J. Appl. Ichthyol. 21 (2005), 161–168
© 2005 Blackwell Verlag, Berlin
ISSN 0175–8659

Received: May 6, 2004
Accepted: September 9, 2004

Dynamics and extent of larval lake sturgeon *Acipenser fulvescens* drift in the Upper Black River, Michigan

By K. M. Smith and D. K. King

Central Michigan University, Mount Pleasant, MI, USA

Summary

Lake sturgeon larval drift is not uniform in time or space and subsequent efforts to determine the relative abundance have suffered because of the lack of information during this early life history period. The purpose of this study was to obtain information about the early life history of lake sturgeon, determine the extent and duration of lake sturgeon larval drift, and examine this relationship to water flow and temperature in the Upper Black River, Michigan. This study also compares the results of other studies to further evaluate the dispersion of larvae. Larval production was quantified using drift nets anchored to the stream bottom from May to June in 2000–2002. Larval drift nets captured 780 larvae in 2000; 2975 larvae in 2001; and 2041 larvae in 2002. For the 2000, 2001, and 2002 spawning season, we estimated that 7107 (95% CL: ± 1470), 17 409 (95% CL: ± 5163), and 15 820 (95% CL: ± 3168) larval lake sturgeon were produced in the Upper Black River (UBR), respectively. Catch per unit effort values of drifting larvae were greatest after peak water flows, with most larvae captured in the middle of the river channel. A mean daily water temperature above 16°C was an important environmental stimulus that influenced peak larval dispersion away from spawning sites. The results of this study suggested that natural reproduction was still occurring in the Black Lake system.

Introduction

The spatial habitat available to all life history stages of the lake sturgeon *Acipenser fulvescens* has been greatly reduced, resulting in population declines throughout the Laurentian Great Lakes. Previous studies have focused on the biology and ecology of adult lake sturgeon to rehabilitate declining populations (Harkness and Dymond, 1961; Priegel and Wirth, 1971; Lyons and Kempinger, 1992; Auer, 1999; Bruch, 1999). These studies have been conducted in water bodies that are either not isolated from the Great Lakes or contain habitat that allows for long distance migration. Smith and Baker (2005) have shown that adults in restricted spatial habitats within Black Lake, Michigan can survive, grow, and produce viable gametes. These authors also suggested that the effect of reduced habitat availability may impact the early life stages more than the adult stage. Prior studies, however, had limited focus on the early life ecology of lake sturgeon. Future rehabilitation efforts may be fruitless with a lack of information regarding annual variation in natural reproduction and environmental factors responsible for reproductive variability.

As non-harvest pressures (pollution, dams, land development) on the resource continue to maintain lake sturgeon populations at a depressed condition, the knowledge of larval dispersion will help to rehabilitate these populations. The production, drift, and habitat of larval lake sturgeon remain the most misunderstood aspect of the life history because the numbers of spawning lake sturgeon have become greatly reduced from their historic levels (Auer and Baker, 2002). Quantifying the larval production will help to rehabilitate populations of lake sturgeon through understanding rates of recruitment. Understanding the period of larval drift will also lead to the protection of important nursery habitats and contribute to knowledge on the early life history of lake sturgeon.

This information will also be beneficial in assessing lake sturgeon populations in riverine systems that are too large to sample adequately. Sampling large river systems that have the potential for distribution of larvae across the width of the river and within the water column (vertical distribution) may require this basic understanding of lake sturgeon larval dispersion to better quantify lake sturgeon reproduction. Problems associated with understanding early life history may require sampling guidelines or better understanding of larval dispersion in the water column.

Black Lake contains one of the few self-sustaining populations of lake sturgeon in Michigan in which there is also a shallow river system to quantify larval production. Recent population studies in Black Lake have shown that the numbers of adult lake sturgeon have declined by 66% over the past 22 years (Baker and Borgeson, 1999). Baker and Borgeson (1999) suggested that recruitment prior to 1997 was low, but quantitative studies on reproduction had not been made. Therefore, studies on larval production and factors that influence juvenile recruitment dynamics are important to develop better management decisions.

The purpose of this study was to obtain information about the early life ecology of lake sturgeon, determine the extent and duration of lake sturgeon larval drift, and examine this relationship to water flow and temperature in the UBR, MI. This study also compares the results of other studies to further evaluate the dispersion of larvae.

Study area

Black Lake in the counties of Cheboygan and Presque Isle is the eighth largest inland lake in Michigan, with a surface area of 4101 ha (Hay-Chmielewski, 1987). Black Lake contains a small, self-sustaining population of lake sturgeon (Baker and Borgeson, 1999; Smith and Baker, 2005). The UBR (Fig. 1), from Kleber Dam to the confluence at Black Lake, is the principal spawning area for the Black Lake population of lake sturgeon. The UBR is a fourth order stream and the largest

