ARTICLE

Effects of Surgically Implanted Acoustic Tags on Body Condition, Growth, and Survival in a Small, Laterally Compressed Forage Fish

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Abstract
    Telemetry studies often assume a lack of adverse effects caused by tag attachment and presence in various species and size-classes, which may lead to inaccurate conclusions about fish behavior in field studies. Studies that examine the effects of tagging are typically performed on salmonids and adult fishes rather than on the small fishes that are increasingly becoming the focus of telemetry studies. The objectives of this study were to assess the effects of intracoelomic acoustic tagging on growth, condition, survival, and tag retention in subadult hatchery Bloaters *Coregonus hoyi* (a focal species for restoration efforts in the Laurentian Great Lakes) and to determine the maximum tag burden below which tag effects are reduced. Fish were either tagged with one of three dummy acoustic transmitters (Vemco V6: *n* = 50; V7: *n* = 50; V9: *n* = 50) or were followed as controls (*n* = 50; anesthesia, PIT-tagging, and handling only) or sham individuals (*n* = 49; anesthesia, surgery, suturing, and PIT-tagging but no acoustic tag implanted). Tags represented 1.3–9.0% of body mass. All fish received a PIT tag for individual identification throughout the 6-month monitoring period (November 2014–May 2015). Survival exceeded 90% in all treatment groups, and the tag retention rate was 100%. All surviving fish appeared healthy and in excellent condition at the conclusion of the experiment. The results of this study suggest that acoustic transmitters with a tag mass : body mass ratio of 9% or less can be successfully implanted intracoelomically into subadult Bloaters—small, laterally compressed pelagic fish—with no adverse effects.

Acoustic telemetry is an increasingly popular tool used to study movements of aquatic organisms in their natural environments. Telemetry has revolutionized aquatic animal tracking by providing insights into the movement, habitat use, distribution, and survival of marine and freshwater species through passive spatial and temporal monitoring of tagged individuals (Cooke et al. 2013; Hussey et al. 2015). Electronic transmitters or "tags" can be externally attached, inserted into the stomach via injection, or surgically implanted into an individual fish depending on the size and species and the objectives of the study (Hussey et al. 2015). Acoustic hydrophones or "receivers" deployed in the animal's environment then detect

and record the acoustic signals transmitted by tagged individuals that are within detection range of the receivers. In acoustic telemetry studies focused on fishes, tags are most frequently surgically implanted into the coelomic cavity, as this method of tagging is generally best suited for most long- or short-term applications (Jepsen et al. 2002; Cooke et al. 2011). Fitting a fish with an acoustic tag via intracoelomic implantation requires capture, anesthesia, surgery, and release, all of which disturb the animal and can cause stress (Cooke et al. 2011; Ashton et al. 2017).

Acoustic telemetry studies rely on the assumption that surgical implantation of tags does not alter the behavior or vitality of the tagged organisms (Oldenburg et al. 2011; Lee et al. 2013). A common conception is that a transmitter should weigh less than 2% of the body mass of a fish in air or 1.25% in water (Winter 1983). This "2% rule" is based on the assumption that implantation of heavier tags could affect the swimming performance, growth, survival, or behavior of the fish (Winter 1983; Brown et al. 1999). However, previous studies have revealed results that both support (Moore et al. 1990; Loher and Rensmeyer 2011) and contradict (Robertson et al. 2003; Brown et al. 2006) the idea that the surgery and presence of the tag do not cause changes in physiology or behavior in different fishes. In the event of tag loss via expulsion through the body wall or through the incision site as a result of insufficient surgical procedures, tagging can have lethal effects (Cooke et al. 2011; Ammann et al. 2013). Assumptions that internal tag attachment and presence do not alter fish behavior may lead to improper inferences about fish movements and habitat use. Interpretation of acoustic telemetry data thus requires first determining whether tagging effects exist to assess how accurately detections represent natural fish movements and the larger population of untagged conspecifics (Bridger and Booth 2003; Hondorp et al. 2015).

The majority of studies that examine tag effects utilize radiotelemetry, focus on salmonids, have short study durations, and often study adult fish rather than various life stages (Brown et al. 2006; Hondorp et al. 2015). The technological differences between radiotelemetry and acoustic telemetry warrant independent assessments of the impact that acoustic tags may have on tagged individuals. Morphological and anatomical variation across fish species and life history stages reinforces the need to evaluate tag effects in particular species and life stages to determine how responses to surgical procedures and tag presence may differ. Acoustic telemetry tags can vary in battery life from several weeks (e.g., Vemco V4, 180 kHz) to as much as 10 years (e.g., Vemco V16, 69 kHz) depending on the tag type and its specifications, thus allowing for longer study durations than some traditional tagging methods. The extended study periods involved with acoustic telemetry create the potential for longer-term tag effects to manifest and influence fish movement and behavior.

Incorporating longer study durations into tagging effect studies can help to address concerns regarding possible impacts of long-term tag presence. Tag size previously limited acoustic telemetry studies to larger fishes, but ongoing efforts to miniaturize tags have permitted the tagging of smaller fishes and previously unsuitable species in addition to raising questions regarding the limits of tag size (Heupel et al. 2006; Lee et al. 2013; Mueller et al. 2017). Biotelemetry studies of additional smaller species and juvenile stages that test the boundaries of transmitter mass : body mass ratios and fish anatomy relative to tag size are often not accompanied by tagging effect studies. Application of acoustic telemetry can provide insights into the lesser-known ecology of the younger life stages of fish, can aid in restoration efforts that often involve the stocking of yearling or juvenile fish, and can offer knowledge that is valuable in conservation practices (Collins et al. 2002; Ammann et al. 2013; Hussey et al. 2015).

