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Cohort-specific estimates of first-year survival are positively associated with size at stocking for lake sturgeon *Acipenser fulvescens* (Rafinesque 1817) stocked in Black Lake, Michigan, USA

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Summary

The authors conducted a gillnet survey in 2013 in Black Lake, Michigan, USA to evaluate the lake sturgeon (*Acipenser fulvescens*) stocking programme that began in 2001. Objectives were to (i) estimate year-class specific abundance of juvenile lake sturgeon in Black Lake; and (ii) determine year-class specific survival of stocked year classes and determine whether year-class-specific first-year survival was related to average size at the time of stocking. Deployed were 15 and 20 cm stretch mesh gillnets at 72 randomly selected sites in Black Lake over a 3-week survey using a Schnabel multiple-mark, multiple-recapture estimator to determine overall abundance of stocked fish. Ages for captured fish were determined from fin ray cross sections and the presence of coded wire tags, and apportioned the overall abundance estimate of juveniles to year class using an age-length key. Overall survival estimates were calculated by dividing the year-class specific abundance estimates by the number of fish stocked that year. Also evaluated was the relationship between first-year survival and average total length (TL) at time of stocking using logistic regression. Overall survival from stocking to 2013 ranged from 0.03 to 0.53. First-year survival was positively associated with average TL at stocking, and ranged from 0.05 for fish stocked at 9 cm TL to 0.84 for fish stocked at 22 cm TL. Estimation of future cohort-specific abundance based on size-based expected survival allows managers to establish annual stocking targets that should lead to the achievement of long-term population goals for adult abundance.

1 | INTRODUCTION

Low natural recruitment is a common feature of sturgeon life histories (e.g. Bruch, 1999) and is one reason sturgeon populations are sensitive to overharvest and other anthropogenic stressors. To compensate for low or absent natural recruitment, hatcheries are increasingly supplementing or restoring sturgeon populations across the northern hemisphere. Large-scale hatchery programmes for sturgeon species are being used to support existing fisheries by producing large quantities of fish to stock (Burtsev, Nikolaev, Maltsev, & Igumnova, 2002; Chebanov, Karnaukhov, Galich, & Chmir, 2002). However, many sturgeon hatchery programmes differ from traditional hatchery production because they are designed to rehabilitate and restore sturgeon populations that have declined to threatened or endangered levels or to maintain and enhance populations of threatened and endangered sturgeons by stocking relatively small numbers of fish (Ireland, Beamesderfer, Paragamian, Wakkinen, & Siple, 2002; Holtgren, Ogren, Paquet, & Fajfer, 2007; Justice et al., 2009). Despite the increasing use of hatcheries to supplement sturgeon populations, particularly in the Great Lakes of North America (Holtgren et al., 2007), there have been few studies evaluating stocking programmes that can be used to guide stocking decisions (e.g. numbers to stock, appropriate size of fish to stock ; Jackson, VenDeValk, Brooking, vanKeeken, & Rudstam, 2002; Schram, Lindgren, & Evrard, 1999).

Lake sturgeon (*Acipenser fulvescens*) is a species of conservation concern across its native range, and is the focus of conservation efforts in the Laurentian Great Lakes (Holey, Baker, Thuemler, & Elliott, 2000). Restoration efforts include habitat management, harvest restrictions, inter-agency collaborations and data sharing, and stocking. Stocking programmes are currently ongoing in seven Great Lakes tributaries. These stocking programmes involve either supplementing remnant populations (2 rivers) or reintroducing populations in rivers that historically supported lake sturgeon (5 rivers). Lake sturgeon stocked into Great Lakes tributaries are raised in streamside rearing facilities (SRFs; Holtgren et al., 2007). These SRFs were designed to raise 1,500 lake sturgeon to 6 month age. The designed capacity was based on 'best professional judgement' in absence of data on survival of stocked lake sturgeon. Lake sturgeon are long-lived, not reaching sexual maturity until age 15–25 (Peterson, Vecsie, & Jennings, 2007). Because of increased interest in stocking as a management option, timely evaluations of the effectiveness of ongoing stocking efforts are important to provide data on appropriate numbers and size of fish to stock to achieve population abundance goals.

