of the mass of Chinook salmon in air.

Twice each day (morning and evening), fishes were checked for mortalities. If any mortalities occurred, brands were used to determine which group the fishes originated from. The L_F and mass were determined for all mortalities. Fishes were held for at least 21 days, whereupon all fishes were removed, euthanized (by exposure to 250 ppm MS-222 solution for at least 10 min following cessation of opercular movement), and L_F and mass were determined.

To determine if 21 day survival varied significantly with treatment, each fish in the study was coded for survival (1 if surviving, 0 otherwise) and with a three-level factor indicating the treatment group (0 = control, 1 = sham, 2 = tagged). These data were entered into a logistic model suitable for binary response and fit to the three-level treatment factor with the control treatment specified as the reference level. Incidental

TABLE II. Mean ± S.D. and range of fork length and mass for sockeye and Chinook salmon tested to determine the influence of transmitter implantation on growth and survival

			L_F (mm)		Mass (g)	
Species	Treatment	*n*	Mean ± S.D.	Range	Mean ± S.D.	Range
Sockeye salmon	Control	50	113 ± 3	105–119	12·1 ± 1·3	7·0–14·7
	Tag	50	113 ± 3	105–123	12·2 ± 1·1	10·2–16·0
	Sham	50	114 ± 3	109–120	12·3 ± 1·0	8·8–14·4
Chinook salmon	Control	50	104 ± 7	93–118	12·1 ± 2·6	6·7–17·1
	Tag	50	105 ± 6	93–116	12·4 ± 2·0	7·5–16·8
	Sham	50	104 ± 6	92–115	12·0 ± 2·3	6·8–16·9

mortalities, occurring as a result of two Chinook and three sockeye salmon jumping out of the aquaria, were excluded from the analysis. To address how survival of each treatment compared to the control group in a pair-wise comparison, three separate binary models were fitted: the first taking only sham and control fishes, the second taking only tagged and control fishes, and the third taking only sham and tagged fishes with pair-wise significance assessed from likelihood ratio F-tests.

Differences in growth among the three groups (tag, sham and control) were assessed using ANOVA tests to compare the population mean L_F and mass of all surviving fishes at the start and the end of the 21 day study period. Start and end pair-wise measurements of L_F and mass on uniquely identified fishes were not available. The L_F and mass of all 150 fishes of both species starting the 21 day study period (50 from each treatment group) were included in the analysis. Measurements on the incidental mortalities as described above, however, were excluded from the L_F and mass measurements taken at the end of 21 days.

RESULTS

SWIMMING PERFORMANCE

Mean U_{crit} for Chinook salmon ranged from 47·5 to 51·2 cm s^{-1} (Table III and Fig. 1). There was no significant difference in the U_{crit} among the three groups (likelihood ratio test, $F_{2,181}$, $P > 0{\cdot}05$). Neither L_F nor tube had a significant influence on U_{crit} (likelihood ratio test, L_F: $F_{2,183}$, $P > 0{\cdot}05$; tube: $F_{4,184}$, $P > 0{\cdot}05$). Mass was not significantly related to swimming speed and (as may be expected) was highly correlated with L_F and was consequently not included in the final model.

The sample data from the experiments showed a maximum difference in the sample means between treatment groups of 0·35 L_F s^{-1} (Table III) for Chinook salmon. This difference was *c.* 8% of the observed mean U_{crit} for the Chinook salmon control group in the study. The data obtained from the U_{crit} experiments were sufficient to detect a difference of $\geq$14·1% with 80% power, and a difference of 20% with power approaching 100% had differences between treatment groups of that size existed.

Mean U_{crit} for sockeye salmon ranged from 46·1 to 48·6 cm s^{-1} (Table III and Fig. 1). In contrast to Chinook salmon, treatment significantly affected U_{crit} of juvenile sockeye salmon (likelihood ratio test; $F_{2,187}$, $P < 0{\cdot}05$). The mean U_{crit} for tagged sockeye salmon was 46·1 cm s^{-1} (4·1 L_F s^{-1}), which was *c.* 5% less than the mean U_{crit} for control and sham fish (both groups were 48·6 cm s^{-1} or 4·3 L_F s^{-1}). There was also a significant influence on U_{crit} from

TABLE III. Mean ± S.D. relative critical swimming speed expressed in cm s^{-1} and in L_F s^{-1} for juvenile sockeye salmon and Chinook salmon