U.S. Copyright Clearance Centre Code Statement: 0175–8659/2005/2103–0161$15.00/0

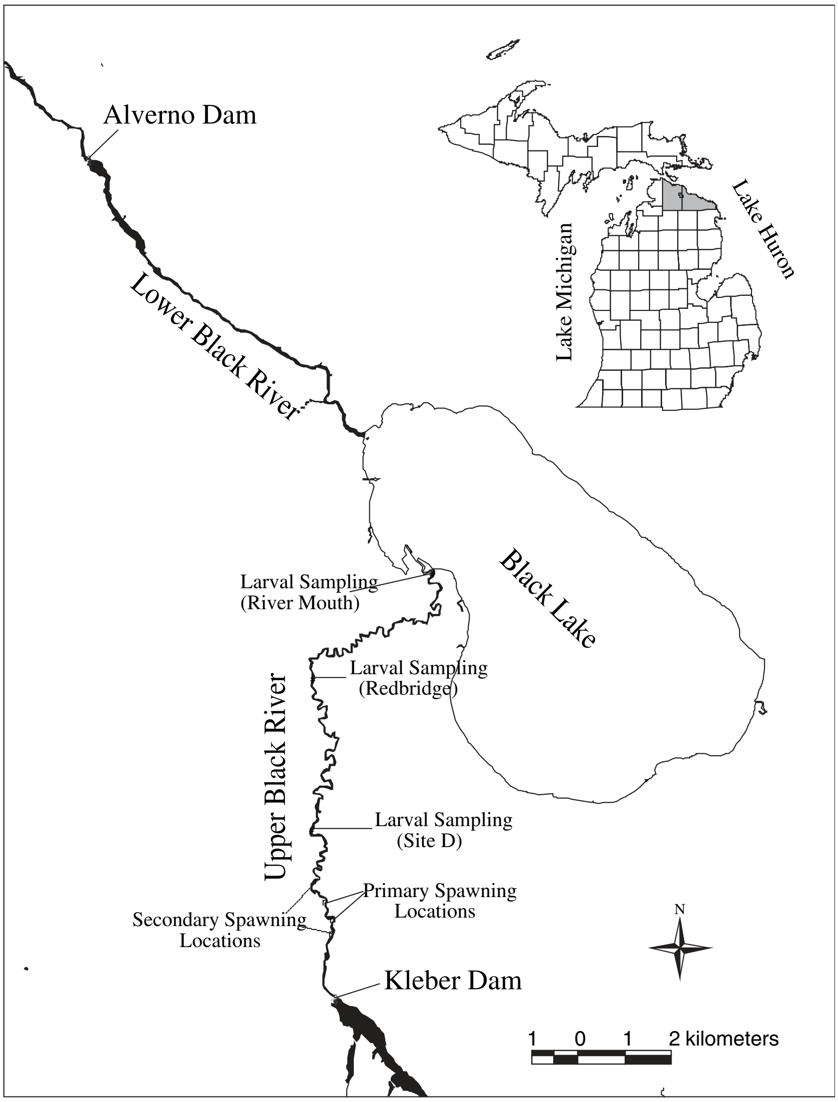

Fig. 1. The Black Lake system, Michigan showing locations of larval drift sampling and areas of observed spawning in the Upper Black River. Upper right corner insert is the State of Michigan with the two counties (Cheboygan and Presque Isle) shaded in gray between which Black Lake is centrally located

source of inflow into Black Lake, contributing an average discharge of 6.4 $m^3 s^{-1}$ (TMWC and NMCG, 1991). The river's watershed covers over 92 470 ha and makes up 65.3% of Black Lake's watershed. The river is 91.7 km long but is restricted to sturgeon migration by the construction of Kleber Dam in 1949, 11 km from its confluence with Black Lake. There are some steep gradients greater than 150 feet (approximately 46 m) per mile (0.6 km) in the smaller headwater tributary streams of the UBR, but the main stream's deepest gradient is located just below Kleber Dam, which drops 23 feet (approximately 7 m) per mile (0.6 km) and provides the spawning adults with clean cobble and well oxygenated water. The Lower Black River is the only source of outflow from the lake and is 16.4 km long from its origin at Black Lake to its confluence at the Cheboygan River. Alverno Dam located on the Lower Black River 8 km downstream from the lake, was constructed in 1903 and now isolates Black Lake and its lake sturgeon population from Lake Huron.

Methods

Lake sturgeon early life history was studied in UBR during spring 2000–2002. Spawning substrate was sampled for the presence of larvae with a dip net that had an opening of 0.5 m and mesh size of 1200 μm. The spawning substrate was assessed at five locations across the width of the channel and five locations below the spawning site at 10 m transects. The spawning substrate was stirred by foot and any suspended matter was captured in the net. Sampling was conducted after spawning activity was observed and then every other day to determine the extent that larvae remained in the substrate and to what extent the larvae utilized their yolk sac prior to drift. Lake sturgeon larvae were collected, measured and then a subsample of 10 larvae mm^{-1} in length was preserved in 70% ethanol for later determination of yolk-sac absorption.

Sampling sites for quantifying the timing, extent and duration of larval emergence and drift were selected at three locations in the UBR shown in Fig. 1. These sampling sites were determined based on access to the river at various downstream locations. Site D larval sampling location (Fig. 1) was 1.14 km downstream from the last part of the spawning locations in UBR. This site was dominated by sand and gravel substrate; water depths at this site allowed for drift nets to be set by personnel wading in the river. The gradient (mean $= 2.2$ m km^{-1}) below Site D begins to flatten out, allowing for the lower section of the river to be inundated with silt and sand. Larval sampling conducted at the Redbridge site and near the river mouth was 6.0 and 10.5 km downstream of the last part of the spawning locations. Water depths at the Redbridge site were greater than 1.7 m; as a consequence, drift nets were deployed from the bridge.

D-shaped larval drift nets were used as sampling gear for the larval lake sturgeon sampling effort. The larval drift nets had openings of 85 cm across the base, 55 cm high and an area of 0.57 m^2. The larval drift nets were 2.5 m in length and made of a knotless 1600 μm mesh netting with a detachable collection bucket (1000 μm mesh and 317.5 cm long) on the cod end. The drift nets were placed into the current and anchored to the river bottom using a crab style anchor that was attached to the net at three points with a nylon rope bridle.

Sampling was conducted between 21.00 and 02.00 hours and each net was checked every hour for the presence of larvae. The sampling period was established based on Kempinger's (1988) study, which showed that larval migration was more significant at night. Continuous hourly sampling was conducted by emptying the contents of the collection bucket into an 18-L bucket without removing the net from the water. Upon collection, contents of the 18-L bucket were placed into white enamel trays and all larvae were sorted, counted and measured to the nearest millimeter total length.

Stream temperature was recorded for every 1-h intervals using two Onset Stowaway XT1 (Onset Computer Corp., Bourne, MA, USA) temperature loggers located between the spawning locations and at the river mouth. Daily water temperatures were also obtained using a handheld mercury thermometer during sampling days. Current velocity readings were taken in front of the drift net opening with a Marsh–McBirney Flo-Mate 2000 (Marsh–McBirney Inc., Fredrick, MD, USA) current meter placed at the middle of the net opening. The cross-sectional area of the channel was measured and the mean velocity was recorded at 3 m transects to calculate discharge each night of sampling. Hourly stream flow was obtained from the US Geological Survey recording station at Kleber Dam in Tower, Michigan to verify calculations.

