

1 **Growth, Survival, and Tag Retention of Steelhead Trout (*O. mykiss*)**

2 **Surgically Implanted with Dummy Acoustic Tags**

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14 Suggested Running Head: Effects of Tag Implantation

15 Key Words: *tagging, tag shedding, surgical implantation, growth, survival, telemetry.*

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18 ABSTRACT

19 Recent advances in micro-electronics make the study of the migration of even
20 small marine animals (>12 cm) over many thousands of kilometres a serious possibility.
21 Important assumptions in long-term studies are that rates of tag loss caused by mortality
22 or tag shedding are low, and that the tagging procedure does not have an unacceptable
23 negative effect on the animal. This paper reports results from a study to examine the
24 retention of relatively large (24x8mm) surgically-implanted dummy acoustic tags over a
25 seven month period in steelhead pre-smolts (*O. mykiss*), and the effects of implantation
26 on growth and survival. Although there was some influence on growth to week 12,
27 survival was high for animals >13 cm FL. In the following 16 week period growth of
28 surgically implanted pre-smolts was the same as the control population and there was
29 little tag loss from mortality or shedding. Currently available acoustic tags can be
30 implanted in salmonid fish ≥ 12 cm FL, although combined losses from mortality and tag
31 shedding were 33-40% for animals in the 12 and 13 cm FL size classes. By 14 cm FL,
32 combined rates of tag loss (mortality plus tag shedding) for surgically implanted tags
33 dropped to <15% and growth following surgery was close to that of the controls. Our
34 results suggest that studies of ocean migration and survival over periods of many months
35 are now feasible even for animals as small as salmon smolts. Surgically implanted
36 salmon smolts are therefore good candidates for freshwater and coastal ocean-tracking
37 studies on relatively long time scales (months). On such time scales, even relatively
38 small salmon smolts may move thousands of kilometers in the ocean.

39 **INTRODUCTION**

40 The potential for sea-floor observatories to dramatically increase our
41 understanding of processes occurring within the ocean has recently been reviewed
42 (National Research Council 2000); surprisingly, no mention was made of the ability of
43 such observatories to potentially allow the tracking of marine animals during their
44 extensive marine migrations. Recent developments in acoustic technology (Voegeli *et*
45 *al.* 1998; Lacroix and Voegeli 2000) offer the prospect of establishing extensive
46 networks of underwater acoustic listening lines. Arrays formed of a series of such lines
47 might eventually stretch the entire length of continents (e.g. Welch et al 2003; see also
48 www.postcoml.org). The development of continental-scale arrays would allow tracking
49 the movements of even quite small animals for months or years over vast regions of the
50 continental shelf. However, although important aspects of the technology needed to
51 eventually allow the deployment of long-term monitoring posts on the seabed still need
52 to be established and validated, an equally critical aspect of this work involves the
53 question of how animals of different sizes recover from tagging with acoustic tags, and
54 their rates of tag retention– the development of long-lived acoustic tags with operational
55 lifetimes of months or years is meaningless if animals die from tagging or rates of tag
56 loss are high.

57 This study was designed to examine the effect of tagging small salmon pre-
58 smolts (steelhead trout; *Oncorhynchus mykiss*) with acoustic tags. The goals were: (1) to
59 determine the appropriate size ranges and protocols for pre-smolt tagging, and (2) to
60 establish rates of tag loss over time.

61 MATERIALS & METHODS

62 Hatchery-reared steelhead trout were selected from part of a large-scale
63 production within the British Columbia Fish Culture program, at the Vancouver Island
64 Trout Hatchery in Duncan, B.C. Approximately 200 pre-smolts (Cowichan River stock)
65 were selected and placed in a single rectangular fibreglass rearing tank several days
66 before the start of the experiments at the end of February, 2001. At the end of the
67 tagging procedure described below, all fish were transferred to a second fibreglass tank,
68 which served to hold all of the control and tagged fish together in freshwater for the
69 duration of the experiment. Feeding and care of pre-smolts followed standard hatchery
70 rearing procedures.

71 Dummy acoustic tags (8mm diameter x 24 mm long; 1.4 g) were cast
72 from quick-setting epoxy resin with a 12mm PIT tag embedded in the body of the tag to
73 allow unique identification of each pre-smolt. The epoxy resin was mixed with a bright
74 yellow colouring agent at the time the hardening agent was added to make it easier to see
75 any tags shed onto the bottom of the hatchery raceway. Control fish also were implanted
76 with a PIT tag, thereby ensuring that all fish used in the experiment were uniquely
77 identified, and allowing the two groups to be placed in the same holding tank and
78 eliminating possible tank effects on the results.

