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Overwinter survival of stocked age-0 lake sturgeon

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Summary

Knowledge of age-specific survivorship is critical when developing management prescriptions for imperiled species such as the lake sturgeon (*Acipenser fulvescens*). Management has focused on population restoration through hatchery supplementation, largely in the absence of data about relationships between hatchery rearing conditions, size/age at release, and estimates of overwinter survival for stocked age-0 lake sturgeon. Young of the year lake sturgeon were reared from egg to age 3 months in two separate hatchery environments: a streamside hatchery on the natal Upper Black River, Michigan, and a traditional hatchery environment. From age 3 to 6 months all fish were reared in the traditional hatchery. Fish (n = 20) originating from each rearing environment were surgically implanted with ultrasonic transmitters at 6 months of age (mean total length: 31.4 cm; mean weight: 106.4 g) and released into Black Lake in December 2005. Tracking using manual and automated hydrophones was conducted during April and May 2006 to estimate overwinter survival and to test for differences in survival of fish reared in different hatchery environments. Eighteen fish (45%) were detected, 16 (40%) of which survived the winter (range of distance traveled between observations of surviving fish was 0.09–0.55 km). The remaining fish were not detected. No significant differences in survival were documented due to rearing environment or size at release. This study represents the first quantified estimate of overwinter survival for stocked age-0 lake sturgeon. The minimum estimate of 40% survival through the first winter is encouraging for hatchery programs, and will aid in the development of management prescriptions for this species.

Introduction

Survival through the first winter of life is a critical determinant of year class strength (Oliver et al., 1979). However, quantified estimates of overwinter mortality are lacking for many species. Survival throughout early life history stages, including the first winter of life, is mediated by a number of selective processes that operate as fish experience high rates of size-dependent mortality due to both predation and energy depletion (Miller et al., 1988). Physiological changes (e.g. metabolic rates, hematological parameters) during winter decrease body condition and deplete energy reserves, although the magnitude of effects differ among individuals from the same cohort (Cunjak, 1988). Overwinter energy reserves are highly correlated with the length of the growing season, which is reduced for temperate species (Post and Parkinson, 2001). Furthermore, fish produced later in the reproductive season are constrained by a shortened growing season that can decrease probabilities of overwinter survival (Biro et al., 2003). Knowledge of age-specific survivorship through the critical first winter is particularly important to quantify as a measure of the success of hatchery programs, which are increasingly used as a part of recovery programs for imperiled species.

Populations of lake sturgeon (*Acipenser fulvescens*), a native fish of the Great Lakes, have been numerically depressed throughout their range due to anthropogenic factors and are believed to be at <1% of historical numbers (Hay-Chmielewski and Whelan, 1997). Restoration activities largely focus on hatchery supplementation (Holey et al., 2000) by necessity due to the small size of remnant populations. However, few data are available on the effectiveness of hatchery programs. Recently, increased attention has been focused on the use of streamside hatcheries (Holtgren et al., 2007) as a restoration tool. Streamside hatcheries use water from streams targeted for release, potentially reducing the degree of domestication and increasing the likelihood of imprinting. Assessing the overall impact of stocking juveniles reared in streamside versus traditional hatchery environments is important to project the effects of supplementation on long-term population abundance. This assessment is complicated by the species' unique life history characteristics (e.g. delayed sexual maturity), and inefficient collection methods for young age classes (Benson et al., 2005a). Low sampling efficiency affects accuracies of survival estimates, which impedes evaluations of post-release survival of juveniles reared in different hatchery environments. Most lake sturgeon culture and stocking efforts in the Great Lakes have reared fish to autumn fingerling size (>20 cm) under the assumption that larger fish survive better following release into the natural environment (Schram et al., 1999). No quantitative data are available on age-specific lake sturgeon survival, including survival through the first winter.

