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Maximum tag to body size ratios for an endangered coho salmon (*O. kisutch*) stock based on physiology and performance

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Abstract Many coho salmon stocks (*Oncorhynchus kisutch*) have been in decline during the past three decades. Canada's most endangered salmon stock, the Thompson River coho salmon, is being studied extensively as managers attempt to reverse these population declines. Investigators are using acoustic telemetry to track the migratory behaviour and survival of the Thompson River (and other) coho salmon stocks. Coho salmon pre-smolts are relatively small compared with salmonid species that are typically studied using acoustic telemetry; therefore the identification of the appropriate sizes of fish and tags to use is critical. This study tested the effects of surgically implanting the three smallest sizes of acoustic tags currently available on the growth, survival, tag retention, swimming performance and physical condition of coho salmon pre-smolts for 300 days post-surgery. Maximum tag size to body size ratios ranged from 15–17% by fork length and 7–8% by mass for the three tag sizes (11 cm fork length for a 6×19 mm tag, 12.5 cm for a 7×19 mm tag, and 14 cm for a 9×21 mm tag). Based on our results, it is unlikely that coho salmon pre-smolts implanted with acoustic transmitters following these size guidelines would have poor survival in studies of freshwater migratory behaviour as a result of the surgery or the tag.

Keywords Pre-smolts · Acoustic telemetry · Tag effects

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Introduction

As with many fish populations world-wide, some Pacific salmon stocks have declined substantially over the last three decades. The largest tributary to the Fraser River, British Columbia's Thompson River contains a severely depleted population of coho salmon (*Oncorhynchus kisutch*; Bradford and Irvine 2000). The Thompson River coho, currently the most endangered salmon stock in Canada, is derived from the extinct Upper Columbia coho run and is genetically distinct from all other coho populations in BC. Investigations into the poor status of this stock have suggested that declining ocean productivity, freshwater habitat alteration, and over-fishing are likely causes (Bradford and Irvine 2000), although a complete fishing closure in 1998 did not improve the situation. In an effort to pinpoint areas of high mortality for this stock, researchers with the Pacific Ocean Shelf Tracking (POST) project (Welch et al. 2003) have used biotelemetry to track the riverine and early marine migratory behaviour of free-ranging Thompson River coho salmon since 2004. This research involves surgically implanting acoustic tags into the body cavity of coho pre-smolts and subsequently tracking them in the freshwater and marine environments. Critical to this type of study is the understanding of what effects the tags and surgery may have on the survival, condition, growth and swimming performance of the animals being monitored.

To date there are no published studies that examine tag effects on coho salmon pre-smolts. Acoustic transmitters small enough to be implanted in coho salmon pre-smolts have only been developed recently, offering a new and unique opportunity to study the early migratory behaviour and survival of this animal. Guidelines for tag to transmitter ratios have been discussed for salmonid species with larger smolts, including Atlantic salmon, *Salmo salar*, (Greenstreet and Morgan 1989; Moore et al. 1990; Lacroix et al. 2004); chinook salmon, *Oncorhynchus tshawytscha* (Adams et al. 1998a,b; Jepsen et al. 2001; Anglea et al. 2004); cutthroat trout, *Salmo clarki* (Zale et al. 2005) and rainbow trout/steelhead, *Oncorhynchus mykiss* (Lucas 1989; Brown et al. 1999; Welch et al. 2007). The maximum tag to body weight ratios discussed in these studies range from 2–12%, demonstrating the high variability in sensitivity and physiology among salmon species (Jepsen et al. 2004). Therefore, the effects of acoustic tags on coho salmon cannot be inferred from studies on other species. Given the small size of the animals being tracked, it is critical that the effects of transmitters on the physiology and performance of the individuals are known. In British Columbia alone, field studies using acoustic telemetry to track coho salmon migration have been carried out in the Thompson, Nimpkish, Stamp, Keogh, Campbell and Cheakamus Rivers (Welch et al. 2004; Melnychuk et al. 2007; Chittenden et al. 2008). The results from this tag effects study are thus important to ongoing coho salmon field work and the Pacific-wide coho conservation effort.

The tracking of salmon pre-smolt migratory behaviours using acoustic telemetry has been limited by tag size. Increasingly smaller transmitters have allowed for the study of smaller fish; however, the limits of tag size to body size are not clear. Jepsen et al. (2002) stated that “few studies have systematically investigated the effects of different tag to body weight ratios”. The objective of our research was to determine the minimum size at which coho salmon pre-smolts could be implanted with three sizes of acoustic tag and suffer no effects. To meet this objective, morphological, behavioural and physiological parameters were measured. A significant difference in any of these parameters between tagged and sham or control fish would suggest that the acoustic tags were having an effect on behaviour and/or survival of tagged fish in the field.