79 Treatment protocol was similar for the two groups of pre-smolts, but we
80 made some slight modifications to our surgical procedure over the 3 day tagging period
81 (19, 20, and 24 February, 2001). Two pre-smolts were netted from the initial holding
82 tank and placed in a bucket of freshwater, into which had been added clove oil (80 ppm
83 target strength). The clove oil was mixed 50:50 with ethanol and shaken, in order to

84 improve the dispersion of the clove oil at the low temperature of the water (7°C). Once
85 quiescent the first (control) pre-smolt was weighed, fork length recorded, and a PIT tag
86 injected into the abdominal cavity using a modified hypodermic syringe before placing
87 the pre-smolt in the second fibreglass raceway. This process took approximately one
88 minute to complete, allowing deeper anaesthesia to be induced in the second pre-smolt.

89 The second pre-smolt was handled identically except for the implantation
90 process. After measuring and recording size, pre-smolts were placed ventral side up in a
91 V-shaped trough formed from a sheet of acrylic plastic. The channel was partially filled
92 with water to ensure that the head and gills remained submerged while the abdomen was
93 exposed above the water line. A small amount of paper towelling was submerged in the
94 trough, cushioning the fish and helping to prevent it from moving during surgery.

95 A fine bladed scalpel was used to make an incision just large enough to
96 allow passage of the dummy tag along the ventral midline anterior to the pelvic fins
97 (11~12 mm), and the tag lightly pushed through the incision and then forwards until the
98 body of the tag lay fully within the abdominal cavity. The tag was then moved
99 backwards using either the point of the scalpel or a pair of pointed forceps, so that the
100 posterior end of the tag was located beyond the posterior end of the incision. In this way
101 the two ends of the 24mm long tag were both located under uncut abdominal
102 musculature and the central section of the tag body lay under the incision. As
103 monofilament suture material is generally viewed as preferable for use in fish (Gilliland
104 1994; Wagner *et al.* 2000), the incision was closed with two simple interrupted sutures
105 tied in Ethicon PDS-II 2-0 monofilament polydioxanone using a FS-1 cutting needle.
106 The two stitches approximately trisected the incision, with the needle and suture passed

107 fully through the abdominal wall on each side of the incision. The position of the tag
108 acted as a shield, facilitating the completion of each suture without puncturing the
109 internal organs or sewing them into the incision.

110 No major attempt was made to sterilise the working area other than to
111 keep it clean and reasonably hygienic, as might be encountered in a field program. The
112 surgeon (DWW) wore surgical gloves but did not change them between fish. The
113 scalpel blade was dipped in betadine antiseptic at the start of each operation, but the
114 blade was only changed when needed to ensure a sharp edge. The drop of betadine left
115 on the tip of the blade was first placed on the abdomen of the fish and then spread out
116 over the area to be incised with the tip of a gloved finger. Care needed to be used here
117 because betadine in contact with the gills is lethal. (A second reason for the use of paper
118 towelling, in addition to holding the anaesthetised fish in one position was to form a dam
119 between the abdomen and the gills, minimising the chance of antiseptic-contaminated
120 water reaching the gills). No antibiotics were used.

121 Some modifications to the surgical procedure were made during the
122 course of the two day procedure. Oxygen was not initially used during surgery, but we
123 found that the pre-smolts came out of their anaesthesia more rapidly with its use, and
124 accordingly used oxygen bubbled into the water using an airstone placed near the head
125 thereafter. The water in the surgical table was still changed after every 2-3 fish to
126 minimise the chance of the betadine antiseptic reaching the gills and to prevent thermal
127 shock from the water in the surgical tray warming to air temperature.

128 Handling procedures were identical except for the surgery, since both the
129 control and surgically implanted pre-smolts were held in the same tank. A record was

130 kept during implantation of the relative size distributions for the two groups, and the
131 tagging sequence was occasionally varied to ensure that the size distribution of pre-
132 smolts tagged using the two procedures was similar. Pre-smolts were fed daily to
133 satiation by an automatic feeder. Hatchery staff maintained the water temperature in the
134 rearing trough at 7°C for the first 10 days after tagging, and then increased the
135 temperature to 11°C for the duration of the experiment. We tried to ensure a similar size
136 distribution of pre-smolts chosen for control and surgical implantation (Table 1), except
137 that the smallest available pre-smolts were clearly too small to be implanted. Below ca.
138 11 cm FL, it was not possible to insert the tag into the body cavity and close the body
139 wall. (There were significant fat bodies lying along the intestinal mesentery of these
140 hatchery-reared fish, occupying space that in a lean wild pre-smolt might make it easier
141 to place the tag in the body cavity).

142 Pre-smolts were netted in small batches from the indoor holding tank on
143 16 May, 2001, ~12 weeks after tagging, and lightly anaesthetised with clove oil. The
144 PIT tag number for each animal was recorded and each animal measured for weight and
145 length, and visually examined to assess the extent of healing. The same procedure was
146 repeated again on 8 September 2001, ~16 weeks later (~29 wks after implantation).
147 During the holding period the tank was checked daily for dead fish or shed tags and the
148 date of recovery was noted. The weight of the dummy tag was subtracted from the fish
149 weights measured during the May and September evaluations.

