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Biological attributes of age-0 lake sturgeon in the lower Peshtigo River, Wisconsin

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Summary

Lake sturgeon *Acipenser fulvescens* are imperiled throughout the Laurentian Great Lakes basin. Efforts to restore this species to former population levels have been ineffective due in part to limited information regarding its early life history. The objectives of this study were to characterize the larval drift and biological attributes of age-0 lake sturgeon in the lower Peshtigo River, Wisconsin. Lake sturgeon larvae were captured from May to June 2002 and 2003 using drift nets, while age-0 juveniles were captured from June through October 2002 and 2003 using wading, snorkeling, backpack electrofishing, and haul-seine surveys. Larval drift occurred within 14 days of adult spawning and extended from 1 to 3 weeks in duration, with two peaks in the number of fish drifting downstream each year. Larvae had a median total length (TL) of 19 mm (range: 13–23; N = 159) in 2002 and 18 mm (range: 13–24; N = 652) in 2003. Catch-per-unit-effort for larvae was 0.18 fish h^{-1} m^2 and 0.94 fish h^{-1} m^2 in 2002 and 2003, respectively. Age-0 juvenile lake sturgeon exhibited rapid growth (i.e. 2.57 mm day^{-1} in TL and 0.66 g day^{-1} in wet weight) throughout summer and fall months; relative condition of fish in both years was approximately 100, indicating good condition. Absolute abundance of age-0 juveniles in 2003 was estimated at 261 fish using the Schnabel estimator. The results from this study indicate that the lower Peshtigo River contains important nursery habitats suitable for age-0 lake sturgeon.

Introduction

Lake sturgeon *Acipenser fulvescens* are found throughout the Laurentian Great Lakes, Mississippi River, and Hudson Bay drainages (Harkness and Dymond, 1961). Throughout their geographic distribution, lake sturgeon were abundant until the late 1800s when population levels declined as a result of commercial overexploitation, habitat degradation, and industrial pollution (Harkness and Dymond, 1961; Organ et al., 1978; Hay-Chmielewski and Whelan, 1997). Because population abundance of lake sturgeon in the Great Lakes is estimated at approximately 1% of their historical levels, this species is imperiled throughout the USA waters of the basin (Hay-Chmielewski and Whelan, 1997; Elliott, 1998). Restoration has been limited by a number of factors, including limited information on the biological attributes of early life stages. As a result, understanding the biological characteristics of age-0 lake sturgeon should facilitate future rehabilitation efforts for this species in the Great Lakes (Holey et al., 2000).

Life history characteristics and biological attributes of lake sturgeon are understood to some extent, particularly for adult fish. This species is potamodromous, spawning in the spring when water temperatures range between 10 and 16°C (Auer and Baker, 2002). Lake sturgeon spawn in strong currents over cobble and gravel substrates, and eggs hatch 5–8 days post-spawning (Kempinger, 1988; LaHaye et al., 1992). After yolk-sac absorption, larval lake sturgeon drift passively downstream with the river current (Kempinger, 1988; Auer and Baker, 2002). After the larval drift period ends, age-0 lake sturgeon are known to inhabit areas with sand substrates and feed on burrowing macroinvertebrates (Kempinger, 1996; Chiasson et al., 1997; Peake, 1999; Hughes, 2002; Benson, 2004). However, details of the biological attributes of these early life stages are not well understood and may vary among systems.

Early life stages of lake sturgeon have been studied in several tributaries of the Great Lakes basin, in New York the lower Niagara River, and the St Lawrence River (Kempinger, 1988; LaHaye et al., 1992; Beamish et al., 1998; Elliott, 1998; Peake, 1999; Auer and Baker, 2002; Hughes, 2002; Holtgren and Auer, 2004). Despite these efforts, many details about the biological attributes of larval and age-0 juvenile life stages such as relative and/or absolute abundance, growth, and condition remain unclear during their river-residence period. Therefore, examination of lake sturgeon early life stages in Lake Michigan tributaries, such as the lower Peshtigo River, Wisconsin, will provide information that should contribute to successful rehabilitation. The objectives of this research were to: (i) determine the timing, distribution, and duration of larval lake sturgeon drift; (ii) determine the abundance of age-0 juvenile lake sturgeon; and (iii) determine the growth and condition of age-0 juvenile lake sturgeon. The results of this research will provide baseline information on the spawning and recruitment success of lake sturgeon in the lower Peshtigo River and the biological attributes of early life stages in this Green Bay tributary.