Species	Treatment	n	U_{crit} cm s^{-1}	U_{crit} L_F s^{-1}
Sockeye salmon	Control	65	48·6 ± 10·7	4·29 ± 0·91
	Tag	66	46·1 ± 11·0	4·06 ± 0·98
	Sham	65	48·6 + 11·2	4·29 ± 0·97
Chinook salmon	Control	63	47·6 ± 13·8	4·34 ± 1·30
	Tag	63	47·5 ± 10·9	4·42 ± 1·04
	Sham	63	51·2 ± 9·7	4·69 ± 0·87

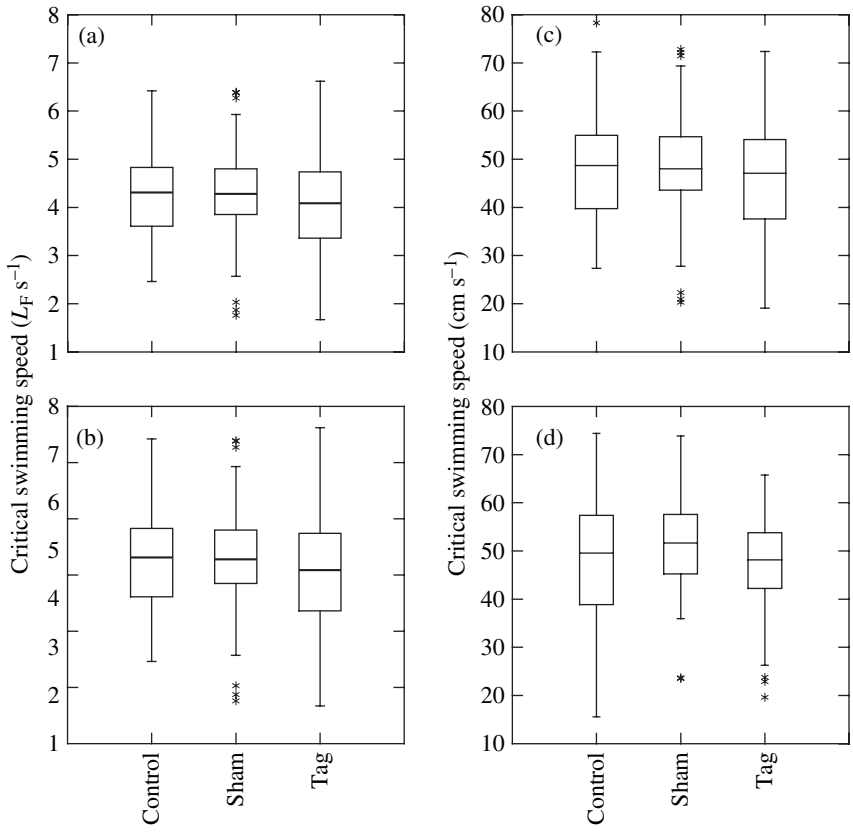

FIG. 1. Box plots of the critical swimming in (a) and (b) body lengths (L_F) s^{-1}, and (c) and (d) cm s^{-1} for the three groups (control, sham and tag) for (a) and (c) sockeye, and (b) and (d) Chinook salmon. The top and bottom edges of the boxes indicate the 25th and 75th percentile of data, the line within each box indicates the median of the data. Whiskers indicate 1·5 × interquartile range beyond the box and * indicate outliers.

the covariates fish mass and the tube the fish were tested in (likelihood ratio test, mass: $F_{1,189}$, $P < 0{\cdot}05$; tube: $F_{5,190}$, $P < 0{\cdot}001$). L_F was also an influence on the U_{crit} because it is a measure of fish size, but was excluded from the final model because it was confounded with mass and explained less deviance than mass.

The sample data from the experiments showed a maximum difference in the sample means between treatment groups of 0·226 L_F s^{-1}, or *c.* a 5% difference between tagged fishes and control fishes (Table III). Data obtained from the U_{crit} experiments were sufficient to detect a difference of $\geq$10·4% with 80% power and a difference of 20% with power approaching 100% had differences between treatment groups of that size existed.