Fish are stocked in freshwater and marine systems worldwide with the aim of reintroducing or re-establishing species to restore aquatic environments to a more natural state and create recreational and commercial fishing opportunities (Holčík 1991; Halverson 2008). The issue with stocking remains that we are often unaware of the fates of these fish after stocking due to difficulty in monitoring them. Acoustic telemetry provides a means by which to monitor reintroduced fishes in diverse environments and to optimize stocking strategies, but juvenile fish bring forth potential issues with tag insertion. As telemetry becomes a more widely used tool, filling gaps in knowledge of tagging impacts on earlier life stages of various species becomes increasingly important.

The goals of this study were to (1) evaluate the possible effects of tagging and tag size on the body condition, growth, and survival of subadult fish; (2) assess surgery healing and tag retention; and (3) determine the maximum tag burden below which tag effects are reduced. To accomplish this, captive juvenile hatchery Bloaters *Coregonus hoyi* were allocated to one of five treatments and were monitored and evaluated for a period of 6 months. Bloaters were used to test these objectives because of their availability in hatcheries, including the opportunity to monitor them for an extended period of time; their lateral body shape and relatively small body size in relation to commonly used acoustic telemetry tags; the notorious fragility of Bloaters and the perceived belief that they are unable to handle a tag; an absence of literature examining acoustic tag effects in ciscoes *Coregonus* spp.; and the involvement of ciscoes in restoration stocking telemetry studies (Bégout Anras et al. 1999; Gorsky et al. 2012; Huuskonen et al. 2012). Bloaters are the focus of a restoration stocking program in the Laurentian Great Lakes that aims to re-establish a self-sustaining population of deepwater ciscoes in Lake Ontario (Baldwin 1999;

Stewart et al. 2017). The ability to tag Bloaters and use acoustic telemetry to monitor their postrelease behavior would contribute to the reintroduction and management of a native freshwater fish species in the Great Lakes. Based on previous studies that examined tag effects in juveniles of various fish species (Ammann et al. 2013; Miller et al. 2014), we predicted that surgery and tag burden would not have a significant impact on the growth or condition of the Bloaters and that a transmitter representing less than 10% of body mass would not produce tag effects. Adhering to surgical procedures employed in the field, we predicted that mortalities would be minimal, with the majority of mortalities occurring within the first 48 h after surgery, and that there would not be a significant amount of tag loss within the 6-month study period (Ammann et al. 2013; Carrera-García et al. 2017).

METHODS

Fish rearing.— The fish specimens used in this experiment were 19-month-old, hatchery-reared Bloaters ($n = 249$) that were obtained from the White Lake Fish Culture Station (Sharbot Lake, Ontario) and reared for the purposes of restoration stocking in Lake Ontario. Fertilized Bloater eggs were collected from northern Lake Michigan in January and February 2013 by the U.S. Fish and Wildlife Service and were reared at the White Lake Fish Culture Station. Fish from the various treatments were reared in one 1,500-L, semi-square fiberglass tank. Tanks were indoors under low lighting and were supplied with a mix of deep and surface water draws from White Lake at a rate of 1,500 L/h. Water temperature was consistent with the White Lake ambient temperature, ranging from 3°C to 12°C during the study period (November 2014–May 2015), and O_2 levels remained high. Fish were fed a diet of Otohime EP1 for the duration of the study. During colder months when Bloaters fed less, food was always presented and available for consumption, but fish showed little interest in feeding. As temperatures warmed, feeding began to increase in April and subsequent months during which fish were fed to satiation at 2–3% of body mass per day. Daily tank maintenance consisted of cleaning and waste removal.

Fish tagging.— The experiment involved allocating fish to one of five experimental treatment groups: control (anesthetized and handled but not subject to surgery), sham (surgery but without insertion of an acoustic tag), V6 (surgically implanted 1.0-g dummy tag), V7 (1.6-g tag), and V9 (2.9-g tag). Dummy acoustic tags were fabricated from Delrin (Wilmington, Delaware) rod stock to closely replicate the mass, dimension, and shape of Vemco Ltd. (Bedford, Nova Scotia) V6 (diameter = 6.0 mm; length = 16.5 mm), V7 (diameter = 7.0 mm; length = 22.0 mm), and V9 (diameter = 9.0 mm; length = 21.0 mm) 69-kHz acoustic coded

transmitters (Figure 1). Dummy tags were spun to diameter on a lathe and cut to length, and the edges were rounded to achieve the appropriate profile. All measurements were within 10% of the actual Vemco tag specifications. Dummy tags had a specific density of 1.41 g/cm³—lower than the specific densities of functioning Vemco acoustic tags, which range from 2.08 to 2.17 g/cm³. This discrepancy in specific densities is largely due to battery weight.

Fish tagging took place over a 3-d period (November 26–28, 2014). Bloaters were pseudo-randomly selected from the holding tank in groups of five, adhering to a minimum size (~20 g) suitable for tagging, and were allocated to one of five treatments. Fish were then placed in an anesthetic solution of buffered tricaine methanesulfonate (MS-222; 200 mg/L); immersion times varied but generally required 100–180 s in order to achieve stage III anaesthesia (Summerfelt and Smith 1990). Fork length (FL) was measured to the nearest 1 mm, and wet mass was recorded to the nearest 0.1 g. Anesthetized Bloaters were placed in a cradle, where their gills were irrigated with a maintenance dose (100-mg/L MS-222) of anesthetic. Each fish received a PIT tag (Oregon RFID FDX-B; 8 × 1.4 mm) in the dorsal flank just below the anterior margin of the dorsal fin. An incision was made immediately adjacent to the linea alba. Incision length mimicked that used in field studies and varied between 8 and 12 mm according to acoustic transmitter size. The incision was closed with three interrupted, independent sutures (Ethicon Coated VICRYL Plus antibacterial suture, size 5-0, with RB-1 tapered needle) tied with a 2–1–2 surgeon's knot. All surgical equipment was disinfected in a betadine solution (1 part betadine : 9 parts water) prior to each surgery. Procedures lasted approximately 130–180 s from the time the fish were placed in the anesthetic solution to the time of placement in the recovery tank after surgery.

