Transactions of the American Fisheries Society 134:1400–1409, 2005

DOI: 10.1577/T04-179.1

Seasonal Movement Patterns and Habitat Preferences of Age-0 Lake Sturgeon in the Lower Peshtigo River, Wisconsin

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Abstract.—Efforts to restore lake sturgeon *Acipenser fulvescens* to former population levels in the Great Lakes will benefit from a thorough understanding of the species' early life history. The rehabilitation of this species will be aided by identifying nursery habitats in riverine environments through characterizing the habitat use and movements of age-0 fish. The objectives of this study were to determine the habitat preferences and movement patterns of age-0 lake sturgeon in the lower Peshtigo River, Wisconsin, a tributary of Lake Michigan. Fish were captured from June through October 2002 and 2003 by means of wading, snorkeling, haul-seine, and backpack electrofishing surveys, and radio transmitters were attached to individuals larger than 74 g. For each capture and relocation site, habitat features were evaluated by measuring water depth, velocity, and temperature and by characterizing substrate type and macroinvertebrate assemblage. Age-0 lake sturgeon were collected and relocated at water depths less than 2 m over sand substrates and at current velocities less than 0.60 m/s. Capture and relocation sites were dominated by dipteran larvae, and the median macroinvertebrate density was lower at these sites than in the remainder of the study area. Macroinvertebrate diversity index values were also lower at capture sites than in the overall study area. Daily movements of age-0 lake sturgeon showed that fish exhibited greater activity after dark, whereas seasonal movement patterns were related to changes in water temperature, particularly during fall months as fish moved from the river to Green Bay. These results suggest that shallow, riverine areas with sand substrates, low current velocity, and a predominance of dipteran larvae should be protected as important nursery habitats in Great Lakes tributaries that support spawning populations of lake sturgeon.

Lake sturgeon *Acipenser fulvescens* are distributed throughout the Laurentian Great Lakes, Mississippi River, and Hudson Bay drainages (Harkness and Dymond 1961). Historically an important commercial species, lake sturgeon populations declined substantially in the late 1800s because of overharvest, habitat loss, dam construction, and industrial pollution (Harkness and Dymond 1961; Scott and Crossman 1973; Organ et al. 1978; Hay-Chmielewski and Whelan 1997). The population abundance of lake sturgeon in the Great Lakes is currently estimated at 1% of their historical levels; hence, this species is now considered imperiled throughout U.S. waters of the basin (Hay-Chmielewski and Whelan 1997; Elliott 1998). Attempts to restore lake sturgeon have been limited by several factors, including limited information on nursery habitat requirements and on the river-residency duration of early life stages. Examination of movement patterns and habitat requirements of age-0 lake sturgeon should facilitate future rehabilitation efforts for this species in the Great Lakes (Elliott 1998; Holey et al. 2000).

Several studies have examined movement patterns of adult lake sturgeon (Fortin et al. 1993; Rusak and Mosindy 1997; McKinley et al. 1998; Auer 1999; Borkholder et al. 2002; Hughes 2002; Knights et al. 2002). However, relatively little re-

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Received October 11, 2004; accepted June 14, 2005
Published online September 30, 2005

search has focused on the life history of the juvenile life stage (Thuemler 1988; Hughes 2002; Holtgren and Auer 2004). Thuemler (1988) followed the movements of stocked age-1 lake sturgeon in the Menominee River, Wisconsin, over 2 years and found that fish moved downstream at rates that varied within and between years. However, the movement patterns of these fish were unrelated to habitat features in the river. Similarly, juvenile lake sturgeon in the lower Niagara River, New York, exhibited variable movement patterns that were not associated with particular environmental factors (Hughes 2002). However, Holtgren and Auer (2004), examining the movement patterns of age-0 lake sturgeon in Portage Lake, Michigan, were able to link telemetry relocations of fish to abiotic and biotic habitat characteristics of each site. Therefore, understanding the relationship between environmental features, habitat use, and movements of age-0 lake sturgeon will provide an important first step in characterizing nursery requirements for this life stage.