The longitudinal and transverse distribution of larvae in UBR was determined by computing mean catch per unit effort (CPUE) values across individual station positions and at each transect. Transects were compared using Kruskal–Wallis (KW) statistical tests. Positions in the water column were compared using Wilcoxon–Mann–Whitney (WMW) tests. CPUE values were calculated to quantify the changes (increase or decrease) in larval abundance over time for all species of fish captured. Catch data was expressed as CPUE (number of larvae 10 m^{-3} water sampled). Cumulative daily water temperature units (CTU) were calculated according to the methodology utilized by Kempinger (1988) to estimate the date of larval hatch and to assess the temperature-dependent period to larval drift. Larval abundance was calculated to estimate the number of larvae drifting past the sampling station. Larvae collected from Site D were used to calculate the larval abundance estimate. The following formula from Veshchev et al. (1994) was used to determine the absolute abundance of migrating larvae.

$$P = \frac{(q \times N)}{O} \times K$$

where P is the number of larvae passing sampling site, q is the flow volume passing the site ($m^3\ h^{-1}$), N is the number of larvae collected in the net after 1 h, O is the volume of water sampled ($m^3\ h^{-1}$) determined by the formula: $V \times S$, V is the current velocity in the net, S is the sectional area of the net (m^2), and K is a collection coefficient determined by comparing the difference in velocities in front of the net and beside the net.

Results

Over the 3-year sampling period, 5016 lake sturgeon larvae were captured in drift samples at Site D in the UBR, Michigan (Fig. 1). Annual catch in the drift nets was 780 larvae during 106 h of sampling between 10 May and 6 June 2000; 2975 larvae during 174 h of sampling between 9 May and 15 June 2001; and 1261 larvae during 68 h of sampling between 2 June and 18 June 2002. Catch per unit effort values were 0.86, 2.33, and 2.16 larvae 10 m^{-3} water sampled for 2000, 2001, and 2002, respectively (Table 1). Estimated larval abundance from drift samples for each sampling year was 7107 (95% CL: ± 1470) larvae in 2000; 17 409 (95% CL: ± 5163) larvae in 2001; and 15 820 (95% CL: ± 3168) larvae in 2002. Drifting larval lake sturgeon ranged in size from 16 to 24 mm TL (mean = 19.2 mm) in 2000, 18 to 25 mm TL (mean = 18.6 mm) in 2001, and 16 to 25 mm TL (mean = 18.4 mm) in 2002.

Period of incubation and larval drift

Yolk-sac larvae captured in the spawning substrate averaged 14.1 mm TL (±2.09 SD) with a minimal length of 11 mm and a maximum length of 17 mm. There was multiple temperature dependent incubation and larval drift periods observed for all 3 years of sampling. In 2000, the eggs laid during the first period of spawning incubated for 7 days prior to hatching. The cumulative temperature unit (CTU) at the time of initial egg hatch was 58.1 (Table 2). Eggs deposited on the substrate on 28 April were observed hatching on 4 May. The period to drift from initial spawning was 13 days (28 April–10 May) at a CTU value of 136.2. The second incubation period lasted 5 days at a CTU value of 62.2 (Table 2). Eggs deposited on the substrate on 8 May were observed hatching on 12 May. The period to drift from initial spawning was 19 days (8 May–26 May) at a CTU value of 172.4.

In 2001, the first hatch of larvae occurred at an incubation period of 7 days. The CTU value during the 29 April–5 May incubation period was 61.1 (Table 2). The period for larval drift occurred 15 days after the April 29 spawning date at a

Table 1
Annual catch rates of larval lake sturgeon at Site D, Upper Black River, Michigan

Year	Date	Effort (h)	Larvae captured	Catch per unit effort (10 m^{-3})
2000	10 May–6 June	106	780	0.86
2001	9 May–15 June	174	2,975	2.33
2002	2 June–18 June	68	1,261	2.16

Table 2
Cumulative temperature units (CTU) between dates of spawning, hatch and actual day of peak larval drift in the Upper Black River, Michigan

Year	Date of spawning	Incubation period (date)	CTU for incubation	No of days to drift (date)	CTU
2000	28 April	7 (4 May)	58.1	13 (10 May)	136.2
2000	8 May	5 (12 May)	62.2	19 (26 May)	172.4
2001	29 April	7 (5 May)	61.1	15 (13 May)	139.4
2001	4 May	6 (9 May)	57.5	17 (20 May)	173
2001	22 May	5 (26 May)	58.1	17 (7 June)	172.1
2002	7 May	11 (17 May)	71.4	24 (31 May)	178
2002	24 May	7 (30 May)	54.7	15 (9 June)	181.2

CTU value of 139.4 (Table 2). The second hatch of larvae occurred at an incubation period of 6 days at a CTU value of 57.5 (Table 2). The period for larval drift occurred 17 days after the 4 May spawning date at a CTU value of 173 (Table 2). The third hatch of larvae occurred at an incubation period of 5 days at a CTU value of 58.1 (Table 2). The period of larval drift occurred 17 days after the 22 May spawning date at a CTU value of 172.1 (Table 2).

In 2002, the first hatch of larvae occurred at an incubation period of 11 days with CTU values (71.4) higher than the calculated values in 2000 and 2001. The period to larval drift occurred 24 days after the spawning date at a CTU value (178.0) that was higher than what was observed in 2000 and 2001. Low water temperatures during the spring prolonged the developmental period illustrated by the higher CTU values needed to reach incubation and similar CTU values to reach drift (Table 2). The second hatch occurred 7 days after the spawning date and 15 days to larval drift with CTU values at 54.7 and 181.2, respectively. For all 3 years the mean period to incubation was 7 days with a mean CTU value of 60.4. The mean period to larval drift during the first and second periods was 17 days with a mean CTU value of 151.2 and 175.5, respectively.