Postsurgical monitoring.— Fish were monitored daily by hatchery staff as part of routine tank inspections during which the occurrence of any activity, such as feeding

FIGURE 1. Size comparison of an average Bloater to the dummy acoustic tags (top to bottom [tag type, diameter × length]: V9, 9.0 × 21.0 mm; V7, 7.0 × 22.0 mm; V6, 6.0 × 16.5 mm) that were surgically implanted for this study (image is a composite of two pictures that used the same quarter as a scale for comparison). [Color figure can be viewed at afsjournals.org.]

events or mortalities, was recorded. Long-term variables of interest included fish biometrics (FL and mass) to assess growth and wound and health scores to evaluate tag retention and overall fish health and recovery. Fish were identified by PIT tag, and each variable was measured for all fish individually at approximately 6-week intervals postsurgery until May 2015 for a total of five sampling events (November 2014; and January, February, April, and May 2015) across a 6-month study period. Health scores were subjective and ranged on a scale from 1 to 3, where 1 indicated excellent condition and apparent health, 2 signified some fungal lesions, and 3 denoted lethargy and moribundity. Wound scores were assigned based on a scale ranging from 0 to 6 (Figure 2) as developed by Wagner (1999). Additional information recorded during sampling events included the number of intact sutures and the number of sutures with tearing of the skin for each individual. At the end of the study period, all fish were euthanized via exposure to a lethal dose (200 mg/L) of MS-222 according to the University of Windsor Animal Care Committee guidelines (Animal Utilization Project Protocol 14-13).

Data analysis.— Initial FL, mass, and tag mass : body mass ratio of Bloaters were compared among the five treatment groups by using one-way ANOVA. Survival at the end of the 6-month study period was calculated as (number of fish alive/total number of fish) × 100. Fulton's condition factor (K) was calculated as $K = (M/FL^3) \times 100$, where M is fish mass (g) and length is FL (cm) of the fish (Ricker 1975). Fish for which there was not a complete set of measurements ($n = 5$) were omitted from further analyses. The use of K as a measure of fish growth and health requires the assumption of isometric fish growth (Blackwell et al. 2000). A linear regression of K as the dependent variable and initial FL as the independent variable suggested that there was no evidence of changing K with initial fish size (i.e., nonisometric fish growth), thus validating our assumption (see Results).

Mean K and the change in K (ΔK) were calculated at each sampling event and between sampling events, respectively. All explanatory variables in the data set were standardized by centering the data to 0 and scaling by the SD to facilitate comparison of variables measured on different scales. A visual test for normality of ΔK was performed using quantile–quantile plots ("qqp" function in the R package "car"), confirming that ΔK followed a normal distribution. A series of linear mixed models (LMMs) was created to analyze the ΔK values at each sampling event in relation to explanatory variables. The fixed effects included in the models were treatment group, ΔK, week, and week^2 (to test for polynomial trend in ΔK through time); tag ID was included as a random effect to account for repeated assessments of individual fish. Week was scaled to values ranging from 0 to 1, representing weeks 0–24 of the study period, in order to create a scale similar to that of the other variables (i.e., K). To evaluate the amount of variance in ΔK explained by the random effect of tag ID, the conditional R^2 (fixed and random effects) and marginal R^2 (fixed effects) were calculated for the maximal (global) model that included all fixed and random effects (Nakagawa and Schielzeth 2013). The best-fitting LMM was selected based on the model producing the lowest value of Akaike's information criterion (AIC). Model fit was visually assessed by plotting the fitted values and residuals of the model and determining whether the assumptions of linearity and additivity were met (Yang 2012). Statistical analyses were performed using R version 3.3.2 (R Core Team 2016), and statistical significance was assumed at α = 0.05.

Rank	Description	Photo
1	• Incision completely closed • No inflammation	Rank 0
2	• Incision closed • Some inflammation along incision	
3	• Incision held in proximity, but edges slide if fish moves • Moderate inflammation	Rank 2
4	• Incision partially opened at one end or middle • Moderate to high inflammation	Rank 4
5	• >50% of wound open • Moderate to high inflammation along wound edges	
6	• Completely open wound • Moderate to high inflammation along wound edges	Rank 6

FIGURE 2. Description of criteria for wound healing scores used to rank the progress of wound healing after surgical insertion of dummy acoustic tags in Bloaters. [Color figure can be viewed at afsjournals.org.]

RESULTS

Tagging Summary

Subadult Bloaters ($n = 249$) were randomly selected and ranged in FL from 13.2 to 19.9 cm (mean $\pm$ SD $= 16.7 \pm 1.2$ cm) and in mass from 21.0 to 95.9 g (53.5 ± 13.3 g), with tag mass : body mass ratios ranging from 1.3% to 9.0% (Table 1). There were no significant differences in initial mass (ANOVA: $F_{4, 273} = 0.642$, $P = 0.633$) or FL (ANOVA: $F_{4, 273} = 1.237$, $P < 0.296$), but the tag mass : body mass ratio significantly differed across treatment groups (ANOVA: $F_{2, 147} = 163.5$, $P < 0.001$; Table 1).