Age-0 lake sturgeon occupy habitats somewhat similar to that of adults in riverine systems (Kempinger 1996; Chiasson et al. 1997; Peake 1999; Hughes 2002; Holtgren and Auer 2004). This life stage tends to prefer sand substrates, specifically open areas devoid of aquatic macrophytes and structure (Kempinger 1996; Peake 1999; Hughes 2002). Several studies have shown that the diet preferences of early life-stage lake sturgeon consist primarily of ephemeropteran and dipteran larvae, macroinvertebrates that are typically associated with fine substrates (Choudhury et al. 1996; Kempinger 1996; Chiasson et al. 1997; Beamish et al. 1998). Juvenile lake sturgeon also typically occupy riverine areas with low flows and shallow water depths (Kempinger 1996; Peake 1999; Hughes 2002). For example, age-0 lake sturgeon in the lower Niagara River were frequently captured in eddies where water velocities and depths were significantly lower than the areas where adults were captured in the main channel (Hughes 2002). Although habitat preferences of juvenile lake sturgeon have been previously described (Kempinger 1996; Chiasson et al. 1997; Beamish et al. 1998; Peake 1999), the physical, chemical, and biological attributes of these areas have not been quantified within this context. To accurately assess habitat use of juvenile lake sturgeon, abiotic and biotic features of the environment must be identified to determine which areas serve as important nursery habitats.

Although the presence of juvenile lake sturgeon has been documented in several Great Lakes tributaries, including the lower Peshtigo River, Wisconsin, the relationship between movement patterns and habitat use of this life stage during their river residence period remains unclear (Elliott 1998; Holey et al. 2000). The objectives of this study were to (1) determine the daily and seasonal movement patterns of age-0 lake sturgeon during their river residence period in the lower Peshtigo River; (2) determine the habitat preferences of age-0 lake sturgeon relative to their distribution in the lower Peshtigo River; and (3) examine the relationship between movement patterns and habitat use of age-0 lake sturgeon relative to physical, chemical, and biological attributes of the lower Peshtigo River. These results will provide information on the nursery habitat requirements of age-0 lake sturgeon that should facilitate restoration of this species throughout the Great Lakes basin.

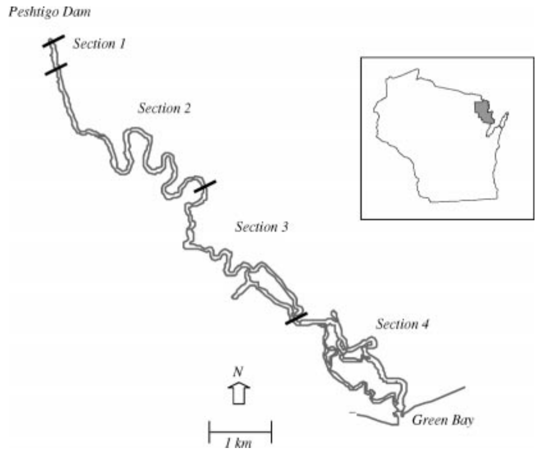

FIGURE 1.—Map of the lower Peshtigo River, a tributary of Green Bay, located in northeastern Wisconsin.

Study Site

The study area for this research was 19 km of the lower Peshtigo River, from the Peshtigo Dam to Green Bay, Wisconsin (Figure 1). Based on general morphology and substrate type, the study area could be divided into the following four areas: section 1, 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; section 2, a wide (97 m) and shallow (up to 1.3 m), gravel–sand run that extended 5.5 km downstream; section 3, a narrower (55 m), deeper (up to 2.5 m) run that extended 6.5 km downstream and contained predominantly sand substrate; and section 4, 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 *Acer* spp.—American beech *Fagus grandifolia* forest for sections 1–3 and cattail *Typha* spp.–bulrush *Scirpus* spp. wetland for section 4. The average discharge of the river was 34 m^3/s in 2002 (range = 9–120 m^3/s) and 29 m^3/s in 2003 (range = 6–107 m^3/s) as measured by the U.S. Geological Survey gauging station located immediately downstream from the Peshtigo Dam.