Seasonal variation in larval drift

Larval drift profiles showed two or three peaks during each of the 3-year sampling periods (Fig. 2). During 2000 there were two peak drift modes, with the first peak occurring on 11 May and the second peak occurring on 29 May (Fig. 2). The first larval drift period lasted 8 days (10–17 May) while mean water temperatures were 17.4°C during this period. Mean discharge during the first larval drift period was 7.34 $m^3 s^{-1}$. Then mean water temperatures dropped to 13.6°C for 8 days until the second drift period began on 26 May. The second drift period lasted for 11 days with mean water temperatures at 16.9°C and a mean discharge of 5.16 $m^3 s^{-1}$. CPUE values were greater during the second larval drift period (17.72 larvae 10 m^{-3}) than the first larval drift period (5.3 larvae 10 m^{-3}).

In 2001, there were three peaks of larval drift, with the first larvae captured on 12 May (Fig. 2). Water temperatures during the 2001 larval sampling period remained relatively stable (range: 13.7–19.7°C). The first larval drift period lasted for 8 days with mean water temperatures at 16.4°C and a mean discharge of 7.02 $m^3 s^{-1}$. The second drift period began on 22 May and lasted for 7 days, while water temperatures remained above 15°C (mean = 16.8°C). Then water temperatures decreased to a mean of 14.3°C and remained below this temperature for 10 days until the beginning of the third drift period on 8 June that lasted for 7 days with mean water temperatures at 17.6°C and a mean discharge of 7.12 $m^3 s^{-1}$. CPUE values were highest during the first larval drift period (25.13 larvae 10 m^{-3}).

In 2002, there were two peak larval drift periods corresponding with two peak spawning events. Low water temperatures consistently below 15°C (mean = 11.7°C) during the spring of 2002 prolonged the development of larvae and resulted in a later larval drift period than what was observed in 2000 and 2001 (Fig. 2). High water levels in the UBR (mean discharge = 13.4 $m^3 s^{-1}$) prior to 31 May prevented sampling at Site D, but larvae captured downstream at the Redbridge site indicated that larvae began drifting on 31 May. The first larvae were captured at Site D on 2 June and the first larval drift period lasted for 8 days with mean water temperature of 17.1°C and a mean discharge of 6.45 $m^3 s^{-1}$. The second drift period began on 9 June and lasted for 10 days while water temperatures averaged 17.8°C and discharge averaged 6.23 $m^3 s^{-1}$. Mean water temperature during all years of larval drift sampling was 16.7°C and mean discharge was 6.63 $m^3 s^{-1}$. CPUE values were greatest during the second larval drift period (16.78 larvae 10 m^{-3}).

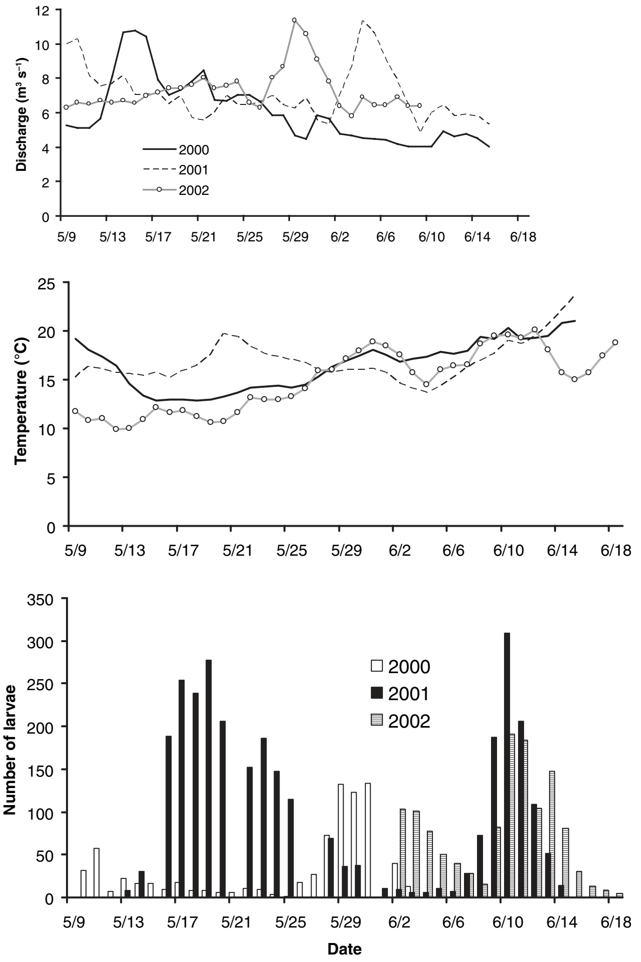

Fig. 2. Daily capture (day month^{-1}) of lake sturgeon larvae at Site D in the Upper Black River, Michigan in relation to mean daily water temperatures and mean daily discharge

Temporal succession of larval drift for two genera of the family Catastomidae (*Catostomus* sp., *Moxostoma* sp.) and lake sturgeon was consistent between 2000 and 2001 (Fig. 3). *Catostomus* sp. larvae appeared first (mean water temperature: 14.6°C) followed by a period of lake sturgeon drift and ending with a period of *Moxostoma* sp. larval drift (mean water temperature: 17.0°C). The peak *Catostomus* sp. drift occurred 3–5 days before the lake sturgeon larval drift and the *Moxostoma* sp. larval drift occurred 2–4 days after the peak lake sturgeon larval drift.