Survival and Tag Retention

Survival of all individuals ($n = 249$) was 100% after the first 48 h of the experimental period. There was no immediate mortality associated with the surgery; the first mortality event occurred a full 3 months from the start of the experiment on March 3, 2015. At the end of the 6-month study period, survival of all Bloaters was 97.2%, with the only mortalities occurring in the V6, V7, and V9 treatment groups, which had survival rates of 98, 94, and 94%, respectively. No fish expelled their tags, resulting in a retention rate of 100% in all treatment groups. The presence of tags was confirmed when fish were lethally sampled at the conclusion of the study.

Growth and Healing

Fulton's K was found to increase with increasing initial FL, but FL explained only 3.5% of the variability in K and may have been largely driven by a few data points (linear regression, $F = 45.7$, df $= 1,218$, $P < 0.001$). Although the potential for minor bias exists, it is minimal, and the majority (96.5%) of the variability in K can be attributed to factors other than fish growth. The maximal LMM (i.e., including all fixed and random effects) revealed that individual ID had no influence on variability in K (conditional $R^2 = 0.342$; marginal $R^2 = 0.342$). Based on AIC values, the best-fitting model included the fixed effects of week and week^2 (Table 2; AIC $= -2,723.3$), consistent with observations that all treatment groups displayed a decrease in mean K for the first 12 weeks of the study followed by an increase in mean K for the final 12 weeks (Figure 3). Treatment group and initial K were not selected as explanatory variables in the model, indicating no effect of treatment or initial K on ΔK throughout the course of the study. Visual inspection of the relationship between fitted values and residuals of the model revealed that assumptions of linearity and additivity were met, signifying good model fit.

After excluding fish that did not have a complete set of measurements due to mortality or evidence of sampling error (V6: $n = 2$; V7: $n = 3$; V9: $n = 3$), all remaining fish in the treatment groups subjected to surgery (sham: $n = 49$; V6: $n = 48$; V7: $n = 47$; V9: $n = 47$) had a health score of 1 at the conclusion of the 6-month study period, denoting excellent condition and apparent health. Mean wound scores for all surgical treatment groups stayed at a score of approximately 2 for all sampling periods after surgery, with minimal variation between treatment groups (Figure 4).

DISCUSSION

Treatment group was found to have no effect on K of hatchery-reared subadult Bloaters throughout the 6-month study period used to assess the influence of surgical tag insertion. The lack of tagging effects in our study is consistent with the results of other studies that have examined tag effects in subadults of other species (Robertson et al. 2003; Ammann et al. 2013; Miller et al. 2014). However, unlike those studies, which reported temporary impairment of growth and health early posttagging with subsequent recovery (Robertson et al. 2003; Neely et al. 2009), our experiment showed no such short-term impacts.

TABLE 1. Summary of characteristics of Bloaters tagged on November 26–28, 2014, separated by treatment group (described in Methods); n is the number of individuals and TFR is tag mass : fish body mass ratio. Within a row, different lowercase letters indicate significant differences between treatment groups.

	Treatment				
Variable	Control	Sham	V6	V7	V9
n	50	49	50	50	50
Mean FL $\pm$ SD (cm)	16.6 $\pm$ 1.2	16.7 $\pm$ 1.3	16.6 $\pm$ 1.2	16.7 $\pm$ 1.2	17.0 $\pm$ 1.3
Range of FL (cm)	13.4–19.0	14.2–19.7	13.2–19.0	14.1–19.5	14.6–19.9
Mean mass $\pm$ SD (g)	52.6 $\pm$ 13.2	52.4 $\pm$ 13.8	52.0 $\pm$ 12.3	53.4 $\pm$ 12.5	57.1 $\pm$ 14.6
Range of mass (g)	21.0–84.0	33.8–94.8	27.7–76.0	29.3–82.2	32.4–95.9
Mean TFR $\pm$ SD (%)	n/a	n/a	2.0 $\pm$ 0.5 x	3.2 $\pm$ 0.7 y	5.4 $\pm$ 1.4 z
Range of TFR (%)	n/a	n/a	1.3–3.6	1.9–5.5	3.0–9.0

Tagging effect studies often occur over a shorter period and consist of frequent sampling events (e.g., Moore et al. 1990; Lee et al. 2013), whereas this study examined

TABLE 2. Linear mixed models constructed to estimate the influence of the explanatory variables—treatment group (treatment), initial condition (IK), week (wk), and week squared (wk^2)—on the change in Fulton's condition factor (ΔK) in Bloaters after tagging. Corresponding Akaike's information criterion (AIC) values and degrees of freedom (df) are listed for each model; the lowest AIC value (bold italics) indicates the best-fitting model.

Model	AIC	df
$\Delta K \sim$ treatment + IK + wk + (treatment $\times$ wk)	−2,623.2	13
$\Delta K \sim$ treatment + IK + (treatment $\times$ wk)	−2,623.2	13
$\Delta K \sim$ treatment + IK + wk	−2,649.9	9
$\Delta K \sim$ treatment + IK	−2,317.4	8
$\Delta K \sim$ treatment	−2,318.8	7
$\Delta K \sim$ IK	−2,357.2	4
$\Delta K \sim$ wk	−2,686.7	4
$\Delta K \sim$ treatment + IK + wk + wk^2 + (treatment $\times$ wk) + (treatment $\times$ wk^2)	−2,644.9	18
$\Delta K \sim$ treatment + IK + wk + wk^2	−2,687.1	10
$\Delta K \sim$ wk + wk^2	***−2,723.3***	***5***

fish only every 6 weeks; thus, it is possible that we may have missed potential differences in growth within the first 6 weeks posttreatment. Despite the potential value of relatively long-term laboratory studies of tag effects that are relevant to acoustic telemetry, not all conditions experienced by tagged fish in a natural environment can be simulated (e.g., stress related to release), but the insights into healing and postsurgical condition represent the majority of stress that would be expected in relation to tagging.