Material and methods

Hatchery-reared Thompson River (Coldwater Creek) coho salmon pre-smolts from the Spius Creek Hatchery near Merritt, BC, were sedated with 0.1 ppm Aquacalm (Syndel Laboratories, Vancouver, Canada) and transported with supplemental oxygen to the DFO/UBC Centre for Aquaculture and Environmental Research in West Vancouver during the springs of 2005 and 2006. The fish were placed in an outdoor 244 cm-diameter fiberglass tank, supplied with aerated fresh water from Cypress Creek and fed to satiation daily.

Treatment groups

The experiments were conducted during 2005 and 2006. In mid-April 2005 (1 week after transport), 224 fish were divided into seven size classes ranging from 9.5 to 13.0 cm fork length (Table 1). Within each size class, the fish were randomly assigned to one of four treatment groups – control (PIT tag only), sham (surgery without transmitter), 6 mm tag (surgery with transmitter: 6×19 mm, 0.9 g in air, 0.5 g in water) and 7 mm tag (7×19 mm, 1.5 g in air, 0.8 g in water). An additional group of fish ($N=120$) were reared separately for another 100 days, until they were large enough (12–14 cm) to be implanted with 9 mm tags (9×21 mm, 3.0 g in air, 2.0 g in water). During this second set of surgeries, in July 2005, the fish were divided into four size groups and randomly assigned to three treatment groups (control, sham, and 9 mm tag). Following surgery these fish were placed into the same tank as the first group. All of the experimental fish were held in the same tank to minimize tank effects. To identify the control fish, it was necessary to mark them with PIT tags. The duration of this study (300 days) reflected the 9–10

Table 1 Number of fish (*N*) in each initial fork length group by treatment for the 6 and 7 mm tag groups

	9.5–10 cm	10–10.5 cm	10.5–11 cm	11–11.5 cm	11.5–12 cm	12–12.5 cm	12.5–13 cm
Control	9	10	10	10	10	–	–
Sham	8	10	10	10	10	11	9
6 mm	7	9	10	8	10	9	9
7 mm	–	–	9	9	9	8	10

month lifespan of acoustic tags being used by many researchers throughout the world.

During 2006, control and 9 mm tag treatments were repeated with 200 fish to add larger size classes (up to 16.5 cm, Table 2) because all of the size groups tested with 9 mm tags in 2005 had low survival and tag retention. The same surgical procedures and rearing methods were used, however no sham group was required as the sham and control fish had already demonstrated similar growth rates during the first year of study.

Surgical procedure

Prior to surgery, the fish were sedated with 0.1 ppm Aquacalm and anesthetized in 60 ppm buffered MS222 (Syndel Laboratories). They were weighed, measured and placed on the surgery table ventral side up. The gills were gently irrigated with a maintenance dose (30 ppm) of MS222, and a wet paper towel was placed over the head of the fish to reduce visual stimuli. Supplemental air and Vidalife (Syndel Laboratories) were included in all water baths. Oxygen levels and water temperatures were maintained to emulate source water (12.2±0.3 ppm and 6.7±0.8°C during the April 2005 surgical period, 9.5±0.8 ppm and 15.5±0.6°C during the July 2005 surgical period, and 10.2±0.8 ppm and 15.5±0.8°C during 2006).

PIT tags were inserted through a 2 mm incision along the midline of the fish, anterior to the pelvic girdle. For the tag treatment groups, a dummy acoustic tag containing a PIT tag was placed into the body cavity through a 10 mm incision in the same location. The incision was closed with two simple interrupted sutures (absorbable Ethicon Monocryl Y513 reverse cutting 4–0, 1.5 metric, 45 cm, PS-2 19 mm, 3/8 circle needle). Sham fish underwent the same procedure as tagged fish, however, only a PIT tag was inserted into the body cavity. The Vemco dummy tags were created to mimic the three smallest acoustic transmitters available, using the same coating and weight distribution as regular Vemco acoustic tags. The surgical tools were disinfected between surgeries with Ovadine (Dynamic Aqua Supply, Canada) and rinsed twice with distilled water. All of the fish were placed in a recovery bath following surgery until normal swimming behaviour was resumed, whereupon they were returned to the communal tank.

Sampling

A total of fourteen measurements of weight, fork length and healing stage were taken for the first surgery group (at 0, 13, 27, 41, 55, 69, 83, 95, 119, 136, 168, 213, 254, and 300 days post-surgery). Similar measurements were taken for the second surgery group on day 0, 22, 39, 71, 116, 157, and 203 post-surgery. The fish were anesthetized in 60 ppm buffered MS222 prior to sampling, and were allowed to recover before being returned to their tank. Tag weights were subtracted from fish weights prior to analysis. The stage of healing was categorized as 'poor' (having no evidence of healing, possibly with gaps between stitches or tag protruding), 'fair' (healing had started with a thin film visible over the

Table 2 Number of fish (*N*) in each initial fork length group by treatment for the 9 mm tag group

