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Feature Article

Effect of internal tagging on egg viability of steelhead

James P. Losee[1,2,*], Rob Allan[3], Andrew Claiborne[3], Amy Edwards[3], John Larson[3], Gabe Madel[3], Jody Pope[4], Gustav Hellstrom[2], and Daniel Palm[2]

[1]Wild Salmon Center, Portland, Oregon, USA
[2]Department of Wildlife, Fish and Environmental Studies, Swedish University of Agricultural Sciences, Umeå, Sweden
[3]Washington Department of Fish and Wildlife, Fish Program, Olympia, Washington, USA
[4]Grays Harbor College, Aberdeen, Washington, USA

*Corresponding author: James P. Losee. Email: jlosee@wildsalmoncenter.org.

ABSTRACT

Objective: Acoustic and radio tagging has been used extensively to study movement patterns of fish in marine and freshwater environments and often relies on internal tagging. Intracoelomic implantation of tags in fish requires the surgeon to make an incision, insert a transmitter in the body cavity, and close the incision with one or more sutures. Techniques to safely carry out these procedures along with the effects of surgery and tag burden on mortality and behavior have been well studied, but secondary effects such as reduced reproductive potential have not been documented. Given the growing use of acoustic telemetry and radiotelemetry and increased conservation concern for fish globally, it is important to understand the costs of scientific research on the target species. This study was designed to describe the effect of intracoelomic implantation of acoustic tags on the egg viability of female winter steelhead *Oncorhynchus mykiss* during their spawning migration.

Methods: We monitored egg development of 108 hatchery-origin steelhead implanted with dummy acoustic tags across different abdominal locations.

Results: Compared to a nontagged control group, we observed significant mortality of embryos for the majority of the treatment groups; however, when incisions were located on the midbody, ventral surface and sutured, we observed no significant negative effect on egg viability, presumably due to reduced water entering the body cavity during and after surgery.

Conclusions: These results provide insight for those tagging fish species of high conservation concern on their spawning migration.

LAY SUMMARY

Implantation of acoustic tags to track fish movements can affect their reproductive potential. We studied the effect of intracoelomic tagging on the viability of the eggs of gravid female steelhead across five different surgery treatment groups.

KEYWORDS: acoustic, radio, telemetry, tracking

Understanding behavior and migration patterns of wildlife is critical for their conservation and management. Recent and long-term abundance decline in native fish species globally has stimulated increased research aimed at describing fish movements. Numerous techniques have been applied to track fish movements in the natural environment, including visual observation (McMillan et al., 2007; Needham & Taft, 1934), seismic monitoring (Dietze et al., 2020), simple external tags (Doornik et al., 2022; Gunnes & Refstie, 1980; Losee et al., 2020; Floy, elastomer, branding, etc.), and electronic tags (PIT, radio, satellite, and acoustic) that can be attached externally or surgically implanted (Hellström et al., 2022; Nathan et al., 2022; Thorstad et al., 2013). When tagging fish, internally researchers are limited by the size of tags that can be safely implanted into the study fish and should follow recommendations from recent research closely to choose the smallest transmitter that can achieve study objectives (Liedtke et al., 2012; Winter, 1996). Improvements to electronic tag technology in recent years resulting in smaller tags and longer battery life have increased the use of internal tagging methods and expanded the size range and species that can be tagged internally. However, with these advancements comes a growing need to account for the effects of the associated surgical methods on animal welfare and the related movement data.

Evaluations of tag effects have been concentrated on post-surgery mortality and movement (Cooke et al., 2011), with

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fewer studies focused on the surgery procedure and sublethal effects (Chomyshyn et al., 2011). Sublethal effects of tagging could include changes to spawning behavior, reduced egg viability (thus, reduced reproductive potential), or changes to inter- and intraspecies interactions. Research associated with intracoelomic tagging suggests that negative sublethal effects of tagging, if they exist, are greatest immediately after surgery (Brown et al., 2011; Welch et al., 2007; Wilson et al., 2017). For instance, Wilson et al. (2017) documented differential movement patterns for spawning Walleye *Sander vitreus* immediately after tagging compared to those tagged the year prior and attributed the differences to short-term effects of the tagging procedure. It should be mentioned, however, that this study was lacking a true control group, a common challenge for research of this kind.