The growth of dummy acoustic-tagged fish was similar to the growth of the sham fish that underwent surgery without insertion of an acoustic tag and the control fish that were anesthetized and handled but not subject to surgery, indicating no treatment effect. Fulton's K for all treatment groups followed the same trend throughout the study, exhibiting decreases for the first 12 weeks followed by increases during the final 12 weeks. Changes in K across all treatment groups may be explained by seasonal fluctuations in metabolic balance and patterns of maturation (Bolger and Connolly 1989). Bloaters fed less during the colder period of the study (weeks 0–12) but began to feed more as temperatures warmed between weeks 12 and 18, mimicking natural feeding cycles. Increases in food consumption may lead to greater lipid content and mass relative to body length, corresponding with the rise in K during this seasonal change. Juvenile Bloaters are leaner than adults and will become more lipid-dense as they approach adult life stages, which may contribute to a
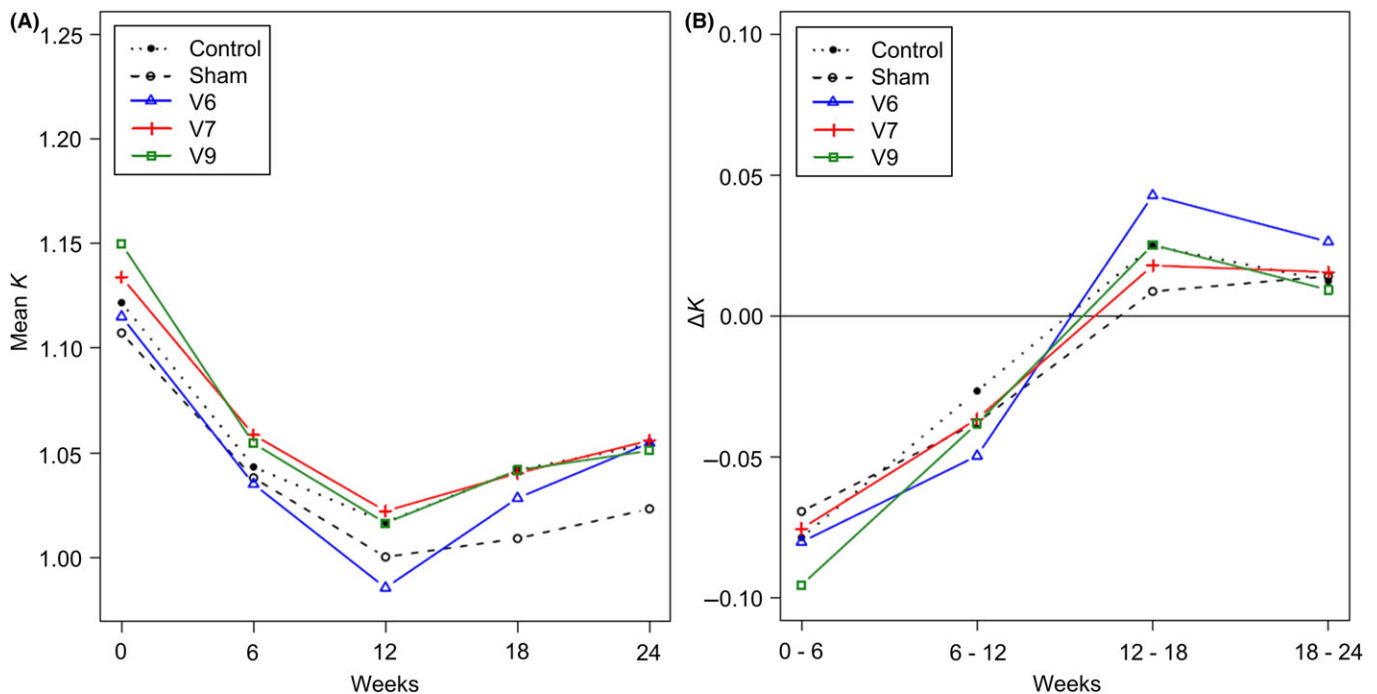

FIGURE 3. Fulton's condition factor (K) for tagged Bloaters by treatment group across the entire study period (November 26, 2014–May 13, 2015): (A) mean K and (B) mean change in K (ΔK). [Color figure can be viewed at afsjournals.org.]
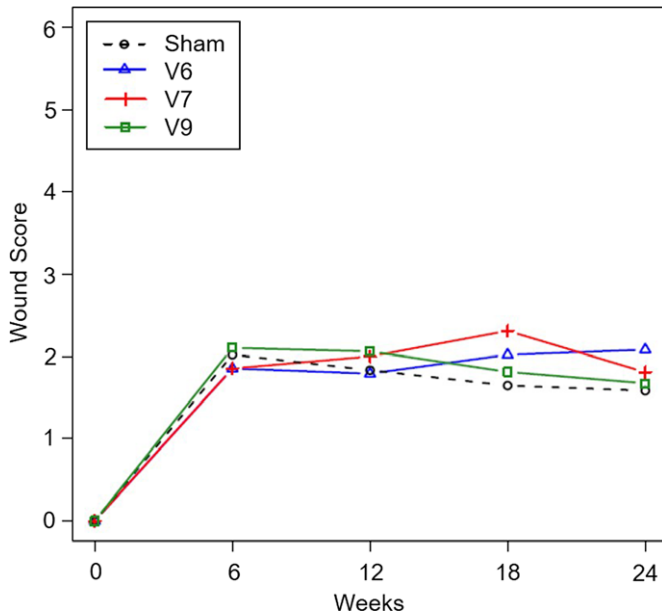
FIGURE 4. Mean wound scores (see Figure 2) of Bloaters in each treatment group at each sampling event. [Color figure can be viewed at afsjournals.org.]