	12–13 cm	13–14 cm	14–15 cm	15–16 cm	16–16.5 cm
Control	16	18	24	20	8
Sham	15	18	–	–	–
9 mm	27	26	21	24	11

incision), ‘good’ (incision mostly fused, no inflammation, some stitches may remain), or ‘complete’ (incision completely fused, no stitches remaining). The tank was monitored twice daily for expelled tags and mortalities. The percentage of tags available for detection was calculated as: 100%×[(number of tags implanted − number of mortalities of tagged fish − numbers of tags expelled)/(number of tags implanted)]. During 2005, all of the fish were necropsied following termination of the experiment, 300 days after the first surgery. Photographs were taken of each healing stage and tag position within the body. During 2006, all pre-smolts were euthanised after 90 days, weighed and measured.

Swimming performance

From 24 to 48 h after the April 2005 surgeries, the swimming performance of 40 fish from the growth and survival study was measured using procedures similar to Lacroix et al. (2004). Five fish from each treatment group (‘control’, ‘sham’, ‘6 mm tag’ and ‘7 mm tag’) with fork lengths of 10.5–11 cm and five from each treatment group with fork lengths of 11.5–12 cm were swum in a 4 L Blazka-style swim tube (Smit et al. 1971) for a total of ten fish per treatment. The average weight was 15.08±2.24 g (standard deviation); the average length was 11.25±0.52 cm. Each smolt was collected from the rearing tank with a dip net, placed in a bucket and transferred into the half-filled swim tube chamber. The chamber was then sealed and filled with water. Each pre-smolt was given 20 min to acclimate at 0.1 m s^{-1}, whereupon the speed was increased by 0.2 m s^{-1}. The velocity was then increased by 0.1 m s^{-1} every 10 min. The trial ended when the fish rested on the back screen for 2 s. No shocks or prodding were used so as to reduce stress to the fish. The fish were returned to the rearing tank following their swim trial.

During July 2005 (9 mm tag), an additional 72 fish were prepared for the second set of swimming performance trials. Twenty-four fish were surgically implanted with 9 mm tags; 24 fish were given sham surgeries and 24 were controls. All pre-smolts had initial fork lengths of 13.5 to 14.5 cm. The average fork length post-swim was 14.18±0.55 cm. The average mass of the pre-smolts post-swim was 29.79±5.01 g. The fish were divided up equally by treatment group and raised indoors in four tanks. Six extra control fish were placed in each tank for later blood analysis [‘Control (2005, NS)’, Table 3]. Ten of the 9 mm tagged pre-smolts expelled their tags during the 92 days leaving a total of 14 dummy tagged fish to be swum. Thus, to keep the three treatment groups even, a total of 42 pre-smolts were swum in the 40 L Blazka-style swim tube using the same methods as previously mentioned. The larger size of the fish tagged with 9 mm tags required a longer swim trial, necessitating a different experimental schedule from the 6 and 7 mm tag groups. Three fish from the same tank (one from each treatment) were swum per day in random order for a total of 14 swim days, up to 90 days post-surgery (on day 1, 2, 3, 4, 5, 7, 25, 27, 28, 31, 33, 34, 40 and 90). Critical swimming speeds (U_{crits}) were calculated using the following formula:

$$U_{crit} = V_f + \left(\frac{T}{t} \times \delta V\right)$$

where V_f is the highest velocity maintained for the prescribed time period, δV is the velocity increment, T is the amount of time the fish swam at fatigue speed and t is the prescribed time period (Brett 1964). Following each swim trial, the fish were euthanized in 120 ppm MS222, weighed and measured. Blood samples and necropsies were performed on each individual to compare post-exhaustive state relative to the different treatment types. In addition to the swim trial fish, one control (a fish that did not swim) was sampled at the end of each trial day. Blood from untreated fish was sampled during July 2005 and May 2006 to give a baseline for comparison (‘2005 initial’, ‘2006 initial’, Table 3). All experimental procedures were approved by the Canadian Council of Animal Care.

Blood analyses

Whole blood samples were taken from the caudal vessel of anesthetized fish with a sterile heparinized syringe for erythrocyte counts and analysis of hematocrit (Klontz 1994). A 5 µL capillary tube was filled with fresh blood and placed into 995 µL Hendrick’s solution for erythrocyte counts. The remaining blood was centrifuged at 13,000 rpm for 5 min. Plasma was collected and stored at -80°C until it was analysed for levels of sodium, potassium, chloride, calcium, glucose and lactate using a Stat Profile Plus 9 blood gas machine (Nova Biomedical Corporation, Massachu-

Table 3 Physiological measurements of coho salmon pre-smolt surgical treatment groups