150

151 **RESULTS**

152 *Effect on Survival*

153 Some difficulty was initially encountered in the early stages of the
154 surgery. It initially took considerable time to induce anaesthesia in the pre-smolts, so we
155 replaced our standard stock solution of clove oil (which was several years old) with
156 freshly purchased clove oil from a pharmacy, where it was sold as a toothache remedy.
157 Use of the new stock resulted in six of the 13 subsequently implanted pre-smolts not
158 recovering from the anaesthesia (including a run of five sequential deaths), and the death
159 of the only PIT tagged pre-smolt associated with the tagging procedure. The problem
160 appeared to be with the clove oil, as surgical times were low (~2 minutes). After
161 switching back to the original stock solution of clove oil no further immediate
162 mortalities were encountered.

163 These deaths were thus associated with a specific anaesthetic problem, and the
164 animals surgically implanted under such conditions did not recover from the surgery.
165 Implanted tags in such cases can be recovered and used in a different animal if animals
166 are held for a brief period of observation post-surgery. We therefore excluded these
167 cases from the analyses reported below, as it seems most relevant to examine what
168 fraction of animals released into the environment would be expected to survive and
169 retain their tags.

170 All but one mortality occurred during the initial 12 wk period. Mortality was
171 strongly associated with size, at least for the smallest animals examined (Table 1). For
172 animals less than ca. 11.5 cm FL, it proved impossible to close the body cavity with the

173 dummy acoustic tag inside, and the few animals that we attempted to surgically implant
174 all died. However, although the dummy acoustic tag filled much of the body cavity,
175 surgically implanted animals >11.5cm FL (20 g) survived the surgery and mortality rates
176 dropped sharply with increasing size over the interval 11-13 cms (Table 1). For animals
177 ≥ 13 cms mortality remained low and constant at <10%. Mortality in the PIT-tagged
178 control group was zero for the same size classes. Over the subsequent 16 wk period (to
179 wk 29, 7 months post-implantation), only one additional dummy-tagged pre-smolt died
180 (on 24 July). The surgical incision on this animal (12.1 cm at time of tagging) had not
181 healed and mesenteric fat was protruding from the incision on both the May and
182 September census. This animal had progressively lost weight between each
183 examination.

184

185 *Effect on Growth*

186 To examine the effect of surgical implantation on growth, we compared relative
187 growth over the first (12 wk) and second (16 wk) study periods for the two groups (Fig.
188 1). Both controls and implanted pre-smolts grew over the initial 12 week study period,
189 although surgically implanted animals grew less for a given size than the controls
190 (ANCOVA, $p < 0.05$). Linear regressions fitted to the data show that the growth patterns
191 had nearly parallel slopes but different intercepts, suggesting that the effect of the
192 surgical implantation was a reduction in growth that was similar for all size groups.
193 Fitting a second model with a common slope but different intercepts supported this
194 suggestion, as the fit was indistinguishable ($R^2 = 0.729$ for both). The difference in
195 intercepts was 2.4g, suggesting that animals of all sizes had reduced growth of roughly

196 2.4g as a result of surgical implantation. For the smallest animals (~20g or ~12 cms) this
197 growth difference corresponds to a 35% reduction in achieved growth.

198 Closer examination of the residuals from the regression lines calculated using the
199 data for the first period indicated that there was some tendency to heteroscedasticity,
200 with the residuals tending to increase with increasing size. Log-transforming the size
201 data and repeating the analysis resulted in a slight increase in R^2 (0.793) and a better
202 residual fit, but showed a statistically significant difference in slopes, so that the
203 difference in growth increment between implanted and control fish decreased even
204 further at larger sizes. Although surgical implantation reduced growth at all sizes
205 examined, the results indicate that growth differences were progressively smaller and
206 showed greater overlap between control and implanted pre-smolts when initial sizes
207 were greater than 14 cm FL (roughly 30 g body mass; Fig. 1).

208 Comparison of growth increments for the second period (16 May to 8 Sept,
209 2001), indicates no statistically significant difference in growth increment for any size
210 group (Fig. 1, lower row). On average, the surgically implanted animals grew slightly
211 more than the controls.

212

213 *Rates of Tag Loss*

214 Tag loss (shedding) was also related to body size (Table 1; Fig. 2). By week 12 a
215 total of 11 dummy acoustic tags (a 13% loss rate) were expelled from the body,
216 apparently without damage to the pre-smolts. In the following 16 wk period only two
217 additional tags were shed, both animals in the 14 cm size class (a 16% loss rate). Pre-
218 smolts recovered from the tank at week 12 that were no longer individually identifiable

219 by the presence of a PIT tag in all cases appeared to be healthy and the surgical incision
220 appeared to be fully healed. When shedding rates are compared for different size classes
221 it is clear that tags were retained over the full size range examined, but that shedding
222 rates dropped from 16-30% in pre-smolts ≤ 13 cm to a low and stable rate of $\sim 7\%$ for
223 animals ≥ 15 cm at implantation (Table 1). Tag shedding rates during the initial 12 wk
224 period were similarly low, but increased to 20% when the two shed tags found on 3 July
225 and 18 August are included in the analysis (wks 19 and 25; Fig. 2). The time course of
226 tag losses (Fig. 3) shows that most tags were shed in a period around 4-12 weeks post-
227 surgery, with only one tag shed >20 weeks post-surgery. The data thus suggests that the
228 process is self-limiting and does not affect all tagged animals..