Methods

Fish sampling.—Age-0 lake sturgeon were captured in the lower Peshtigo River from July through October 2002 and from June through November 2003 by means of wading (with dip nets), snorkeling (with dip nets), haul-seine, and backpack electrofishing surveys. All captured fish were measured (total length, fork length, and maximum girth, all to the nearest 1 mm) and weighed (to the nearest 0.01 g). At each capture location, latitude and longitude were recorded with a Magellan 315 Global Positioning System unit (Orbital Company, San Dimas, California), and water depth and current velocity were measured with a Price AA flowmeter attached to a top-set wading rod (Scientific Instruments, Inc., Milwaukee, Wisconsin). Water-quality parameters (i.e., temperature, dissolved oxygen, specific conductance, turbidity, and pH) were determined at each sample site by using a Hydrolab Quanta (Hydrolab-Hach Corporation, Loveland, Colorado). A substrate sample was collected with a petite Ponar dredge (15-cm^2 sample area) at each capture site. Silt and fine sand were rinsed from substrate samples by using a 12-L sieve bucket with 30-μm mesh before the remainder of the sample was preserved in 70% nondenatured ethanol.

Habitat sampling and analyses.—Physical habitat features and the macroinvertebrate assemblage of the study area were collected from the lower Peshtigo River from June through August in 2002 only with a petite Ponar dredge. Substrate samples were collected every 50 m along a longitudinal gradient from the Peshtigo Dam to the river mouth (N = 667 substrate samples). At each transect, three samples were collected at points equidistant across the width of the river. After the dominant substrate type was visually identified from each dredge sample, a 12-L sieve bucket with 30-μm mesh was used to rinse silt and fine sand from substrate samples before they were preserved in 70% nondenatured ethanol. Dominant substrate type was classified according to the criteria of McMahon et al. (1996). At each site, latitude, longitude, depth, velocity, and water-quality parameters were measured as described previously.

All substrate samples were processed in the laboratory. Macroinvertebrates were separated from the substrate, identified to family, and enumerated by using a stereomicroscope with transmitted light at 0.63–4.0× magnification. The predominant taxon in each sample was considered to be the macroinvertebrate family with the greatest number of individuals. Macroinvertebrate density was measured as the total number of individuals from all taxa in each sample. Diversity of macroinvertebrate taxa was estimated by means of Simpson's diversity index (D) to determine the probability of randomly selecting two individuals from each sample that were the same species. The index is computed as follows:

$$D = 1 - \sum p_i^2,$$

where p_i is the proportion of species i in each sample (Krebs 1999).

Using the coordinates from each substrate collection site, map layers of the macroinvertebrate assemblage characteristics were developed with ArcView GIS 3.2 (ESRI, Inc., Redlands, California). The distribution of the predominant macroinvertebrate taxa, their density, and diversity were interpolated to estimate the areas of each category. Factor analysis was used to determine the importance of habitat characteristics to the locations of captured fish. The Strauss index of selectivity (L) was used to determine whether age-0 lake sturgeon selected for particular habitat features. The index is computed as follows:

$$L = r_i - p_i,$$

where r_i is the proportion of fish captured in habitat feature i and p_i is the proportion of habitat feature i in the overall study area (Strauss 1979). This index was also calculated for biotic and abiotic variables identified in the factor analysis that explained variability in fish capture locations.

Radiotelemetry.—Radio transmitters (Model F1910; Advanced Telemetry Systems, Isanti, Minnesota) were externally attached to age-0 lake sturgeon in September and October 2002 and September through November 2003. Transmitters were 23 mm long, 9 mm in diameter, and 1.6 g in weight and had a pulsed microprocessor beeper frequency. To minimize effects on growth and movement

(Sutton and Benson 2003), only fish that weighed at least 74 g received a transmitter so that the weight of the attachment did not exceed 2% of fish body weight. Each transmitter was uniquely coded by frequency (148.0–149.0 MHz).

Juvenile lake sturgeon were anesthetized with a 70-mg/L solution of tricaine methanesulfonate. Transmitters were attached to the left side of each fish by running the two attachment wires from the transmitter beneath the second and fourth dorsal scutes with a sterilized cutting needle. Transmitters were anchored with disk-backing plates on the right side of the fish, and wire sleeves were crimped to hold it in place. Because transmitter batteries had a minimum life span of 14 d, fish were recaptured with dip nets every 14–21 d so that transmitters could be replaced. When a fish was recaptured to replace an existing transmitter, the transmitter was removed and a new one attached by threading the wires under the third and fifth dorsal scutes. After transmitters were attached, each fish was allowed to recover for up to 10 min before being released at the capture location. After release, each fish was observed to make sure it could maintain position in the current and to check that the transmitter was operating properly.

