North American Journal of Fisheries Management 39:574–581, 2019

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1002/nafm.10294

MANAGEMENT BRIEF

Assessing Acoustic Tagging Effects on Survival, Growth, and Swimming Ability of Juvenile Lake Sturgeon

M. M. McCabe*
Great Lakes Institute for Environmental Research, University of Windsor, 2990 Riverside Drive W, Windsor, Ontario N9C 1A2, Canada

J. A. Chiotti and J. C. Boase
U.S. Fish and Wildlife Service, Alpena Fish and Wildlife Conservation Office, Detroit River Substation, 9311 Groh Road, Grosse Ile, Michigan 48138, USA

A. T. Fisk
Great Lakes Institute for Environmental Research, University of Windsor, 2990 Riverside Drive W, Windsor, Ontario N9C 1A2, Canada

T. E. Pitcher
Great Lakes Institute for Environmental Research, University of Windsor, 2990 Riverside Drive W, Windsor, Ontario N9C 1A2, Canada; and Department of Biological Sciences, University of Windsor, 401 Sunset Avenue, Windsor, Ontario N9B 3P4, Canada

Abstract

Acoustic telemetry is used to quantify fish movement, ecology, and habitat use and can contribute to assessing the success of species supplementation. In this field, a better understanding of the effects of tag burden (or the impact of an acoustic telemetry tag, which is related to the ratio of tag weight to body weight) is critical to ensure postrelease monitoring. Research on the effects of acoustic tag burden on imperiled fishes at different ontogenic stages, such as juvenile Lake Sturgeon *Acipenser fulvescens*, is limited. Our study provides key information for the selection of the largest acoustic tag with the greatest battery life possible (taking into account tag burden) to monitor the release success and movements of juvenile Lake Sturgeon stocked for reintroduction. We characterized tag burden effects by examining survival, TL, weight, Fulton's condition factor, and swim performance of individuals. We examined four groups of fish: control (anesthetized and no acoustic tag inserted; $n = 24$), sham control (anesthetized with incision sutured but no acoustic tag inserted; $n = 24$), Vemco V8 acoustic tag (2.0 g in air; $n = 24$), and Vemco V9 tag (4.4 g in air; $n = 24$). Acoustic tags were inserted into anesthetized fish, and the incision was sutured; tag burden (mean ± SE) ranged from 2.2 ± 0.06% to 4.6 ± 0.10% of total body weight. Results showed that the two tag burden treatments had no significant effects on growth or survival (compared to both control groups) across a 114-d study period and that critical swim speed at 12–20 d postsurgery was not significantly impacted by increasing tag burden. Because neither of the acoustic tag sizes had significant deleterious effects on the metrics studied, we recommend using a larger V9 tag (i.e., the most powerful tag with the longest battery life) for postrelease monitoring of reintroduced juvenile Lake Sturgeon.

Acoustic telemetry has become a useful method to better understand movement and spatial ecology across fish species (Crossin et al. 2017). Fish receive a surgically implanted transmitter (acoustic tag) and are released back into the water, where stationary or mobile receivers record and store the unique sound signals released by the transmitter. These data are then retrieved and interpreted to understand movement patterns and survival of individuals. Acoustic telemetry studies function under the assumption

*Corresponding author: mmmccabe11@gmail.com
Received October 3, 2018; accepted April 15, 2019

that the tag and implantation method have little or no deleterious effects on the implanted individual based on the relationship of tag weight to total body weight (i.e., tag burden; Miller et al. 2014; Liss et al. 2017). Winter (1983) was the first to propose the "2% rule," which indicates that if the tag weight is no more than 2% of a fish's total body weight, the tag will have negligible effects on growth, condition, and survival. This rule has been contested over time using larger tags with greater tag burdens (up to 12% of total body weight) showing negligible effects, and there is general consensus that the maximum allowable tag burden varies across fish species (Brown et al. 2006; Cooke et al. 2011). Given the large variation in morphology, tag effects studies are best compared via species-specific studies or studies of fish with similar morphologies or swimming capabilities (Miller et al. 2014). Nevertheless, larger tags have greater detection ranges and longer battery lives, leading to extended detection time. Understanding the maximum tag burden that does not have deleterious effects on growth, survival, and swimming ability (specific to the species of interest) is critical for choosing the most relevant and longest lasting tag.

In sturgeon species, the effect of tagging on larger individuals is well understood, while research on tag effects in juveniles is limited in scope (Carrera-García et al. 2017). In young-of-the-year Siberian Sturgeon *Acipenser baeri*, research has shown that tagging (using tags constituting ~1–3% of total body weight) can affect swimming ability, distance, and speed (Carrera-García et al. 2017). Research by Liss et al. (2017) also showed that surgical techniques used in juvenile White Sturgeon *A. transmontanus* reduced growth over a 24-d period when a tag representing about 1.1% of total body weight was implanted. Further research on the tagging of juvenile Green Sturgeon *A. medirostris*, however, showed no significant differences in either swimming ability or growth between tagged and nontagged individuals (Miller et al. 2014). In juvenile Lake Sturgeon *A. fulvescens* (80–100 g in weight), the effect of tag burden (2% and 4% of total body weight) on postrelease dispersal rates was compared in two river systems (Snobl et al. 2015). Using a field-based study, researchers found that dispersal rates and survival did not significantly differ between tagged juveniles within the two systems (Snobl et al. 2015). However, the tags' effects on growth trajectories or condition factor were not examined. With high variation in results of tag effects studies in sturgeon species, it is essential to use species-specific studies to quantify the effects of tag burden.