229 Some insight into the process of tag expulsion was obtained from examination of
230 those tagged animals (N=18; 22%) that initially appeared to be in the process of
231 shedding the tag. These fish all had distended abdomens, apparently as a result of the
232 tag being firmly pressed against the abdominal muscles from the inside (Fig. 4). (The
233 remaining pre-smolts did not show evidence of the outline of the tag against the body
234 wall). In each case the surgical incision was well-healed and showed no evidence of
235 being likely to rupture. One pre-smolt was observed in the last stages of tag expulsion
236 (Fig. 4). The abdomen was greatly distended around the tag and a “pore” had formed
237 near the anterior end, through which the tag was completely exposed and clearly visible.
238 The tissue forming the pore was remarkable for the absence of any evidence of
239 trauma—the edge of the opening was smooth and neither the skin nor the underlying
240 abdominal muscles showed any evidence of a ragged edge or infection, and there was no
241 evidence of oozing from the wound. Rather than giving the impression of an ulcerated

242 wound in the abdominal wall, the neatly rounded hole into the abdominal cavity seemed
243 to cause little trouble for the fish and no evidence of significant trauma.

244

245 **DISCUSSION**

246 Studies of the large scale movement patterns at sea of animals such as salmon
247 pre-smolts will require monitoring their movements over thousands of kilometers and
248 many months (or years) at sea. Newly-developed acoustic tracking technologies (e.g.
249 Klimley *et al.* 1998; Voegeli *et al.* 1998; Lacroix and Voegeli 2000; Lacroix *et al* 2004;
250 Welch *et al* 2004; Lacroix and Knox 2005) show great promise in revolutionising the
251 study of the ocean migrations of these animals. An important aspect of such studies will
252 involve the development of sampling protocols that will permit designing studies around
253 animals of an appropriate size and age.

254 The purpose of the current study was to determine minimum size guidelines for
255 applying the acoustic tags now commercially available to salmon pre-smolts. These tags
256 have active lifespans approaching 4-6 months. Two important aspects were initially
257 identified during the planning phase: (a) to identify those sizes at which mortality is
258 minimised and (b) the sizes at which growth is not seriously disrupted. In addition to
259 these initial issues, we were surprised to discover that a significant proportion of pre-
260 smolts appear to have a well-developed biological mechanism for eliminating these large
261 tags from their body cavities, apparently with little trauma to the body. Tag shedding is
262 a serious issue for long-term studies because either the death of the salmon pre-smolt or
263 the shedding of the tag results in the loss of the tagged animal from the study population.

264 Although steelhead trout and Atlantic salmon pre-smolts can be quite large (often
265 >16 cm), the other species of Pacific salmon seldom achieve that size in freshwater. As
266 a result, we implanted the tags into animals as small as 10.8 cm. Our results indicate that
267 for animals ≥ 14 cm fork length, overall rates of tag loss were relatively low and roughly
268 constant (13%) over the initial 12 weeks of the study, and losses from mortality and tag
269 shedding were equivalent contributors (Table 1; Fig. 2). Losses over the following 16
270 wks were minor. At smaller sizes mortality and tag shedding rates both increased, but
271 some tags were successfully retained to the end of the study even for animals in the 11
272 cm size range. At sizes less than 11 cm FL it was not possible to close the body cavity
273 around these large tags. We suspect that mortality in the 11-12 cm size class might be
274 lower for wild pre-smolts, because the hatchery fish used in this study had substantial
275 mesenteric fat bodies that largely filled the abdominal cavity. This limited the amount of
276 space available for accommodating an acoustic tag and would not be as large a problem
277 in lean wild fish.

278 Several studies have examined the effect of surgical implantation of tags in small
279 salmon. Lucas (1989) and Moore *et al.* (1990) noted no difference in growth between
280 control and implanted groups of rainbow trout and Atlantic salmon, respectively. In
281 contrast, Adams *et al.* (1998*a,b*) found initially reduced growth of surgically implanted
282 chinook relative to control animals during the first 3 wks post-surgery for animals of
283 similar size (11.4-15.9 cm) to those used in the present study. They also noted that the
284 growth rates and swimming capabilities of surgically implanted fish was superior to that
285 of animals where the tag was placed in the stomach. Lacroix *et al.* (2004) used Atlantic
286 salmon smolts and found similar results to our study, with an initial period of mortality

287 followed several months later by a period of tag shedding.

288 Our results indicate that animals of all sizes examined grew after surgical
289 implantation, but that there was some reduction in growth relative to controls over the
290 initial 12 wk period. For pre-smolts greater than 14 cms initial size (~30 g), the growth
291 depression was less evident and a substantial proportion of the surgically implanted
292 animals achieved individual growth rates that were greater than the mean rate for the
293 controls (Fig. 1). No difference in growth was evident after week 12.