GROWTH AND SURVIVAL

Implanted Chinook salmon had significantly lower 21 day survival than controls ($F_{1,96}$, $P < 0{\cdot}01$), but the survival of sham fish did not significantly differ from that of control fish ($F_{1,97}$, $P > 0{\cdot}05$) (Table IV). There were no significant

TABLE IV. The number of juvenile Chinook and sockeye salmon that died (and per cent survival of the original group number) during the 21 day laboratory test, by treatment types. Mortalities from fishes that jumped out of the tank are not included in the estimates

Species	Control	Sham	Tag
Sockeye salmon	0 (100%)	0 (100%)	0 (100%)
Chinook salmon	2 (96%)	7 (86%)	12 (76%)

differences in growth among treatments (control, sham and tag) either at the beginning or at the end of the test period for L_F or mass (L_F: $F_{2,271}$, $P > 0{\cdot}05$; mass: $F_{2,271}$, $P > 0{\cdot}05$). Within all the groups, there was a significant increase in both L_F and mass with increases in time ranging from 4·0 to 5·9 mm and increases in mass ranging from 1·9 to 3·1 g ($F_{1,271}$, $P < 0{\cdot}001$ for both L_F and mass).

None of the sockeye salmon died during the 21 day experiment (Table IV). Since there were no non-incidental mortalities, there is no basis for statistically analysing survival results for sockeye. There were no significant differences in growth among treatments for L_F or mass (L_F: $F_{2,293}$, $P > 0{\cdot}05$; mass: $F_{2,293}$, $P > 0{\cdot}05$; Table V). Although there were no differences among treatment groups, all groups lost mass (0·7–1·0 g) over the 21 day test.

DISCUSSION

SWIMMING PERFORMANCE

Two days after implantation, the swimming performance of juvenile Chinook salmon was not influenced by the surgical implantation of an acoustic transmitter (see Table VI for antenna specifications and mass in relation to fish size for this and other studies discussed). Similar results have been found by other researchers studying juvenile salmonids carrying similar transmitter loads

TABLE V. Mean ± S.D. fork length and mass of sockeye and Chinook salmon at the beginning and end of a 21 day test period. Fishes were either controls, implanted with a 0·75 g acoustic transmitter or had surgery performed but no transmitter inserted (sham). The mean change in L_F and mass is also shown

			L_F (mm)			Mass (g)		
Species	Treatment	n	Beginning	End	Change	Beginning	End	Change
Sockeye salmon	Control	50	112·8 ± 2·8	111·9 ± 2·8	−0·9	12·1 ± 1·3	11·4 ± 1·0	−0·7
	Sham	50	113·7 ± 2·6	112·1 ± 3·0	−1·6	12·3 ± 1·0	11·4 ± 1·0	−0·9
	Tag	50	112·9 ± 3·0	111·1 ± 3·4	−1·8	12·2 ± 1·1	11·2 ± 1·1	−1
Chinook salmon	Control	50	104·2 ± 7·2	109·9 ± 7·1	5·7	12·1 ± 2·6	14·6 ± 3·2	2·5
	Sham	50	103·9 ± 6·1	109·8 ± 6·4	5·9	12·0 ± 2·3	15·1 ± 3·1	3·1
	Tag	50	105·2 ± 6·0	109·2 ± 5·7	4	12·4 ± 2·0	14·3 ± 2·7	1·9

TABLE VI. Species and mass (range) of fishes and size of tags and percentage of body mass of fishes, which were examined for swimming performance by several authors and for this study

Species	*n*	Mean mass of tagged fish (g)	Antenna length (cm)	Tag mass in air (g)	Tag excess mass (g)	Per cent tag mass in air	Per cent tag mass in water
Sockeye salmon[1]	196	11·5 (9·1–13)	None	0·75	0·41	5·8–8·2	3·2–4·5
Chinook salmon[2]	189	13·1 (7·5–23·1)	None	0·75	0·41	3·2–10	1·8–5·5
Chinook salmon[3]	156	34–36 (25–45)	None	1·5	1	1·6–6·7	2·2–4·0
Rainbow trout[4]	38	7·4 (5–10)	2·5	0·6	0·4	6–12	4–8
Chinook salmon[5]	128	NA (10–46)	31	1	0·7	2·2–10	1·5–7
Atlantic salmon[6]	80	29·2–31·9 (NA)	28	0·75	0·5	Mean 2·4–2·5	