Early research on Black Lake, MI (USA) focused on the *Acipenser fulvescens* population status and led to the conclusion that lake sturgeon natural recruitment was not sufficient to support the population and the harvest fishery in the lake (Baker & Borgeson, 1999). Harvest was subsequently reduced and stocking was initiated in 2001. Lake sturgeon have been stocked in Black Lake most years since 2001, with numbers and sizes of fish stocked varying among years (Table 1) in part because stocking has been conducted as part of the ongoing research at Black Lake (e.g. Crossman, Forsythe, Scribner, & Baker, 2011). Most stocked year classes have been tagged with coded wire tags (CWT), where the anatomical location of tagging varied among years to provide a year-class specific mark.

We attempted to quantify the numbers of stocked fish by year class using a gillnet survey in Black Lake. Our objectives for the survey were to (i) estimate year-class specific abundance of juvenile lake sturgeon in Black Lake; and (ii) determine year-class specific survival of stocked year classes and whether year-class-specific first year survival was related to size at stocking.

2 | MATERIALS AND METHODS

2.1 | Study area

This study was conducted in Black Lake, Michigan, USA (Figure 1). Black Lake is a 4,100 ha lake in the Cheboygan River watershed that supports a remnant population of approximately 1,100 adult lake sturgeon (Pledger, Baker, & Scribner, 2013). Black Lake is an ideal location to conduct evaluations of stocked lake sturgeon because the lake is isolated from water bodies supporting other populations by dams, and because the lake is small enough to be easily sampled. For a detailed description of Black Lake and the lake sturgeon

TABLE 1 Total number of lake sturgeon *Acipenser fulvescens* stocked in Black Lake, Michigan (USA) by year since 2001, mean size at stocking (cm TL, range in parentheses), year-class specific tag if present, year-class specific abundance estimated in 2013 (95% confidence interval (CI) in parentheses), and estimated first-year % survival of stocked lake sturgeon from the 2001–2009 year classes

Year class	Number stocked	Mean size at stocking (cm TL, range in parentheses)	Marks/tags	Estimated abundance in 2013 (95% CI in parentheses)	Estimated first-year survival (%)
2001	890	14.7 (12.1–26.1)	CWT, snout	154 (34–274)	30
2002	23	30.5 (29.3–39.0)	None	174 (45–303)	[a]
2003	2,878	22.1 (15.7–31.4)	CWT, snout	1531 (1193–1869)	84
2004	0			150 (32–268)	
2005	7,533	8.4 (5.4–19.8)	None	249 (−139 to 637)	5
2006	4,188	16.0 (5.6–22.0)	CWT, dorsal anterior scute	1712 (1360–2064)	56
2007	1,000	15.7 (7.1–24.4)	CWT, dorsal posterior scute	1005 (717–1293)	130
2008	0			23 (−125 to 171)	
2009	1,520	15.5 ([b])	CWT, dorsal anterior scute	541 (321–761)	42
2010	3,250	12.2 (8.5–18.0)	CWT, snout	167	[a]
2011	2,604	9.9 (4.9–15.4)	CWT, dorsal posterior scute	24	[a]
2012	3,261	11.7 (7.5–16.7)	CWT, dorsal anterior scute		[a]
2013	3,250	10.7 (6.5–14.8)	CWT, snout		[a]

[a]Survival not calculated.
[b]Min and max data not available.