To aid Lake Sturgeon restoration efforts in the Great Lakes, small juvenile Lake Sturgeon (i.e., 18–28 cm) are stocked using hatchery supplementation (Crossman et al. 2009; J. A. Chiotti, personal observation). There is a lack of literature describing their postrelease movement patterns and survival; some research shows that overwintering survival can be as high as 40%, with no significant differences in survival depending on whether the sturgeon were streamside reared or hatchery reared (Crossman et al. 2009). More research is needed to quantify and characterize postrelease success, with the overall goal of creating self-sustaining populations of Lake Sturgeon in the Great Lakes (Dittman et al. 2015).

In our study, we examined growth (i.e., changes in TL, weight, and Fulton's condition factor *K*), survival, and swimming performance to evaluate tag burden (up to ~5% of total body weight) on juvenile Lake Sturgeon. This study could have important management implications in that it is the first to build upon prior literature on Lake Sturgeon by accounting for how tag burden can impact movement, growth, condition, swimming ability, and survival in juveniles (Peake et al. 1995; Snobl et al. 2015). The results of our study will serve to aid in the selection of the largest acoustic tag with negligible effects on survival, growth, and swimming ability, allowing for greater detection ranges and extended detection times.

METHODS

The juvenile Lake Sturgeon used in this study were approximately 10 months old (mean TL ± SE = 29.2 ± 0.3 cm; weight = 103.1 ± 4.1 g) at the start of the study and originated from the St. Clair River, Sarnia, Ontario. All animals were reared and cared for in accordance with animal care protocols approved by the University of Windsor Animal Care Committee (Animal Utilization Project Protocols 17-13 and 17-22). Throughout the study, the sturgeon were held in 1,000-L holding tanks (where they were also held during postsurgery recovery periods) maintained at temperatures of 14.7 ± 0.16°C, with dissolved oxygen levels kept high (~85–90%). A natural photoperiod with daylight hours indicative of outside conditions was maintained throughout the study by using a preprogrammed lighting system and exterior windows to allow for natural light. Juvenile sturgeon were fed EWOS Microcrumble Number-2 pellets at 2% of body weight per day throughout the study.

Experimental design.— For all treatment groups, surgeries to implant acoustic tags were completed for this experiment at three time points (treatments were randomly assigned to the fish selected for surgeries): April 4, 2018 ($n = 28$); April 22, 2018 ($n = 32$); and May 12, 2018 ($n = 36$). All surgeries were completed by one surgeon in April and another surgeon in May to minimize bias. Our experimental design included a control ($n = 24$ fish), a sham control (sham; $n = 24$ fish), a VEMCO V8 tag (telemetry acoustic transmitter) treatment ($n = 24$ fish; 69.0 kHz, 20.5 mm long, 2.0 g in air, 0.9 g in water; https://vemco.com/), and a VEMCO V9 tag treatment ($n = 24$ fish; 69.0 kHz, 24 mm long, 4.4 g in air, 2.1 g in

water; Figure 1). The sham control was used to determine whether the surgery had a significant impact on the metrics studied (although it had no specific field-based implications). The two tag sizes (V8, which lasts 199 d on average; and V9, which lasts 550 d on average; https://vemco.com/) were chosen because they each possessed an appropriate battery life (the longest battery life that provides the largest amount of data) for realistic movement-related studies of juvenile Lake Sturgeon and were deemed the largest possible based on the body cavity size of the juveniles used in the study. Control fish were anesthetized and did not undergo surgery. They were injected in the left second lower scute with a PIT tag (Figure 1; except in one instance where the initial injection failed and had to be redone on the right side). Fish in each treatment received a PIT tag (12.5 mm long; Biomark APT_{12}) at the beginning of the study to establish individual identity throughout the experiment. The sham treatment fish were anesthetized and operated on without acoustic tag insertion. A PIT tag was inserted during surgery, and the incision was sutured closed (details below). The V8 and V9 acoustic tag treatment fish were anesthetized, an acoustic tag was surgically inserted into the body cavity, and the incision was sutured closed. The acoustic tags used in this study were "dummy" (inactive) tags purchased from VEMCO and had the same specifications (e.g., weight and buoyancy) as active tags.