Materials and methods

Study site

The study area for this research was the 19-km lower Peshtigo River from the Peshtigo Dam to Green Bay, Wisconsin (Fig. 1). Based on general morphology and substrate type, the study area could be divided into the following four areas: (i) a wide (75 m) and shallow (1 m or less) riffle that extended 1.0 km downstream from the Peshtigo Dam and contained large gravel and small cobble substrates; (ii) a wide (97 m) and shallow (up to 1.3 m), gravel-sand run that extended 5.5 km

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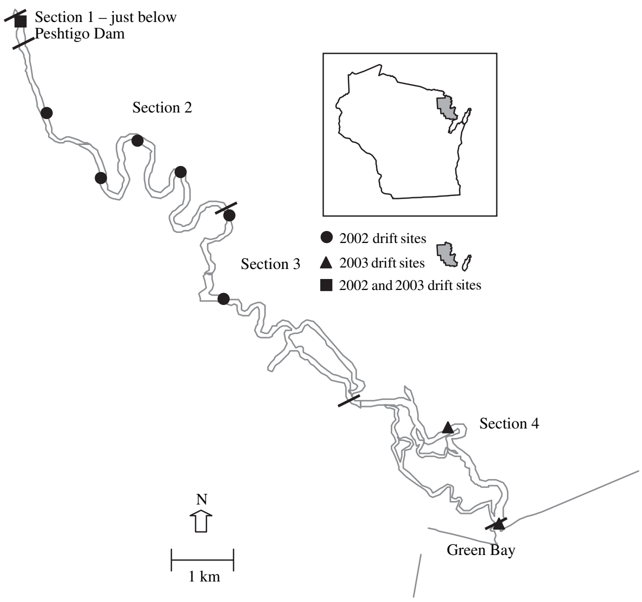


Fig. 1. Map of the lower Peshtigo River located in northeastern Wisconsin showing larval lake sturgeon drift-net locations in 2002 and 2003

downstream; (iii) a narrower (55 m), deeper (up to 2.5 m) run that extended 6.5 km downstream and contained predominantly sand substrate; and (iv) a relatively wide (75 m), shallow (up to 1.3 m), straight run that extended 6.0 km downstream to Green Bay and contained sand substrate. The riparian area of the river had limited development and consisted primarily of maple-beech forest for sections 1–3 and cattail-bulrush wetland for section 4. The average discharge of the river was 34 $m^3 s^{-1}$ in 2002 (range: 9–120) and 29 $m^3 s^{-1}$ in 2003 (range: 6–107) as measured by the U. S. Geological Survey (USGS) gauging station located immediately downstream from the Peshtigo Dam.

Larval lake sturgeon

Larval lake sturgeon were captured from the lower Peshtigo River using drift nets during May and June 2002 and 2003. Drift nets consisted of a D-shape frame (76.2-cm wide × 53.3-cm high; Research Nets, Inc., Bothell, WA, USA), with a cable bridle attached to rings on the frame. Each net had a 3.4-m long and 1.6 mm mesh bag, with a grommeted frame collar and nylon cup collar to fit a removable collecting bucket (333-μm mesh). Nets were anchored in gravel or sand substrates using trap-net anchors. Larval lake sturgeon drift sampling began approximately 5 days after spawning commenced on May 25, 2002 and May 9, 2003 and continued for 5 weeks until larvae were no longer captured in the drift nets. Identification of the timing of lake sturgeon spawning was based on visual observations of fish aggregating below the Peshtigo Dam and a milky appearance to the water, which suggested the discharge of milt by males. Based on previous research in the Wolf River, Wisconsin, nets were deployed during peak periods in larval drift, which extended from 21.00 to 02.00 hours (Kempinger, 1988).

In 2002, seven drift-net sites were monitored during the larval drift period (Fig. 1). Two net sites were monitored each night, with nets being checked each hour. Each time larval lake sturgeon were captured in the nets at the most downstream site, both the upstream and downstream net sites were moved approximately 1.5-km downstream the following night. This resulted in the new upstream site becoming the previous night's downstream site and the new downstream site being located approximately 1.5 km further downstream. The most upstream drift-net site in 2002 was located at a known lake sturgeon spawning area located immediately below the Peshtigo Dam, while the most downstream drift-net site was situated 10-km below the dam. Two of the seven sites were sampled with four drift nets set equidistantly across the river because the width at those locations was greater than at the other sites. The other five sites were monitored with three drift nets set equidistantly across the width of the river. During each sampling period, water depth and current velocity were measured using a Price AA flowmeter attached to a top-set wading rod (Scientific Instruments Inc., Milwaukee, WI, USA) and water chemistry (i.e. temperature, dissolved oxygen, specific conductance, turbidity, and pH) was determined using a Hydrolab Quanta (Hydrolab-Hach Corporation, Loveland, CO, USA) at each drift-net location.