greater mass : length ratio and nonisometric growth as the fish age (Clemens and Crawford 2009). There was no evidence that initial K or individual fish ID influenced the trend in K.

Our study had high survival relative to several other studies examining tag effects in different species (e.g., Knights and Lasee 1996; Brown et al. 2006). The first mortality in Bloaters occurred at 67 d posttreatment, indicating a lack of mortality directly attributed to the surgical procedure and no treatment effect. High survival of the test fish likely reflects minimal mortality associated with good health of individuals in addition to low experimental mortality.

There was no tag expulsion observed in our study. Transmitter expulsion has been observed in several studies involving other species, including Chinook Salmon *Oncorhynchus tshawytscha*, steelhead *O. mykiss*, and Brown Trout *Salmo trutta* (e.g., Welch et al. 2007; Jepsen et al. 2008; Brown et al. 2010), while other studies have observed minimal or no transmitter expulsion (e.g., Martinelli et al. 1998; Carrera-García et al. 2017). Although there are currently no other studies that have examined acoustic transmitter effects in Bloaters or other ciscoes, Smith et al. (2017) and Hadden et al. (2018) reported high retention (>90%) of internal radio transmitters and PIT tags in juvenile Least Ciscoes *C. sardinella*. Transmitter expulsion can be related to numerous factors, including (but not limited to) tag burden (mass and volume), fish morphology, environmental conditions, and the skill level of the surgeon (Jepsen et al. 2002). The negligible tag

expulsion in our study may be attributed to fish morphology, tailoring the tagging procedures to the species, well-regulated environmental conditions, and exceptional incision healing as a function of proficient surgeon practices.

The cold water temperatures used in this study (3–12°C) were biologically relevant for Bloaters; however, these temperatures also likely contributed to the high success of tagging. Temperature is a primary determinant in fish response to tagging and handling (Walsh et al. 2000; Deters et al. 2010). Bloaters are likely to exhibit higher tagging-induced mortality at warmer water temperatures. The time of year during which the study was conducted is also relevant to ongoing restoration efforts in Lake Ontario, as it corresponds with the yearly tagging and stocking of Bloaters in late October and early November. We suggest that future tag effect studies aim to closely mimic environmental conditions encountered by the species in a natural environment and to replicate circumstances specific to release of the tagged fish (e.g., annual time of tagging and release).

Surgically implanted dummy acoustic transmitters representing 1.3–9.0% of body mass had no effect on growth, condition, or survival of tagged Bloaters for 6 months postsurgery. Similar to several other tagging effect studies (e.g., Jepsen et al. 2003; Lacroix et al. 2004), the tag mass : body mass ratio in this study exceeded the "2% rule" and demonstrated that subadult Bloaters were able to handle a tag burden of up to 9% of body mass with no adverse effects. Various studies suggest maximum tag burdens that diverge from this for different species (e.g., Lacroix et al. 2004; Chittenden et al. 2009), illustrating that the appropriate tag mass : body mass ratio is driven by species, life stage, study objectives, and tagging methods (Jepsen et al. 2003). The relatively large acceptable tag burden for Bloaters revealed in our study reiterates the importance of determining tag effects for a variety of species and size-classes prior to assuming the absence of negative effects.

The negligible mortality, lack of treatment effect, and 100% dummy transmitter retention observed in this experiment suggest that acoustic transmitters with a tag mass : body mass ratio of 9% or less can be successfully implanted intracoelomically into subadult Bloaters with no adverse effects. The ability of the Bloater—a small, sensitive fish species—to withstand surgery and the burden of a tag indicates the potential to use acoustic telemetry to provide information on the fates of small freshwater fishes after stocking in large water bodies, such as the Great Lakes. Based on the findings of this study, we have commenced an evaluation of Bloater behavior, distribution, and survival in Lake Ontario by using acoustic telemetry. Future research should examine short-term acoustic telemetry tag effects, the impact of tagging and tag burden

on swimming performance, and the effects of tag volume on condition in fish that are anatomically and morphologically different.

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REFERENCES

Ammann, A. J., C. J. Michel, and R. B. MacFarlane. 2013. The effects of surgically implanted acoustic transmitters on laboratory growth, survival and tag retention in hatchery yearling Chinook Salmon. Environmental Biology of Fishes 96:135–143.

Ashton, N. K., S. A. Liss, R. W. Walker, R. S. Brown, C. Klassen, S. Backhouse, P. Bates, and R. L. Townsend. 2017. How low can you go? Determining a size threshold for implantation of a new acoustic transmitter in age-0 White Sturgeon. Northwest Science 91:69–80.

Baldwin, B. 1999. Native prey fish re-introduction into Lake Ontario: Bloater (Coregonus hoyi). Great Lakes Fishery Commission, Lake Ontario Committee, Discussion Paper, London, Ontario.