1, 2, this study; 3, Anglea *et al.*, 2004; 4, Brown *et al.*, 1999; 5, Adams *et al.*, 1998*a*; 6, Robertson *et al.*, 2003.
NA, data not available from published paper.

as this study. Two of these studies (Brown *et al.*, 1999; Anglea *et al.*, 2004) examined fishes that had a mass <45 g and were implanted with transmitters with no or very short antennas. Brown *et al.* (1999) determined that the U_{crit} of juvenile rainbow trout was not negatively influenced by surgical implantation of a transmitter. The authors determined that an 8% difference in U_{crit} between tagged and control fish was not statistically significant, which is in contrast to this study where a statistical significance was found when the U_{crit} between tagged and control sockeye salmon differed by only 5%. Anglea *et al.* (2004) determined that an 8% difference in the U_{crit} between implanted and control Chinook salmon was not statistically significant. Unlike the results of these studies, the U_{crit} of juvenile sockeye salmon implanted with an acoustic transmitter was lower than control fish by 5%; the statistical analysis determined this was significant even after accounting for other experimental covariates.

Other studies have examined swimming performance of juvenile salmonids implanted with a radio transmitter. Although the extra drag of an external antenna found on radio transmitters makes it difficult to directly compare to swimming performance studies using transmitters without antennae, some interesting observations are noted. One other study was found that examined the swimming performance of Chinook salmon (95–120 mm) in the size range similar to the present study. These fish were implanted with a transmitter that had a 31 cm whip antenna (Adams *et al.*, 1998*a*; Table VI). Contrary to the present study, Adams *et al.* (1998*a*) found that the U_{crit} of the tagged fish was significantly lower than that of control fish by 13–20% both 1 and 21 days after gastric or surgical implantation. Adams *et al.* (1998*a*) also found that the U_{crit} of larger (120–160 mm; Table VI), surgically implanted Chinook salmon

was significantly lower than controls by 12% when fish were only given 1 day to recover after surgical implantation, but was not different when allowed 21 days to recover after surgery. Again, these differences were larger than the 5% difference that was found in sockeye salmon during this study. Robertson *et al.* (2003) examined the swimming performance of juvenile Atlantic salmon *Salmo salar* L. about two to three times the size of fish examined in the present study. Similar to Adams *et al.* (1998*a*), they implanted fish with radio transmitters that had fairly long antennas (28 cm). In contrast to Adams *et al.* (1998*a*), however, they did not find that the 7–11% reduction in U_{crit} of tagged fish as compared to untagged fish was statistically significant 1, 5 or 10 days after surgical implantation.

Due to the large number of fishes tested during this study, the statistical analysis was very robust. This large sample size and low variance allowed a statistical difference to be found when only a small difference (5%) existed between the U_{crit} of control and tagged sockeye salmon. This study was originally designed to find a 20% difference in U_{crit} between the control group and the treatment group with 80% power ($\alpha = 0{\cdot}10$). Due to the large sample sizes for this study, power would have approached 100% for finding a 20% difference ($\alpha = 0{\cdot}1$ or $0{\cdot}05$) if one did occur. As the sample sizes for experiments increase, the power to find small differences also increases.

It is not known whether a 5% reduction in the upper U_{crit} of sockeye salmon would be biologically significant. It is conceivable that a 5% reduction in the upper U_{crit} of tagged sockeye salmon would impair their ability to avoid a predator. It is also conceivable that a 5% reduction in swimming performance would affect the sockeye salmon's ability to be successfully passed through fish bypass systems at dams. A 5% difference in swimming speed between a tagged and untagged sockeye salmon, however, is *c.* $0{\cdot}2\ L_F\ s^{-1}$ or *c.* $2{\cdot}5$ cm s^{-1}. These differences in the average U_{crit} between treatments were well within the range of variation within treatment groups within the study. Further, many of the studies cited above failed to find a statistical difference between the U_{crit} of tagged and control fishes when the difference ranged from 7 to 20%. Therefore, it is suggested that differences in U_{crit} values of 5% may not constitute a biologically significant difference. Studies with large samples like this one should continue to be done that have the power to detect these differences should they exist.