Diel variation of larval drift

Diel patterns of periodicity at Site D for larval drift were similar between years, with no lake sturgeon captured during the 21.00 hour sampling and only a few larvae captured during the 02.00 hour (Fig. 4) sampling. In 2000, 2001, and 2002 larval drift captured during the 22.00 hour was 76, 488, and 282 larvae, respectively (mean = 282). The 23.00 hour resulted in the highest capture of larvae during all three sampling years with a collection of 399, 1198, and 509 larvae captured in

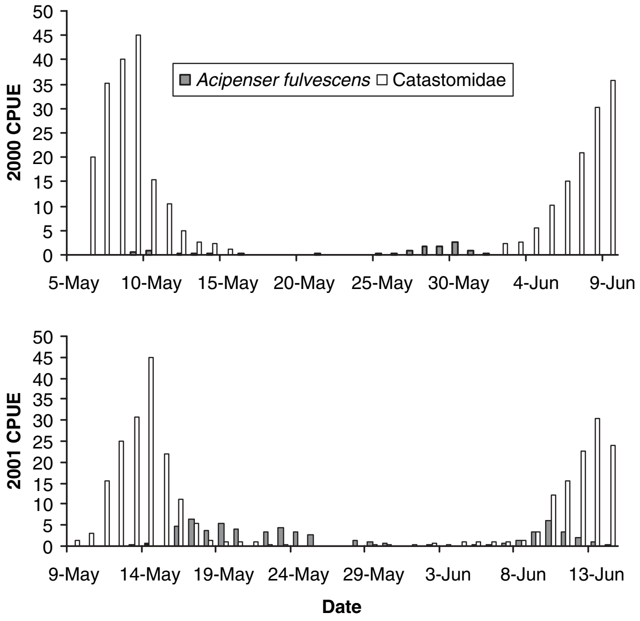

Fig. 3. Catch per unit effort (number of larvae 10 m^{-3} water sampled) of *Catastomidae* spp. and lake sturgeon *Acipenser fulvescens* larvae at Site D in the Upper Black River, Michigan (2000 and 2001)

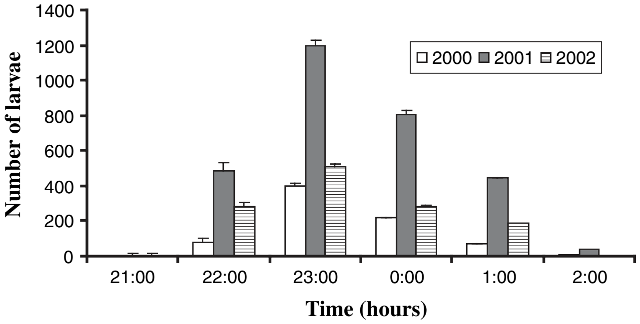

Fig. 4. Hourly catch of larval lake sturgeon at Site D in the Upper Black River, Michigan (2000–2002). Error bars represent standard deviations

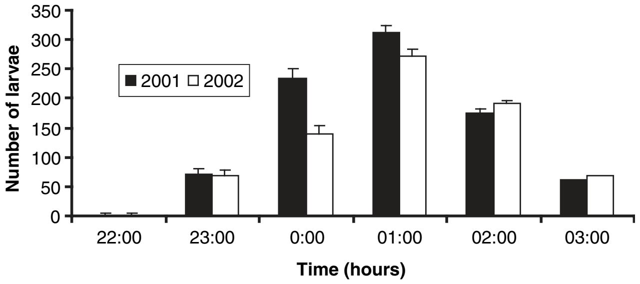

Fig. 5. Hourly catch of larval lake sturgeon at the Redbridge site in the Upper Black River, Michigan (2001–2002). Error bars represent standard deviations

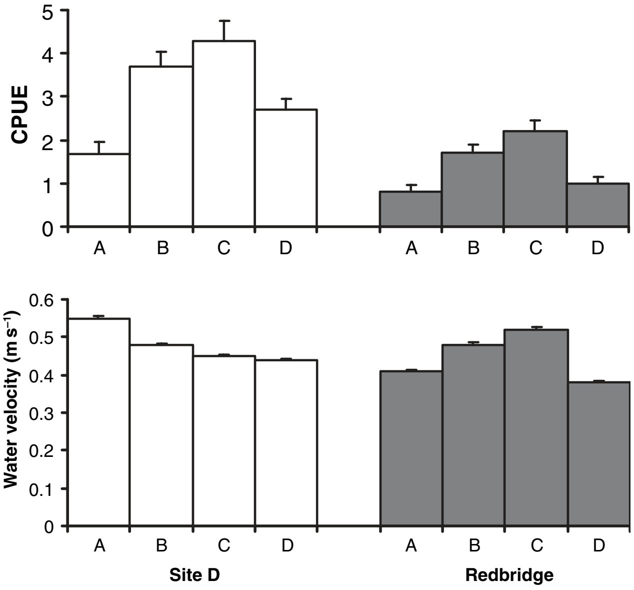

Fig. 6. Mean catch per unit effort (number of larvae 10 m^{-3} water sampled) values for larval lake sturgeon at each net station (Site D and Redbridge) across the water column of the Upper Black River, Michigan. Error bars for the top graph represent standard error; bottom graph represents standard deviations

2000, 2001, and 2002, respectively (mean = 702). The drift rate then began to decrease steadily with 216, 807, and 284 larvae collected during the midnight hour in 2000, 2001, and 2002, respectively (mean = 435). The 01.00 hour resulted in 69, 445, and 186 larvae collected in 2000, 2001, and 2002, respectively (mean = 233).

Hourly capture of lake sturgeon at the Redbridge site showed a 2-h delay in peak capture of drifting larvae than what was observed at Site D (Fig. 5). In 2001 and 2002 larval drift began nightly during the 23.00 hour with 71 and 69 larvae captured, respectively. The midnight hour resulted in 234 and 139 larvae in 2001 and 2002, respectively. The peak hourly capture of larvae at the Redbridge site was during the 01.00 hour of sampling with 312 and 272 larvae captured in 2001 and 2002, respectively. A total of 176 and 191 larvae were captured during the 02.00 hour in 2001 and 2002, respectively. The final hour of capture (03.00 hour) resulted in the capture of 62 and 69 larvae in 2001 and 2002, respectively.