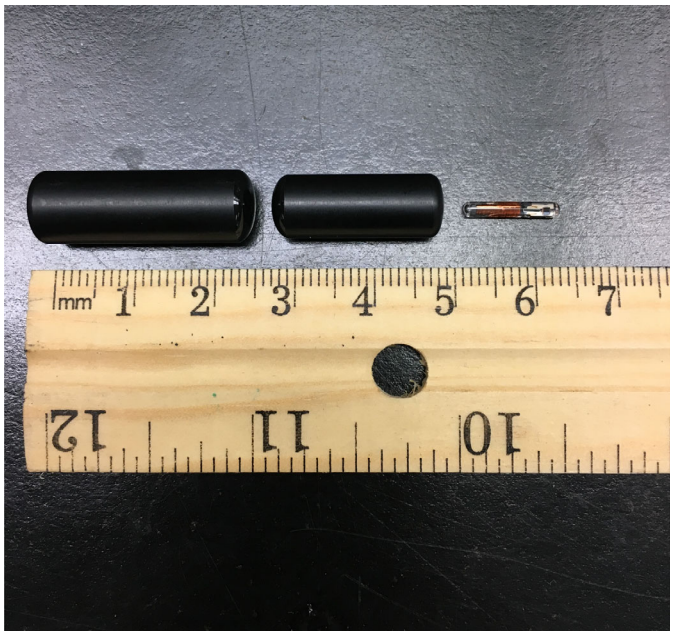

FIGURE 1. Acoustic tags and a PIT tag inserted into Lake Sturgeon (left to right): VEMCO V9 acoustic tag (tag weight in air = 4.4 g; inserted into anesthetized fish), VEMCO V8 acoustic tag (tag weight in air = 2.0 g; inserted into anesthetized fish), and a PIT tag (0.1-g tag inserted into anesthetized fish and injected into control fish). [Color figure can be viewed at afsjournals.org.]

Surgical implantation and injection of PIT tags.— Acoustic tags, PIT tags, and surgical equipment were all sterilized using a betadine solution and rinsed with distilled water prior to implantation or use on fish. Food was withheld for 24 h prior to surgery. All fish were anesthetized using a 110-mg/L dose of MS-222 (tricaine methanesulfonate) buffered 2:1 with sodium bicarbonate. Fish were monitored until opercular movements were slowed and the fish were unresponsive to light physical stimulus (~2–4 min); they were then removed from the anesthetic and placed on their backs into a V-shaped holding trough for surgery. During this time, the gills were continuously irrigated using distilled water. A 3-cm incision was made off-center of the abdominal midline by using a sterile number-11 scalpel blade, and the acoustic tag (for the treatment groups) was inserted with a PIT tag into the abdominal cavity. For control fish, the PIT tag was injected on the bottom left-hand side of the fish near the anal fins. The incision site was sutured closed using three simple interrupted sutures (5-0 Ethicon Vicryl Plus absorbable sutures; 3–3–2 surgeon knot sequence) with an RB-1 tapered needle at 0.75-cm intervals along the incision length. Sturgeon were then placed into a 1,000-L holding tank and assessed over 4 h for postsurgery recovery or until such time that the fish returned to an upright position and were able to maintain this position while swimming.

Growth, condition, and survival postsurgery.— Using a Shapiro–Wilk normality test, our data met the assumptions of parametric testing. Growth, condition, and survival after surgery were staggered across ~19-d (±1 d) postsurgery intervals from April 27 to September 7, 2018, for the first surgery timepoint; from May 11 to September 21, 2018, for the second surgery timepoint; and from May 12 to August 28, 2018, for the third surgery timepoint. Growth measurements were accounted for by measuring TL (from tip of the snout to the end of the upper lobe of the caudal fin; ±0.2 cm) and total weight (±0.5 g; using an Ohaus VALOR 7000 Scale; https://us.ohaus.com/). These data were converted to a specific growth rate (SGR, % per day), calculated as $SGR = [(\log_e W_2 - \log_e W_1) \times 100]/(t_2 - t_1)$, where W_2 and W_1 are the measurements (body weight, g; or TL, mm) of the fish at time t_2 and t_1 (d). We also calculated K to determine body condition of the sturgeon by using the relationship between TL and weight: $K = (\text{live weight}/\text{TL}^3) \times 100$ (Craig et al. 2005).

Swim performance experimental protocols.— A 30-L swim tunnel (Loligo Systems, Viborg, Denmark; https://www.loligosystems.com/) was used to measure swim performance across the four treatment groups of juvenile Lake Sturgeon at 12 d postsurgery (3–5 fish were selected randomly/swum per day, depending on swimming ability,

until all fish from each treatment group had been swum). During swim performance testing, the swim tunnel was continuously flushed with new water at the fish's acclimation temperature of 11°C. Each of the fish examined for swim performance ($n = 15$ for each treatment group; $n = 60$ in total) were then placed one at a time into the working section (45.0 × 14.0 × 13.5 cm) of the swim tunnel (rapidly transferred from a holding tank by using a dip net, with less than 15 s of air exposure) and allowed to recover in the working section of the flume for 20 min using a speed of 0.2-TLs/s (i.e., low) flow over the fish (with water flow generated by a propeller, powered by a motor at the side of the flume) in order that the fish exerted only minimal effort to hold itself in position. For sturgeon, we considered a high speed to be approximately 1.8 TLs/s, which was the maximum speed any given sturgeon could maintain during our study. After the recovery period, the critical swim speed (U_{crit}) tests were started. Speed was increased sequentially by 0.2 TLs/s every 20 min. Speed increases and acclimation periods chosen were based on prior literature describing juvenile sturgeon critical swim tests (Miller et al. 2014; Downie and Kieffer 2017). When the fish was pinned to the downstream end for 5 s, the swim test was terminated. Here, we used an electrical shock grid to deliver a quick and short, mild shock once a fish was pinned on the grate to ensure that the individual was not resting against the grate. The total amount of time the fish swam, sequential speed intervals swam, TL, and weight were then recorded. Values of U_{crit} were then calculated using the formula based on Brett (1964),