In 2003, three drift-net sites were monitored each night at the known spawning location below the Peshtigo Dam and checked hourly each sampling night (Fig. 1). One drift net was set 12-km downstream from the dam and two additional nets were set at the mouth of the river to determine if larvae were drifting into Green Bay. Drift nets set at the two downstream locations were checked every 2.5 h, and all nets were set equidistantly across the width of the river. Of the drift-net sites in 2002 and 2003, only drifts nets set at the spawning location were monitored in both years. During each sampling period, water depth and current velocity were measured as described previously. Daily discharge was recorded at the USGS gauging station located at the Peshtigo Dam during both study years.

Following each hourly sampling period, the contents of each drift net were sorted individually in white plastic trays. Larval lake sturgeon were separated from debris and distinguished from other larval fishes. All larvae were measured for total length (TL) to the nearest 1 mm using digital calipers, enumerated for each net, and released live near the vicinity of capture.

Age-0 juvenile lake sturgeon

Age-0 juvenile lake sturgeon were captured in the lower Peshtigo River and nearshore waters of Green Bay from June through October 2002 and June through November 2003 using wading, snorkeling, backpack electrofishing, and haul-seine surveys (Benson, 2004). All fish were measured for TL, fork length (FL), and girth to the nearest 1 mm and weighed to the nearest 0.01 g. Each captured age-0 juvenile lake sturgeon was examined for the presence of a passive integrated transponder (PIT) tag and, when present, the identification number was recorded using a portable PIT tag reader (Model FS 2001F; Biomark, Inc., Boise, ID, USA). All untagged fish were implanted with an individually coded PIT tag (14 mm long × 2.1 mm diameter, 125-KHz; Biomark, Inc.) below the second and third dorsal scutes using a 12-gauge needle.

Data analyses

Catch-per-unit-effort (CPUE) of larvae at each drift-net location was calculated in both years as the number of larvae $h^{-1} m^2$ of drift-net opening. Estimates of larval drift CPUE were calculated only from fish captured at the Peshtigo Dam site. The Schnabel estimator, a multiple capture-mark-recapture census, was used to estimate absolute abundance ($\hat{N}$) of age-0 juvenile lake sturgeon in 2003 as:

$$\hat{N} = \frac{(\sum C_t M_t)}{(R_t)},$$

where C_t was the number of fish collected at time t, M_t was the number of fish marked and released at time t, and R_t was the total number of marked recaptures (Schnabel, 1938). Confidence intervals (95% CI) for the population estimate were calculated using a Poisson distribution:

$$\text{LowerCI} : \hat{N} = \frac{(M+1)(C+1)}{\text{UL}+1}$$

$$\text{UpperCI} : \hat{N} = \frac{(M+1)(C+1)}{\text{LL}+1}$$

where, M was the number of marked fish, C was the number of fish collected, UL was the upper limit, and LL was the lower limit, both determined from the Poisson distribution table based on the number of recaptured fish (Krebs, 1999). Absolute abundance of age-0 juvenile fish was not estimated in 2002 because no individuals were recaptured during that sampling year.

Growth and condition were estimated for age-0 juvenile lake sturgeon collected in 2002 and 2003. Incremental changes in TL (mm) and wet weight (g) of age-0 juvenile lake sturgeon each week were used to determine average gain in length and weight starting at the end of the larval drift period in 2003 as:

$$L_I = L_{t+1} - L_t$$
$$W_I = W_{t+1} - W_t,$$

where L_I was the length increment, L_{t+1} was the length at time $t+1$, L_t was the length at time t, W_I was the weight increment, W_{t+1} was the weight at time $t+1$, and W_t was the weight at time t. In 2002, too few lake sturgeon were captured to accurately assess growth. Relative condition (K_n) was used to estimate physiologic condition of age-0 juvenile lake sturgeon in 2002 and 2003 as:

$$K_n = \left(\frac{W}{W\prime}\right) \times 100$$

where, W was the wet weight (g) of the fish and W' was the length-specific weight for a fish in the population as predicted by a weight–length regression equation calculated for this population from fish captured in both years (Le Cren, 1951).

Statistical analyses

Non-parametric comparisons were used to analyze all medians because data were not normally distributed. Median daily discharge and water temperature were compared between years using a Mann–Whitney test. Median length, weight, and condition of age-0 juvenile fish captured in 2002 and 2003 were compared using a Mann–Whitney test. In addition, a linear regression model was used to evaluate growth of age-0 juvenile lake sturgeon, where $\log_{10}$ wet weight was the predicted value and $\log_{10}$ TL the independent variable. All statistical analyses were analyzed using SPSS 11.0.1 statistical analysis program (SPSS Inc., Chicago, IL, USA), and methods of statistical testing followed those outlined in Zar (1999). All statistical analyses were considered significant at $P < 0.05$.