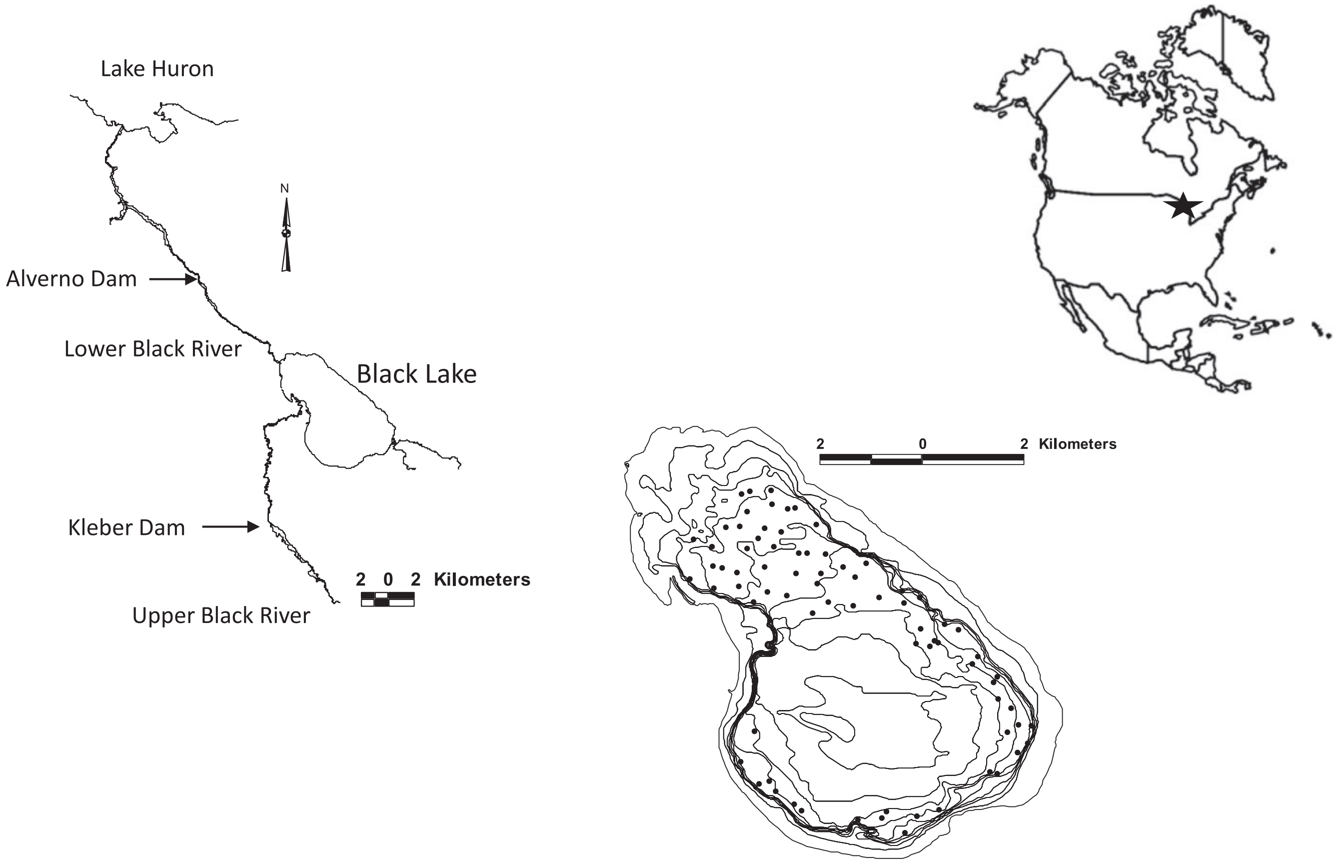

FIGURE 1 Maps showing location of Black Lake watershed, Michigan (USA), detail of Black Lake watershed, and detail of Black Lake with depth contours (1.65 m). Dots on Black Lake detail map indicate where nets were set during 2013 gillnet survey

population therein see Baker and Borgeson (1999) and Smith and Baker (2005).