Each lake sturgeon was tracked at least once, but usually twice each day (once during daylight and once at night), by using a hand-held, four-element Yagi antenna and a Challenger Model R2000 programmable scanning receiver (Advanced Telemetry Systems). During each tracking occasion, fish with transmitters were typically observed visually to determine their behavior during both day and night hours. Fish were tracked only as long as they remained in the river or as long as the transmitter continued to function. Before their downstream movement to Green Bay, fish remained in the same general area as where they were first captured. Movements within this area between each tracking observation were measured to determine home range size of fish in terms of longitudinal river length (m). Latitude and longitude were recorded at each relocation site, and depth, current velocity, and water quality were measured as described previously. A petite Ponar dredge was used to collect a substrate sample from each relocation site, and substrate samples were processed and analyzed as described previously.

Statistical analyses.—Daily movements of lake sturgeon were determined by measuring the distance moved by each fish during subsequent observations. The daily movement patterns of individual fish were compared to daily water temperature and discharge. Median distances moved between tracking periods were calculated and used to estimate the median daily rate of movement. Seasonal movements among fish were compared by determining the monthly movement rates for fish that were tracked for at least 1 month in 2003. Differences in abiotic and biotic habitat features of the tracking locations, and medians of the entire study area, were analyzed with a Mann–Whitney test. This test was used to determine if there were differences between abiotic and biotic habitat features of tracking locations in 2002 and 2003, as well as between sampling years relative to the habitat features of the overall study area. The Mann–Whitney test was also used to compare the range of daily movement rate ranges between 2002 and 2003. For all statistical analyses, we used SPSS 11.0.1 statistical analysis program (SPSS, Inc., Chicago, Illinois), and methods of statistical testing followed those outlined in Zar (1999). All statistical analyses were considered significant at $P < 0.05$.

Results

Thirteen age-0 lake sturgeon were captured in 2002, and 245 fish were captured in 2003. Fish captured in 2002 had a median total length of 235 mm (range = 209–272 mm) and median wet weight of 57 g (range = 35–90 g). In 2003, age-0 lake sturgeon had a median total length at first capture of 136 mm (range = 40–316 mm) and median wet weight of 10.4 g (range = 0.2–134 g). Differences in median length and weight of lake sturgeon between years were due to the timing of sampling; fish in 2002 were captured only during fall months after their summer growth, whereas fish in 2003 were captured throughout both summer and fall.

Habitat Use

Age-0 lake sturgeon in 2002 and 2003 were found only over sand substrates throughout the lower two-thirds of the study area, primarily sections 3 and 4. During both sampling years, only two fish were captured from section 2 and no fish were collected from section 1. The predominant substrate type in the lower Peshtigo River was sand (75.9%), which was located almost entirely in sections 3 and 4 of the river. The remaining substrate types, which were located primarily in sections 1 and 2 of the study area, consisted of gravel (14.9%), cobble (4.9%), silt (4.0%), and boulders (0.4%). The median current velocity for the overall

TABLE 1.—Median current velocity, water depth, and temperature at age-0 lake sturgeon capture and telemetry tracking relocation sites and the entire study area in the lower Peshtigo River, Wisconsin, 2002 and 2003. Ranges of values are given in parentheses, and *N* is the sample size.

Sites	*N*	Velocity (m/s)	Depth (m)	Temperature (°C)
2002 capture sites	13	0.33 (0.21–0.48)	0.56 (0.32–0.90)	19.3 (14.5–26.1)
2003 capture sites	242	0.29 (0.00–0.53)	0.66 (0.20–1.74)	21.7 (8.9–27.2)
Relocation sites	433	0.32 (0.00–0.59)	1.30 (0.40–6.50)	11.44 (1.16–19.71)
Study area	552	0.38 (0.00–0.89)	1.24 (0.20–7.62)	25.3 (23.1–28.4)

