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ARTICLE

Effects of Passive Integrated Transponder Tags on Survival, Growth, and Swimming Performance of Age-0 Shovelnose Sturgeon

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Abstract
Innovative tools that benefit conservation biology are critical because freshwater fishes are being lost at unprecedented rates. Although mark–recapture is important to characterize population ecology and describe life history traits of declining species, techniques for tagging small-bodied individuals are limited. Recent advances in passive integrated transponder (PIT) tag technology may transform our understanding of fish ecology by providing opportunities to tag small-bodied fishes and early life stages of larger species. Despite the potential value of new PIT tags (8.4 × 1.4 mm), 30% smaller than those previously available, limited research has evaluated their suitability when implanted into small fishes. We evaluated the effectiveness of these tags when surgically implanted into two size-classes (small: 40–70 mm FL; and large: 80–120 mm FL) of age-0 Shovelnose Sturgeon *Scaphirhynchus platorynchus*. This species is closely related to the endangered Pallid Sturgeon *S. albus* and is often used as a surrogate in research. We compared by size-class, tag loss (retention and mortality), growth rates, and swimming performance (U_{crit}) of Shovelnose Sturgeon implanted with PIT tags versus control and sham treatment groups. We found that application opportunities for advanced PIT tag technology for larger age-0 sturgeon (>80 mm) are abundant due to little tag loss, uncompromised growth rates, and unchanged swimming performance. However, managers tagging smaller sturgeon earlier in the growing season should expect high mortality rates, impacts to growth, and worsened swimming performance. These findings provide critical information concerning the suitability of surgically implanted PIT tags in age-0 sturgeon to study young sturgeon ecology that was previously unavailable.

Conservation biology has never been more critical than it is today as species from numerous taxa disappear at unprecedented rates (Richter et al. 1997; Cardinale et al. 2012). Prevalent human mediated stressors risk further declines to both distribution and local abundance of fish species worldwide and seriously threaten aquatic ecosystem stability (Richter et al. 1997; Ricciardi and Rasmussen 1999; Cardinale et al. 2012). Conservation of fish biodiversity has largely lagged behind that of terrestrial systems due to difficulties associated with describing population demographics and life history characteristics of organisms in aquatic systems (Allan and Flecker 1993; Cooke et al. 2012).

Mark–recapture techniques have long been important to studies of animal population ecology and include numerous applications to the fisheries sciences (Jolly 1965; Pollock et al. 1990). Recapturing tagged individuals can help characterize life history traits, estimate demographic rates, document behavior, or establish survival (Nielsen 1992; Ruetz et al. 2006;

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Kaemingk et al. 2011; Hamel et al. 2012). Mark–recapture studies assume that the marks or tags (1) are readable for an indefinite or known retention period, (2) have negligible effects on life history traits or behaviors, and (3) do not impact the direction or magnitude of results (Gibbons and Andrews 2004; Bolland et al. 2009). When selecting tagging methods, investigators must carefully select tagging methods that meet model assumptions (Ruetz et al. 2006) and address study objectives within their budgets (Gibbons and Andrews 2004; Lower et al. 2005; Bolland et al. 2009).

Biologically inert passive integrated transponder (PIT) tags are common to research and management when the identification of individual large-bodied animals is needed or when repeated, nondestructive sampling is desired (Gibbons and Andrews 2004; Knaepkens et al. 2007; Archdeacon et al. 2009). Their indefinite life span, easy internal placement, high detection efficiency, and unique identification numbers make PIT tags particularly appropriate for use in fisheries research (Gibbons and Andrews 2004; Knaepkens et al. 2007; Archdeacon et al. 2009; Ficke et al. 2012). Passive integrated transponder tags implanted in large-bodied fishes generally have had minor effects on life history characteristics and are often retained in tissues at high rates (Baras et al. 2000; Roussel et al. 2000; Ruetz et al. 2006; Knaepkens et al. 2007). However, variation in physiological effects of PIT tags among studies has prompted concern about their application to additional orders, guilds, and size-classes without prior evaluation (Prentice et al. 1990; Baras et al. 2000; Bruyndoncx et al. 2002; Archdeacon et al. 2009; Hamel et al. 2012). Preliminary tests could be especially important for small-bodied fishes and early life stages as tag effects tend to increase with the tag size to fish size ratio (Baras et al. 2000; Archdeacon et al. 2009; Bolland et al. 2009).

Recent advances in PIT tag technology may transform our understanding of small fish ecology by providing opportunities for their use with small-bodied fishes and early life stages of larger species (Gibbons and Andrews 2004; Lower et al. 2005; Dixon and Mesa 2011; Ficke et al. 2012). Although novel small size PIT tags (8.4 × 1.4 mm) potentially enable the unique identification of small-bodied individuals and species (Baras et al. 1999; Archdeacon et al. 2009; Dixon and Mesa 2011; Ficke et al. 2012; Mesa et al. 2012), limited research has evaluated their suitability when implanted into small fishes (Dixon and Mesa 2011). Field studies that employ PIT tags are also often interested in animal movement and must therefore ensure that locomotion is not affected by the experimental methods (Roussel et al. 2000). Knowledge of tag loss (mortality and tag ejection), effects to growth, and fish behavior resultant of implanted PIT tags is required to describe their constraints when applied to small-bodied individuals before magnanimous prospects can be fully realized (Lower et al. 2005; Archdeacon et al. 2009; Bolland et al. 2009).