2.2 | Survey methods

We fished 15 and 20 cm stretch mesh gillnets to capture juvenile lake sturgeon in Black Lake. The survey involved 12 days of effort over the period 12–29 August 2013. Each day of survey effort consisted of three boat crews setting and retrieving gillnets. Each crew set two net gangs daily with each gang consisting of one 15 cm stretch mesh net 182 m × 3.7 m tied to one 20 cm stretch mesh net 182 m × 3.7 m. Crews set nets in the morning, typically by 9:00 hr, and retrieved nets in the afternoon, usually by 16:00 hr. During the day nets were checked every 1–1.5 hr. Captured fish were removed and placed in large live wells for processing after the entire net was checked. To minimize same-day recaptures, boats moved several hundred meters away from the nets before processing and releasing fish.

Sampling sites throughout Black Lake were selected randomly using the R package 'SPSurvey', version 2.1 (http://cran.r-project.org/web/packages/spsurvey). Shallow sites were eliminated as were sites in depths below the thermocline (~11 m) given anoxic conditions. A total of 72 randomly selected sites were fished over the 12 survey days. Captured fish were measured for total length (TL) and fork length (FL) (cm), scanned for the presence and location of CWT and PIT tagged prior to release. When a CWT was detected, the tag location and size of the fish were used to assign fish to a particular cohort. In addition, we removed a small (~2 cm) segment of pectoral fin ray from the proximal end of one (left or right) of the leading pectoral fin ray as close to the articulation as possible to determine age for fish that did not have a detected CWT. Because fish were released immediately following collection of biological data and fin ray collection we did not anesthetize the fish during handling. Fin ray samples were sectioned and age was assigned using previously published methods (Rossiter, Noakes, & Beamish, 1995), except that we did not embed fin rays in epoxy prior to sectioning. Age was determined by two independent readers without knowledge of fish size.

2.3 | Data analysis

Abundance of juvenile lake sturgeon in the length range vulnerable to the gear fished was calculated using the Schnabel multiple-mark multiple-recapture estimator (Ricker, 1975):

$$N = \frac{\sum (C_i \times M_i)}{R+1} \quad (1)$$

where N is the estimated abundance, C_i is the number of fish captured on day i, M_i is the total number of marked fish at large prior to day i, and R is the total number of fish recaptured during the survey. Fish were not added to the pool of marked fish at-large until the day following initial capture and tagging. The 95% confidence interval of the juvenile abundance estimate was calculated by treating R as a Poisson variable and substituting the Poisson values for R in equation (1).

Year-class specific abundance was estimated using an age-length key (Ricker, 1975) and apportioning total juvenile abundance among year classes. The age-length key was constructed from ages determined either from the presence and location of a CWT or from age assigned from examination of pectoral fin ray cross section. Fin ray cross-section age for a particular fish was used only when the two independent readers agreed on the age. We calculated 95% confidence intervals (CIs) for the year-class specific abundance estimates using the method outlined in Baker and Borgeson (1999). Assumptions were made to determine year-class specific first-year survival. First, we assumed that natural recruitment in Black Lake was zero during the period in question. This assumption is supported by previously published work in Black Lake (Baker & Borgeson, 1999) and recent surveys for age-0 fish where capture had failed (data not shown). Second, we assumed annual survival for ages 1 and older lake sturgeon in Black Lake as 95%. This value was based on estimated annual survival rates for adults in Black Lake of 98% (Pledger et al., 2013) based on multiple mark-recapture data spanning years 2001–2015. In addition, annual survival calculated for juvenile Menominee River lake sturgeon ranges from 95% to 99% based on multiple mark-recapture data spanning years 2000–2014 (Michigan and Wisconsin DNRs, unpublished data).