Bégout Anras, M. L., P. M. Cooley, R. A. Bodaly, L. Anras, and R. J. P. Fudge. 1999. Movement and habitat use by Lake Whitefish during spawning in a boreal lake: integrating acoustic telemetry and geographic information systems. Transactions of the American Fisheries Society 128:939–952.

Blackwell, B. G., M. L. Brown, and D. W. Willis. 2000. Relative weight (W_r) status and current use in fisheries assessment and management. Reviews in Fisheries Science 8:1–44.

Bolger, T., and P. L. Connolly. 1989. The selection of suitable indices for the measurement and analysis of fish condition. Journal of Fish Biology 34:171–182.

Bridger, C. J., and R. K. Booth. 2003. The effect of biotelemetry transmitter presence and attachment procedures on fish physiology and behavior. Reviews in Fisheries Science 11:13–34.

Brown, R. S., S. J. Cooke, W. G. Anderson, and R. S. McKinley. 1999. Evidence to challenge the "2% rule" for biotelemetry. North American Journal of Fisheries Management 19:867–871.

Brown, R. S., D. R. Geist, K. A. Deters, and A. Grassell. 2006. Effects of surgically implanted acoustic transmitters > 2% of body mass on the swimming performance, survival and growth of juvenile Sockeye and Chinook Salmon. Journal of Fish Biology 69:1626–1638.

Brown, R. S., R. A. Harnish, K. M. Carter, J. W. Boyd, K. A. Deters, and M. B. Eppard. 2010. An evaluation of the maximum tag burden for implantation of acoustic transmitters in juvenile Chinook Salmon. North American Journal of Fisheries Management 30:499–505.

Carrera-García, E., J. Kordek, C. Gesset, L. Jacobs, and M.-L. Acolas. 2017. Tracking juvenile sturgeon in the wild: miniature tag effects assessment in a laboratory study on Siberian Sturgeon (Acipenser baerii). Fisheries Research 186:337–344.

Chittenden, C. M., K. G. Butterworth, K. F. Cubitt, M. C. Jacobs, A. Ladouceur, D. W. Welch, and R. S. McKinley. 2009. Maximum tag to body size ratios for an endangered Coho Salmon (O. kisutch) stock based on physiology and performance. Environmental Biology of Fishes 84:129–140.

Clemens, B. J., and S. S. Crawford. 2009. The ecology of body size and depth use by Bloater (Coregonus hoyi Gill) in the Laurentian Great Lakes: patterns and hypotheses. Reviews in Fisheries Science 17:174–186.

Collins, M. R., D. W. Cooke, T. I. J. Smith, W. C. Post, D. C. Russ, and D. C. Walling. 2002. Evaluation of four methods of transmitter attachment on Shortnose Sturgeon, Acipenser brevirostrum. Journal of Applied Ichthyology 18:491–494.

Cooke, S. J., J. D. Midwood, J. D. Thiem, P. Klimley, M. C. Lucas, E. B. Thorstad, J. Eiler, C. Holbrook, and B. C. Ebner. 2013. Tracking animals in freshwater with electronic tags: past, present and future. Animal Biotelemetry [online serial] 1:5.

Cooke, S. J., C. M. Woodley, M. B. Eppard, R. S. Brown, and J. L. Nielsen. 2011. Advancing the surgical implantation of electronic tags in fish: a gap analysis and research agenda based on a review of trends in intracoelomic tagging effects studies. Reviews in Fish Biology and Fisheries 21:127–151.

Deters, K. A., R. S. Brown, K. M. Carter, J. W. Boyd, M. B. Eppard, and A. G. Seaburg. 2010. Performance assessment of suture type, water temperature, and surgeon skill in juvenile Chinook Salmon surgically implanted with acoustic transmitters. Transactions of the American Fisheries Society 139:888–899.

Gorsky, D., J. Zydlewski, and D. Basley. 2012. Characterizing seasonal habitat use and diel vertical activity of Lake Whitefish in Clear Lake, Maine, as determined with acoustic telemetry. Transactions of the American Fisheries Society 141:761–771.

Hadden, J. T., N. J. Smith, and T. M. Sutton. 2018. Effects of transmitter application procedures on growth, survival, and tag retention of juvenile Least Cisco Coregonus sardinella. Fisheries Research 199:196–201.

Halverson, M. A. 2008. Stocking trends: a quantitative review of governmental fish stocking in the United States, 1931 to 2004. Fisheries 33:69–75.

Heupel, M. R., J. M. Semmens, and A. J. Hobday. 2006. Automated acoustic tracking of aquatic animals: scales, design and deployment of listening station arrays. Marine and Freshwater Research 57:1–13.

Holčík, J. 1991. Fish introductions in Europe with particular reference to its central and eastern part. Canadian Journal of Fisheries and Aquatic Sciences 48:13–23.

Hondorp, D. W., C. M. Holbrook, and C. C. Krueger. 2015. Effects of acoustic tag implantation on Lake Sturgeon Acipenser fulvescens: lack of evidence for changes in behavior. Animal Biotelemetry [online serial] 3:44.

Hussey, N. E., S. T. Kessel, K. Aarestrup, S. J. Cooke, P. D. Cowley, A. T. Fisk, R. G. Harcourt, K. N. Holland, S. J. Iverson, J. F. Kocik, J. E. Mills Flemming, and F. G. Whoriskey. 2015. Aquatic animal

telemetry: a panoramic window into the underwater world. Science 348:1255642.