Transverse distribution of larval drift

Larvae were not uniformly distributed across the river channel (Fig. 6). Capture of larval lake sturgeon showed numerically higher mean CPUE at collection Site D stations located in the middle of the river (stations B and C), and maximal values were observed at station C for all years of sampling. There was no statistical difference in the number of larvae captured between stations B and C ($P = 0.25$), but there was a statistical difference between station A and the other three nets for all three years of sampling ($P = 0.025$). Mean water velocities for all three years combined at collection Site D stations A, B, C, and D were 0.55, 0.48, 0.45, and 0.42 m s^{-1}, respectively (Fig. 6). Capture of larval lake sturgeon at the Redbridge collection site showed numerically higher mean CPUE at stations located in the middle of the river (stations B and C) with maximal values at station C for all years combined (Fig. 6). There was a statistical difference between the number of larvae captured at station D and the other three nets for both years combined ($P = 0.012$). Station D at the Redbridge collection site was set on a sand pointbar in shallower water than the other three stations. Mean water velocities for both years of sampling at the Redbridge collection site were 0.41, 0.48, 0.52, and 0.38 m s^{-1} for stations A, B, C, and D, respectively.

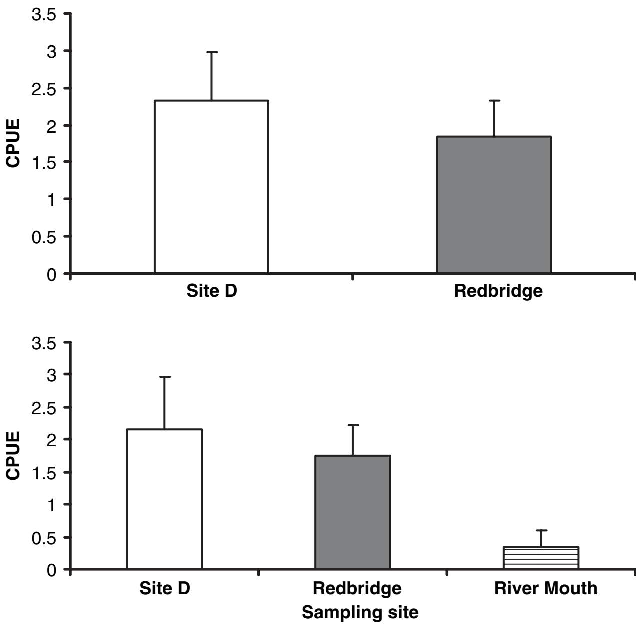

Fig. 7. Mean catch per unit effort (number of larvae 10 m^{-3} water sampled) values for lake sturgeon larval captures at each longitudinal transect in the Upper Black River, Michigan. For each sampling location net positions in the water column were pooled. Error bars represent standard error

Longitudinal variations in larval drift

Mean CPUE values for lake sturgeon decreased downstream from Site D to the Redbridge site during both years of sampling. In 2001, CPUE values decreased from 2.33 larvae 10 m^{-3} at Site D to 1.84 larvae 10 m^{-3} at Redbridge (Fig. 7). In 2002, CPUE values decreased from 2.16 larvae 10 m^{-3} at Site D to 1.76 larvae 10 m^{-3} at Redbridge and 0.34 larvae 10 m^{-3} at the river mouth (Fig. 7). There was no statistical difference between the number of larvae captured between Site D and Redbridge ($P < 0.08$), a difference in sampling distance of 4.86 km. However, there was a statistical difference observed between catch rates at Site D and the river mouth in 2002 ($P = 0.025$), a distance of 9.36 km.

Discussion

The difference in larval production estimates among years suggests that lake sturgeon reproduction can be rather variable and the survival of drifting larvae could reflect this variability in year-class strength. The results of this study corroborate the results of previous studies that have shown the potential of multiple larval drift profiles (Kempinger, 1988; D'Amours et al., 2000). In a subsequent study (Smith, 2003) observations of multiple spawning adults arrived in association with important water temperatures and flow events. The larval drift periods correlated with these spawning groups, suggesting that there is synchronization in larval drift and spawning activities. Mean water temperatures above 16°C were important environmental cues for peak larval drift and should be something to look for during groundwork larval drift sampling. Ceskleba et al. (1985) reported that eggs incubated at 13 and 16°C in the Wild Rose State Fish Hatchery, Wisconsin had a hatching success rate of 63.5 and 55.5%, respectively.

Period of incubation and larval drift

Two lake sturgeon developmental stages (incubation and larval drift) were temperature-dependent according to CTU values. The incubation period for lake sturgeon eggs ranged from 5 to 11 days, with CTU values ranging from 58.1 to 71.4. Kempinger (1988) showed that the incubation period for lake sturgeon eggs in the Wolf River, Wisconsin ranged from 8 to 14 days, with CTU values ranging from 54.9 to 59.9. Wang et al. (1985) found similar incubation periods with mean CTU values at 58.8. The larval drift period for lake sturgeon in the UBR was also temperature-dependent, with mean CTU values during the first drift period at 151.2 and 175.5 during the second drift period. These two differences in larval drift may suggest genetic discreteness between the different spawning stocks, but more genetic analyses would be needed to answer this question. If nothing else, these two larval drift periods are an indication of the effects of water temperature on the development of lake sturgeon larvae.

Seasonal and diel variation in larval drift

Larval drift patterns of lotic spawners show several similarities in temporal and spatial synchronism, diel drift patterns, and longitudinal and transverse distribution that influence their reproductive success (Pavlov, 1994). Temporal succession of the larvae of those species captured in the UBR remained constant between each year of sampling, with white sucker *Catostomus commersoni* appearing first followed by lake sturgeon and finally golden redhorse *Moxostoma erythrurum*. This temporal succession of larvae between species is supported by the difference in water temperatures at initial spawning, with white suckers spawning at 9°C followed by lake sturgeon and golden redhorse spawning when water temperatures reach 15–15.5°C (Scott and Crossman, 1973).

The timing and duration of larval drift and the size of drifting larvae during downstream migration are similar to other studies conducted on the early life history of lake sturgeon (Kempinger, 1988; Lahaye et al., 1992). The results of downstream migration of larvae after peak spawning activity were 13–19 days in the UBR. Kempinger (1988) found peak downstream movements at 14, 15, and 11 days post-hatch and Lahaye et al. (1992) found that larvae began drifting away from the spawning grounds at 18 days after peak spawning.