To determine year-class specific first year survival we first estimated year-class specific abundance at age-1 for each stocked year class. Year-class specific abundance at age-1 was estimated by sequentially back-calculating abundance-at-age X-1 using an assumed annual survival rate of 0.95 for ages 1+ and dividing estimated abundance in year X by 0.95. For example, to determine abundance at age 1 for the 2001 stocked year class we divided the 2001 year-class abundance estimated in 2013 by 0.95 to yield an estimated abundance in 2012, etc. to ultimately arrive at year-class abundance at age-1. Then, we divided abundance at age-1 by the number of fish stocked for that year class to estimate year-class specific first-year survival. Confidence intervals (95%) for survival estimates were calculated as ± 2× the *SE* of the survival estimate.

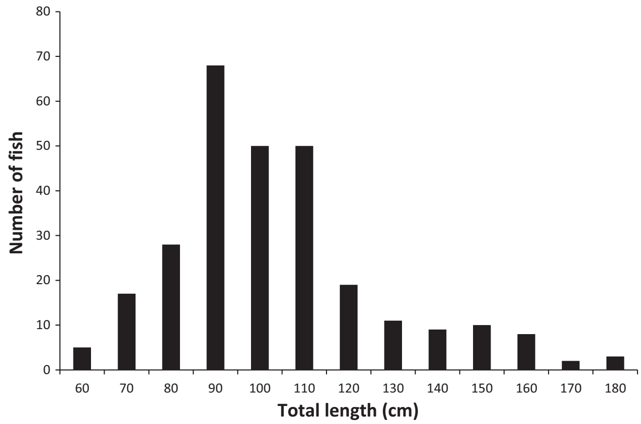

FIGURE 2 Length-frequency distribution of 283 lake sturgeon, *Acipenser fulvescens*, captured during 2013 gillnet survey of Black Lake, MI (USA)

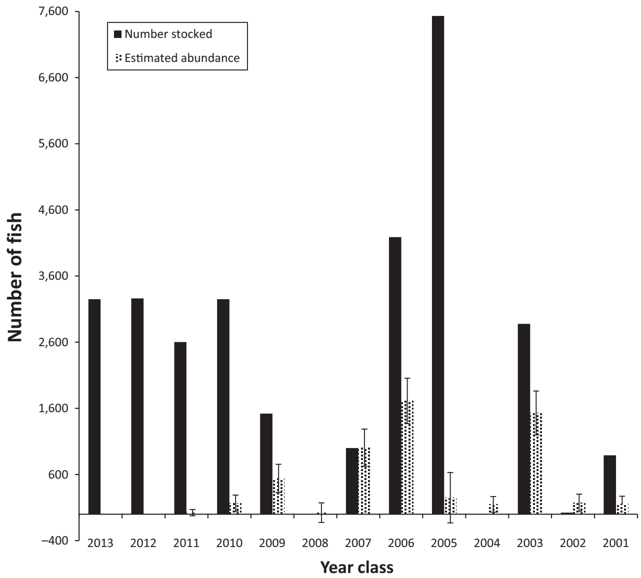

FIGURE 3 Number of lake sturgeon, *Acipenser fulvescens*, stocked and 2013 estimated abundance (error bars = 95% confidence intervals) for 2001–2011 year classes of age-0 lake sturgeon stocked in Black Lake, Michigan (USA). Fish in the 2010–2013 year classes were too small to be fully vulnerable to capture by gillnets

3 | RESULTS

We captured 283 unique individual *Acipenser fulvescens* ranging from 57 to 186 cm TL (Figure 2). The upper end of the juvenile length class was established at 133 cm, given the largest size fish with a CWT. Using this criteria, 252 unique juvenile lake sturgeons were captured (133 cm or fewer) during the survey, with five recaptures. Estimated juvenile abundance was 6,114 (95% CI 3,135–22,926).