study area was 0.38 m/s, which was not significantly different from current velocity estimates for the sites where age-0 lake sturgeon were captured in 2002 (median = 0.33 m/s; $Z = 0.840$, $P = 0.401$; Table 1). Current velocity at capture locations in 2003 was not compared against the overall study area velocity measurements, which were only taken in 2002. Median current velocity at capture locations between years was not significantly different ($Z = -1.427$, $P = 0.153$). The median depth of the lower Peshtigo River was 1.24 m. Fish were captured at a median depth of 0.56 m in 2002 and at 0.66 m in 2003 (Table 1). In 2002 and 2003, the median depth at which fish were captured was significantly less than the median depth of the entire study area ($Z = -4.821$, $P < 0.001$ and $Z = -13.923$, $P < 0.001$, respectively). The median depth at fish capture locations was not significantly different between years ($Z = -0.414$, $P = 0.679$).

The predominant macroinvertebrate taxon at lake sturgeon capture locations in both years, as well as in the entire study area, was Chironomidae (Diptera) larvae (Table 2). Ceratopogonidae (Diptera) larvae, Oligochaeta, and Hydropsychidae (Trichoptera) larvae were also found in samples but at lower densities. Lower Densities of Ceratopogonidae larvae and higher densities of Oligochaeta were lower and higher, respectively, at 2002 capture locations ($Z = -2.494$, $P = 0.013$) than at 2003 capture locations. Chironomidae were proportionally more abundant at 2003 capture sites than in the entire study area ($Z = -5.032$, $P < 0.001$). In 2002, the median density of macroinvertebrates at capture locations was 53 individuals/m^2 and the median macroinvertebrate diversity was 0.14. By comparison, in 2003 the median macroinvertebrate density at capture locations was 33 individuals/m^2 and median diversity was 0.24. Throughout the study area, the median macroinvertebrate density was 67 individuals/m^2 and median diversity was 0.26. Macroinvertebrate density at capture locations in 2002 was significantly lower than for the entire study area ($Z = -2.877$, $P = 0.004$) and significantly higher than at capture locations in 2003 ($Z = -2.199$, $P = 0.028$). Similarly, macroinvertebrate density at 2003 capture locations was significantly lower than for the entire study area ($Z = -3.890$, $P < 0.001$). The macroinvertebrate diversity for age-0 lake sturgeon capture locations in 2002 and 2003 was not significantly different from that for the entire study area ($Z = -1.272$, $P = 0.203$ and $Z = -0.298$, $P = 0.766$, respectively) or between years ($Z = -1.337$, $P = 0.181$).

Two factors were retained in the factor analysis and together explained 74% of the variability in age-0 lake sturgeon capture locations (Table 3). The highest loading for the first factor was macroinvertebrate diversity, indicating that factor 1 was biotic and that 52% of the variability in lake sturgeon capture locations could be explained by this component. The second highest factor loadings were for water depth and velocity, indicating that these two constructs were abiotic and ex-

TABLE 2.—Macroinvertebrate assemblage characteristics (percentages of all five macroinvertebrate categories shown) at age-0 lake sturgeon capture sites, relocation sites, and the entire study area in the lower Peshtigo River, Wisconsin, 2002 and 2003. Median macroinvertebrate density and diversity are also reported, with ranges in parentheses. Category ''other'' refers to macroinvertebrates that were found in very small percentages, and *N* is the sample size. Density is the number of individuals/m^2; diversity was calculated according to Simpson's diversity index.

Sites	*N*	Chironomidae	Ceratopogonidae	Oligochaeta	Hydropsychidae	Other	Density	Diversity
2002 capture sites	13	55.6	11.1	11.1	0.0	22.2	53 (0–907)	0.14 (0.00–0.56)
2003 capture sites	242	58.4	30.0	4.2	0.0	7.4	33 (0–2,013)	0.24 (0–0.72)
2003 relocation sites	433	32.6	55.8	1.0	0.5	10.1	50 (0–580)	0.44 (0.00–0.83)
Study area	552	56.4	17.8	3.7	4.9	17.2	67 (0–2,727)	0.26 (0–0.87)

TABLE 3.—Factor analysis loadings for biotic and abiotic variables from age-0 lake sturgeon capture sites in the lower Peshtigo River, Wisconsin, in 2002 and 2003. Two components were extracted based on eigenvalues equal to one and explained 74% of the variance in the data matrix.