Dependent variable	Treatment group	*N*	Mean	Standard error
Weight (g)	2005 initial (NS)	12	24.2667	1.7588
	Control (2005, S)	11	34.2364	1.5900
	Sham (2005, S)	12	28.2333	1.8130
	9 mm tag (2005, S)	13	28.8923	2.5640
	Control (2005, NS)	10	26.9200	0.0320
	2006 initial (NS)	30	16.7367	0.5292
Fork length (cm)	2005 initial (NS)	12	13.1917	0.3880
	Control (2005, S)	11	14.6273	0.2300
	Sham (2005, S)	12	14.0250	0.2200
	9 mm tag (2005, S)	13	14.1462	0.2120
	Control (2005, NS)	10	13.7400	0.2420
	2006 initial (NS)	30	11.6400	0.1230
Condition factor (g/cm^3)	2005 initial (NS)	12	1.0493	0.0485
	Control (2005, S)	11	1.0865	0.0330
	Sham (2005, S)	12	1.0161	0.0470
	9 mm tag (2005, S)	13	1.0207	0.2470
	Control (2005, NS)	10	1.0010	0.2370
	2006 initial (NS)	30	1.0507	0.0116
Erythrocytes (#/mL)	2005 initial (NS)	12	1.3883 e^6	5.5882 e^4
	Control (2005, S)	11	1.2932 e^6	7.6495 e^4
	Sham (2005, S)	12	1.3658 e^6	7.3238 e^4
	9 mm tag (2005, S)	13	1.1508 e^6	7.0365 e^4
	Control (2005, NS)	10	1.2720 e^6	8.0228 e^4
Hematocrit	2005 initial (NS)	12	0.5477	0.0519
	Control (2005, S)	11	0.4258	0.0360
	Sham (2005, S)	12	0.4451	0.0350
	9 mm tag (2005, S)	13	0.3880	0.0330
	Control (2005, NS)	10	0.3937	0.0380
	2006 initial (NS)	24	0.4675	0.0137
Mean cell volume (nm^3)	2005 initial (NS)	11	3.3247 e^{-4}	0.0000
	Control (2005, S)	14	3.2084 e^{-4}	0.0000
	Sham (2005, S)	13	4.1697 e^{-4}	0.0000
	9 mm tag (2005, S)	13	3.1432 e^{-4}	0.0000
	Control (2005, NS)	12	3.7125 e^{-4}	0.0000
Sodium, plasma (mmol/L)	2005 initial (NS)	10	207.9600	2.7237
	Control (2005, S)	11	241.6727	10.7290
	Sham (2005, S)	12	236.4000	10.2720
	9 mm tag (2005, S)	13	239.9077	9.8690
	Control (2005, NS)	10	233.8800	11.2530
Potassium, plasma (mmol/L)	2005 initial (NS)	10	4.0880	0.4378
	Control (2005, S)	11	8.3091	1.0330
	Sham (2005, S)	12	11.6667	0.9890
	9 mm tag (2005, S)	13	7.1354	0.9500
	Control (2005, NS)	10	9.9640	1.0840
	2006 initial (NS)	26	5.7651	0.5544
Cloride, plasma (mmol/L)	2005 initial (NS)	10	176.9200	3.0264
	Control (2005, S)	11	171.6727	4.6260
	Sham (2005, S)	12	170.5667	4.4290
	9 mm tag (2005, S)	13	175.3231	4.2560
	Control (2005, NS)	10	174.4800	4.8520
	2006 initial (NS)	26	146.7532	3.9209
Calcium, plasma (mmol/L)	2005 initial (NS)	10	1.8280	0.0253

Table 3 (continued)

Dependent variable	Treatment group	*N*	Mean	Standard error
	Control (2005, S)	11	1.6218	0.0390
	Sham (2005, S)	12	1.4300	0.0370
	9 mm tag (2005, S)	13	1.6431	0.0350
	Control (2005, NS)	10	1.5120	0.0400
	2006 initial (NS)	26	1.1873	0.0331
Glucose, plasma (mmol/L)	2005 initial (NS)	10	6.0000	0.5750
	Control (2005, S)	11	8.1455	0.5700
	Sham (2005, S)	12	8.3333	0.5460
	9 mm tag (2005, S)	13	8.1231	0.5240
	Control (2005, NS)	10	7.3600	0.5980
	2006 initial (NS)	26	6.0780	0.3231
Lactate, plasma (mmol/L)	2005 initial (NS)	10	6.6000	0.4511
	Control (2005, S)	11	6.9455	0.7290
	Sham (2005, S)	12	5.9333	0.6980
	9 mm tag (2005, S)	13	7.8154	0.6710
	Control (2005, NS)	10	4.7600	0.7650
	2006 initial (NS)	25	7.6220	0.5171
Cortisol, plasma (mmol/L)	2005 initial (NS)	5	35.8605	13.7980
	Control (2005, S)	11	94.5211	32.4660
	Sham (2005, S)	12	70.2966	31.0840
	9 mm tag (2005, S)	13	84.3371	29.8640
	Control (2005, NS)	10	92.7771	34.0510

Pre-smolts sampled after the completion of a swim trial were labeled with an 'S'; those that did not swim were labeled 'NS'

setts). Cortisol was measured using a cortisol Elisa kit from Immuno Biological Laboratories America, Inc. (Minneapolis, MN, USA). Condition factors were calculated as mass × fork length^{-3} (Goede and Barton 1990). Erythrocyte counts were determined manually with a microscope and hemacytometer.