$$U_{crit} = U_f + \left[\left(\frac{T_f}{t}\right) \times U_v\right],$$

where U_{crit} is the critical swim speed (TLs/s); U_f is the speed (cm/s) of the last interval the fish swam before fatigue; T_f is the time (s) the fish swam at the final velocity before fatigue; t is the time increment (1,200 s) at that velocity; and U_v is the velocity increment (0.2 TLs/s, which was increased every 20 min) used throughout the test. To calculate U_{crit} measurements in TLs per second, we divided the U_{crit} by the TL of each fish. The same fish that were used in our U_{crit} testing were used for growth (length, weight, and K) and survival measurements throughout the study period.

Statistical analysis.— Total length (cm), weight (g), and K of Lake Sturgeon (from the four treatments) were examined at 19-d intervals over the 114 d ($n = 7$ time intervals) by using a repeated-measures ANCOVA coding for TL, body weight, or K at the start of the experiment as the covariate (to standardize for initial size or condition, which can affect the trajectory of both factors, where $\alpha = 0.05$). Survival data throughout the 114 d of the experiment were analyzed using a contingency table (chi-square test) accounting for deaths based on treatment. Individuals who did not survive during the experimental period were excluded from the body length and weight analyses. Critical swim speeds of the four treatment groups ($n = 15$ for each group) were analyzed using a one-way ANCOVA coding for TL at the start of swim performance testing as a covariate (to account for the effect of any body size differences on swim performance). All statistical testing was conducted using IBM SPSS Statistics version 24.

RESULTS

No significant differences among treatments were found in TL growth rate ($F_{3, 88} = 0.53$, $P = 0.67$; Figure 2A;

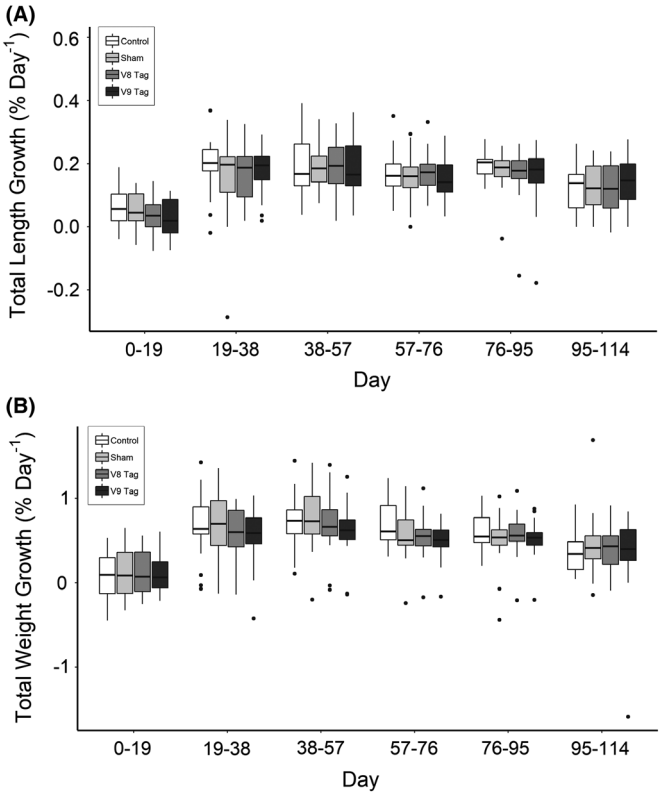

FIGURE 2. Box plots displaying Lake Sturgeon specific growth rates (% per day) in **(A)** TL and **(B)** weight across four treatment types and between measurement timepoints: 0–19, 19–38, 38–57, 57–76, 76–95, and 95–144 d postsurgery. The thick middle line in the box indicates the median value; the upper and lower ends of each box represent the 25th and 75th percentiles of data. Error bars extend to show the minimum and maximum values of data points; outliers are represented by filled circles. The four treatments were as follows: control (anesthetized and no acoustic tag inserted), sham control (anesthetized with incision sutured but no acoustic tag inserted), V8 acoustic tag (tag weight in air = 2.0 g; inserted into anesthetized fish), and V9 acoustic tag (tag weight in air = 4.4 g; inserted into anesthetized fish).

TABLE 1. Mean (±SE) TL (cm), measured at 19-d increments postsurgery, of juvenile Lake Sturgeon that received implanted acoustic tags. The control group was anesthetized and had PIT tags injected but did not receive acoustic tags. The sham group was anesthetized and operated on without acoustic tag insertion, and the incision was sutured closed. The V8 (2.0 g in air) and V9 (4.4 g in air) acoustic tags were inserted into the body cavity, and the incision was sutured closed. Fish in each group (including the control) received PIT tags (12.5 mm long) to establish identity throughout the experiment (see Methods).