For species in which early life stages are considered bottlenecks to population recovery, such as Pallid Sturgeon *Scaphirhynchus albus*, small PIT tags may facilitate management by increasing our understanding of early life history (Schiemer et al. 2002). The closely related and sympatric Shovelnose Sturgeon *S. platorynchus* has commonly been used as a surrogate in research (Koch and Quist 2010) to assist management of Pallid Sturgeon complicated by the extreme rarity of Pallid Sturgeon in the environment (DeVries et al. 2015). This research practice has been largely accepted (Koch and Quist 2010; Hamel et al. 2012) because both species have similar morphology (Snyder 2002), exhibit comparable foraging and swimming behaviors (Adams et al. 2003; Braaten and Fuller 2007; Braaten et al. 2012), and occupy similar habitats (Phelps et al. 2010). Hamel et al. (2012, 2013) evaluated PIT tag effects and retention time in large Pallid Sturgeon and Shovelnose Sturgeon individuals (421–720 mm FL), but to our knowledge, no research exists for early sturgeon life stages.

Novel PIT tag methodologies may provide valuable insight into young sturgeon ecology; however, research is first required to describe the suitability of PIT tags for age-0 individuals. Therefore, the objectives of this study were to evaluate effects of small (8.4 × 1.4 mm) PIT tags on tag retention, survival, growth, and swimming performance of two size-classes of age-0 Shovelnose Sturgeon. Conclusions generated will provide fisheries scientists with critical information concerning the suitability of PIT tags for age-0 sturgeon.

METHODS

Fish Collection and Husbandry

Shovelnose Sturgeon were the progeny of captured wild broodstock, which originated from the Missouri River downstream of Gavins Point Dam, Nebraska. Larvae hatched on June, 13, 2013, at the Valentine Fish Hatchery (Nebraska Game and Parks Commission), and approximately 35,000 individuals were transported to the Fisheries Research Unit (South Dakota State University, Brookings) the following day. All individuals were housed at low densities in 40-L tanks within a 1,000-L water recirculating system until mean fork length was at least 40 mm. During this initial growth period, sturgeon were reared in approximately 15°C water and were fed chironomid larvae and a mixture of dry food (70% Otohime and 30% Cyclopeeze) ad libitum.

Study design.—We evaluated the effects of implanted PIT tags on two size-classes of age-0 Shovelnose Sturgeon, small (40–70 mm FL) and large (80–120 mm FL), in the first growing season. Pilot investigations resulted in 100% mortality of individuals less than 40 mm FL when implanted with PIT tags. Small and large age-0 trials were conducted during different times to allow sturgeon to reach the desired sizes and represent a comparison of individuals tagged at different times during their first growing season. During each study period, two independent experiments, using separate fish, were conducted to simultaneously evaluate the effects of implanted tags on retention, survival, and growth (experiment 1) and swimming performance (experiment 2). Three treatment groups were compared during experiment 1: handled (control), incision only (sham), or incision and PIT tag implantation (PIT). The sham treatment group was not used during experiment 2. Fish were tagged using the same procedure in all experiments.

*Tagging technique.—*Although not directly applicable to field studies, we withheld food for 36 h prior to PIT tag implantation to allow for consistent gut evacuation among individuals. All fish were removed from the housing tanks, anesthetized in tricaine methanesulfonate (MS-222 at 100 mg/L of water), measured (mm), and weighed (g) before being subjected to random treatments. Fish assigned to the control group were anesthetized and immediately placed into treatment specific recovery tanks, whereas other individuals were subjected to their respective treatment (i.e., sham or PIT). We made a 2–3-mm medial incision between the midventral line and the ventral scutes anterior to the pelvic girdle using a 3.0-mm microsurgical scalpel for sham and PIT tag treatment individuals. For PIT treatment fish, we implanted a PIT tag (HPT8 MiniChip; 8.4 × 1.4 mm, 0.036 g; Biomark, Boise, Idaho) into the peritoneal cavity and maneuvered it into the abdominal cavity by hand (Knaepkens et al. 2007; Archdeacon et al. 2009). To decrease handling time, we left all surgical wounds open (Archdeacon et al. 2009). We sanitized all PIT tags and surgical equipment in 95% ethyl alcohol before each use to decrease the risk of infection (Dixon and Mesa 2011). We recorded total handling time during experiment 1 (i.e., time to measure, anesthetize, weigh, and tag) for all individuals in all treatment groups. The initial tag weight in air (g) to fish weight (g) ratio was calculated and expressed as a percentage for the PIT tag treatment individuals (Table 1). We placed all individuals in aerated replicate-specific recovery tanks for 10 min before returning them to long-term monitoring tanks. During pilot investigations respiration rate, movement behaviors, and righting response visually approximated normal within 10 min. Initial mortality was ascribed to fish that died during the procedure or recovery period and was expressed as a percentage by treatment. We did not feed fish from any treatment the day following implantation. All fish were offered a daily ration of chironomid larvae equal to 10% of the tank biomass on all subsequent days.