Statistical analyses

The size data were found to be normally distributed (normal scores>0.2 using Kolmogorov–Smirnov) with equal variance ($F_{76,\ 3,410}$=31.927–54.67, $p<$ 0.0001). General linear models (GLM) were developed for each initial size group (Tables 1, 2 and 3) with days since surgery and treatment as fixed factors, and weight, fork length and healing as dependent variables. GLMs were also created for swimming performance data and blood data. Multivariate analyses and Scheffe's post-hoc method were used to analyse differences between treatments, as N values varied between treatments and sample days. Percent data (hematocrits) were arcsine transformed prior to statistical analysis. In all cases, significance was established at $p<0.05$.

Results

For each tag type, we examined growth, healing rates, survival, tag retention, swimming performance and physical condition for up to 300 days post-surgery. All control and sham groups had 88% survival or higher until the termination of the study.

Growth

For the smallest tag (6 mm diameter), there was a significant difference in body size (weight and length) among the three treatments in the 9.5–10 cm group until 140 days post-surgery. Similarly, in the 10–10.5 cm and 10.5–11 cm groups, there was a significant difference between the tagged and control/sham fish in body size until 140 days post-surgery; however there was no observable difference between the sham and control groups (Fig. 1a). For the three previously mentioned size groups, there was no size difference among treatment groups after 140 days post-surgery. The 10.5–11 cm group tagged with 7 mm diameter transmitters had significant differences between the control/sham groups and the tagged group in length (data not shown) but not weight (Fig. 2a). There was no significant size difference among treatments above an initial fork length of 11 cm for fish implanted with either the 6 or 7 mm tag (Figs. 1b and 2b).

Survival and tag retention were low in the 9 mm tag treatment group when the initial fork length was < 13 cm, which left too few fish to compare size statistically. The size groups were therefore pooled into 1 cm size groups to get large enough numbers for a statistical analysis. There was no significant difference in size between tagged and control/sham fish above an initial fork length of 14 cm.

Healing rates

The controls in all size groups of the first set of surgeries had a 'good' healing status 2.5 months post-surgery, and were all completely healed 3 months post-surgery. The sham groups showed greater variance in healing time; 90% of individuals reached a 'good' status between 2.5 and 3 months, and a 'complete' status between 3 and 5 months. Eighty percent of fish tagged with 6 and 7 mm tags had a 'good' status by three months and were completely healed at 7 months post-surgery. Healing improved slightly as initial size at surgery increased.

For the second group of surgeries (larger fish, 9 mm tag), the control fish reached a 'good' healing status by the first sampling 22 days post-surgery, and were completely healed by day 71. The sham fish had a 'good' healing status between day 39 and 116, however they never reached 'complete'. In the largest size group (13–14 cm) tagged with large tags in the first year's study a few survivors had a 'good' status at day 116. During the second year, the majority of pre-smolts of initial fork length 14–16.5 cm tagged with large tags were completely healed by 90 days post-surgery. Necropsies of the experimental fish showed that some tags were adhering to the body cavity wall, fat tissue or organs. Some tags were surrounded by tissue and expelled through the incision site.

Survival and tag retention

We observed 100% survival and tag retention in all size groups of fish tagged with 6 mm tags up to 50 days post-surgery. There were two mortalities in