Results

Larval lake sturgeon

Larval lake sturgeon were captured from the lower Peshtigo River, Wisconsin, in 2002 and 2003. Spawning of adult lake sturgeon took place on May 26 and June 2, in 2002 (Fig. 2a). The drift of larval lake sturgeon began on June 1 and ended on June 15, 2002. One peak in the larval drift in 2002 was observed on June 2, when the greatest number of larvae were captured in the drift nets. In 2003, spawning occurred on May 8, 10, 12 and 17. Yolk-sac larvae were first captured on May 12, and drifting larvae were captured from May 21 to June 6 (Fig. 2b). During 2003, there were two distinct peaks in the numbers of drifting larvae, which occurred on May 26 and 31.

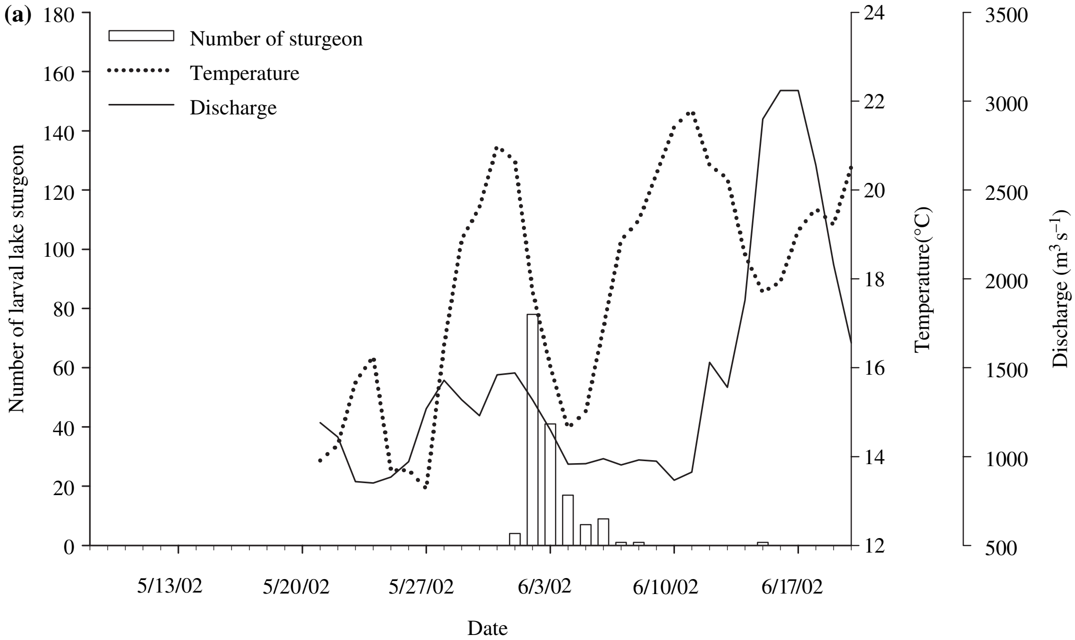
The size range of larval lake sturgeon captured during the drift period varied during each study year. Larvae captured in 2002 had a median TL of 19 mm (range: 13–23; N = 159). In 2003, larval lake sturgeon that were captured had a median TL of 18 mm (range: 13–24; N = 652).

During the study period, larval lake sturgeon were captured throughout the lower Peshtigo River. In 2002, larvae were captured in drift nets located 9-km downstream from the Peshtigo Dam. In 2003, larvae were captured in drift nets set at the mouth of the river, a distance approximately 19-km downstream from the Peshtigo Dam. The median daily discharge (2002: 34.8 $m^3 s^{-1}$; range: 24.1–86.6; 2003: 36.2 $m^3 s^{-1}$; range: 19.0–75.0) and water temperature (2002: 18.5°C; range: 13.3–21.8; 2003: 16.9°C; range: 11.1–22.0) during the larval drift period in the Peshtigo River study area were not significantly different between 2002 and 2003 ($Z = -0.053$, $P = 0.958$ and $Z = -1.994$, $P = 0.046$, respectively; Fig. 2). CPUE for larvae captured in drift nets was 0.18 fish $h^{-1} m^2$ and 0.94 fish $h^{-1} m^2$ in 2002 and 2003, respectively.