EXPERIMENT 1: RETENTION, SURVIVAL, AND GROWTH

We indiscriminately selected individuals from our source population for both size-class trial periods and assigned each to one of the three treatment groups. Each treatment group ($n = 30$) was equally divided into three 40-L tanks within the same 1,000-L water recirculating system for three replicates. The experiment was conducted early in the first growing season with small age-0 sturgeon (n = 90) and repeated later when a separate group of larger age-0 sturgeon (n = 90) reached the desired size. We monitored trials for 49 d following the procedure; an adequate amount of time to ensure necessary healing and recovery occurred to sufficiently evaluate tag retention, survival, and growth (Kaemingk et al. 2011; Tiffan et al. 2015).

*Survival and tag retention.—*We monitored tanks daily for mortalities and expelled PIT tags throughout the study. We visually located expelled tags in the housing tanks daily and removed any individuals that ejected their PIT tag on a weekly basis when handling fish to monitor growth rates. We conducted necropsies on sham and PIT tag treatment mortalities to anecdotally describe incision condition and internal abnormalities related to the surgical procedure. Survival and PIT tag retention during the study period were expressed as the percentage of individuals within each replicate.

We conducted failure-time analyses (LIFETEST procedure in SAS) to test for homogeneity among treatment specific survivorship curves by sturgeon size-class (Fox 2001). For both size-classes, a Wilcoxon chi-square test was used to analyze cumulative survivorship and retention

TABLE 1. Mean (SE) passive integrated transponder (PIT) tagging data for small (40–70 mm FL) and large (80–120 mm FL) age-0 Shovelnose Sturgeon in a 49-d evaluation. Tagging treatments included control (handled only), sham (handled with incision), and PIT (incision and placement of a PIT tag). Different letters denote statistically significant differences ($P < 0.05$).

	Small fish			Large fish		
Variable	Control	Sham	PIT	Control	Sham	PIT
Initial FL (mm)	53.3 (0.67)	53.4 (0.65)	55.9 (0.81)	99.4 (2.50)	100.5 (1.84)	98.1 (2.07)
Initial weight (g)	0.72 (0.025)	0.73 (0.026)	0.82 (0.029)	3.3 (0.212)	3.5 (0.195)	3.2 (0.190)
Initial tag to fish weight (%)[a]	No tag	No tag	4.6 (0.16) y	No tag	No tag	1.2 (0.08) z
Treatment handling time (s)[b]	58.5 (1.18) z	63.1 (0.68) y	70.3 (1.14) x	57.8 (1.05) z	69.6 (1.06) y	81.3 (2.21) x
Initial mortality (%)	0 (NA)	7 (NA)	17 (NA)	0 (NA)	0 (NA)	0 (NA)
Survival to 49 d (%)[b]	97 (2.7) y	100 (NA) y	73 (5.4) z	100 (NA)	100 (NA)	90 (4.7)
Tag retention to 49 d (%)[a]	No tag	No tag	60 (1.3) z	No tag	No tag	97 (2.7) y

[a] Letters compare PIT treatment between size-classes of fish.

[b] Letters compare different treatments within size-classes.

among treatments (Fox 2001). This analysis compares survivorship among treatment groups or tag retention between size-classes over the entire distribution of failure times (i.e., mortality or tag ejection at 0–49 d), rather than solely on the final trial day. It manages right-censored data and does not assume that data are normally distributed (Fox 2001). All individuals that survived or retained their tag through day 49 were considered right-censored during this analysis. For both analyses, significance was determined at $\alpha = 0.05$. If differences were observed in survivorship or retention among treatment groups, we performed a Šidák multiple-comparison post hoc test to isolate the source of variation (Fox 2001).

We used logistic regression to assess the effect of initial fork length on survival and tag retention. The logistic response form is

$$Y_i = e^{(\beta_0+\beta_1 X_i)} \Big/ \left[1 + e^{(\beta_0+\beta_1 X_i)}\right],$$

where Y_i is the survival or tag retention probability of fish i on day 49, β_0 is the regression intercept, β_1 is the regression slope, and X_i is the fork length of fish i. Parameters were estimated using nonlinear regression.

Relative daily growth.—We weighed (g) all individuals prior to initial tagging and on a weekly basis for the duration of the study to evaluate the effects of the surgical procedure (sham) and tag implantation (PIT) on fish growth. We calculated relative daily growth rates (RDGR) for each control and sham replicate group and for all PIT-tagged individuals as

$$\mathrm{RDGR} = [(m_t - m_0)/m_0]/\Delta t,$$

where m_t is the mass (minus the mass of the PIT tag) of a fish at time t, and m_0 is initial mass of the same fish measured at the time of the surgical procedure. Two-way repeated measures ANOVA was used to test the null hypothesis that RDGR did not differ among treatments through time by size-class ($\alpha = 0.05$). Growth data for both small and large age-0 sturgeon failed the sphericity test, so we used the adjusted Greenhouse-Geisser probabilities to compare growth among treatment groups through time. If differences were observed, we performed a Student–Newman–Keuls post hoc test by week to partition treatment effects into distinct groups (Zar 2010).