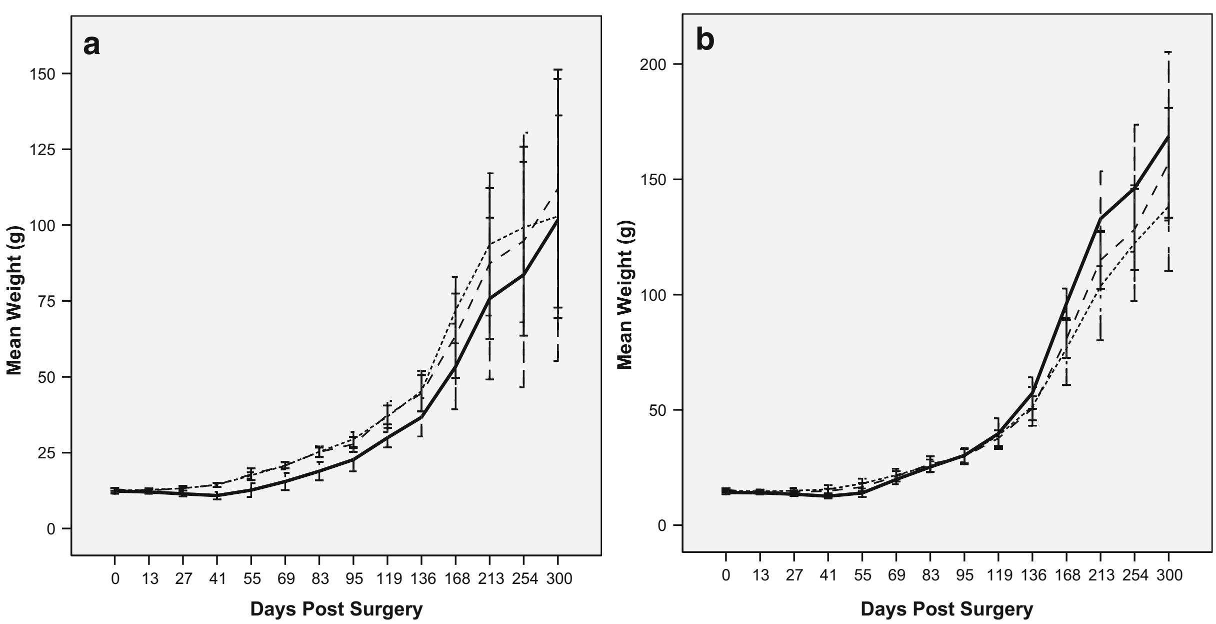

Fig. 1 Weight over time for the 6 mm tag group of initial fork length **a** 10.5–11 cm and **b** 11–11.5 cm. The control group is defined by a *dashed line*, the sham group a *dotted line* and the tagged group a *solid line*. Standard error bars are included for all three. In the 10.5–11 cm group, note the significant difference between tagged and control/sham weight up to 140 days post-surgery. There were no significant differences between treatment groups for fish with initial fork lengths over 11 cm

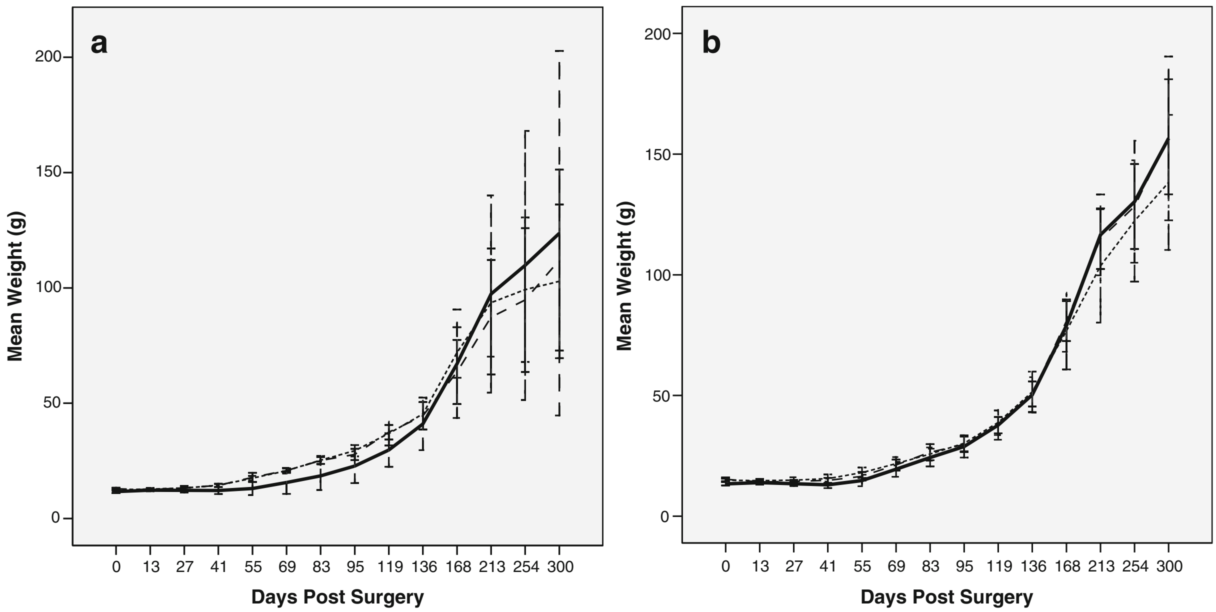

Fig. 2 Weight over time for the 7 mm tag group of initial fork length **a** 10.5–11 cm, and **b** 11–11.5 cm. The control group is defined by a *dashed line*, the sham group a *dotted line* and the tagged group a *solid line*. Standard error bars are included for all three. There were no significant differences in weight among treatment groups in either group

the smallest size group 75 and 78 days post-surgery, and some tag loss in three of the size groups (Table 4, 6 mm tag group). Above initial fork lengths of 10 cm, survival was 100% and tag retention was over 88% until the termination of the experiment, 300 days post-surgery. For the 7 mm tag group there was 100% survival in four out of five of the tagged groups, however there was some tag loss in pre-smolts up to an initial fork length of 12.5 cm (Table 4, 7 mm tag group). All control fish and over 90% of the sham fish survived until the end of the study.