Treatment	*n*	Day 0	Day 19	Day 38	Day 57	Day 76	Day 95	Day 114
Control	23	28.4 ± 0.3	28.8 ± 0.4	29.9 ± 0.4	31.0 ± 0.4	32.0 ± 0.4	33.1 ± 0.4	34.0 ± 0.3
Sham	24	29.5 ± 0.4	29.9 ± 0.5	30.8 ± 0.5	32.0 ± 0.5	33.0 ± 0.4	34.1 ± 0.5	35.0 ± 0.5
V8 tag	23	29.4 ± 0.3	29.6 ± 0.4	30.5 ± 0.4	31.6 ± 0.4	32.7 ± 0.4	34.3 ± 0.5	34.5 ± 0.4
V9 tag	23	29.3 ± 0.3	29.5 ± 0.4	30.9 ± 0.4	31.6 ± 0.4	32.6 ± 0.4	33.6 ± 0.5	34.5 ± 0.48

TABLE 2. Mean (±SE) weight (g), measured at 19-d increments postsurgery, of juvenile Lake Sturgeon that received implanted acoustic tags. The control group was anesthetized and had PIT tags injected but did not receive acoustic tags. The sham group was anesthetized and operated on without acoustic tag insertion, and the incision was sutured closed. The V8 (2.0 g in air) and V9 (4.4 g in air) acoustic tags were inserted into the body cavity, and the incision was sutured closed. Fish in each group (including the control) received PIT tags (12.5 mm long) to establish identity throughout the experiment (see Methods).

Treatment	*n*	Day 0	Day 19	Day 38	Day 57	Day 76	Day 95	Day 114
Control	23	96.2 ± 3.8	98.3 ± 4.6	112.1 ± 5.2	128.4 ± 5.8	145.7 ± 5.4	161.7 ± 5.3	174.2 ± 4.7
Sham	24	105.3 ± 4.8	108.7 ± 5.7	124.3 ± 6.2	142.2 ± 7.2	158.0 ± 7.5	173.7 ± 8.0	189.0 ± 8.2
V8 tag	23	104.6 ± 3.8	109.8 ± 4.9	122.9 ± 5.9	140.1 ± 6.4	155.3 ± 6.7	179.1 ± 7.8	186.5 ± 7.5
V9 tag	23	106.2 ± 4.1	113.9 ± 5.2	126.9 ± 5.9	143.8 ± 6.7	158.0 ± 7.0	174.6 ± 7.8	188.2 ± 9.4

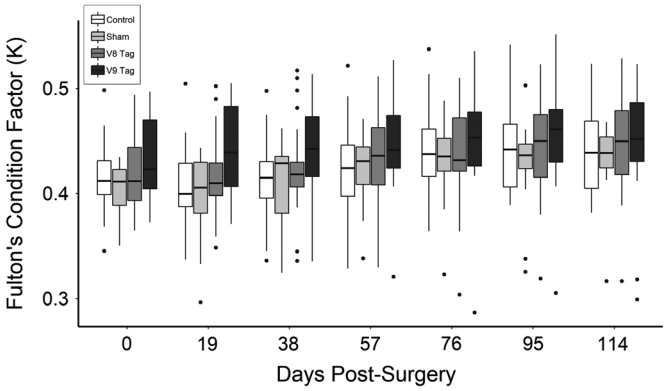

FIGURE 3. Box plots displaying Fulton's condition factor (*K*) of juvenile Lake Sturgeon at 19-d increments postsurgery (19, 38, 57, 76, 95, and 114 d) across four treatment types. The thick middle line in the box indicates the median value; the upper and lower ends of each box represent the 25th and 75th percentiles of data. Error bars extend to show the minimum and maximum values of data points; outliers are represented by filled circles. The four treatments were as follows: control (anesthetized and no acoustic tag inserted), sham control (anesthetized with incision sutured but no acoustic tag inserted), V8 acoustic tag (tag weight in air = 2.0 g; inserted into anesthetized fish), and V9 acoustic tag (tag weight in air = 4.4 g; inserted into anesthetized fish).

Table 1), body weight growth rate ($F_{3, 52} = 0.59$, $P = 0.63$; Figure 2B; Table 2), or *K* ($F_{3, 88} = 0.43$, $P = 0.73$; Figure 3; Table 3). Survival of Lake Sturgeon was high overall (95 ± 0.07% across treatments), with only three deaths (one from each treatment group besides the sham control), which occurred on April 21 (a V8-tagged fish), May 4 (a V9-tagged fish), and May 18 (a control fish), 2018. During the study, there was no significant difference in survival rates across the treatment groups ($\chi^2 = 0.016$, df = 95, $P = 0.99$). Swim performance was similar across treatments, and U_{crit} averaged 1.22 ± 0.037 TLs/s. No significant differences were found in U_{crit} among treatment types (control: mean ± SE = 1.1 ± 0.09 TLs/s, sham: 1.2 ± 0.08 TLs/s, V8: 1.2 ± 0.06 TLs/s, V9: 1.3 ± 0.05 TLs/s; $F_{3, 55} = 0.90$, $P = 0.45$; Figure 4). No sturgeon expelled their acoustic tags during our study period; however, one PIT tag was lost.