Age was determined for 108 juvenile lake sturgeon based on the presence and location of a CWT. Age was determined for an additional 78 fish from examination of fin ray cross sections. We confirmed that most juveniles in Black Lake were from stocked year classes by apportioning total estimated juvenile lake sturgeon abundance to year-class specific abundance using the age-length key (Table 1, Figure 3). We then examined the year-class specific length frequency distribution of the catch and determined the 2009 year class to be the youngest that was fully vulnerable to the survey gillnets. The length range of the 2009 year class was from 58 cm TL to 79 cm TL, with a mean length of 70 cm. Only five fish were captured from the 2010–2013 year class, all <62 cm TL. Both the 15 and 20 cm meshes used in this survey captured fish as small as 58 cm TL. Therefore, juvenile abundance and survival were only estimated for the 2001–2009 year classes.

Survival from year of stocking to 2013 ranged from 3% to 53% among the stocked year-classes sampled. First-year survival estimates

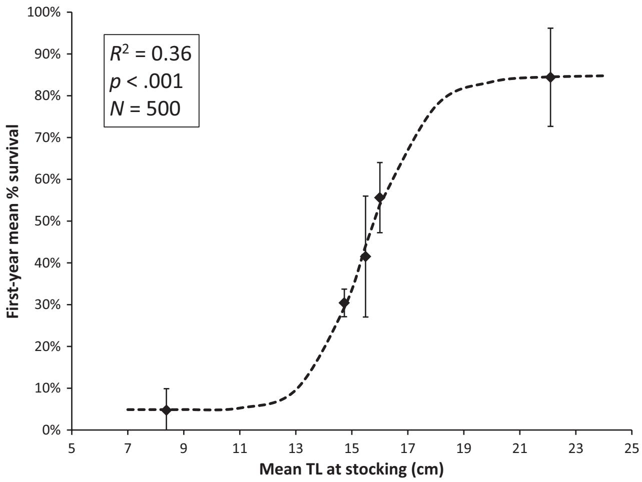

FIGURE 4 Estimated first-year mean % survival for age-0 lake sturgeon, *Acipenser fulvescens*, stocked in Black Lake, Michigan (USA) as a function of average fish size (TL, cm) at stocking (does not include estimate for 2007 year class). Error bars = 95% confidence intervals of the mean % survival

across year classes were highly variable (Table 1). The highest first-year survival estimate was for the 2007 year-class. The estimated abundance at age-1 was actually greater than the number stocked and resulted in a first-year survival estimate of 130%. The lowest first-year survival estimate (5%) was for the 2005 year-class. A plot of first-year survival against average fish TL (cm) at time of stocking suggests first-year survival is dependent on fish length at stocking (Figure 4, not including the 2007 year-class). Estimated first-year survival was low (5%) for lake sturgeon stocked at an average TL less than 9 cm, increased with average stocking size from 15 to 17 cm TL, and was highest when fish were stocked at an average TL of 22 cm (84%).

4 | DISCUSSION

Post-stocking survival has been shown to be positively associated with size at stocking for a number of fish species (e.g. Storck & Newman, 1988; Hyvarinen & Vehanen, 2004), including white sturgeon (*Acipenser transmontanus*, Ireland et al., 2002; Justice et al., 2009) and pallid sturgeon (*Scaphirhynchus albus*, Steffensen, Powell, Stukel, Winders, & Doyle, 2016), which corroborates our study for lake sturgeon. However, our study results differ from those for other sturgeon species because we stocked only age-0 fish. Other stocked sturgeon species have been evaluated for post-stocking survival of fish stocked as age-0, yearling, and older fish. First-year survival rate for white sturgeon stocked at age-1 in the Kootenai River was estimated to be 60% and approached 100% after the first year (Ireland et al., 2002). Justice et al. (2009) found that post-stocking survival for white sturgeon stocked in the Kootenai River was also density- and size-dependent and ranged from 45% for age-1 fish to near 100% for age-3 fish. Survival of stocked pallid sturgeon in the lower Missouri River (USA) was 5% for age-0, 40% for age-1 and 93% for age-2 (Steffensen et al., 2016). The average size of stocked pallid sturgeon was 23.2 cm at age-0 and 26.6 cm at age-1 (no size data were reported for fish stocked at age-2 and older). These studies are consistent with our results that show post-stocking survival of lake sturgeon is positively related to size at stocking. Our results also indicate over-winter survival of stocked young-of-the-year lake sturgeon is likely higher than previously determined. Lake sturgeon overwinter survival was determined to be at least 40% (Crossman, Forsythe, Baker, & Scribner, 2009) but transmitter failure and emigration of tagged fish may have resulted in under-estimation of true survival. Based on our results, post-stocking survival of YOY lake sturgeon is ~0.60 if fish are raised to a minimum size of 16 cm before stocking, and first-year survival increases to ~80% when fish are ≥20 cm when stocked.