EXPERIMENT 2: SWIMMING PERFORMANCE

We compared a distinct group of control (n = 20/size-class) and PIT (n = 20/size-class) treatment fish from both sturgeon size-classes to evaluate the swimming performance of fish implanted with PIT tags. We measured critical swimming velocities of fish over a period of 30 d (t = 1, 7, 14, and 30 d), where t = 1 was 1 d post PIT tag implantation. We sampled five replicate individuals for each size-class, treatment, and interval combination. Once assessed, we removed individuals from the experimental population to ensure that the same fish was not assessed more than once. We starved fish for 36 h prior to the swimming trials to ensure a postabsorptive state. Only fish to be used for upcoming swimming trials were starved at each time interval. For both size-classes, we conducted critical swimming tests at 15°C water temperatures.

We used critical swimming speed tests (U_{crit}; Brett 1964) to evaluate the swimming performance of sturgeon and to determine if PIT tag implantation affected locomotion. During this experiment, we exposed individuals to increasing water velocities (increments) for constant periods of time (intervals) until they were no longer able to maintain their position in the water column. The critical swimming speed (cm/s) was measured as

$$U_{\mathrm{crit}} = u_1 + \left(\frac{u_2 \cdot t_1}{t_2}\right),$$

where u_1 is the highest completed velocity, u_2 is the velocity increment, t_1 is the time spent by the fish swimming at the fatigue velocity, and t_2 is the time interval. We normalized the absolute critical swimming velocity data with respect to fish size by dividing U_{crit} (cm/s) by fish fork length (cm) to provide relative swimming velocity values in body lengths (BL)/s.

We used a Blazka-type mini-swim tunnel (1.5 L; Loligosystems) to evaluate swimming performance of small age-0 sturgeon. Methods to quantify U_{crit} for these individuals follow those of Guan et al. (2008). For each trial, we placed an individual fish into the swim chamber and allowed it to acclimate for 15 min in static water (0 cm/s). After the acclimation period, we increased velocity by 1 cm/s with 2-min increments. We defined fatigue as the time at which the fish could no longer hold position and became impinged on the downstream grid for 10 s.

The swimming protocol for the large age-0 size-class followed methods established by Adams et al. (1998). We introduced fish into a 10-L Brett-type swimming chamber and allowed them to acclimate for a period of 1 h. During this acclimation period, we maintained the water velocity at 5 cm/s for 30 min, then increased to 10 cm/s for the remaining time. These velocities did not induce active swimming against the current. To start the critical swimming test, the water velocity was increased to 15 cm/s and was incrementally increased by 5 cm/s at 30-min intervals. We ended the trial once the fish could not hold ground against the current and was impinged against the downstream grid for 10 s.

A two-way ANOVA was performed on swimming performance metrics to describe differences between the control and PIT tag treatments by size-class. Both time interval (d) and treatment (control and PIT) were used as factors in this analysis. All results were considered significant at $\alpha = 0.05$. No direct comparisons were made between small and large age-0 size-classes because different protocols and flumes were used to evaluate swimming performance. The range of fish lengths in which each flume was effective did not include all experimental sturgeon.

RESULTS

Survival and Tag Retention

Initial mortality of small age-0 sturgeon varied among treatment groups and was highest for PIT-tagged fish (17%; Table 1). Few sham (7%) and zero control fish perished during the initial procedure in the small, age-0 size-group. No initial mortality occurred in any treatment for the large, age-0 sturgeon.

Significantly different survival was observed in treatment groups and occurred rapidly during the small age-0 trials (Table 1; $\chi^2 = 14.38$, df = 2, $P < 0.01$); 24% more mortality was noted in the PIT treatment than the control (Šidák: $P < 0.01$). Survival rates of small age-0 sturgeon in the sham and control groups were indistinguishable (Šidák: $P = 0.89$).

Handling time increased significantly as treatment procedures became more elaborate for both small ($F_{2,\ 87} = 32.33$, $P < 0.01$) and large ($F_{2,\ 87} = 56.69$, $P < 0.01$) size-classes (Table 1). Although tagging larger sturgeon took approximately 11 s longer than small individuals ($F_{1,\ 58} = 19.05$, $P < 0.01$), processing time had little effect on the likelihood of sturgeon mortality ($\chi^2 = 63.74$, $N = 65$; $P = 0.22$). Survival probability, however, was closely related to initial length for age-0 sturgeon. The predicted length at which 90% survival is expected through 49 d was 81 mm FL (Figure 1A).

Ejection of PIT tags was 37% more likely from small age-0 sturgeon than the large size-class (Table 1; $\chi^2 = 11.95$, df = 1, $P < 0.01$). Tag loss occurred only during the first 2 weeks of the study, a period in which wounds were not generally fully healed, irrespective of size-class (Figures1B, 2A). Twelve tags were shed from small size-class (Table 1; Figure 2A). One PIT tag was ejected from a large size-class fish during the first week of the study (Table 1; Figure 2B). The predicted FL at which 90% tag retention is expected through 49 d was 87 mm (Figure 1B). Necropsies anecdotally suggested that tag ejection increased with incision size relative to fish size and incision distance from abdominal muscles. Cumulative tag loss (ejection + mortality) from the small size-class was 69% and from the large size-class was 13% (Figure 2A, 1B).