Ultrasonic telemetry is a valuable fisheries technique used to estimate parameters such as mortality, distance traveled, and range size (Flavelle et al., 2002; Taverny et al., 2002; Zamora and Moreno-Amich, 2002). Despite limitations (e.g. sample size, battery life, and handling-induced mortality), telemetry allows the collection of multiple observations from a single individual, which is an advantage over passive capture techniques such as gillnetting (Zamora and Moreno-Amich, 2002). Recent advancements in telemetry technology, particularly the decreasing size of the transmitter, have increased opportunities to study species over a greater range of ages. This is especially important for studies interested in assessing the survival of fish released during the first year of life. Telemetry studies on sturgeon have generally been conducted in the spring and summer (Hay-Chmielewski, 1987; Holtgren and Auer, 2004; Smith and King, 2005). Research through the winter has described overwinter movement patterns and

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identified habitats that serve as both important nursery grounds for subadults and staging areas for adults (Quist et al., 1999; Sulak and Clugston, 1999; Li et al., 2007).

There is a critical need for determining over-winter survival of age-0 sturgeon. Our overall goal was to provide estimates of overwinter survival. Our specific objectives were to: (i) estimate overwinter survival of hatchery-reared juvenile lake sturgeon released at a traditional (autumn fingerling) age; (ii) determine differences in survival between juvenile lake sturgeon reared in two different hatchery environments, a streamside hatchery on the natal river and a traditional non-natal hatchery environment. This study provides both the first quantitative estimate of overwinter survival and the first attempt at assessing the effects of hatchery-rearing environment on overwinter survival for juvenile lake sturgeon.

Study site

Juvenile lake sturgeon used in this study were produced from gametes collected from a population located in Black Lake, Michigan (See Smith and King, 2005 for site description). Black Lake encompasses approximately 4000 hectares. Black River, the primary habitable tributary to Black Lake provides spawning habitat for adults and nursery habitat for juveniles. The population of lake sturgeon is closed to immigration by dams.

Methods

Rearing environment

Twenty juvenile lake sturgeon were reared from eggs to 3 months of age in each of two environments, a streamside hatchery using water from the natal Upper Black River, and a traditional hatchery [The Michigan Department of Natural Resources (MDNR) Wolf Lake hatchery] using a non-natal (ground water) source. Rearing conditions and feeding regimes were consistent between the two hatcheries. Fish were reared in circular fiberglass tanks (1.22 m in diameter; 500 L) with a flow rate that resulted in two total water turnovers every hour. Fish were initially fed live brine shrimp nauplii in 200 ml aliquots once every 2 h from dawn (0700) until dusk (2100). Juvenile lake sturgeon were transitioned from brine shrimp nauplii onto live cultured blackworms (tubificid annelids; J.F. Enterprises, CA) starting at day 21 following hatch. Blackworms were fed for approximately 1 week prior to the start of feeding frozen bloodworms (chironomid midge larvae). A 1 kg sheet of frozen bloodworms was fed per day, spread out over several feedings; the amount was increased by approximately 0.5 kg every 2 weeks for the duration of rearing.

Water temperature at the streamside hatchery mimicked temperature of the Upper Black River while water temperature at the traditional hatchery was variable until early June and then maintained at a constant temperature above 20°C for the duration of rearing (Fig. 1). Boiler malfunctions at the traditional hatchery resulted in several temporary temperature fluctuations (Fig. 1). When juvenile lake sturgeon reached 3 months of age all individuals being reared at the streamside hatchery were transported to the traditional hatchery, a distance of 472 km, and further reared for an additional 3 months. Because the streamside hatchery could not be operated during the autumn, fish were relocated from the streamside hatchery to the traditional hatchery to increase growth by using warmer water, available only at the traditional hatchery, to a size that would allow insertion of the ultrasonic transmitters. Feeding was temporarily suspended the day prior to transfer to the traditional hatchery. Juvenile lake sturgeon were transported in an insulated aerated stocking trailer (volume: 1000 L) maintained at ambient streamside hatchery temperature. The temperature at the streamside hatchery at the time of transport was within one degree of the traditional hatchery. Fish were acclimated over a 1-h period upon arrival at the traditional hatchery by slowly pouring buckets of water from the traditional hatchery into the stocking trailer. No mortality occurred during the transport. Regular feeding levels were resumed the following day.