Age-0 juvenile lake sturgeon

Age-0 juvenile lake sturgeon were captured in 2002 and 2003 in the lower Peshtigo River. Age-0 juvenile fish in 2002 had a median TL of 235 mm (range: 209–272) and wet weight of 56.9 g (range: 35.1–90.0; N = 14). In 2003, age-0 juvenile fish had a median TL of 136 mm (range: 40–316) and wet weight of 10.4 g (range: 0.2–134.0; N = 219). Age-0 juvenile lake sturgeon in 2003 exhibited variable growth in TL and wet weight (range: 0.31–3.60 mm and 0.02–1.92 g, respectively) from June 13 to September 19, 2003 (Table 1). The median daily growth of age-0 fish was 2.50 mm in TL (range: −0.29 to 5.14) and 0.37 g wet weight (range: −0.24 to 3.30). There was a significant positive relationship between $\log_{10}$-transformed TL and wet weight estimates for age-0 juvenile lake sturgeon ($r^2 = 0.999$; $F = 14\,496.010$, $P < 0.001$), with growth of these fish being linear during this life stage. The median relative condition of age-0 fish captured in 2002 (103; range: 82–117) and 2003 (100; range: 72–150) was not significantly different ($Z = -0.295$, $P = 0.768$).

Although 219 age-0 juvenile lake sturgeon were captured throughout the entire study period, only 84 of the captured fish were large enough for PIT tag insertion. Of the 84 fish that received PIT tags, 18 were later recaptured. The absolute abundance of age-0 juvenile lake sturgeon in the Peshtigo River in 2003 was estimated at 261 individuals (95% CI: 164–386 individuals).



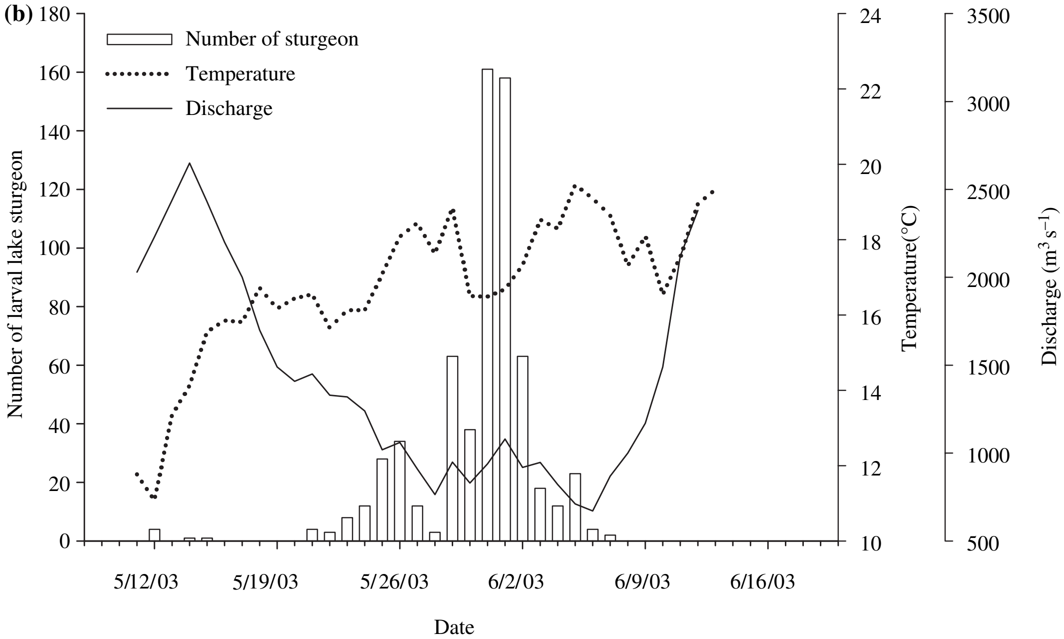


Fig. 2. Larval lake sturgeon abundance, water temperature, and discharge over the (a) 2002 and (b) 2003 sampling seasons in the lower Peshtigo River, Wisconsin. Spawning events were observed for adult lake sturgeon between May 25 and June 2, 2002 and May 8 and 17, 2003

Table 1
Biological statistics and weekly growth of juvenile lake sturgeon in the lower Peshtigo River, Wisconsin, in 2003

Date	n	K_n	TL (mm)	WT (g)	Change in TL	Change in WT	TL (growth day^{-1})	WT (growth day^{-1})
June 20	22	101.32	46.50	0.42				
June 27	27	100.96	67.00	1.16	20.50	0.74	2.93	0.11
July 4	6	98.54	86.50	2.53	19.50	1.37	2.79	0.20
July 11	29	97.32	116.00	5.73	29.50	3.21	4.21	0.46
July 18	40	99.74	125.00	7.70	9.00	1.97	1.29	0.28
July 25	14	100.49	146.50	11.99	21.50	4.29	3.07	0.61
August 8	12	98.73	189.00	25.66	42.50	13.67	3.04	0.98
August 15	18	96.30	187.00	25.31	−2.00	−0.36	−0.29	−0.05
August 22	3	108.00	223.00	48.41	36.00	23.11	5.14	3.30
August 29	9	105.73	225.50	46.75	2.50	−1.66	0.36	−0.24
September 5	17	103.73	241.00	60.05	15.50	13.31	2.21	1.90
September 12	5	95.99	256.00	71.77	15.00	11.72	2.14	1.67
September 19	16	100.09	258.00	73.02	2.00	1.25	0.29	0.18

'n', sample size; K_n, median relative condition; TL, median total length; WT, median wet weight.