Huuskonen, H., H. Haakana, A. Leskelä, and J. Piironen. 2012. Seasonal movements and habitat use of River Whitefish (*Coregonus lavaretus*) in the Koitajoki River (Finland), as determined by Carlin tagging and acoustic telemetry. Aquatic Ecology 46:325–334.

Jepsen, N., A. Koed, E. B. Thorstad, and E. Baras. 2002. Surgical implantation of telemetry transmitters in fish: how much have we learned? Hydrobiologia 483:239–248.

Jepsen, N., J. S. Mikkelsen, and A. Koed. 2008. Effects of tag and suture type on survival and growth of Brown Trout with surgically implanted telemetry tags in the wild. Journal of Fish Biology 72:594–602.

Jepsen, N., C. Schreck, S. Clements, and E. B. Thorstad. 2003. A brief discussion on the 2% tag/body mass rule of thumb. Pages 255–259 *in* M. T. Spedicato, G. Lembo, and G. Marmulla, editors. Aquatic telemetry: advances and applications. Proceedings of the Fifth Conference on Fish Telemetry. Food and Agriculture Organization of the United Nations, Rome.

Knights, B. C., and B. A. Lasee. 1996. Effects of implanted transmitters on adult Bluegills at two temperatures. Transactions of the American Fisheries Society 125:440–449.

Lacroix, G. L., D. Knox, and P. McCurdy. 2004. Effects of implanted dummy acoustic transmitters on juvenile Atlantic Salmon. Transactions of the American Fisheries Society 133:211–220.

Lee, J. S. F., E. P. Tezak, and B. A. Berejikian. 2013. Telemetry tag effects on juvenile Lingcod *Ophiodon elongatus* movement: a laboratory and field study. Journal of Fish Biology 82:1848–1857.

Loher, T., and R. Rensmeyer. 2011. Physiological responses of Pacific Halibut, *Hippoglossus stenolepis*, to intracoelomic implantation of electronic archival tags, with a review of tag implantation techniques employed in flatfishes. Reviews in Fish Biology and Fisheries 21:97–115.

Martinelli, T. L., H. C. Hansel, and R. S. Shively. 1998. Growth and physiological responses to surgical and gastric radio transmitter implantation techniques in subyearling Chinook Salmon (*Oncorhynchus tshawytscha*). Hydrobiologia 372:79–87.

Miller, E. A., H. E. Froehlich, D. E. Cocherell, M. J. Thomas, J. J. Cech Jr., A. P. Klimley, and N. A. Fangue. 2014. Effects of acoustic tagging on juvenile Green Sturgeon incision healing, swimming performance, and growth. Environmental Biology of Fishes 97:647–658.

Moore, A., I. C. Russell, and E. C. E. Potter. 1990. The effects of intraperitoneally implanted dummy acoustic transmitters on the behaviour and physiology of juvenile Atlantic Salmon, *Salmo salar* L. Journal of Fish Biology 37:713–721.

Mueller, R. P., J. Janak, S. A. Liss, R. S. Brown, Z. Deng, and R. A. Harnish. 2017. Retention and effects of miniature transmitters in juvenile American Eels. Fisheries Research 195:52–58.

Nakagawa, S., and H. Schielzeth. 2013. A general and simple method for obtaining R^2 from generalized linear mixed-effects models. Methods in Ecology and Evolution 4:133–142.

Neely, B. C., K. D. Steffensen, and M. A. Pegg. 2009. A comparison of gastrically and surgically implanted telemetry transmitters in Shovelnose Sturgeon. Fisheries Management and Ecology 16:323–328.

Oldenburg, E. W., A. H. Colotelo, R. S. Brown, and M. B. Eppard. 2011. Holding of juvenile salmonids for surgical implantation of electronic tags: a review and recommendations. Reviews in Fish Biology and Fisheries 21:35–42.

R Core Team. 2016. R: a language for statistical computing. R Foundation for Statistical Computing, Vienna. Available: https://www.R-project.org/. (May 2018).

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191:1–382.

Robertson, M. J., D. A. Scruton, and J. A. Brown. 2003. Effects of surgically implanted transmitters on swimming performance, food consumption and growth of wild Atlantic Salmon parr. Journal of Fish Biology 62:673–678.

Smith, N. J., P. L. McCall, and T. M. Sutton. 2017. Effects of different tagging protocols on survival, growth, and tag retention in juvenile Least Cisco *Coregonus sardinella*. Fisheries Research 187:68–72.

Stewart, T. J., A. Todd, and S. LaPan. 2017. Fish community objectives for Lake Ontario. Great Lakes Fishery Commission, Fisheries Management Document 2017-01, Ann Arbor, Michigan.

Summerfelt, R. C., and L. S. Smith. 1990. Anaesthesia, surgery and related techniques. Pages 213–272 *in* C. B. Schreck and P. B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

Wagner, G. N. 1999. Investigation of effective fish surgery techniques. Master's thesis. University of Guelph, Guelph, Ontario.

Walsh, M. G., A. K. Biorgo, and J. J. Isely. 2000. Effects of implantation method and temperature on mortality and loss of simulated transmitters in hybrid Striped Bass. Transactions of the American Fisheries Society 129:539–544.

Welch, D. W., S. D. Batten, and B. R. Ward. 2007. Growth, survival, and tag retention of steelhead trout (*O. mykiss*) surgically implanted with dummy acoustic tags. Hydrobiologia 582:289–299.

Winter, J. D. 1983. Underwater biotelemetry. Pages 371–395 *in* L. A. Nielsen and D. L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Yang, H. 2012. Visual assessment of residual plots in multiple linear regression: a model-based simulation perspective. Multiple Linear Regression Viewpoints 38:24–37.