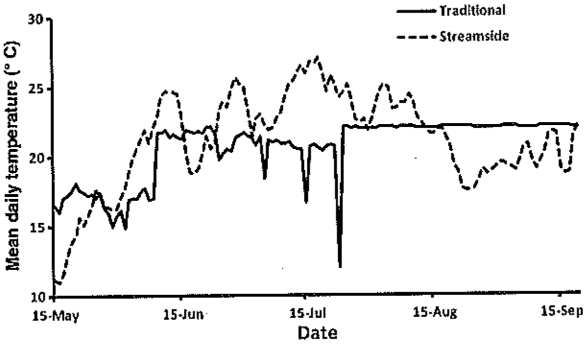

Fig. 1. Mean daily temperature at two hatchery environments (Traditional and Streamside) used to rear juvenile lake sturgeon (*Acipenser fulvescens*) in 2005

Transmitter implantation and monitoring

Juvenile lake sturgeon were surgically implanted with small coded ultrasonic transmitters; 1.7 ± 0.01 cm (mean ± 1 SE) in length and 0.7 ± 0.001 cm in diameter with a mass of 1.95 ± 0.01 g in water (Vemco, model V7, Nova Scotia, Canada). Sonic transmitters were set at an operating frequency of 69 kHz and programmed to emit a coded pulse randomly between 40 and 120 s. Prior to surgery, streamside hatchery fish were mean ± SE 31.1 ± 0.3 cm total length (TL) and 106.4 ± 2.6 g weight (W). Traditional hatchery fish were 31.5 ± 0.34 cm TL and 106.4 ± 3.3 g W. All surgeries were conducted between 8 and 12 December 2005. Fish were not fed 24 h prior to surgery. Holding tank temperatures were slowly reduced to 10°C over a 3-day period prior to the surgeries. The weight of the transmitter did not exceed 2% of the fish weight, well within the generally accepted 2% rule (Winter, 1996). Fish were anesthetized using tricaine methane sulfonate (MS222; 125 mg L^{-1}; Summerfelt and Smith, 1990) in an aerated container prior to surgery. Sedation was maintained with a constant dose of MS222 (50 mg L^{-1}) recirculating through a portable surgical table (LaVigne, 2002). Temperature was maintained at 10°C throughout all surgeries. Transmitters were anchored to the wall of the peritoneal cavity using non-absorbable sutures to reduce movements of the transmitter in the body cavity. Incisions were closed using 3–0 gauge non-absorbable monofilament nylon sutures (Ethicon) in an interrupted pattern. Ovadine antiseptic was applied to the wound to promote rapid healing. Following surgery, fish were monitored for a 3-day period for complications from the surgical procedure.

On 16 December 2005 juvenile lake sturgeon were returned 472 km to the release site in the same aerated stocking trailer used to transport the streamside fish to the traditional hatchery. Fish were acclimated from the transport trailer temperature (10°C) to Black Lake temperatures (3°C) by slowly pouring in buckets of lake water over 2.5 h. Juvenile lake sturgeon were transferred to the lake submersed in buckets to ensure that the gill filaments were not exposed to freezing air temperatures. Fish were held in a net pen set in shallow water, monitored, and acclimated for a 3-h period prior to release into Black Lake.