Discussion

Previous research has examined larval drift and growth of age-0 juvenile lake sturgeon, but few studies have quantitatively assessed the biological attributes of these early life stages (Kempinger, 1988, 1996; LaHaye et al., 1992; DiLauro et al., 1998; Fajfer et al., 1999; Auer and Baker, 2002). Although larval lake sturgeon passively drift downstream in rivers where adults spawn, the timing and duration of drift and distance of downstream movement are variable among years and systems (Kempinger, 1988; LaHaye et al., 1992; Auer and Baker, 2002). Biological attributes of larval and juvenile lake sturgeon, such as relative and absolute abundance, growth, and condition, have not been sufficiently examined in Great Lakes tributaries. In the lower Peshtigo River, larval lake sturgeon drifted downstream from the spawning site located at the dam, with some fish moving as far downstream as the river mouth (approximately 19 km) over a period of 2–3 weeks. In the months following the drift period, age-0 juvenile lake sturgeon grew rapidly and were in good physiologic condition. Based on the results of our research, suitable nursery habitats in Great Lakes tributaries facilitate rapid growth and good condition of lake sturgeon early life stages during their river-residence period.

Median water temperature and discharge in the lower Peshtigo River were similar during both study years. From spawning through the early larval drift period, water temperatures were within the ranges suggested by Wang et al. (1985) for successful egg incubation (10–18°C) and hatching (14–16°C). Discharge in the lower Peshtigo River during both years was much lower than in the Sturgeon River, Michigan (range: 21–96 $m^3 s^{-1}$), and Des Prairies (range: 1569–1811 $m^3 s^{-1}$) and L'Assomption (range: 21.3–69.6 $m^3 s^{-1}$) rivers, Quebec (LaHaye et al., 1992; Auer and Baker, 2002). Based on these results, tributaries with water temperature and discharge regimes similar to the lower Peshtigo River provide suitable abiotic habitat features for early life stages of lake sturgeon.

Peaks in larval lake sturgeon drift have been compared to the timing of adult spawning in several Great Lakes tributaries and the St Lawrence River (Kempinger, 1988; LaHaye et al., 1992; Elliott, 1998; Auer and Baker, 2002). In the Wolf (Wisconsin), Des Prairies, and L'Assomption rivers, lake sturgeon larvae hatched 5–8 days after fertilization and began drifting within 10 days of hatching (Harkness and Dymond, 1961; Priegel and Wirth, 1974; Kempinger, 1988; LaHaye et al., 1992). Based on results from the Wolf River, the timing of larval drift appears to be dependent on water temperature (Kempinger, 1988). Similarly, yolk-sac larvae were captured in the lower Peshtigo River up to 8 days after adult fish were observed spawning and drifting larvae were captured at least 9 days after observing the first yolk-sac larvae. Based on this research, the peaks in larval lake sturgeon drift are determined by the timing of adult spawning activities and the egg incubation period, which are controlled by water temperatures.

The duration of larval drift for lake sturgeon is variable among river systems and years (Kempinger, 1988; LaHaye et al., 1992; Auer and Baker, 2002). Larval drift duration in the lower Peshtigo River in 1998 continued for < 14 days (Elliott, 1998). Similarly, most of the larval drift in this system occurred within 1 week in 2002, with only one fish captured during the second week of the drift period. In contrast, larval drift continued for 3 weeks in 2003. Despite this variability, larval drift was characterized by two peaks in the number of drifting larvae, most likely due to more than one spawning event. In 2002 and 2003, there were two peaks in the number of larval lake sturgeon, corresponding with two separate periods of observed spawning activity. Variability in the duration of larval lake sturgeon drift has also been observed in other river systems. In the Sturgeon River, larval drift continued for 14 days (Auer and Baker, 2002). From 1981 through 1984, larval lake sturgeon were captured over a period of 2–4 weeks in the Wolf River (Kempinger, 1988); the author concluded that drift duration was dependent on water temperature during spawning and egg development periods, with higher water temperatures resulting in shorter incubation and drift periods. Up to three peaks of larval catches have been observed in the Wolf River, where adult lake sturgeon were found to have two and sometimes three reproductive events in years with fluctuating water temperatures which interrupted spawning activities (Kempinger, 1988). Adult lake sturgeon in other rivers have also been observed to have multiple spawning events and, as a result, multiple peaks in the number of drifting larvae (LaHaye et al., 1992; Auer and Baker, 2002).