The mean lengths of larval lake sturgeon in the Wolf River, Wisconsin during downstream movement from the Shawano Dam spawning grounds were 17.5, 18.4, and 18.8 mm in 1982, 1983 and 1984, respectively. The mean lengths of larvae captured in the UBR were 19.2, 18.6, and 18.4 mm, respectively. Mean larval length data in Lahaye et al. (1992) suggested that the mean length of larvae at downstream migration levels off at 20 mm, which the authors suggest corresponds with the probable length at initiation of active feeding. In examining all larvae collected in the UBR and examining all larvae held in the holding tanks during the larval headstart program (Smith, 2003), active feeding began at approximately 23–24 mm total length. Harkness and Dymond (1961) found similar results for hatchery-raised sturgeons, with active feeding beginning at larval lengths between 22 and 25 mm.

Larval lake sturgeon drift is not uniform, with differences observed based on sampling time, distance from spawning site, and location of sampling across the width of the channel. In the UBR larval drift peaked during the 23.00 hour at collection Site D, a distance of 1.14 km downstream of the spawning locations and during the 01.00 hour at the Redbridge collection site, a distance of 6.0 km downstream of the spawning locations. Several other authors have shown that lake sturgeon exhibit nocturnal drift with greatest CPUE values between 21.00 and 02.00 (Kempinger, 1988; Lahaye et al., 1992; D'Amours et al., 2000).

Transverse variations in larval drift

Transverse larval drift distribution showed that larvae were predominantly captured within the middle section (position C) of the river. Several authors have indicated that larval drift was closer to shore in some rivers because physical conditions were more favorable for drifting larvae (Johnston et al., 1995). In comparison, stellate sturgeon in the Volga River were found to drift in the middle section of the river channel (Veshchev and Novikova, 1983). D'Amours et al. (2000) suggested that larvae remained in the same general corridor that corresponds to the site of egg deposition during downstream drift. Water velocity in the UBR did not seem to be the main factor that determined where larvae were captured based on CPUE values, but rather larvae seemed to drift in the middle section of the river channel and perhaps remained towards the same general egg deposition corridor as described by D'Amours et al. (2000).

The vertical distribution of lake sturgeon larval drift has been shown to exhibit interannual variability throughout the water column. Kempinger (1988) showed that mean CPUE values in the Wolf River, Wisconsin were higher along the bottom during 1983, but were higher near the surface in 1984. D'Amours et al. (2000) observed that lake sturgeon larvae drift using the entire water column, but show a tendency to be more abundant at mid-depth and near the bottom. Our study showed a vertical distribution of drifting larvae to be abundant near the bottom and mid-depth of the water column. Kempinger's (1988) study was conducted 150 m downstream of the Shawano Dam, Wisconsin. Therefore, his findings of drifting larvae near the surface may have been a result of high water velocities and turbulent flow causing the larvae to remain near the surface in the upstream part of the study site. D'Amours et al. (2000) also showed that the proportion of larvae caught at the surface during the night tended to decrease with longitudinal distance downstream of the spawning site. Although lake sturgeon larvae may not be confined to an epibenthic zone during downstream migration, they certainly show more of a benthic behavior at the larval stage than would planktivorous larvae. For lake sturgeon, future studies of larval relative abundance should concentrate their efforts along the bottom and mid-depth of the river and less effort should be spent near the surface, with respect to distance downstream of the spawning site.

Longitudinal variations in larval drift

Logistical problems prevented any indication as to the dispersion of larvae throughout the UBR in each year of the study. Lake sturgeon larval catch rates did not significantly decrease downstream from Site D to the Redbridge sampling location in 2001 and 2002, a drift distance of 4.86 km. Larval catch rates had a significant decrease downstream from Site D to the river mouth in 2002, a drift distance of approximately 9.36 km. Auer and Baker (2002) showed that lake sturgeon larvae drift to 26 rkm below the spawning site within 15–27 days and to 45 rkm within 25–40 days, with the average size of the larvae increasing with distance downstream. We did not observe any differences in the average size of drifting larvae in the UBR. Combining the results of both studies, possibly lake sturgeon may utilize areas within a downstream distance between 11 and 26 km for important nursery habitat. These data indicate that the lower river sections are important habitat for young-of-the-year lake sturgeon and that these sections are particularly important habitats needing protection to rehabilitate populations throughout the Great Lakes basin.

The few lake sturgeon that were captured at downstream locations were in the same range of lengths as the larvae captured at the upstream location. This data indicates that a few larvae probably dispersed out into Black Lake with the short migratory distance in the UBR. D'Amours et al. (2000) stated that lake sturgeon larvae on a given night travel the 19-km stretch of Des Prairies River, Quebec during the 6 h of sampling. The UBR from Kleber Dam to Black Lake is only 11 km long; therefore it was likely that most of the larvae drifted out to Black Lake.

Electrofishing surveys conducted in the UBR have captured young-of-the-year lake sturgeon approximately 4–5 months post-hatch (Smith, 2003). This may be an indication that there are also a few lake sturgeon that remain in the river for the first 4–8 months of their lives. Kempinger (1988) has noted that young-of-the-year lake sturgeon in the Wolf River, Wisconsin remain in the spawning river for their first year of life. Future studies are required to better understand the dynamics and extent of larval and juvenile river residency and habitat requirements in the UBR, Michigan.