Manual tracking conducted on successive days followed transects that spanned the length and breadth of the lake. Tracking was also conducted upstream and downstream of Black Lake in the Black River. When possible, tracking was conducted for two successive days on a weekly schedule. Tracking was conducted from 15 April to 1 June 2006. Movements of sonically tagged fish were monitored from a boat using a Vemco receiver (Model VR100) equipped with both omni-directional (VH65) and directional (V10) hydrophones. The directional hydrophone had a horizontal beam width of 22 degrees and a vertical beam width of 150 degrees. Transmitters had a potential detection range of 1 km. Hydrophones were deployed every 500 m on calm days and every 250 m or less during days with moderate waves. Recorded positions of detected fish were made using a handheld WAAS enabled GPS receiver and bearings were taken using a magnetic compass adjusted to obtain true magnetic north. Fish locations were triangulated with a minimum of three geographic points. Three automated hydrophone receivers (Vemco, Model VR2) were strategically placed within Black Lake to detect movement between distinct zones. Collected positioning data were managed and analyzed using geographic information system (GIS) software (ESRI, ARCMAP v. 8.3). GIS data were managed in the form of Universal Transverse Mercator (UTM) units. Water temperature was monitored near the release site for the duration of the observational period at 1-h intervals using an Onset HOBO Pro underwater temperature logger (Onset Computer Corp., Bourne, MA).

Data analysis

Juvenile lake sturgeon locations were calculated using the bearing angle and the GPS coordinates from that observation using the telemetry software Locate II (Nams, 2001), which uses the method of least squares to estimate the error associated with the predicted location. Juvenile lake sturgeon that exhibited active movement patterns after ice cover breakup were assumed to have survived. Average inter-observational distance traveled between tracking events was calculated for each individual as further evidence of survival. This was calculated by taking straight-line measurements between successive detection points. We also calculated the inter-observational distance of each individual from the release site by taking straight-line measurements to each detection point from the release location. A chi-square test was used to determine significance of differences in survival attributed to rearing location. We determined how survival varied as a function of the independent variables, length and weight, using a logistic regression. A t-test was used to examine differences in the size at stocking for juvenile lake sturgeon between the two hatchery environments and to test for differences between hatchery environments in distance travelled.

Results

There were no significant differences in length or weight of juvenile lake sturgeon prior to release between hatchery rearing environments (TL: d.f. = 19, t = 0.42, P = 0.68; Weight: d.f. = 19, t = −0.29, P = 0.78). Sixteen juvenile lake sturgeon were detected and determined to be actively moving during the period of observation (Table 1). This corresponds to a minimum survival of 40%. Seven of these individuals were reared at the streamside hatchery environment and nine individuals were reared in the traditional hatchery environment. A chi-square test revealed no significant difference in the number of fish surviving between the two rearing environments (d.f. = 1, χ^2 = 0.25, P = 0.62). Of the remaining 24 fish released, only two other fish were located but assumed to be

Table 1
Number of observations (Obs), average inter-observational distance traveled (Mean ± 1 SD), and average inter-observational distance (Mean ± 1 SD) traveled from release site for juvenile lake sturgeon (*Acipenser fulvescens*) surgically implanted with ultrasonic transmitters and released into Black Lake, Michigan, December 2005

ID	Loc	TL (cm)	W (g)	Obs	Distance travelled (Km)	Distance from release site (Km)
36	S	28.6	102.1	4	0.46 ± 0.03	0.12 ± 0.01
42	S	29.2	93.1	5	0.11 ± 0.01	0.03
44	S	29.2	92.9	6	0.08 ± 0.01	0.04 ± 0.01
49	S	31.8	101.8	3	0.14 ± 0.10	0.08 ± 0.02
50	S	33.7	118.6	4	0.21 ± 0.05	0.03 ± 0.01
55	S	28.8	90.0	2	0.16 ± 0.02	0.06 ± 0.03
56	S	31.8	112.6	7	0.10 ± 0.10	0.13 ± 0.01
Mean ± SE		30.4 ± 0.7	101.6 ± 4.1	4.43	0.18 ± 0.05	0.07 ± 0.02
22	T	31.4	110.5	8	0.04 ± 0.02	0.1 ± 0.02
24	T	30.3	101.6	4	0.55 ± 0.15	0.05 ± 0.01
27	T	32.4	116.9	3	0.14 ± 0.04	0.06 ± 0.01
28	T	30.8	99.1	5	0.09 ± 0.03	0.09 ± 0.01
29	T	29.2	94.6	4	0.25 ± 0.11	0.11 ± 0.02
30	T	30.5	97.7	2	0.17 ± 0.08	0.07 ± 0.04
31	T	30.6	103.0	5	0.10 ± 0.05	0.07 ± 0.02
51	T	31.6	105.0	6	0.32 ± 0.10	0.09 ± 0.03
52	T	33.0	126.6	3	0.12 ± 0.04	0.11 ± 0.01
Mean ± SE		31.1 ± 0.4	106.1 ± 3.4	4.44	0.20 ± 0.05	0.08 ± 0.01