GROWTH AND MORTALITY

None of the surgically implanted sockeye salmon incurred mortality over the 21 day test. Twenty-three of the 150 Chinook salmon, however, died over the course of 21 days. The group implanted with transmitters had a significantly lower survival rate than the control group. The same surgeon conducted surgeries on both species, suggesting that the surgical procedure itself was not the reason for the differences in mortality. The mortality may be attributed, in part, to the poor condition of the Chinook salmon at the beginning of the test. During the transfer of Chinook salmon from Rocky Reach Dam to PNNL, several fish were observed with 'tailrot' and several fish with minor scale loss. Mortality may also have been related to the holding temperature for Chinook salmon. Chinook salmon were held in water that was 3° C warmer

than sockeye salmon. This may have increased the likelihood of complications due to bacteria or fungus. Immediately, a low, chronic mortality was noted in each holding tank. Most of the Chinook salmon that died had either 'tailrot' and significant scale loss. Some dead fish, however, had no obvious external signs of disease or injury. Fish used in the swimming performance component of the study were apparently not affected by this disease problem, probably because the fish used in the growth and survival experiments were held longer than those used in the swimming performance experiments.

Similar to the present results for implanted sockeye salmon, Adams *et al.* (1998*b*) found that only one out of 48 surgically implanted juvenile Chinook salmon (mean mass 28 g) died during a 54 day study of survival and growth; this single fish died 36 days after being surgically implanted with a transmitter. Fish used in the Adams *et al.* (1998*b*) study had been implanted with a transmitter with a mass of 1·0 g in air and 0·7 g in water and represented a mean of 3·6% of the fish's mass in air. They found no mortality out of 48 fish gastrically implanted with transmitters. They also found no mortality in control Chinook salmon or in sham-tagged fish. Robertson *et al.* (2003) found no mortality during a 45 day experiment on juvenile Atlantic salmon. Considering the fact that there was 100% survival in sockeye salmon and other researchers had very high survival in implanted Chinook salmon, it is advisable that the no firm conclusions be drawn on the influence of transmitter implantation on the survival of Chinook salmon of the size examined during this study.

There was no indication that being implanted with transmitters influenced the growth of either sockeye or Chinook salmon; however, other studies have found opposite results. Two studies that implanted juvenile salmonids with radio transmitters with 28 cm (Robertson *et al.*, 2003) or 31 cm antennas (Adams *et al.*, 1998*b*; Table VI) did find differences in growth between control and tagged salmonids. Contrary to this study, Adams *et al.* (1998*b*) found that during the first 21 days after juvenile Chinook salmon (mean mass 28 g) were implanted with radio transmitters, they had lower growth rates than control or sham fish. These fish had been implanted with a transmitter with a mass of 1·0 g in air and 0·7 g in water and represented a mean of 3·6% of the fish's mass in air. They did not find a difference between control or sham fish. Robertson *et al.* (2003) found juvenile Atlantic salmon tagged with radio transmitters had lower growth than control fish during the first 9 days of an experiment and during the first 36 days of another experiment.

Moore *et al.* (1990) did not find any difference in growth among juvenile Atlantic salmon implanted with transmitters, control or sham fish. They examined fish with a mean mass of 54–59 g and mean L_F of 166–173 mm. They implanted the fish with dummy tags with a mass of 1·3 g in air or 2·2–2·4% of the fish's mass in air.

For Chinook salmon, there was no negative influence found from transmitter implantation on swimming performance or growth. Thus, there is little evidence that being implanted and carrying a transmitter with a mass 3·2–10% of a fish's body mass in air (1·8–5·5% of the body mass in water) would negatively influence Chinook salmon. Although there was a negative influence on survival from implantation, this was probably due to the health of the fish used in this study.

There was also no negative influence from transmitter implantation on growth, or survival of juvenile sockeye salmon. Tagged sockeye salmon did have lower U_{crit} than control or sham-tagged fish. The difference between tag and control groups, however, was only 5%. None of the other studies that were examined found that a difference this small would result in an impairment of swimming ability. Thus, it is suggested that a difference this small, although statistically significant, may not be biologically significant.

To determine the influence of transmitter implantation on fishes, a suite of tests should be conducted as suggested by Jepsen *et al.* (2004). In addition to the U_{crit}, survival and growth studies completed here, it is also suggested that sprint swimming and predation studies be completed. It is also suggested that work be done to examine how transmitter implantation influences the buoyancy of fishes. These tests will provide additional insight as to the biological significance of carrying the burden of acoustic transmitters. This will allow managers to make more informed decisions about how much of a burden juvenile salmonids can carry when they serve as research subjects.

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