294 Various studies have commented on the issue of determining an appropriate ratio
295 of tag weight to fish weight, with several authors advocating a 2% rule. More recent
296 studies suggest that a higher ratio may be reasonable. Zale et al 2005 (review),
297 suggested 4% was appropriate in at least some studies, while Lacroix et al 2004
298 suggested that the ratio should not exceed 8% for Atlantic salmon smolts in the 25-45g
299 range. In our study, the tag to body weight ratio of the 14 cm size class (33 g) is 4.2%,
300 close to Zale *et al's* suggestion.

301 Tag loss via extrusion directly through the body wall or passage into the intestine
302 and then out the anus has been noted previously (Summerfelt & Mosier 1984; Chisholm
303 & Hubert 1985; Marty & Summerfelt 1986, 1990; Baras & Westerloppe 1999; Lacroix
304 *et al.* 2004). Shedding rates seem to be species-specific, ranging from 59% in a 24 week
305 study of rainbow trout (Chisholm & Hubert 1985), 49-59% over a 17 wk study in
306 channel catfish (*Ictalurus punctatus*; Marty & Summerfelt 1990), and essentially zero in
307 a 120 wk study in tilapia (*Oreochromis aureus*; Thoreau & Baras 1997). In our study,
308 we observed an overall tag shedding rate of 13% to week 12, with the highest shedding
309 rates in the smallest size classes, but with rates that then dropped quickly and stabilized

310 at about 7% over 12 wks in pre-smolts ≥ 14 cm . Two additional shed tags over the
311 following 16 wk period raised the shedding rate to 20% for the 14 cm size class (Table
312 1). This suggests that, as with mortality, the loss of animals from a tracking study are
313 relatively small and occur over a relatively short duration early in the study period.
314 Multi-year studies are likely to be feasible because tag-induced mortality and tag loss are
315 transitory phenomenon, and not processes that persist over the long-term.

316 Tag shedding rates may be compared with the shedding rate for the PIT-tagged
317 controls used in our study of 1%, with similar to rates of tag loss reported in other
318 studies (ranging from 1-5% for coded wire tagged salmon (e.g. Eames & Hino 1983,
319 Blankenship 1990) and 3% for PIT-tagged brown trout (Ombredane *et al.* 1998)). Thus
320 rates of tag loss may be expected to be higher than for the simpler CWT or PIT tag
321 technologies. Studies need to balance the additional information gain with the higher
322 expected loss rates of these larger and more expensive tags.

323 The mechanism by which extrusion occurs appears to be similar to that of
324 mammals (Lucas 1989), with the tag first being completely encapsulated and adhesion of
325 the capsule to either the coelomic wall or the intestines. Subsequent contraction of the
326 myofibrils within the encapsulation tissue resulting in the tag being pressed in close
327 contact with the intestine or the body wall. Contact necrosis then appears to result in the
328 gradual passage of the tag through the wall of the intestine or abdomen, and then out of
329 the body (Marty & Summerfelt 1986; Summerfelt & Mosier 1984).

330 We did not examine the detailed histological changes occurring within the body
331 cavity. However, the lack of any visual evidence of disruption of the initial incision and
332 the markedly distended shape of the abdominal wall around the tag in a number of cases

333 (Fig. 3) strongly suggested that encapsulation of these tags was initially occurring and
334 that the pressure from capsule contraction would eventually force these tags out of the
335 body. Surprisingly, during the following 16 wk period only two tags were shed, and all
336 of the animals initially noted at wk 12 to have significantly distended abdomens were
337 categorized as nearly normal by wk 29; abnormalities were restricted to minor lumps
338 only slightly detectable by finger tip or eye.

339 Although this distension presumably has some effect on swimming ability, the
340 lack of any ulceration evident in the tag extrusion process (Fig. 3) strongly suggests that
341 the biological mechanism underlying the extrusion process is well-developed and does
342 not appear to place great stress on the animal. Furthermore, the regression of many
343 animals initially expected to shed their tags at wk 12 suggests that most tag loss was
344 over by the seventh month of this study.

345 The foreign body response (Coleman *et al.* 1974) is not unique to fish, and is
346 found to frequently occur when implants are placed into humans. For example,
347 encapsulation of artificial breast implants in women has been reported to occur at rates
348 of 27-40% within the first year following surgery (Little & Baker 1980; Moufarrage *et*
349 *al.* 1987) and is thought to represent a rejection mechanism expressed in these patients.
350 As the reported rates of encapsulation in women are similar to those seen for the dummy
351 acoustic tags used in the present study, this suggests that a broader biological mechanism
352 is at work that determines the biological basis of the host response to the implant, since
353 surgical implantation in humans occurs under highly sterile conditions with much more
354 care taken in the choice of biomaterials. It is significant that in the case of breast
355 implants, only a proportion of the patients developed a capsule around the breast

356 implants, as was the case in the present study. In the majority of women, encapsulation
357 of the breast implant seems to be uncommon if not expressed during the first year of
358 implantation and surgical intervention to remove the implant and surrounding capsule
359 was rarely needed.