DISCUSSION

Growth and Survival

Our results suggest that an acoustic tag burden of 4.63 ± 0.098% of body weight for juvenile Lake Sturgeon has no significant effects on growth rate related to TL, weight, *K*, or survival up to 114 d postsurgery compared to control treatments. When using behavioral metrics to assess tag burden, we also found that U_{crit} was not significantly affected by a tag burden of 2.2 ± 0.06% to 4.6 ± 0.10% across the same time interval postsurgery. These results indicate that acoustic tags can be used effectively to facilitate postrelease monitoring of juvenile Lake Sturgeon.

TABLE 3. Mean (±SE) Fulton's condition factor (*K*), measured at 19-d increments postsurgery, of juvenile Lake Sturgeon that received implanted acoustic tags. The control group was anesthetized and had PIT tags injected but did not receive acoustic tags. The sham group was anesthetized and operated on without acoustic tag insertion, and the incision was sutured closed. The V8 (2.0 g in air) and V9 (4.4 g in air) acoustic tags were inserted into the body cavity, and the incision was sutured closed. Fish in each group (including the control) received PIT tags (12.5 mm long) to establish identity throughout the experiment (see Methods).

Treatment	*n*	Day 0	Day 19	Day 38	Day 57	Day 76	Day 95	Day 114
Control	23	0.41 ± 0.007	0.41 ± 0.008	0.41 ± 0.008	0.42 ± 0.009	0.44 ± 0.008	0.44 ± 0.009	0.44 ± 0.009
Sham	24	0.40 ± 0.005	0.41 ± 0.007	0.41 ± 0.007	0.43 ± 0.006	0.43 ± 0.007	0.43 ± 0.007	0.43 ± 0.006
V8 tag	23	0.41 ± 0.07	0.43 ± 0.009	0.43 ± 0.009	0.44 ± 0.01	0.44 ± 0.01	0.44 ± 0.01	0.45 ± 0.01
V9 tag	23	0.41 ± 0.008	0.44 ± 0.009	0.44 ± 0.009	0.43 ± 0.09	0.44 ± 0.01	0.45 ± 0.01	0.43 ± 0.01

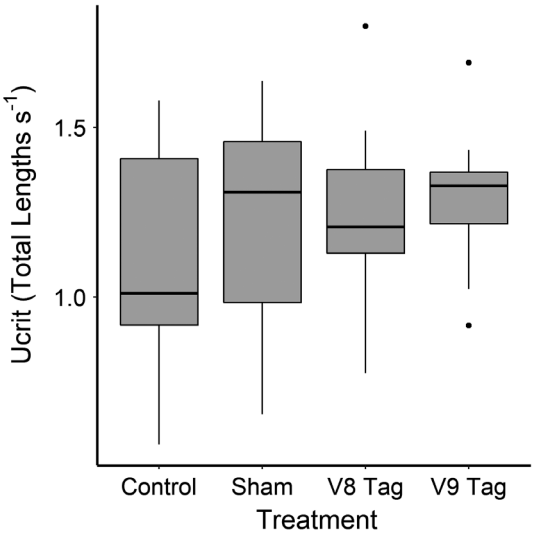

FIGURE 4. Box plots displaying critical swim speed (U_{crit}; TLs/s) of juvenile Lake Sturgeon from the four experimental treatments. The thick middle line in the box indicates the median value; the upper and lower ends of each box represent the 25th and 75th percentiles of data. Error bars extend to show the minimum and maximum values of data points; outliers are represented by filled circles. The four treatments were as follows: control (anesthetized and no acoustic tag inserted), sham control (anesthetized with incision sutured but no acoustic tag inserted), V8 acoustic tag (tag weight in air = 2.0 g; inserted into anesthetized fish), and V9 acoustic tag (tag weight in air = 4.4 g; inserted into anesthetized fish).

Consistent with laboratory studies on other species of sturgeon, our results suggest that tags representing up to 5% of juvenile weight have no significant effects on growth or survival of juvenile Lake Sturgeon. Effects of acoustic tag burden have been reported in terms of incision wound healing, tag retention, growth, and survival of juvenile Green Sturgeon (mean ± SE = 43.5 ± 0.6 cm to 66.3 ± 0.6 cm; 299.5 ± 10.8 g to 1,266.9 ± 57.3 g) and at a lower tag burden (1.31 ± 0.04% of body weight) using an experimental design similar to that used in this study and across a 140-d study period (Miller et al. 2014). Acoustic tags did not significantly affect Green Sturgeon growth or survival, and the wound inflammation declined similarly in all treatments throughout the duration of the study (Miller et al. 2014). Carrera-García et al. (2017) also examined tagging effects on swimming performance of juvenile Siberian Sturgeon (mean ± SD = 16.1 ± 1.0 cm to 23.2 ± 2.4 cm; 15.1 ± 2.6 g to 39.7 ± 10.2 g) when tag weight represented 1.3–2.6% of total body weight. Results showed that tagging did not affect body length or weight at 15 or 30 d posttagging; after 1 month, survival of tagged Siberian Sturgeon was high at 98% (Carrera-García et al. 2017).