Relative Daily Growth

Comparisons of growth rates among small age-0 treatment groups revealed a significant interaction between time and treatment (Figure 3A; $F_{12,\ 72} = 6.46$, $P < 0.01$). The interactions were ordinal, and post hoc comparisons among treatment groups by sample period identified a prolonged impact of PIT tag implantation on growth throughout the study. Small, age-0 fish implanted with PIT tags had negative growth rates and lost weight during the first three trial weeks. Growth rates of control and sham groups were not distinguishable for small age-0 sturgeon at any time. Growth rates of large, age-0 fish were unaffected by the surgical procedure or tag implantation (Figure 3B; $F_{6,\ 174} = 0.54$, $P = 0.49$).

Swimming Performance

The initial PIT tag to fish weight ratio for small, age-0 fish exceeded common guidelines (4.6%, SE = 0.16), but for the large, age-0 individuals, the tag weight was not expected to be a considerable burden (Table 1; 1.2%, SE = 0.08). All swimming performance data met the assumptions of normality and homogeneity of variance without transformation. A significant difference in normalized U_{crit} was detected between the control and PIT tag treatments for small fish (Figure 4A; $F_{1,\ 32} = 8.27$, $P < 0.01$). However, differences between treatment groups were only observed for 1 week following the procedure suggesting a short recovery period. The interaction term (treatment × time) was not significant for small sturgeon ($F_{3,\ 32} = 1.62$, $P = 0.37$). No significant differences in swimming performance were observed between the control and PIT treatments for the large fish ($F_{1,\ 32} = 0.58$, $P = 0.45$). The interaction term was also found to be nonsignificant (Figure 4B; $F_{3,\ 32} = 0.73$, $P = 0.54$).

DISCUSSION

Few studies have tested the potential limitations of newly developed, small (8.4 × 1.4 mm) PIT tags with fish, and to our knowledge, no research has evaluated their suitability for age-0 sturgeon (Bangs et al. 2013; Tiffan et al. 2015; Ward et al. 2015). Previous studies of the impacts of PIT tag implantation involving sturgeon either utilized larger PIT tags (Hamel et al. 2012; Steffensen et al. 2010) or larger individuals (Johnson et al. 2014). Impacts of surgically implanted PIT tags on age-0 Shovelnose Sturgeon were size-class-specific. Significant effects on survival and growth were only observed for smaller individuals tagged early in their first growing season. Effects on larger sturgeon were generally minor. Surgically implanted tags had acute effects on small, age-0 sturgeon swimming performance that were observed for 1 week following the procedure. Large, age-0 sturgeon tagged near the end of their first growing season are suggested for future tagging activities; however, we have provided coefficient values to estimate tag loss and describe potential impacts if researchers choose to tag smaller individuals (Figures 1A and 2B).

Survival and Tag Retention

Functional tag loss, defined as the combination of mortality and tag ejection, is of ultimate interest to capture–recapture study designs because each would remove individuals from the pool of PIT-tagged fish released. Initial mortality was relatively high for small, age-0 sturgeon (17%). Because few studies have evaluated initial mortality of such small fish when implanted with PIT tags, this rate provides a frame of reference for further study. Investigator judgment must be employed to decide if that rate meets the needs of specific project goals. Consistent with similar research on more than