360 In tracking studies in fisheries, where tags with multi-year lifespans are now
361 available, issues concerning long-term retention of the tags are just as important as direct
362 effects of tagging on mortality. Tagging studies should be designed recognizing the
363 potential for continued rates of loss of tags over the long-term from mortality or
364 shedding to affect the goals of such studies. Ideally, protocols need to be developed to
365 minimize long-term rates of tag loss.

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CONCLUSIONS

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In both the Atlantic and Pacific oceans there is growing recognition that marine survival has dropped sharply for many stocks of salmon, making formerly viable populations unsustainable even in the absence of exploitation. This phenomenon was unexpected and not consistent with standard fisheries models, which predict that populations recover rapidly when fishing pressure is relaxed. The increased mortality experienced at sea has in many cases been greater than the combined influence of large-scale sport and commercial fisheries on some stocks, such as southern British Columbia coho or steelhead (e.g. Ward 2000; Smith and Ward 2000; Welch *et al.* 2000). In a large number of British Columbia salmon stocks ocean survival has dropped to one-tenth that of only 25 years ago. Such changes make it imperative that a better understanding be developed of where salmon go in the ocean, because other stocks of salmon whose rivers are in reasonable geographic proximity have much higher ocean survival. Large-scale telemetry studies offer great promise for answering a number of fundamental biological questions about the ocean life of salmon.

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ACKNOWLEDGMENTS

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We thank Ray Billings and Brian Martin of the Vancouver Island Trout Hatchery, British Columbia Fisheries, for their generous support of the experiments described here, Mary Thiess for statistical advice, Erika Welch for field assistance, and Adrian LaDouceur, Marc Trudel, and Jen Zamon for comments on the manuscript. This

387 project was supported as part of the Northwest Power Planning Council's Innovative

388 Proposal process (Proposal 22001), funded under BPA Contract 00003839.

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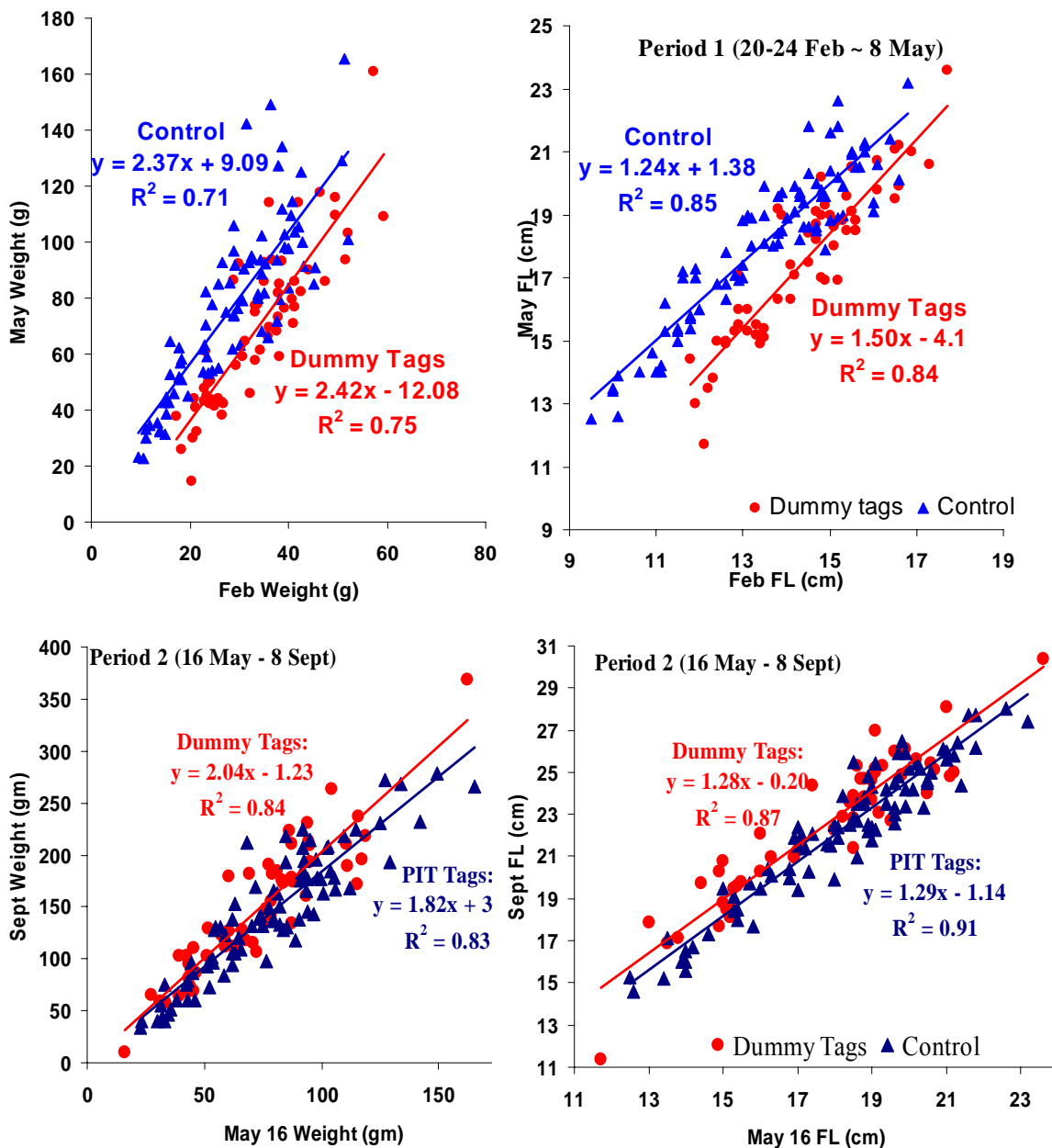
472 Table 1. Rates of potential acoustic tag loss by size class to week 29. The initial number
 473 of fish (N) in each 1 cm size category is indicated, as is the mean weight of each length
 474 class. Mortality rates for fish surgically implanted with dummy acoustic tags dropped
 475 sharply for animals greater than 12 cm fork length. Although the rate of tag shedding
 476 (but not mortality) remained fairly high for the 13 cm size class, no dummy tags were
 477 lost before 39 days after implantation. Tag weight ranges from 15% of body weight in
 478 the <11 cm size class to 3.5% in the 15-16 cm size class.