Variable	Biotic constructs	Abiotic constructs
Temperature (°C)	−0.34532	−0.43394
Velocity (m/s)	−0.14524	0.86948
Depth (m)	0.11174	0.61771
Macroinvertebrate density (individuals/m^2)	−0.02249	−0.24500
Macroinvertebrate diversity[a]	0.99664	−0.00199

[a] Simpson's diversity index.

plained an additional 22% of the variability in capture locations. Lake sturgeon were found to show strong positive selection for sand substrates in both 2002 and 2003 (Table 4). In both years, fish were also found to positively select areas with macroinvertebrate diversity index values that ranged from 0.26 to 0.50, depths less than 0.50 m, and water velocities between 0.20 and 0.40 m/s (Table 4).

Radiotelemetry

Lake sturgeon with attached radio transmitters were each located for an average of 10 d in 2002 and 31 d in 2003 (Table 5). In 2002, the mean fork length at first capture of tracked fish was 236 mm (range = 224–244 mm) and the average wet weight was 84 g (range = 76–90 g). The mean fork length of fish tracked in 2003 was 240 mm (range = 223–253 mm) and the average wet weight was 82 g (range = 74–95 g). The home range of individuals in both sampling years varied from 0 to 500 m in river length. In 2002, all four fish with attached transmitters initially remained near the location where they were first captured and released. After the first week of tracking, river discharge increased from 24 to 62 m^3/s over a 3-d period. As discharge increased, water temperatures in the river dropped from 16°C to less than 13°C, at which point fish began to move downstream. Within 3 d, three fish had left the river and moved into Green Bay. The transmitter for the fourth fish failed, and downstream movements of this individual are not included in these analyses.

Eleven fish were fitted with transmitters in 2003. Transmitters failed on three fish and the transmitter was displaced on a fourth fish; therefore, movements of these individuals were not included in the analyses. Movement patterns of the seven age-0 lake sturgeon that were tracked in 2003 differed from those for fish tracked in 2002. River discharge during the tracking period in 2003 was significantly lower than in 2002 ($Z = -5.535$, $P < 0.001$). As water temperatures dropped below 13°C in 2003, fish did not immediately leave the river as in 2002. Instead, fish in 2003 began moving slowly downstream when water temperatures

TABLE 4.—Strauss selectivity index values for habitat features of age-0 lake sturgeon capture locations in the lower Peshtigo River, Wisconsin, in 2002 and 2003.

Habitat feature	Habitat feature types	Index value
Substrate type	Sand	0.98
	Gravel	−1
	Cobble	−1
	Silt	−1
	Boulder	−1
Macroinvertebrate diversity[a]	Low (0–0.25)	−0.007
	Medium–low (0.26–0.50)	0.140
	Medium–high (0.51–0.75)	−0.147
	High (0.75–1.00)	−1
Depth (m)	0.00–0.50	0.25
	0.51–1.00	−0.30
	>1.01	−0.96
Flow (m/s)	0.000–0.100	−0.733
	0.101–0.200	−0.394
	0.201–0.300	−0.288
	0.301–0.400	−0.221
	>0.401	−0.771

[a] Simpson's diversity index.

TABLE 5.—Capture, relocation, and daily movement data for age-0 lake sturgeon fitted with radio transmitters in the lower Peshtigo River, Wisconsin, in 2002 and 2003. Range of daily movement is in parentheses.

Year	Fish no.	Fork length (mm)	Wet weight (g)	Days observed	Mean daily movement (m/d)	Date of last contact	Fate of sturgeon
2002	1	224	76	10	204 (0–2,212)	8 Oct 2002	Left the river
	2	244	83	8	555 (0–4,382)	10 Oct 2002	Left the river
	3	240	90	7	409 (0–1,963)	8 Oct 2002	Left the river
	4	237	88	17	15 (0–77)	17 Oct 2002	Unknown
2003	5	230	82	13	203 (0–1,828)	30 Sep 2003	Left the river
	6	242	88	18	238 (0–2,186)	7 Oct 2003	Left the river
	7	239	78	47	137 (0–3,094)	6 Nov 2003	Left the river
	8	240	74	33	148 (0–1,416)	23 Oct 2003	Left the river
	9	223	75	54	112 (0–1,179)	14 Nov 2003	Left the river
	10	253	95	15	659 (0–4,625)	19 Oct 2003	Left the river
	11	253	84	25	83 (0–984)	17 Nov 2003	Left the river
	12	232	74	6	97 (22–220)	25 Sep 2003	Unknown
	13	238	89	57	108 (0–3,150)	17 Nov 2003	Unknown
	14	249	84	31	98 (0–438)	22 Oct 2003	Unknown
	15	236	81	44	86 (0–1,731)	17 Nov 2003	Unknown