Studies focused on sublethal effects associated with tagging, such as fertility, egg retention, and productivity, are uncommon in the literature (Bridger & Booth, 2003; Cooke et al., 2011). Existing results range widely from no effect (Peressin et al., 2021) to significant effects of surgical implantation (Adams et al., 1998; Berejikian et al., 2007). Considerations for sublethal effects become particularly important when surgical methods required for tagging are focused around the spawning period, when gravid anadromous fish lend themselves to capture. During the spawning period, lethal and sublethal effects associated with tagging are difficult to detect but could lead to population level effects. A review of intracoelomic tagging effects in fish by Cooke et al. (2011) highlighted the effect of tagging on reproductive fitness of study animals as an important data gap with few studies published on the topic.

This study was designed to examine the effect of intracoelomic tagging on the viability of eggs of gravid female steelhead *Oncorhynchus mykiss* (anadromous Rainbow Trout) intercepted during the spawning migration. By monitoring egg survival across five surgery treatment groups, this new information will contribute to the growing body of information that provides researchers insight into the negative effects of common intracoelomic tagging techniques on gravid fish and help to design best practices.

METHODS

Study overview

This study was designed to measure the effect of surgical treatments associated with acoustic tagging on reproductive potential of steelhead. We achieved this by tagging sexually mature hatchery-origin females captured in the wild with dummy acoustic tags, fertilizing the eggs, and measuring the proportion of those eggs that did not survive to the stage immediately before hatching for each treatment group.

Steelhead collection and sampling

In December of 2021, adult winter-run steelhead were intercepted during their upstream spawning migration at a permanent weir in Forks Creek, a tributary of the Willapa River, in Pacific County, Washington. Here, the Washington Department of Fish and Wildlife (WDFW) produces hatchery steelhead from a segregated broodstock originally derived from Chambers Creek stock in Puget Sound. Steelhead were trapped and identified as hatchery or wild based on adipose fin status (clipped vs. unclipped). Hatchery-origin adult female steelhead with no visible health issues (e.g., injury, infections, etc.) were collected and used in the study ($N = 130$). Wild fish were released upstream to continue their spawning migration.

Handling, surgery, and tag implantation

On December 15, fish were captured and anesthetized using Aqui-S (50% isoeugenol) solution at 20 mg/L concentration for approximately 5 min. Prior to surgery, fish girth (cm; widest part of body anterior to the dorsal fin) and fork length (cm) were measured, general body condition was reported, and scales from the preferred area for age were collected (Clutter & Whitesel, 1956; Scarnecchia, 1979). Fish were then transferred to a cradle for surgery, with gills fully submerged, and assigned to one of five treatment groups. All tags and surgery tools were disinfected before use and between fish. Dummy acoustic tags were surgically implanted in fish in all treatment groups except for the control group (treatment 1). The two most common incision locations for implantation of tags in the body cavity of adult salmonids are both on the ventral surface offset from the midline, either on the anterior body or anterior midbody (Cooke et al., 2011; Wagner & Stevens, 2000). To improve the chances of detecting an effect of surgery at these two body locations, if one exists, we included treatment groups without incision closure (e.g., sutures). Treatment groups are illustrated in Figure 1 and defined as follows:

- Treatment 1. Control group. Fish were sampled similar to other treatments and held submerged upside down in surgery cradle for approximately 2 min with no incision made.
- Treatment 2. Incision placed on the midbody, ventral surface slightly off-centered to the fish's left side, midway between the pectoral and ventral fins, and closed with two sutures, each tied with a surgeon's knot.
- Treatment 3. Incision placed on the anterior body, ventral surface, slightly off-centered to the fish's left side, extending to the end of pectoral fin, and closed with two sutures, each tied with a surgeon's knot.
- Treatment 4. Incision location was consistent with treatment 2, but the incision was not closed with sutures.
- Treatment 5. Incision location was consistent with treatment 3, but the incision was not closed with sutures.