One likely source of error in our analysis of year-class specific survival and abundance is aging error (Bruch, Campana, Davis-Foust, Hansen, & Janssen, 2009). Errors in fish age determination can affect the accuracy of survival estimates, year-class specific abundance, etc. (Campana, 2001). The use of CWTs for stocked fish in Black Lake helped minimize but not eliminate aging error because we had to rely on fin ray cross-sections for untagged fish (2002 and 2005 stocked year classes were not tagged with CWTs). In addition, prior work on stocked lake sturgeon has shown that CWT detection rates are not 100%. Lake sturgeons have been stocked in Burt and Mullett lakes, west of Black Lake in Cheboygan County, MI (USA) since 2003. Neither lake supports natural reproduction of lake sturgeon, and surveys in these lakes in 2010–2011 (Michigan Department of Natural Resources unpublished data) resulted in a CWT detection rate of 70% for fish known to be stocked (tagged). Our CWT detection rate for the juvenile lake sturgeon in Black Lake (51%) was lower, but was expected considering that two stocked year-classes in Black Lake were not tagged. We sought to minimize aging error by only using age data from fin ray cross-sections when two independent readers were in agreement. However, it is still likely that some aging errors influenced our results. Evidence for aging error includes the fact that estimated abundance of non-stocked year classes [2008, 2004, 2002 (only 23 fish stocked in 2002)] increased with age. This result is expected because aging error (variability) typically increases with fish age for many species, including lake sturgeon (Bruch et al., 2009), and underestimation of the true age of fish from structures like otoliths, scales and fin rays is the most common source of error (Campana, 2001). Furthermore, estimated abundance for the 2007 stocked year-class exceeded the number of fish stocked. This is also likely the result of aging error because we have not found evidence of significant natural recruitment in Black Lake. It is also possible that our assumed annual survival rate (95%) for fish older than age-1 was too high, which would lead to over-estimating abundance at age 1. Finally, although we believe it is unlikely, natural recruitment may also explain the small numbers of fish estimated for non-stocked year-classes and the estimated abundance for the 2007 year-class exceeding the number stocked.

Stocking is increasingly used to rehabilitate and restore lake sturgeon populations throughout the species native range. Our results are the first to document the importance of size-at-release on subsequent survival for stocked lake sturgeon. Our findings can help in the refinement and design of restoration stocking efforts for the species.

A benefit of releasing *Acipenser fulvescens* with high first-year survival is the number of fish that need to be reared and released annually can be relatively low, depending on management goals. Releasing just a few hundred fish annually over the course of a lake sturgeon generation (20–25 years) may be sufficient to restore or repatriate self-sustaining populations. Raising fewer *A. fulvescens* in SRFs or traditional hatchery environments may result in reduced operational costs (e.g. fish food) as well as lower densities in rearing tanks. Reduced rearing densities would likely lead to faster growth (Fajfer, Meyers, Willman, Carpenter, & Hansen, 1999; Bauman, Baker, Marsh, & Scribner, 2016) and larger fish size at stocking with correspondingly higher post-stocking survival.

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