Manual tracking conducted 15 April–1 June 2006. Data presented for individuals determined to have survived the winter. Other characteristics include: individual fish ID number, hatchery rearing location (Loc: S, streamside; T, traditional), total length (TL) and weight (W).

dead after several consecutive tracking excursions identified them to be in the same location. Locations were close to the release site and a stationary automated receiver recorded these individuals over an extended time period. All detected and surviving individuals remained within 1 km of the release location (Table 1) until the end of May 2006. Manual tracking and automated receivers documented a number of fish moving extensively within this zone. There was no significant difference in inter-observational distance traveled between fish from the different hatchery environments (d.f. = 14, $t = -0.24$, $P = 0.81$) or in inter-observational distance from the release site (d.f. = 14, $t = -0.96$, $P = 0.351$). Average distance traveled between detection events was 0.19 ± 0.14 km (Table 1). Water temperatures ranged between 1.4 and 22.3°C (mean ± SE, 14.4 ± 0.5°C) during the observational period. Juvenile lake sturgeon survival was not significantly associated with either total length (Residual Deviance = 50.4, d.f. = 38, $P = 0.08$) or weight (Residual Deviance = 52.4, d.f. = 38, $P = 0.25$).

Discussion

Our quantitative estimate of overwinter survival is the first recorded for hatchery-reared juvenile lake sturgeon. Our study was not exhaustive and the estimate presented (40%) should be considered as a minimum value of survival. This result is encouraging considering the number of deleterious factors associated with long-term hatchery rearing, including elevated levels of domestication (Huntingford, 2004). Our survival estimate for age-0 lake sturgeon is comparable to estimates produced for other non-Acipenseriform species. For example, Biro et al. (2004) estimated overwinter survival for age-0 rainbow trout (*Oncorhynchus mykiss*) stocked into two different lakes to be 27 and 33%, respectively. Overwinter survival of wild juvenile coho salmon (*Oncorhynchus kisutch*) has been documented as high as 46% (Quinn and Peterson, 1996) and monthly survival estimates for largemouth bass (*Micropterus salmoides*) have been found to be as high as 54% during the winter months (Miranda and Hubbard, 1994). Finally, Jonas et al. (1996) found that survival of autumn stocked muskellunge (*Esox masquinongy*) was low (2.3%) and attributed the results to a significant loss in energy reserves through the winter.

Greater stored energy reserves of larger age-0 individuals of some fish species increase probabilities of over-winter survival relative to smaller individuals (Shuter et al., 1980; Miranda and Muncy, 1987). We did not document a significant difference in the sizes of fish detected versus not detected in our study. However, our estimates of survival of hatchery stocked fish might be inflated because hatchery fish are generally larger and in better condition than their wild counterparts due to a longer hatchery growing season. Hatchery-reared juvenile lake sturgeon in our study were approximately 31.23 cm TL and 106.41 g in wet weight at the time of release in early December. Wild juvenile lake sturgeon captured in the autumn months as late as November in the Peshtigo River, Wisconsin, were as large as 31.6 cm TL and weighed as much as 134 g (Benson et al., 2005b), indicating that sizes of wild fish are comparable, if not larger than hatchery produced fish. Even though hatcheries provide progeny for stocking that are of good condition at the time of release, tradeoffs in elevated levels of domestication and reduced foraging ability might reduce probabilities of survival if monitored over a longer period.