During surgery, female steelhead were supported upside down for 2 min by a closed cell foam block in a modified PVC pipe that permitted the fish's head to be fully submerged but allowed the ventral surface between the pectoral and ventral fins to be exposed to the air above the water line. After a 1–1.2-cm incision was made, a dummy acoustic transmitter, length 24 mm, diameter 9 mm (V9; Innovasea, Halifax, Canada), was inserted and the incision was closed with two sutures tied with surgeon's knots (4-0 RB-1 Taper antibacterial Ethicon Vicryl Plus violet braided; Johnson & Johnson, United States).

Following surgery, each fish received a Floy tag posterior to the dorsal fin for identification. Tagged fish were then held with aerated water until swimming upright and responsive prior to being transferred to a common hatchery holding pond, where they remained for >12 d prior to spawning.

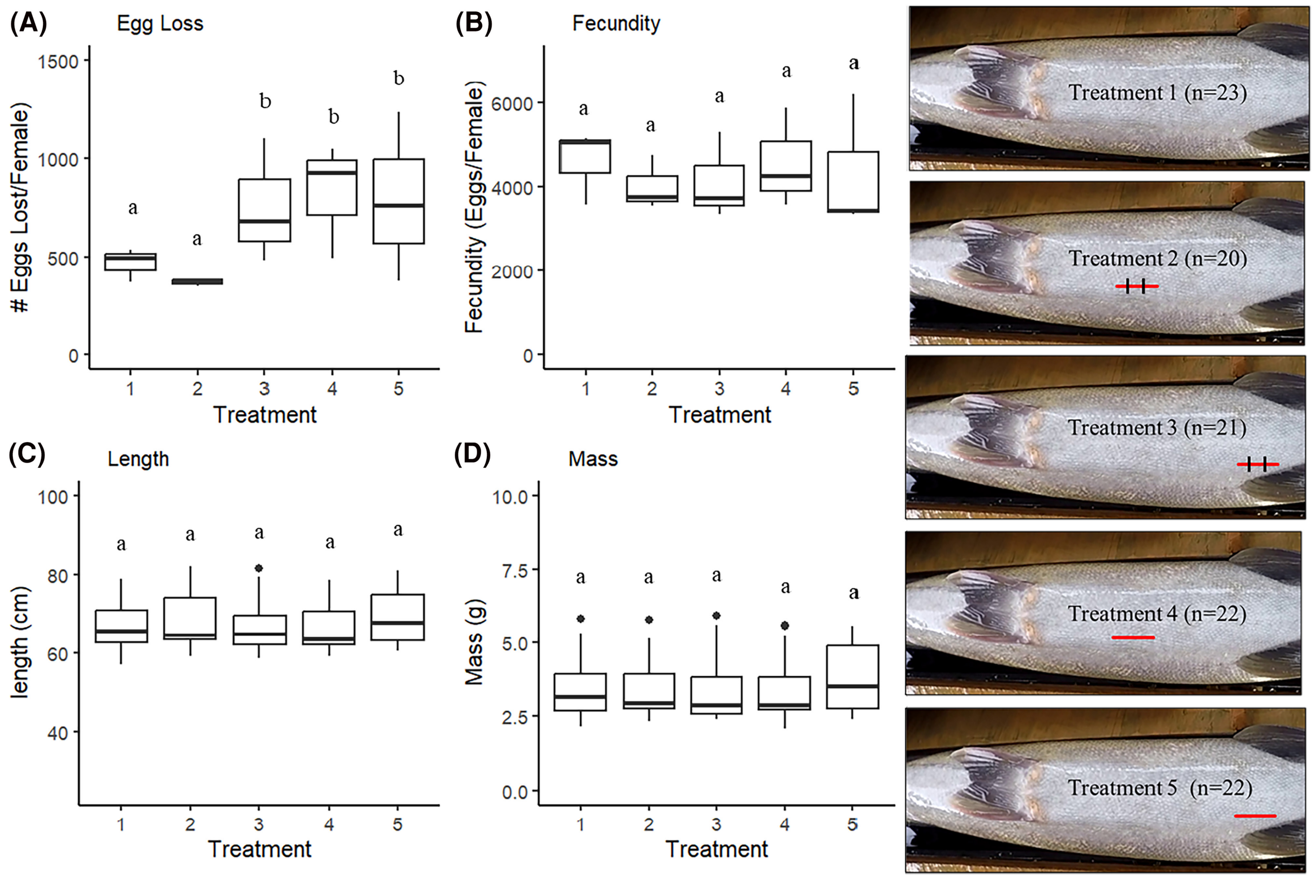

Figure 1. Box plots of (A) egg loss, (B) fecundity, (C) fork length, and (D) body mass associated with five surgery treatments for steelhead. Letters above boxes are associated with pairwise comparisons. Boxes that do not share a letter are significantly different from each other ($P < 0.05$). Lower and upper fences are 25th and 75th percentiles, and the median is in between. Bars represent 10th and 90th percentiles.

Egg fertilization, handling, and mortality quantification
Spawning of hatchery origin adult steelhead took place three separate times (December 27, 2021; January 11, 2022; and January 25, 2022). During each spawning event, all females were inspected for ripeness by feeling the belly to determine if the eggs had separated from the skein. Ripe steelhead were euthanized with a blunt force to the head using a Zephyr Gun and then sampled for fork length, girth (cm), and weight (kg). Once euthanized, eggs were extracted from individual fish by cutting the belly open. Eggs were weighed to the nearest kg and were fertilized with milt using a 1:1 male to female ratio. After fertilization, the eggs were transferred into individually labeled Marisource incubation trays, where they were disinfected by water hardening in a 100 mg/L iodophor solution for 1 