479

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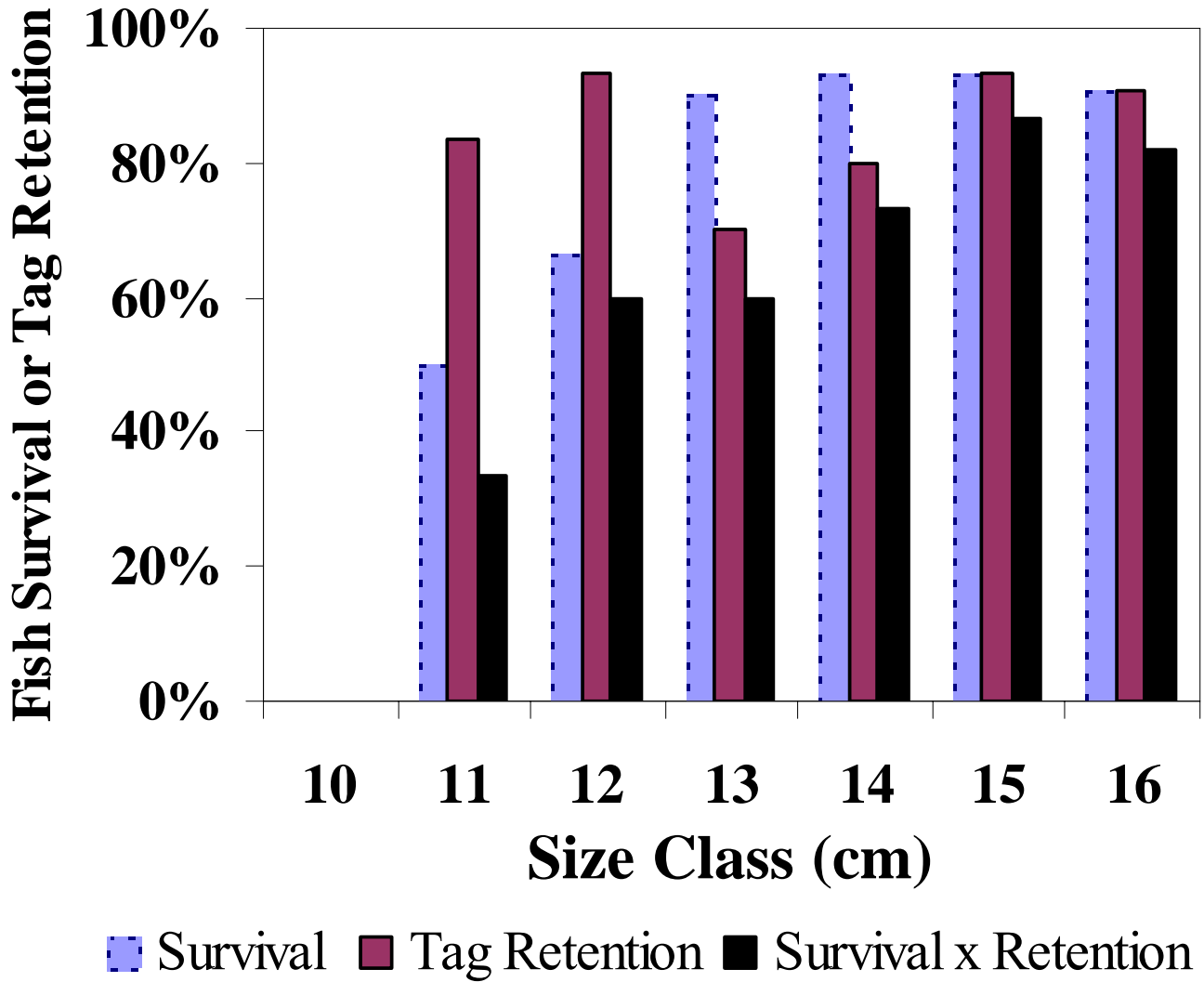
Fork Length (cm)	<11	11-12	12-13	13-14	14-15	15-16	16-17	
Mean Weight (g)	11.1	16.8	21.6	26.7	33.3	39.6	53.3	
<u>N</u>								Total
Dummy	1	6	15	20	15	15	11	83
PIT	7	15	7	16	18	16	6	85
<u>Mortality</u>								
Dummy	100.0%	50.0%	33.3%	10.0%	6.7%	6.7%	9.1%	15.7%
PIT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
<u>Tag Shedding</u>								
Dummy	--	16.7%	6.7%	30.0%	20.0%	6.7%	9.1%	13.3%
PIT	0.0%	0.0%	0.0%	6.3%	0.0%	0.0%	0.0%	1.2%
<u>Overall Loss</u>								
Dummy	100.0%	66.7%	40.0%	40.0%	26.7%	13.3%	18.2%	28.9%
PIT	0.0%	0.0%	0.0%	6.3%	0.0%	0.0%	0.0%	1.2%