dropped below 13°C and left the river singly, over a 1-month period, at a slower rate than in 2002. In 2003, the median daily movement for fish was 38 m/d (range = 0–4,625 m/d; Table 5), significantly higher than the median of 0 m/d (range = 0–5,121 m/d) in 2002 ($Z = -4.921$, $P < 0.001$). Six of the seven fish tracked in 2003 were observed for at least 1 month; their mean monthly movement was 3,480 m/month (range, 2,569–4,897 m/month).

Age-0 lake sturgeon tracked by using radiotelemetry were located predominantly over sand substrates and at a median current velocity of 0.32 m/s, which was significantly lower than in the remainder of the study area ($Z = -3.523$, $P < 0.001$; Table 1). The depth at relocation sites (median = 1.30 m) was not significantly different from that of the overall study area ($Z = -0.465$, $P = 0.642$; Table 1). The predominant macroinvertebrate family at relocation sites was Ceratopogonidae, followed by Chironomidae (Table 2). The macroinvertebrate density at relocation sites (median = 50 individuals/m^2) was significantly lower than in the study area ($Z = -2.716$, $P = 0.007$; Table 2). In contrast, macroinvertebrate diversity at relocation sites (median = 0.44) was significantly greater than in the study area ($Z = -6.134$, $P < 0.001$; Table 2).

Discussion

Several studies have examined the habitat preferences and food habits of age-0 lake sturgeon, but few have attempted to characterize their movement patterns (Thuemler 1988; Kempinger 1996; Chiasson et al. 1997; Beamish et al. 1998; Peake 1999; Hughes 2002; Holtgren and Auer 2004). Evaluations of habitat use and diet preferences have determined that sturgeon inhabit areas with sand substrates and low current velocities and prefer to feed on Diptera and Ephemeroptera larvae. However, studies that attempted to characterize age-0 lake sturgeon habitat use did not determine availability within the systems studied or compare seasonal preferences of these fish. Trends in movement patterns of age-0 sturgeon, regardless of species, have not been conclusive, although some have suggested that long-term movements are influenced by water temperature (Thuemler 1988; Carr et al. 1996; Kempinger 1996; Sulak and Clugston 1998). In the lower Peshtigo River, we determined that age-0 lake sturgeon used areas with sand substrates, low current velocities, and macroinvertebrate assemblages dominated by dipterans. Movement patterns indicated that declines in water temperature during fall months prompted fish to move downstream, possibly in search of warmer and deeper waters. Based on our results, the habitat preferences and movement patterns of age-0 lake sturgeon in the lower Peshtigo River were similar to previous studies of this life stage in other Great Lakes tributaries.

Age-0 lake sturgeon in the Peshtigo River were found throughout the lower two-thirds of the river over sand substrates in areas with shallow depths and low current velocities. Auer and Baker (2002) determined that larval lake sturgeon in the Sturgeon River, Michigan, settled out of the current near the river mouth and used the lower 10 km of that system as nursery habitat. Juvenile lake sturgeon were typically captured from the Sturgeon