The 9 mm tag was too large to fit in the body cavity of the smallest size group (12–13 cm) and as a result, many fish had to be euthanized during surgery. Of those that did survive, the majority expelled their tags very quickly and few lived until the end of the experiment (Table 4, 9 mm tag group). Above initial fork lengths of 14 cm, there was 100% survival to day 50 post-surgery; however tag retention began to fall after three weeks. By three months, there were only 42% of the tags remaining in fish up to 16 cm. Above 16 cm there was 55% tag retention (Table 4, 9 mm tag group).

Swimming performance

There were no significant differences in U_{crit} or variance between treatment groups in either $m{\cdot}s^{-1}$ or bl s^{-1} (Table 5). Pre-smolts that were included in the swim trials had no difference in survival, tag retention, healing or growth when compared with pre-smolts that were not included in the swim trials. There was no difference in swimming performance between rearing tanks.

Blood analyses

Plasma levels of calcium were lower in sham groups than in control and tag groups (Table 3). No other significant differences were found in blood analyses between swum groups. Initial levels of plasma sodium, potassium, chloride, glucose and cortisol were all significantly lower than levels observed in swum fish.

Discussion

Acoustic telemetry has proven to be a very useful method to track the early marine migratory behaviour and survival of fish species, including salmon pre-smolts (Welch et al. 2003). With the development of 6 and 7 mm diameter acoustic tags, the pre-smolts of smaller salmonids such as coho, are now able to be tracked. We conducted this study to determine the maximum tag to

Table 4 Percent survival and tags available for detection over time in the 6 mm tag group, 7 mm tag group and 9 mm tag group

Days since surgery	% Surv	% Tags	% Surv	% Tags	% Surv	% Tags	% Surv	% Tags	% Surv	% Tags
6 mm tag group										
Initial size group	9.5–10 cm		10–10.5 cm		10.5–11 cm		11–11.5 cm		11.5–12 cm	
50	100	100	100	100	100	100	100	100	100	100
100	72	43	100	89	100	100	100	88	100	100
300	72	43	100	89	100	100	100	88	100	100
7 mm tag group										
Initial Size Group	10.5–11 cm		11–11.5 cm		11.5–12 cm		12–12.5 cm		12.5–13 cm	
7	100	100	100	100	100	100	100	100	100	100
14	100	100	100	89	100	100	100	100	100	100
35	100	78	100	89	100	100	100	100	100	100
42	100	67	100	89	100	100	100	100	100	100
50	100	55	100	78	100	89	100	75	100	100
100	100	55	100	78	100	89	89	50	100	100
300	100	55	100	78	100	67	89	50	100	100
9 mm tag group										
Initial size group	12–13 cm		13–14 cm		14–15 cm		15–16 cm		16–16.5 cm	
1	100	59	100	100	100	100	100	100	100	100
7	48	48	92	92	100	100	100	100	100	100
21	48	41	92	92	100	100	100	100	100	100
28	48	26	92	88	100	81	100	88	100	91
35	48	18	92	81	100	67	100	67	100	73
50	48	15	92	62	100	52	100	46	100	64
90	48	7	92	54	95	43	100	42	100	55
200	48	4	92	35	–	–	–	–	–	–

body size ratios at which coho pre-smolts would suffer no adverse effects on survival, growth, physiology and swimming performance.

Further investigations could be made into the tags' effects on the buoyancy, startle response, disease resistance, and foraging ability of coho salmon pre-smolts. Laboratory environments can not replicate conditions that the tagged fish might encounter in the wild. Therefore, while we are able to find tag to body size ratios at which the survival, growth, swimming

Table 5 Critical swimming speeds of control, sham and tag groups

	Treatment group	N	Mean	Standard error
U_{crit} (m s^{-1})	Control (6, 7 mm)	10	0.3531	0.0260
	Sham (6, 7 mm)	10	0.4436	0.0260
	6 mm tag	10	0.3705	0.0260
	7 mm tag	10	0.3470	0.0260
	Control (9 mm)	13	0.9963	0.0630
	Sham (9 mm)	13	1.0548	0.0600
	9 mm tag	13	1.0908	0.0600
U_{crit} (bl s^{-1})	Control (6, 7 mm)	10	3.1558	0.2340
	Sham (6, 7 mm)	10	3.9390	0.2340
	6 mm tag	10	3.3076	0.2340
	7 mm tag	10	3.0718	0.2340
	Control (9 mm)	13	6.8218	0.4310
	Sham (9 mm)	13	7.5346	0.4140
	9 mm tag	13	7.7811	0.4140

performance and physiology of coho pre-smolts was not significantly affected in an artificial environment, there may be affected behaviours in the field, such as foraging or predator avoidance ability.