481 FIGURE 1. Comparison of achieved growth for implanted pre-smolts over the first
482 (12 wk) and second (16 wk) periods. Growth of surgically implanted pre-smolts was
483 reduced relative to the controls in the first period (top row), but not the second (lower
484 row).
485



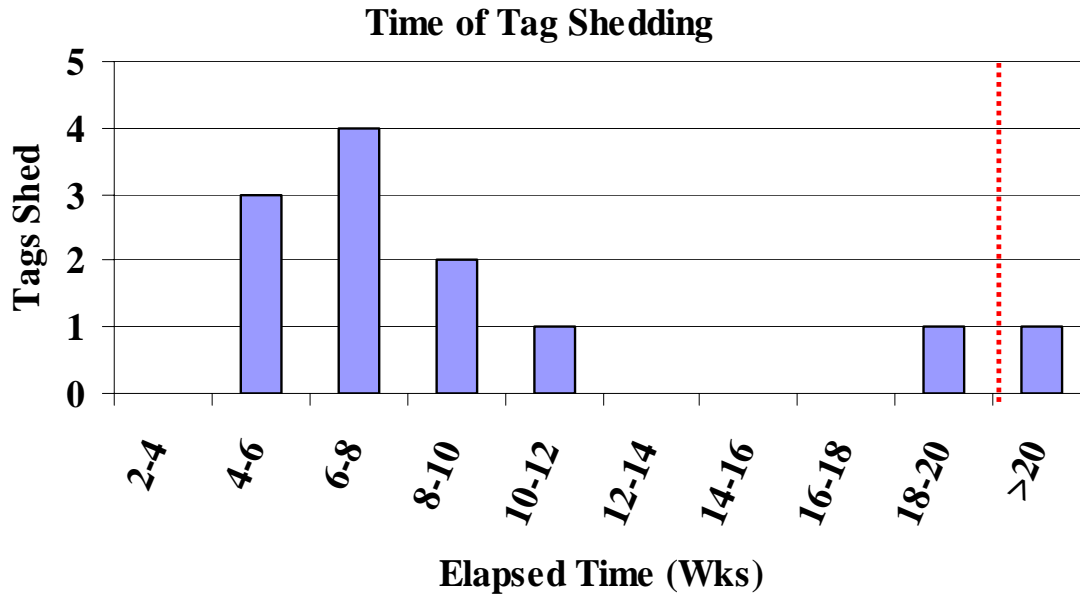
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487 FIGURE 2. Comparison of rates of pre-smolt survival, tag retention, and overall tagging
488 success (survival x retention) to six months post-implantation. Overall success increases
489 rapidly with initial size at implantation from 33% for 11.5 cm pre-smolts to >80% of the
490 surgically implanted pre-smolts.



491

492 Fig. 3. Time course of tag shedding. Tag losses have been binned into consecutive two
493 week periods. Median time to loss was 7.9 wks, average time 9.8 wks. A total of
494 13 tags were shed from a starting population of 90 implanted smolts.



495

496 FIGURE 4. Example of a different pre-smolt in the process of extruding a tag. (*Top*)
497 The abdomen is distended by the pressure of the tag against the abdominal wall.
498 The right side of the abdomen shows some slight evidence of abrasion of the skin
499 surface at the anterior end on the side facing the camera, presumably from
500 contact with the tank wall. (*Middle*) The opposite (left) side of the pre-smolt
501 shows a well-developed “pore”, through which the head of the dummy tag is
502 clearly visible. (*Bottom*) Close-up view of the pore. Note the clean unulcerated
503 edge of the pore; the skin and abdominal muscles have neatly drawn back, with
504 no evidence of infection. This tag was shed 7 weeks after the photographs were
505 taken and 19 weeks post-implantation.

506

507 (*Figure on next page*)

508 Fig 4. (Full caption on previous page)