h. Individual trays were identified by treatment group with flow-through spring water. The eggs were treated with Parasite S at a concentration of 1/600 for 15 min daily to avoid fungus in the incubators. The ambient daytime temperature ranged from 32°F to 61°F (0°C to 16°C) during the study period (December 2021–February 2022). Approximately 30 d after fertilization, during later stages of embryonic development, about when visual inspection of eggs shows a pigmented eye (Aral et al., 2011), egg mortality was estimated by pouring the eggs and water mixture into water with a 14" (35.6 cm) drop, causing the chorionic membrane to rupture in the dead or infertile eggs and turn opaque. Viable eggs were defined as embryos surviving to the eyed egg stage. Estimates of egg mortality for each treatment group were gathered using a Van Gaalen Model N-100 egg sorter, which counts and separates the live and dead eggs. A subsample of this count was verified by hand.

Statistical analysis

Differences in egg viability (viable eggs/female), fecundity (eggs/female), fork length (mm), and mass (kg) for female steelhead between the five treatment groups was tested using one-way ANOVA followed by Fisher's protected least significant difference post hoc test using R statistical software (R Development Core Team, 2021). In all post hoc tests, a Bonferroni correction was used, resulting in an adjusted level of 0.01 to achieve a P-value of 0.05 (i.e., $\alpha = 0.05/4 = 0.01$) across multiple comparisons presented as realized experiment-wide error rate. To evaluate egg loss between the time of tagging and spawning, we tested for differences in girth of females at the beginning of the study prior to surgery compared to girth prior to spawning for each treatment group. Additionally, we used a one-way ANOVA to test for differences in fork length between treatment groups for males used for spawning. To compare patterns of relative egg loss (viable vs. nonviable), logistic regression was used (Hosmer et al., 2013) with proportion of nonviable eggs as the response variable. This analysis was followed by Tukey's post hoc test to test for differences in the proportion of nonviable eggs across five treatment groups.