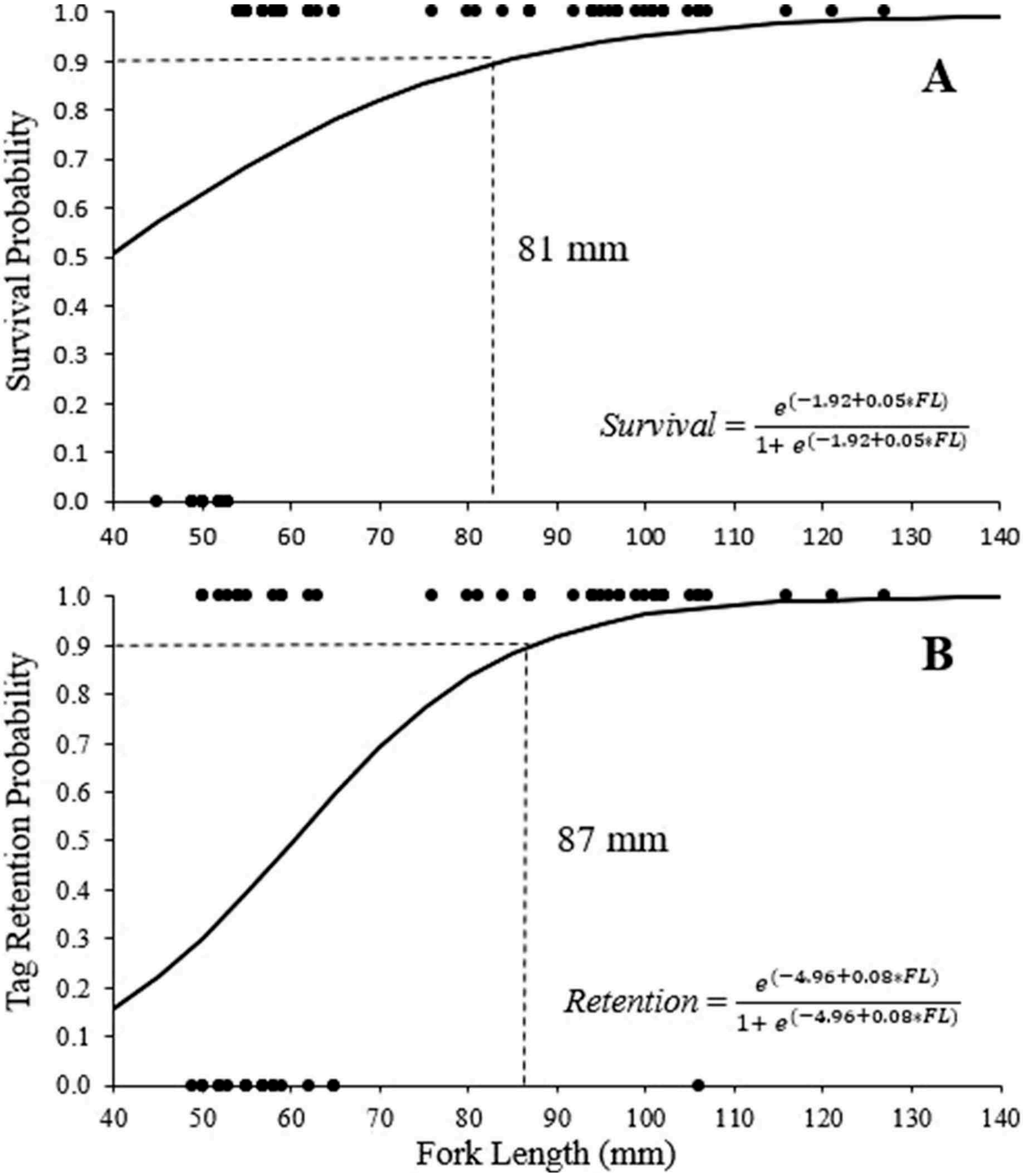

FIGURE 1. Relationship between fork length and **(A)** probability of survival and **(B)** probability of tag retention to day 49 for all age-0 Shovelnose Sturgeon (n = 60) that received passive integrated transponder tags via surgical incision. The horizontal dotted lines represent estimates for 90% survival or retention.

70-mm fish tagged with small PIT tags (Tiffan et al. 2015; Ward et al. 2015), none of the large sturgeon initially succumbed to the surgical procedure. By waiting to PIT-tag age-0 sturgeon until individuals exceed 80 mm FL, managers can reduce concerns of high initial mortality.

Survival of the small sturgeon was relatively low (73%) compared with similarly sized individuals of different species subjected to comparable PIT tag implantation procedures. In many cases, short-term survival rates of small individuals (<70 mm) of other species exceeded 90% (Dixon and Mesa 2011; Bangs et al. 2013; Tiffan et al. 2015). Mortality of our small sturgeon ceased on day 20, which is within the 28-d period when mortality as a result of the tagging procedure is generally expected (Archdeacon et al.

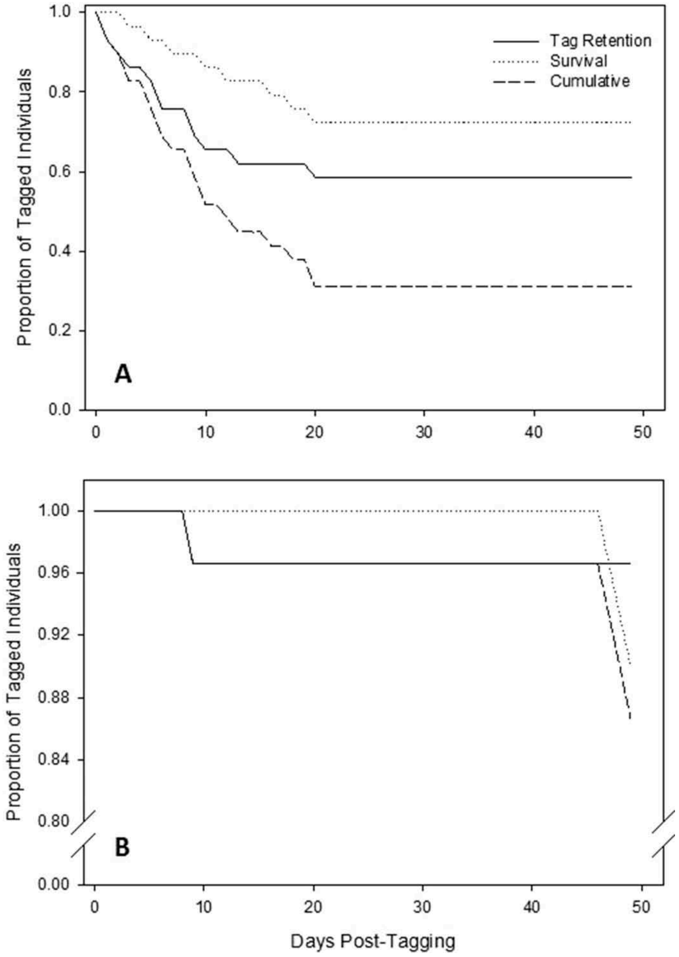

FIGURE 2. Daily survival and retention of passive integrated transponder tags, and cumulative population retention over a 49-d trial period for **(A)** small (40–70 mm FL) and **(B)** large (80–120 mm FL) age-0 Shovelnose Sturgeon (n = 30 per size-class) that received tags via surgical implantation. Tag retention was calculated only for living fish; cumulative population tag retention represents combined survival and individual fish tag retention.