The distance that larval lake sturgeon drift downstream is typically dependent on the current velocity of their spawning tributary. Some larval lake sturgeon in the lower Peshtigo River drifted as far as 19 km from the dam to the river mouth at Green Bay. However, total larval catch at the mouth of the river was 94% less than the total catch at the dam. On average, current velocity in the lower Peshtigo River steadily decreased from the dam to the river mouth. At lower velocities, drifting larvae may settle out in areas with lower flows that contain sand substrates and shallow depths before reaching the river mouth. Unlike the Peshtigo River, lake sturgeon larvae in the Sturgeon River were found to drift more than 61 km from the spawning grounds (Auer and Baker, 2002). One difference between these two systems is that the average velocity in the lower Peshtigo River (53 cm s^{-1}) was much less than the Sturgeon River (73 cm s^{-1}) during the drift period. Therefore, distances that larval lake sturgeon drift downstream in Great Lakes tributaries may be related in part to current velocity of that particular system as well as availability of required habitat features.

Although the absolute abundance of larval lake sturgeon has not been determined in Great Lakes tributaries, relative abundance has been estimated using CPUE. CPUE data for larvae collected in the Sturgeon River during an 8-year period ranged from 0.05 to 2.09 larvae $h^{-1} m^2$ (Auer and Baker, 2002). During 4 years of sampling in the Wolf River, CPUE ranged from 0.09 to 1.60 larvae $h^{-1} m^2$ (Kempinger, 1988). Similarly, the CPUE of larvae captured in drift nets from the lower Peshtigo River was 0.18 and 0.94 larvae $h^{-1} m^2$ in 2002 and 2003, respectively. Although relative abundance of lake sturgeon larvae can be compared between systems, estimates of absolute abundance are important to better determine spawning and recruitment success of lake sturgeon in Great Lakes tributaries.

Estimates of absolute population abundance have not been reported for age-0 juvenile lake sturgeon in Great Lakes tributaries. As a result, the number of fish in the lower Peshtigo River could not be directly compared to other river systems containing populations of age-0 juvenile lake sturgeon. Although age-0 fish have been captured in the Wolf and Sturgeon rivers, they were not sampled completely throughout these systems and fish were not sufficiently abundant to accurately assess their population levels (Kempinger, 1996;

Holtgren and Auer, 2004). Therefore, a larger sampling effort is needed in Great Lakes tributaries that support populations of age-0 juvenile lake sturgeon in order to accurately estimate abundance for comparisons between or among systems.

Age-0 juvenile lake sturgeon in the lower Peshtigo River grew rapidly in length and weight and appeared to be in good condition during their first year of life. Rapid growth within the first 5 months of life has also been exhibited by lake sturgeon in the Wolf River, where fish reached TLs > 270 mm (Priegel and Wirth, 1974; Kempinger, 1996). Because the relative condition of age-0 juvenile sturgeons has not been previously reported, direct comparisons of fish collected from the lower Peshtigo River could not be made to other systems. However, age-0 juvenile lake sturgeon from the lower Peshtigo River were in good physiologic condition, indicating that this river contains suitable nursery habitats for this life stage.

The results of this study indicate that the lower Peshtigo River serves as an important nursery area for early life stages of lake sturgeon. Larval drift patterns indicated that fish remained in the lower river, with relatively few individuals moving immediately into Green Bay. The subsequent capture of age-0 juvenile lake sturgeon over summer and fall months that exhibited rapid growth and were in good physiologic condition confirms that this area of the river provides suitable nursery habitat. Future research efforts should focus on estimating the population abundance of age-0 lake sturgeon in other rivers to determine the number of fish being recruited from Great Lakes tributaries. This information should enable researchers to more effectively assess the success of the ongoing lake sturgeon restoration efforts throughout the Great Lakes basin and allow for the development of more appropriate rehabilitation practices.

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References

Auer, N. A.; Baker, E. A., 2002: Duration and drift of larval lake sturgeon in the Sturgeon River, Michigan. J. Appl. Ichthyol. **18,** 557–564.

Beamish, F. W. H.; Noakes, D. L. G.; Rossiter, A., 1998: Feeding ecology of juvenile lake sturgeon, *Acipenser fulvescens*, in northern Ontario. Can. Field-Nat. **112,** 459–468.

Benson, A. C., 2004: Characterization of early life-history stages of lake sturgeon in the lower Peshtigo River, Wisconsin, and nearshore waters of Green Bay. MS thesis. Purdue University, West Lafayette, Indiana, USA.