Table 1. Results from evaluation of egg mortality for intracoelomic tagged steelhead across five surgery treatment groups.

Treatment #	Treatment group	Surgery location	Sample size (N)	Fecundity (eggs/female) ± SE	Egg loss (%) ± SE
1	Control	No surgery	23	4,199 ± 182.9	10.5 ± 0.28
2	Sutured	Midbody	20	3,948 ± 32.6	10.3 ± 0.02
3	Sutured	Anterior body	21	3,894 ± 203.4	19.9 ± 2.20
4	No suture	Midbody	22	3,947 ± 212.9	21.3 ± 1.13
5	No suture	Anterior body	22	3,567 ± 275.5	20.6 ± 3.66

RESULTS

We implanted dummy tags in 130 hatchery-origin steelhead (26 in each treatment). Between the time of surgery and spawning (12–40 d), 22 fish died and were removed from the study. Mortalities were distributed across all treatment groups, with four mortalities in treatments 1 and 5, three mortalities in treatment 2, six mortalities in treatment 3, and five mortalities in treatment 4. One-hundred eight fish survived to spawning and were included in the study (Table 1). All incisions were inspected and showed variations in healing condition. However, all incisions were closed at the time of spawning, including the treatment fish that did not receive sutures (treatments 4 and 5).

Overall, female steelhead ranged in length from 57.0 to 82.0 cm (mean ± SD = 67.3 ± 6.6 cm). Weight ranged from 2.1 to 6.4 kg (mean ± SD = 3.5 ± 1.1 kg) and fecundity ranged from 3,357 to 6,194 (mean ± SD = 3,911 ± 202), with no significant differences between treatment groups for any of these metrics (ANOVA: df = 4, $P > 0.05$). Significant differences in egg mortality were observed between treatment 1 and treatments 3, 4, and 5 and between treatment 2 and treatments 3, 4, and 5 (Fisher's protected least significant difference: $P < 0.001$; Figure 1A). The number of nonviable eggs was least for treatments 1 and 2 and greatest for treatment groups 3, 4, and 5 (Figure 1). Male steelhead body length used for spawning ranged from 58.0 to 92.0 cm (mean ± SD = 67.7 ± 7.0 cm) and was not significantly different across treatment groups (ANOVA: df = 4, $P > 0.05$). Further, girth did not differ significantly before surgery (mean ± SD = 34.6 ± 5.3 cm) compared to girth measured prior to spawning (mean ± SD = 33.9 ± 3.7 cm; t-test, $t = 2.8$, df = 231, $P > 0.05$).

The proportion of eggs that were viable versus nonviable was different between surgery treatment groups (logistic regression: $P < 0.001$). Specifically, eggs in treatments 1 (control group) and 2 had significantly lower probability of mortality than all other treatment groups (Tukey post hoc test: $P < 0.01$) but were not different from each other.

DISCUSSION

Surgically implanting tags in the body cavity of fish to investigate movement is becoming increasingly used, and small transmitters weighing less than 2% of the body weight of the study subject like those used in this study have been shown to mitigate risk (Winter, 1996). However, negative effects associated with the surgical procedure have not been fully evaluated. The current study demonstrated that intracelomic tagging can result in significant egg loss. These negative effects were exacerbated when wounds were not properly closed with sutures, highlighting water entering the body cavity as a proximate cause for egg loss. Numerous studies have described other secondary effects of surgery, like egg retention in steelhead (Berejikian et al., 2007), egg resorption in Rainbow Trout (Martin et al., 1995), and increased stress and changes in short-term behavior on a variety of fish species (Jadot et al., 2005; Wilson et al., 2017). However, results from the current study represent the first documentation of significant decreased egg viability as a result of tagging an anadromous salmonid. Together, this new information provides insight for researchers using surgical means to track fish near the spawning period and could help to shape methods to mitigate the negative effects of internal tag implantation.