Acoustic tag burden studies have also been tested in field settings. Snobl et al. (2015) found that tags up to 4% of total body weight did not alter survival or movement of juvenile Lake Sturgeon (26.6–30.5 cm; 80–100 g). In that study, postrelease dispersal rates were compared in two groups of Lake Sturgeon (48 total) implanted with sonic radio transmitters that represented 2% and 4% of total body weight. The sturgeon were released into two tributaries of Lake Winnebago, Wisconsin, and dispersal rates were compared in the two groups. Results indicated that tag burden did not impair dispersal rates or survival of the age-0 Lake Sturgeon tested; however, the researchers did not account for differences in swimming performance (Snobl et al. 2015). Because our study fish are native to the St. Clair River system and not the Winnebago system, our swim performance results are likely reflective of system-based differences among Lake Sturgeon as well (i.e., ecosystem differences, such as variations in flow rate). These results emphasize the importance of applying our findings to field-based settings (e.g., applying the study to areas where releases could occur) and suggest the use of swim performance/dispersal rates to characterize the effects of tag burden.

Swim Performance

In our study, swimming performance of juvenile Lake Sturgeon was not significantly affected by the implanted acoustic tags (relative to control treatments), consistent with other studies of juvenile sturgeon species. Miller et al. (2014) found that there were no significant effects on U_{crit} (at 8–53 d postsurgery) across tagged groups of Green Sturgeon and that inflammation after tag implantation was not related to U_{crit}. Carrera-García et al. (2017) also

found similar results using video tracking to categorize U_{crit} at 2, 7, 12, 21, and 26 d posttagging. Our swim performance results are similar to those reported for other juvenile sturgeon of similar TLs that were not implanted with acoustic tags. Adams et al. (2003) found similar results when using U_{crit} testing with juvenile Shovelnose Sturgeon *Scaphirhynchus platorynchus* and Pallid Sturgeon *S. albus* (17.82–17.98 cm; 22.13–33.86 g). Those fish were swum using a swim tunnel at temperatures of 20°C and 10°C, and no differences were found in swim speeds between the groups, with values of 1.7 TLs/s (Adams et al. 2003). These results are consistent with other studies focused on U_{crit} of juvenile sturgeon, and our swim speed results are similar to those across other, nontagged juvenile sturgeon species (Shovelnose Sturgeon and Pallid Sturgeon: mean ± SE = 18.8 ± 0.3 cm, 32.7 ± 1.2 g), not accounting for tag burden (Cai et al. 2013).

Our results suggest that acoustic tag burden in Lake Sturgeon juveniles can be pushed to nearly 5% of body weight while having no significant negative effects on swimming ability, TL, weight, or survival. Our study, however, was limited in the amount of time the fish were studied (114-d study period) and the use of a smaller sample size ($n = 93$; or $n = 60$ for swim test data, where no fish had died). It should be noted that using a small sample size (treatment group $n \leq 16$) for U_{crit} testing is common across various studies (Adams et al. 2003; Miller et al. 2014; Downie and Kieffer 2017). Studies have also shown that a smaller sample size used during U_{crit} testing can show significant results between treatment groups within sample sizes of $n \leq 15$, suggesting sufficient power to detect any deleterious tag burden effects if they exist (Cunningham and McGeer 2016; Brown et al. 2017). A longer study might have revealed long-term effects of tag burden on juvenile Lake Sturgeon. We were also limited in the size of acoustic tag that we could implant into the peritoneal cavity due to the overall elongated shape of the sturgeon at the time of surgery.

We only examined four potential metrics of possible tag burden effects. Swim performance can be categorized by using swim tests outside of U_{crit}, including endurance testing or accounting for varying swim behaviors, such as tail beat frequency, burst swimming, and prolonged swimming (Katopodis and Gervais 2016). Incorporating one or various metrics could account for differences in swimming ability not identified by critical swim testing. Aside from swim performance, other physiological metrics could be used to account for tag burden effects, including the use of respirometry to study metabolic rates (Dutil et al. 2007). It is now more widely accepted that tag burden is more closely related to a wider range of factors than total body weight (Thorstad et al. 2013). Thorstad et al. (2013) stressed that the study objective, tagging method, and species tested are critical factors that play into how tag burden can impact a species based on the total body weight : tag weight ratio. In Lake Sturgeon reintroduction efforts, more realistic field tests are needed to study tag burden where results have relevance to behavior and postrelease monitoring. The results of our study suggest that tag burdens of 2.2 ± 0.06% from V8 tags and 4.6 ± 0.10% from V9 tags cause no significant negative effects on juvenile Lake Sturgeon (28.2 ± 0.15 cm; 90.7 ± 1.5 g) from the St. Clair River in terms of swimming behavior and growth. Our results can therefore be applied in field settings to select for a long-lasting tag (with an appropriate battery life) that is optimized to accomplish studies related to the movement ecology of juvenile Lake Sturgeon.