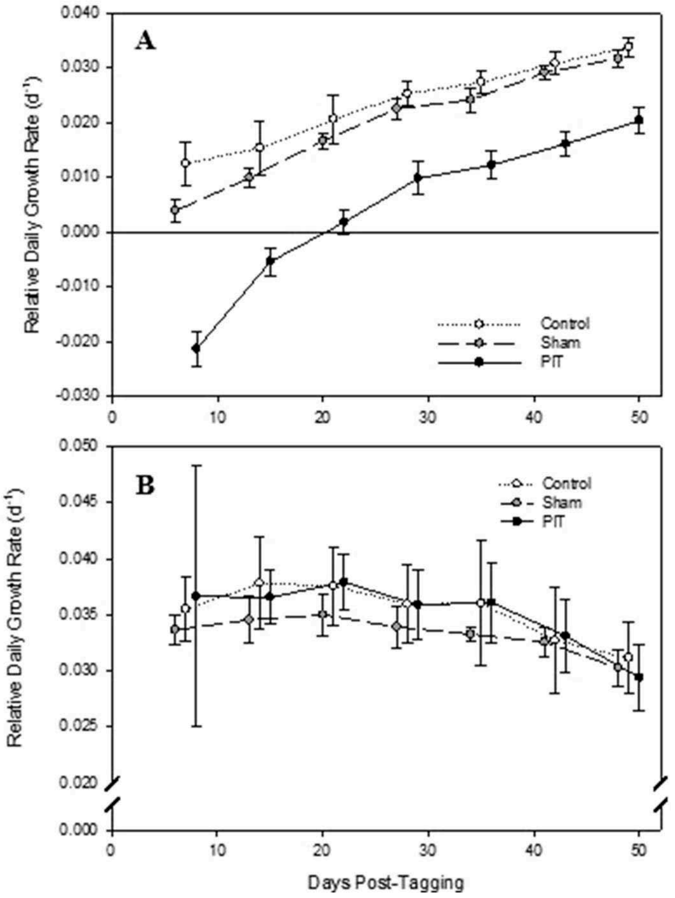

FIGURE 3. Mean relative daily growth rates (error bars = 2 SE) during the 49-d trial for **(A)** small (40–70 mm FL) and **(B)** large (80–120 mm FL) age-0 Shovelnose Sturgeon by treatment procedure (n = 30 per treatment) as described in Table 1.

2009; Bangs et al. 2013). Short-term survival of our large sturgeon was much higher (94%) than the small sturgeon and was comparable to survival rates of Humpback Chub *Gila cypha* (Ward et al. 2015) and Chinook Salmon *Oncorhynchus tshawytscha* (Knudsen et al. 2009; Tiffan et al. 2015) greater than 70 mm. All three mortalities of our large sturgeon occurred unexpectedly at the end of the study period from unknown causes. Post mortem condition and prior growth rates were good and healing of the incision appeared complete. We speculate that these delayed mortalities were caused by negative impacts on the digestive tract related to the abdominal PIT tag placement.

The probability of survival and tag retention for the duration of the study was substantially higher for age-0 sturgeon of greater initial length. The observed relationship between length and mortality induced by PIT tag implantation is not novel, and several studies have recognized increased survival probability with increasing fish length (Baras et al. 1999; Acolas et al. 2007; Archdeacon et al. 2009; Bangs et al. 2013; Ward et al. 2015).

Tag retention was relatively low (60%) for small, age-0 sturgeon. However, high (97%) tag retention was observed for large, age-0 sturgeon. Retention rates for other species have commonly surpassed 90% and have not been reported below 70% (Bangs et al. 2013; Tiffan et al. 2015; Ward et al. 2015). Retention rates may have differed if inserted into intramuscular locations typical for PIT tag implantation in sturgeon, such as the operculum or dorsal muscle (Hamel et al. 2012, 2013). We selected the abdominal cavity because the ratio of tag to muscle tissue mass was considered to be insufficient for implantation and potentially fatal in small sturgeon. When similarly sized tags were implanted into the abdominal cavity and dorsal musculature of Humpback Chub (Ward et al. 2015), Chinook Salmon (Tiffan et al. 2015), and Zander *Sander lucioperca* (Hopko et al. 2010), ejection rates were equivalent to those we found for Shovelnose Sturgeon.