In the current study, egg loss was greatest for fish with incisions left unsutured, allowing water to enter the body cavity, but also for those fish with incisions made anterior to the midbody, near the water line in the cradle. In contrast, when the incision was made at the midbody, above the water line, and closed with sutures, egg loss was not different from the untagged control group. For nearly a century, the importance of water in "hardening" eggs (Yamamoto, 1951) has been known. For instance, His (1873, cited in Yamamoto 1962) showed that the ova of Brook Trout *Salvelinus fontinalis* lost their viability in less than 30 min when exposed to water. Later, Zotin (1958) showed that unfertilized eggs exposed to water rapidly exhibited an increased membrane toughness, causing the micropyle to close, thus impairing fertilization. This information, along with other studies (Groot & Alderdice, 1985; Taranger & Hansen, 1993; Yamamoto, 1962), highlights the role of water in "activating" the egg membrane and the potential mitigating effect of suturing incisions to support closure and healing of the wound. In contrast, Chomyshyn et al. (2011) saw no short-term effect on health and condition of immature Bluegill *Lepomis macrochirus* tagged in the body cavity but advised that negative effects may be restricted to gravid fish. Also of note, implantation of tags at an incision made at the midventral body location, as was done in this study, may also reduce danger of puncturing the ovaries of female fish as reported by Schramm and Black (1984). Overall, our results highlight the benefit of taking care to ensure that water does not enter the body cavity during surgery and that the incision is properly closed.

Pacific salmon *Oncorhynchus* spp., steelhead, and Coastal Cutthroat Trout *O. clarkii* are known to exhibit complex migrations before returning to their natal freshwater rivers and streams to spawn (Beamish, 2018). In their natal streams, they segregate naturally by stock or race at a predictable location and time, making for an ideal setting to capture and tag individuals of a specific stock on their way to the spawning grounds. For iteroparous fish like steelhead, tagged individuals that survive spawning can then be tracked across various habitats. While the benefits of this information to researchers and managers has been shown to be exceptionally important, it is prudent to consider the short- and long-term implications to productivity of these study animals. Results from the current study highlight the potential for significant egg loss and thus reduced productivity associated with tagging, and it is likely that these results have implications for fish research beyond the *Oncorhynchus* family. Depending on the number of individuals internally tagged and the size of the population being studied, it is possible that tagging fish during the spawning period can have a negative, population level effect. Keeping water out of the body cavity during and after the surgical process may mitigate the negative effects of tagging as observed here, but avoiding the spawning period for tagging represents the best way to reduce egg loss. For instance, Yamamoto (1955) showed that tagging prior to ovulation may reduce and eliminate risk of egg hardening as shown in Chum Salmon *Oncorhynchus keta*. Future research aimed at understanding egg development as it relates to the spawning migration would be helpful for researchers balancing the cost and benefits of tagging mature salmonids in their natal rivers.

We documented egg mortality associated with intracoelomic tagging in an anadromous salmonid but also identified ways to eliminate or minimize this risk. Because fecundity is closely linked with productivity, especially for species like steelhead that are of high conservation concern, intracoelomic surgery of gravid fish should be conducted carefully to reduce or account for the effects described above. With incision locations focused around the midbody and caution taken to prevent water from entering the body cavity, it is possible that intracoelomic tagging can be used with minimal cost to the study organism.

DATA AVAILABILITY

Data are available upon request.

ETHICS STATEMENT

This research meets the ethical guidelines and legal requirements of the WDFW.

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CONFLICTS OF INTEREST

There is no conflict of interest declared in this article.

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