Chiasson, W. B.; Noakes, D. L. G.; Beamish, F. W. H., 1997: Habitat, benthic prey, and distribution of juvenile lake sturgeon (*Acipenser fulvescens*) in northern Ontario rivers. Can. J. Fish. Aquat. Sci. **54,** 2866–2871.

DiLauro, M. N.; Krise, W. F.; Fynn-Aikens, K., 1998: Growth and survival of lake sturgeon larvae fed formulated diets. Prog. Fish-Cult. **60,** 293–296.

Elliott, R. F., 1998: Great Lakes native fish restoration – lake sturgeon *Acipenser fulvescens*. Fisheries Stewardship Progress Report, U.S. Fish and Wildlife Service – Green Bay Fisheries Resources Office, Green Bay, Wisconsin, USA.

Fajfer, S.; Meyers, L.; William, G.; Carpenter, T.; Hansen, M. J., 1999: Growth of juvenile lake sturgeon reared in tanks at three densities. North Am. J. Aquacult. **61,** 331–335.

Harkness, W. J. K.; Dymond, J. R., 1961: The lake sturgeon: the history of its fishery and problems of conservation. Ontario Department of Lands and Forests, Toronto, Ontario, Canada, 112 pp.

Hay-Chmielewski, E. M.; Whelan, G. E., 1997: State of Michigan lake sturgeon rehabilitation strategy. Fisheries Special Report No. 18. Michigan Department of Natural Resources, Ann Arbor, Michigan, USA, 51 pp.

Holey, M. E.; Baker, E. A.; Thuemler, T. F.; Elliott, R. F., 2000: Research and assessment needs to restore lake sturgeon in the Great Lakes. Great Lakes Fishery Trust, Muskegon, Michigan, USA.

Holtgren, J. M.; Auer, N. A., 2004: Movement and habitat of juvenile lake sturgeon (*Acipenser fulvescens*) in the Sturgeon River/Portage Lake system, Michigan. J. Freshw. Ecol. **19,** 419–432.

Hughes, T. C., 2002: Population characteristics, habitats, and movements of lake sturgeon (*Acipenser fulvescens*) in the lower Niagara River. MS thesis. State University of New York College at Brockport, Brockport, NY, USA.

Kempinger, J. J., 1988: Spawning and early life history of lake sturgeon in the Lake Winnebago System, Wisconsin. In: 11th Annual Larval Fish Conference. R. D. Hoyt (Ed.). American Fisheries Society, Symposium 5, Bethesda, Maryland, USA, pp. 110–122.

Kempinger, J. J., 1996: Habitat, growth, and food of young lake sturgeons in the Lake Winnebago System, Wisconsin. North Am. J. Fish. Manage. **16,** 102–114.

Krebs, C. J., 1999: Ecological methodology, 2nd edn. Addison-Welsey Educational Publishers, Inc., Menlo Park, California, USA.

LaHaye, M.; Branchaud, A.; Gendron, M.; Verdon, R.; Fortin, R., 1992: Reproduction, early life history, and characteristics of the spawning grounds of the lake sturgeon (*Acipenser fulvescens*) in Des Prairies and L'Assomption rivers, near Montréal, Quebec. Can. J. Zool. **70,** 1681–1689.

Le Cren, E. D., 1951: The length–weight relationship and seasonal cycle in gonad weight and condition in the perch *Perca fluviatilis*. J. Anim. Ecol. **20,** 201–219.

Organ, W. L.; Towns, G. L.; Walter, M. O.; Pelletier, R. B.; Reige, D. A., 1978: Past and presently known spawning grounds of fishes in the Michigan coastal waters of the Great Lakes. Michigan Department of Natural Resources, Fisheries Division, Lansing, USA.

Peake, S., 1999: Substrate preferences of juvenile hatchery-reared lake sturgeon, *Acipenser fulvescens*. Environ. Biol. Fish. **56,** 367–374.

Priegel, G. R.; Wirth, T. L., 1974: The lake sturgeon: its life history, ecology, and management. Wisconsin Department of Natural Resources, Publication 4-3600(74), Madison, USA.

Schnabel, Z. E., 1938: The estimation of the total fish population of a lake. Am. Math. Monogr. **45,** 348–368.

Wang, Y. L.; Binkowski, F. P.; Doroshov, S. I., 1985: Effect of temperature on early development of white and lake sturgeon, *Acipenser transmontanus* and *A. fulvescens*. In: North American sturgeons. F. P. Binkowski and S. I. Doroshov (Eds). Dr W. Junk Publishers, Dordrecht, the Netherlands, pp. 73–78.

Zar, J. H., 1999: Biostatistical analysis, 4th edn. Prentice-Hall, Upper Saddle River, New Jersey, USA.

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