ACKNOWLEDGMENTS

Funding for this project was provided through the Natural Sciences and Engineering Research Council's Discovery Grant Program and Collaborative Research and Training Experience Grant Program as well as through the Canadian Foundation for Innovation/Ontario Research Fund for the Freshwater Restoration Ecology Centre. We appreciate Natalie Klinard and Sarah Larocque for their guidance and assistance with surgeries. We also thank Celine Lajoie, Jason Lewis, Colby Nolan, and Ryland Corchis-Scott for their help with sturgeon measurements. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service. Reference to trade names does not imply endorsement by the U.S. Government. There is no conflict of interest declared in this article.

REFERENCES

Adams, S. R., G. L. Adams, and G. R. Parsons. 2003. Critical swimming speed and behavior of juvenile Shovelnose Sturgeon and Pallid Sturgeon. Transactions of the American Fisheries Society 132:392–397.

Brett, J. R. 1964. The relation of size to oxygen consumption and sustained swimming speed of Sockeye Salmon (*Oncorhynchus nerka*). Journal of the Fisheries Research Board of Canada 22:1491–1501.

Brown, D. R., J. Thompson, M. Chernick, D. E. Hinton, and R. T. Di Giulio. 2017. Later life swimming performance and persistent heart damage following subteratogenic PAH mixture exposure in the Atlantic Killifish (*Fundulus heteroclitus*). Environmental Toxicology 36:3246–3253.

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.

Cai, L., R. Taupier, D. Johnson, Z. Tu, G. Liu, and Y. Huang. 2013. Swimming capability and swimming behavior of juvenile *Acipenser schrenckii*. Journal of Experimental Zoology Part A: Ecological Genetics and Physiology 319:149–155.

Carrera-García, E., J. Kordek, C. Gesset, L. Jacobs, and M. 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.

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.

Craig, J. M., M. V. Thomas, and S. J. Nichols. 2005. Length–weight relationship and a relative condition factor equation for Lake Sturgeon (*Acipenser fulvescens*) from the St. Clair River system (Michigan, USA). Journal of Applied Ichthyology 21:81–85.

Crossin, G. T., M. R. Heupel, C. M. Holbrook, N. E. Hussey, S. K. Lowerre-Barbieri, V. M. Nguyen, G. D. Raby, and S. J. Cooke. 2017. Acoustic telemetry and fisheries management. Ecological Applications 27:1031–1049.

Crossman, J. A., P. S. Forsythe, E. A. Baker, and K. T. Scribner. 2009. Overwinter survival of stocked age-0 Lake Sturgeon. Journal of Applied Ichthyology 25:516–521.

Cunningham, J. L., and J. C. McGeer. 2016. The effects of chronic cadmium exposure on repeat swimming performance and anaerobic metabolism in Brown Trout (*Salmo trutta*) and Lake Whitefish (*Coregonus clupeaformis*). Aquatic Toxicology 173:9–18.

Dittman, D. E., M. A. Chalupnicki, J. H. Johnson, and J. Snyder. 2015. Reintroduction of Lake Sturgeon (*Acipenser fulvescens*) into the St. Regis River, NY: post-release assessment of habitat use and growth. Northeastern Naturalist 22:704–716.

Downie, A. T., and J. D. Kieffer. 2017. Swimming performance in juvenile Shortnose Sturgeon (*Acipenser brevirostrum*): the influence of time interval and velocity increments on critical swimming tests. Conservation Physiology 5(1):cox038.

Dutil, J. D., E.-L. Sylvestre, L. Gamache, R. Larocque, and H. Guderley. 2007. Burst and coast use, swimming performance and metabolism of Atlantic Cod *Gadus morhua* in sub-lethal hypoxic conditions. Journal of Fish Biology 71:363–375.

Katopodis, C., and R. Gervais. 2016. Fish swimming performance database and analyses. Canadian Science Advisory Secretariat Research Document 2016/002.

Liss, S. A., N. K. Ashton, R. S. Brown, R. W. Walker, P. Bates, C. Klassen, and S. Backhouse. 2017. Evaluation of four surgical implantation techniques for age-0 White Sturgeon (*Acipenser transmontanus* Richardson, 1836) with a new acoustic transmitter. Journal of Applied Ichthyology 34:382–389.

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.

Peake, S., F. W. H. Beamish, R. S. McKinley, C. Katopodis, and D. A. Scruton. 1995. Swimming performance of Lake Sturgeon (*Acipenser fulvescens*). Canadian Technical Report of Fisheries and Aquatic Sciences 2063.

Snobl, Z. R., R. P. Koenigs, R. M. Bruch, and F. P. Binkowski. 2015. Do tags exceeding 2% of total body weight impair Lake Sturgeon movement? North American Journal of Fisheries Management 35:880–884.

Thorstad, E. B., A. H. Rikardsen, A. Alp, and F. Økland. 2013. The use of electronic tags in fish research—an overview of fish telemetry. Turkish Journal of Fisheries and Aquatic Sciences 13:881–896.

USFWS (U.S. Fish and Wildlife Service). 2017. First year: Lake Sturgeon study successful. USFWS, Genoa National Fish Hatchery, Genoa, Wisconsin. Available: https://www.fws.gov/midwest/fisheries/fishlines-2017-10-26/feature2.html. (June 2018).

Winter, J. D. 1983. Underwater biotelemetry. Pages 371–396 *in* L. A. Nielson and D. L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.