Conclusion

Natural resource agencies have recently started to focus efforts on lake sturgeon restoration and rehabilitation. Prior studies, however, have not focused on the early life history of lake sturgeon; future rehabilitation efforts may be fruitless without information regarding annual variation in natural reproduction and assessment techniques designed to evaluate the dispersion of larvae from spawning sites. Lake sturgeon spawn in large river systems that have the potential for broad distribution of larvae across the width of the river as well as larval vertical distribution in a deep water column. A basic understanding of lake sturgeon larval dispersion is necessary to better quantify reproduction. Problems associated with understanding lake sturgeon early life history may require sampling guidelines or standardized procedures to gain information on fundamental aspects of their reproductive ecology and early life history, given their wide geographic distribution. This study was conducted to build on information to determine the extent and duration of lake sturgeon larval drift and has led to present studies evaluating genetic data to determine progeny contributions from individual adults and estimates of effective breeding size. Key information from this study indicated that larval lake sturgeon drift was not uniform. Differences were observed based on sampling time, distance from spawning site, and location of sampling across the width of the channel. Vertical drift distributions were abundant near the bottom, with transverse larval distributions increasing in abundance from the egg depositional corridor to the middle of the river channel. Larval drift was associated with mean daily water temperatures above 16°C, with the highest CPUE values of drifting larvae observed after peak water flows. Multiple discrete larval drift groups were observed and corresponded to multiple spawning groups. Annual variation of larval drift ranged from 7107 (95% CL: ± 1470) to 17 409 (95% CL: ± 5163) in the Black Lake system.

Acknowledgements

We thank the Michigan Department of Natural Resources and Sturgeon for Tomorrow, Black Lake Chapter for funding this study. We also thank the numerous volunteers who contributed to this project, particularly Brenda and Gil Archambo, and Doug and Ellie Wilson, and the technicians who worked on this project, Matt Kerr, Melissa Ryneski, and Tom Tryban.

References

Auer, N. A., 1999: Population characteristics and movements of lake sturgeon in the Sturgeon River and Lake Superior. J. Great Lakes Res. **25,** 282–293.

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.

Baker, E. A.; Borgeson, D. J., 1999: Lake sturgeon abundance and harvest in Black Lake, Michigan, 1975–1999. N. Am. J. Fish. Manage. **19,** 1080–1088.

Bruch, R. M., 1999: Management of lake sturgeon on the Winnebago System – long term impacts of harvest and regulations on population structure. J. Appl. Ichthyol. **15,** 142–152.

Ceskleba, D. G.; AveLallemant, S.; Thuemler, T. F., 1985: Artificial spawning and rearing of lake sturgeon, *Acipenser fulvescens*, in Wild Rose State Fish Hatchery, Wisconsin, 1982–1983. Environ. Biol. Fish. **14,** 79–85.

D'Amours, J.; Thibodeau, S.; Fortin, R., 2000: Comparison of lake sturgeon (*Acipenser fulvescens*), *Stizostedian* spp., *Catastomus* spp., *Moxostoma* spp., quillback (*Carpiodes cyprinus*), and mooneye (*Hiodon tergisus*) larval drift in Des Praires River, Quebec. Can. J. Zool. **79,** 1472–1489.

Harkness, W. J. K.; Dymond, J. R., 1961: The Lake Sturgeon. Ontario Department of Lands and Forests, Fish and Wildlife Branch, Toronto, Ontario, Canada. pp. 115.

Hay-Chmielewski, E. M., 1987: Habitat preferences and movement patterns of the lake sturgeon (*Acipenser fulvescens*) in Black Lake, Michigan. Report No. 1949. Michigan Department of Natural Resources Fisheries Research, MI.

Johnston, T. A.; Gaboyry, M. N.; Janusz, R. A.; Janusz, L. R., 1995: Larval fish drift in the Valley River, Manitoba: influence of abiotic and biotic factors, and relationships with future year-class strengths. Can. J. Fish. Aquat. Sci. **52,** 2423–2431.

Kempinger, J. J., 1988: 11th Annual Larval Fish Conference on Spawning and early life history of lake sturgeon in the Lake Winnebago System, Wisconsin. Am. Fish. Soc. Symp. **5,** 110–122.

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 Montreal, Quebec. Can. J. Zool. **70,** 1681–1689.

Lyons, J.; Kempinger, J. J., 1992: Movements of Adult Lake Sturgeon in the Lake Winnebago System. Research Report 156. Wisconsin Department of Natural Resources, Madison, WI, pp. 18.

Pavlov, D. S., 1994: The downstream migration of young fishes in rivers: mechanisms and distribution. Folia Zool. **43,** 193–208.

Priegel, G. R.; Wirth, T. L., 1971: The Lake Sturgeon: Its Life History, Ecology and Management. Wisconsin Department of Natural Resources Publication, Madison, WI, 4:3600 (77). pp. 20.

Scott, W. B.; Crossman, E. J., 1973: Freshwater Fishes of Canada. Fisheries Research Board of Canada, Ottawa, Canada, Bulletin 184. pp. 966.

Smith, K. M., 2003: Spawning stock abundance and larval production of lake sturgeon (*Acipenser fulvescens*) in Black Lake, Michigan. Master's thesis. Central Michigan University, Mount Pleasant, MI. pp. 115.

Smith, K. M.; Baker, E. A., 2005: Characteristics of spawning lake sturgeon in the Upper Black River, Michigan. N. Am. J. Fish. Manage. (in press).

TMWC and NMCG, 1991: Black Lake Watershed: nonpoint source management plan. Prepared by Ann Baughman, Doug Fuller at the Tipp of the Mitt Watershed Council, Conway, MI and Rick Deuell, Diane Rekowski at the Northeast Michigan Council of Governments, Gaylord, MI. pp. 129.

Veshchev, P. V.; Novikova A., 1983: Reproduction of the stellate sturgeon (*Acipenser stellatus*) under regulated flow conditions in the Volga River. J. Ichthyol. **23,** 42–50.

Veshchev, P. V.; Slivka, A.; Novikova, A.; Shekhodanov, K., 1994: Guidelines for counting sturgeon eggs and migrating larvae in rivers. Hydrobiol. J. **30,** 5–13.

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: Biology and Aquaculture Potential. P. Binkowski and S. I. Doroshov (Eds). Dr W. Junk, Dordrecht, The Netherlands. pp. 43–50.

Author's address: Kregg M. Smith, Central Michigan University,
Mount Pleasant, MI 48859, USA.
E-mail: smithkrm@michigan.gov

Present address: Michigan Department of Natural
Resources, 621 N 10th Street, Plainwell, MI 49080,
USA.