Juvenile lake sturgeon maintained activity throughout the observational period; however, individuals remained within a very small area close to the release location. Smith and King (2005) found that yearling sturgeon in Black Lake had individual areas of activity that were likely associated with preferred habitats. Restricted movements have also been documented by Fox et al. (2002), who found that Gulf sturgeon (*Acipenser oxyrinchus desotoi*) remained in localized areas for extended periods before rapidly dispersing due to competition, food, or physical parameters. Taverny et al. (2002) also documented similar restricted movement behaviors when tracking juvenile European sturgeon (*Acipenser sturio*). Juvenile lake sturgeon in our study could have preferred habitats adjacent to the river mouth because of potentially higher productivity (e.g. ice free earlier). Furthermore, dispersal following release in December might not have been very high as colder water temperatures reduced activity.

We failed to detect 55% of released fish. This could be attributed to equipment failure associated with the ultrasonic transmitters. Or fish could have passed the hydroelectric dam on the outlet from Black Lake in the Lower Black River; survival rates of fish attempting this is unknown, but if there is a natural propensity to disperse downstream to more productive feeding areas then this could have occurred. We did not survey downstream of the dam on the Lower Black River or in adjoining Lake Huron. Additional automated receivers below the hydroelectric dam would be important for future movement studies in this system to determine if fish can survive downstream passage through the facility. Mortality due to predation is likely and has been noted with other hatchery-stocked fish (Olla et al., 1998). However, transmitters should have been identified either within the predator itself or on the substrate after expulsion. Furthermore, if fish died near the release location at the mouth of the river the transmitter could become buried in sediment exiting the Upper Black River and rendering the signal undetectable; this was unlikely because the signal strength should penetrate through moderate amounts of bottom substrate (Vemco, personal communication). Lack of significant differences in survival between fish reared in different hatchery environments could be attributed to several factors. First, streamside reared fish were transported and kept at the traditional hatchery for approximately 3 months. Retention of fish in traditional rearing conditions lacking fluctuating temperature regimes and natural river odors may have diminished any potential fitness advantage incurred at the streamside hatchery. Secondly, data collected by Crossman (2008) suggests that the effects of different hatchery rearing environments have a size/age threshold beyond which the effects of hatchery environment may not be important. Our results support and extend this finding.

Streamside hatcheries are emerging as a valuable tool to potentially reduce the degree of domestication selection and increase the likelihood of imprinting to natal streams where lake sturgeon restoration is occurring. Unfortunately, there is still relative uncertainty regarding the mechanism (or life stage) by which imprinting occurs in sturgeon. Our ability to infer on movements post-release with respect to imprinting on the natal stream is confounded because we reared the fish together for the final 3 months in a non-natal water source. Future studies would benefit from rearing juvenile sturgeon entirely separately and then focusing efforts on a more detailed monitoring program following release. A longer monitoring period would provide an opportunity to determine if seasonal movement differences could be attributable to hatchery origin.

In conclusion, our minimum estimate of over-winter survival (40%) is important for designing restoration programs. Survival of juveniles past the young-of-the-year stage is high and similar to adult stages (Gross et al., 2002). It is generally accepted that mortality rates of young-of-the-year sturgeon are high (Nilo et al., 1997), with the young-of-the-year age class having the strongest effect on overall population growth (Gross et al., 2002). Hatchery restoration programs have the ability to target these early age classes in an attempt to increase survival and augment population abundance. Hatchery rearing environment did not affect survival probabilities of age-0 lake sturgeon. However, further research is needed in identifying the contribution of hatchery-reared sturgeon to population growth. Finally, future studies aimed at identifying overwinter survival of wild or hatchery-reared juvenile lake sturgeon should incorporate finer scale monitoring immediately following release and assessments should continue for as long as possible thereafter.

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