Surgically implanted tags that were up to 8% of the fish's mass and up to 17% of their fork length had no significant effect on the survival, growth, swimming performance, or physical condition of Thompson River coho salmon pre-smolts. Swimming performance trials conducted on 5–10 g rainbow trout implanted with acoustic tags demonstrated no observable effect from tags that were 6–12% of the fish's weight (Brown et al. 1999), which contradicted Winter's controversial '2% rule' (1983). Predator avoidance and swimming performance in juvenile chinook were not significantly affected by implanted tags that were 6.7% of the fish's body mass (Anglea et al. 2004). Adams et al. (1998b) found that radio tags implanted in chinook up to 12 cm lowered their critical swimming speeds; a lower 2.2–5.6% tag to body mass ratio was recommended. Cutthroat trout implanted with tags that were 4% of their body weight had only slight decreases in growth and performance (Zale et al. 2005). Thompson River coho salmon pre-smolts had no difference in swimming performance 24 to 48 h post-surgery for fish 10.5–12 cm long implanted with 6×19 mm (6% by weight, 17% by length) and 7×19 mm tags (10% by weight, 17% by length). The U_{crit} values we measured (Table 5) were similar to those observed for coho smolts (3.5–5.5 bl s^{-1}) by Glova and McInerney (1977). Coho salmon pre-smolts with fork lengths of 13.5–14.5 cm implanted with 9×21 mm tags had similar U_{crits} to sham and control fish (the tags were 10% of their weight in air and 7% of their fork length).

The condition factors of the Coldwater River coho salmon pre-smolts were >1.0 g cm^{-3} on average, which resembled other hatchery-reared coho populations but was likely greater than their wild-reared counterparts (Chittenden et al. 2008). Plasma levels of sodium and chloride were higher than normal in all groups (Wedemeyer et al. 1990), suggesting a possible bias due to measurement or storage time. Potassium was high for swum fish only (Wedemeyer et al. 1990). Plasma concentrations of sodium, chloride and potassium ions have been found to increase with exercise and stress levels in fresh water, which could explain differences found between swum and non-swum fish (Graham et al. 1982). Erythrocyte counts, hematocrits, mean cell volumes, calcium, glucose, lactate and cortisol levels were within normal ranges for coho pre-smolts (Wedemeyer et al. 1990).

Previous work examining the effects of tag insertion into salmonids has shown substantial variation between species in terms of growth, survival and tag retention. In their research on Atlantic salmon, Lacroix et al. (2004) compared the effects of three lengths of 8 mm diameter tags. They recommended using fish with a tag to fork length ratio of 16% or less, and a tag to fish mass ratio of 8% or less. With the tags they used, this corresponds to fish that were 14–15 cm long or 35–45 g. This study, carried out on coho salmon pre-smolts between 9.5 and 16.5 cm long, found no differences in growth between tag, control and sham groups above fork lengths of 11 cm for 6 mm and 7 mm-diameter surgically implanted acoustic tags and above 14 cm for 9 mm-diameter tags. All coho salmon pre-smolts implanted with 6 mm tags had excellent survival and tag retention above fork lengths of 10 cm; the same results were found in pre-smolts over 12.5 cm for the 7 mm tag. Rainbow trout/steelhead were found to have reduced growth to day 21 for 11.4–15.9 cm fish (Lucas 1989) and less than 15% tag loss to day 84 in fish over 14 cm tagged with 8×24 mm acoustic tags (Welch et al. 2007). The coho salmon pre-smolts implanted with 9×21 mm tags had excellent survival above initial fork lengths of 14 cm; however tag retention in pre-smolts up to 16.5 cm dropped from 81–91% after one month to 42–55% after three months. These results are of major importance to long-term field studies that estimate survival of coho salmon pre-smolts implanted with 9 mm transmitters. For shorter-term telemetry studies, smaller fish could be tagged to cover more of the population curve, as long-term survival, growth and tag retention may not be as important. However, the swimming ability and behaviour of the smaller fish could be more affected than that of the larger fish.

This study examined the effects of three sizes of implanted acoustic tags on the long-term growth, healing, survival, tag retention, swimming performance and physical condition of endangered Thompson River coho salmon pre-smolts. We recommend that coho be greater than 11 cm (17% tag to fork length ratio) or 15 g (7% tag to body mass ratio) for implantation with a 6×19 mm tag (0.9 g in air, 0.5 g in water). Although 11 cm fish tagged with a 7×19 mm tag (1.5 g in air, 0.8 g in water) grew at similar rates to control groups, when survival and tag retention are taken into consideration, a minimum of 12.5 cm is more appropriate (15% tag to fork length ratio or 7% tag to body mass ratio). If a 9×21 mm tag (3.0 g in air, 2.0 g in water) is being used, pre-smolts over 14 cm (15% tag to fork length ratio), or 35 g (8% tag to body mass ratio) are recommended, however tag retention levels dropped significantly after 1 month.

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