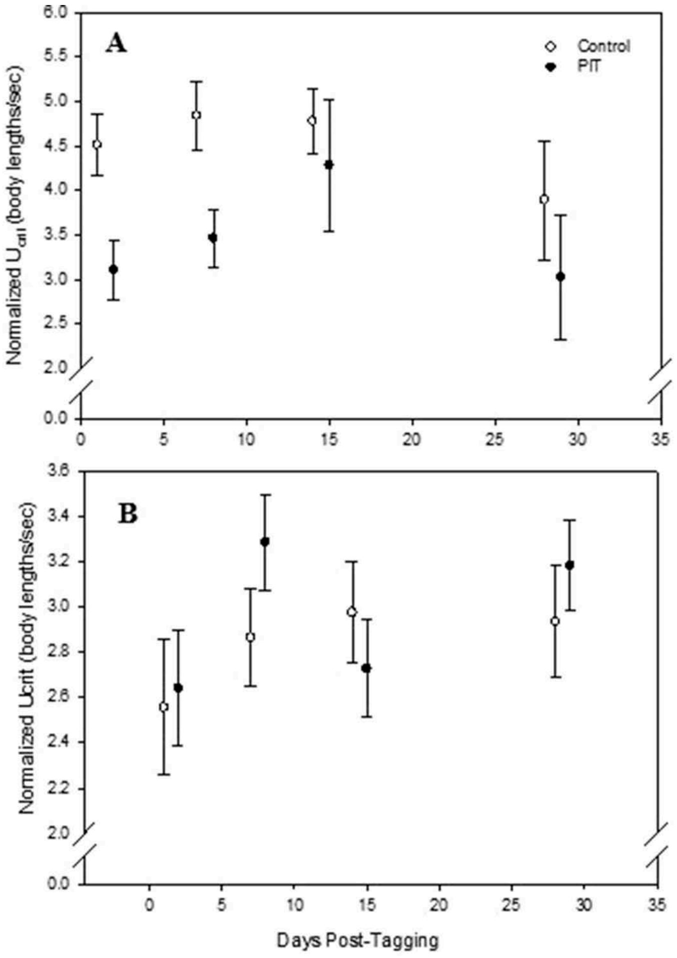

FIGURE 4. Critical swimming velocity (U_{crit}) in body lengths per second for **(A)** small (40–70 mm FL) and **(B)** large (80–120 mm FL) Shovelnose Sturgeon by treatment procedure (n = 20 per treatment), as described in Table 1. Error bars = 1 SE.

For several salmonids, retention of PIT tags increased when tags were inserted into the body cavity rather than the dorsal musculature (Dieterman and Hoxmeier 2009). Although retention rates may have increased by using sutures or cyanoacrylate to close the incision wound (Hamel et al. 2012), these methods were not applied in this study, to reduce handling stress and consequent mortality (Omberdane et al. 1998). For both size-classes, tag ejection occurred shortly after the procedure and decreased rapidly as incisions healed (Baras et al. 1999).

Size-dependent survival and tag retention after PIT tag insertion may be related to increased space available within the abdominal cavity. Larger individuals are potentially able to better cope with the stressors associated with the surgical procedure. This understanding of size-specific mortality and retention allows for refined estimates of survival (or retention) in application by simply incorporating length of sturgeon tagged.

Relative Daily Growth

Although growth rates of large, age-0 sturgeon were unaffected by PIT tag implantation, growth of small, age-0 fish was substantially and continuously impacted throughout the study period. The small sturgeon actually lost weight during the first 3 weeks. These fish were probably not eating at equivalent rates to the sham and control treatment groups. The decrease in growth through time observed during all large, age-0 sturgeon treatment groups had little relation to the tagging procedure and probably resulted from the housing or repeated handling. The substantial and chronic influence of inserted PIT tags on the small sturgeon growth rates violates the unobtrusive assumptions of tagging studies, potentially limiting their application to small, age-0 sturgeon (<80 mm FL). The effects of peritoneal placement of small PIT tags on growth vary considerably across studies, potentially related to morphological differences of species and the size of individuals subjected to the tagging procedure (Knudsen et al. 2009; Ashton et al. 2013; Tiffan et al. 2015). Influences of tagging technique on growth of other species have generally been acute and restricted to the first week following the procedure (Tiffan et al. 2015).

Swimming Performance

Similar to our results for large, age-0 sturgeon, research has generally found no effect of PIT tag implantation on the swimming performance of small-bodied salmonids (Adams et al. 1998; Newby et al. 2007) and nonsalmonids (Knaepkens et al. 2007; Ficke et al. 2012). The sizes of fish used in previous studies are often greater than the small, age-0 sturgeon we used. However, after a short (1 week) recovery period, swimming performance of small, age-0 sturgeon was equivalent to control individuals. A limited number of studies have quantified swimming performance (i.e., U_{crit} or endurance swimming tests) as part of their assessment of detrimental tagging effects.

Management Implications

This systematic evaluation of innovative PIT tag methodologies will facilitate the knowledge acquisition about young sturgeon ecology. Applications of advanced PIT tag technology for larger, age-0 sturgeon (>80 mm, late growing season) are plentiful given low mortality, minimal tag loss, uncompromised growth rates, and unchanged behaviors. However, if the goal is to tag smaller sturgeon in situ, managers should expect high tag loss and influences on behavior and growth in the short term and compensate accordingly. Small PIT tags offer great opportunities for ecological and behavioral studies of young sturgeon and fisheries scientists now have critical information concerning the suitability and impacts of PIT tag implantation on age-0 sturgeon that was previously unavailable. This research alleviates many concerns about the constraints of PIT-tagging small-bodied sturgeon, making managers better able to study young sturgeon ecology late in their first growing season.

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