River and lower Niagara River, New York, at relatively shallow depths (Holtgren and Auer 2004; Hughes 2002). Laboratory studies examining the behavior of juvenile lake sturgeon found that fish preferred areas with sand substrates and low current velocities, possibly because of their weak swimming abilities (Peake et al. 1997; Peake 1999). Juvenile Gulf of Mexico sturgeon *A. oxyrinchus desotoi* also exhibited a similar preference for sand substrates and low current velocities in laboratory experiments (Chan et al. 1997). In the Wolf (Wisconsin), lower Niagara, and Mattagami and Groundhog (Ontario) rivers, age-0 and older juvenile lake sturgeon had similar substrate and velocity preferences as laboratory fish and avoided aquatic macrophytes and coarse substrates (Kempinger 1996; Chiasson et al. 1997; Hughes 2002). Juvenile Russian sturgeon *A. guldenstadti*, ship sturgeon (also known as the thorn sturgeon) *A. nudiventris*, sevryuga sturgeon *A. stellatus*, and beluga sturgeon *Huso huso* also avoided areas with submerged vegetation and selected open, sandy areas (Sbikin and Bibikov 1988). Russian sturgeon were better able to access prey items found in sand than in coarse substrates, which may explain the preference that juvenile sturgeons have for finer substrate types (Levin 1988). Age-0 and older juvenile white sturgeon *A. transmontanus* were typically found over sand as well, in addition to coarser substrates (Parsley et al. 1993).

Suitable nursery areas for lake sturgeon are in part determined by the availability of benthic macroinvertebrate prey (Chiasson et al. 1997). In the lower Peshtigo River, the benthic macroinvertebrate assemblage was dominated by dipteran larvae (primarily Chironomidae). However, there was a difference between the macroinvertebrate density and predominant taxa of dipteran larvae present throughout the study area and age-0 lake sturgeon capture locations (Chironomidae) compared with those in relocation sites (Ceratopogonidae). Differences in the density of the predominant macroinvertebrate taxon between relocation sites and the remainder of the study area could also be a result of sampling relocation sites only during the fall, when water temperatures were declining. In contrast, the remainder of the study area was sampled during warmer summer months. Similarly, differences between lake sturgeon capture and relocation sites may have resulted from capture locations being sampled only during the summer. Therefore, habitat preferences of age-0 fish in the lower Peshtigo River did not change during summer and fall months, even though the available macroinvertebrate assemblage varied on a temporal basis. In juvenile lake sturgeon nursery areas located in the Mattagami and Groundhog rivers, the benthic macroinvertebrate community was similarly dominated by larval dipterans (Chironomidae and Ceratopogonidae; Chiasson et al. 1997). Although macroinvertebrate densities in the lower Peshtigo River were variable, they were low relative to the Mattagami and Groundhog rivers. Based on the benthic macroinvertebrate fauna collected in these systems, diversity was also low but similar to that in the Peshtigo River. Juvenile lake sturgeon in the Wolf, Mattagami, and Groundhog rivers primarily consumed dipteran and ephemeropteran larvae (Kempinger 1996; Beamish et al. 1998). Similarly, the diet of juvenile shortnose sturgeon *A. brevirostrum* in the upper Hudson River estuary, New York, consisted primarily of chironomid larvae (Carlson and Simpson 1987). Therefore, the lower Peshtigo River appears to contain suitable nursery habitat for age-0 lake sturgeon, in part because the benthic macroinvertebrate assemblage is dominated by dipteran larvae, an important dietary item for this life stage.

Because daily movements of age-0 lake sturgeon have not been previously examined, diurnal and nocturnal activities for this life stage are not well understood. In the lower Peshtigo River, age-0 lake sturgeon exhibited variable daily movement patterns. During the day, fish were typically stationary on the river bottom and oriented in an upstream direction. While fish were immobile on the river bottom, their mottled dorsal surface enabled them to remain camouflaged against the sand. In contrast, at night the fish were typically observed swimming continuously while remaining close to the bottom, presumably foraging on benthic macroinvertebrates located in or on the substrate.

The home range of age-0 lake sturgeon ranged from 0 to 500 m in longitudinal river length, individuals remaining in the same locations from several days to weeks. Large-scale movements by these fish, such as the downstream movement from the Peshtigo River into Green Bay during fall months, typically occurred at night. Similar nocturnal movements of age-0 lake sturgeon have been observed in the Wolf, Mattagami, Groundhog, and lower Niagara rivers (Kempinger 1996; Chiasson et al. 1997; Hughes 2002). Juvenile lake sturgeon and shortnose sturgeon were also primarily nocturnal in laboratory environments (Richmond and Kynard 1995; Peake 1999). Levin (1988) noted that gammarids and chironomid larvae emerged from the substrate at night; their increased vulnerability to predation at that time may partially explain the nocturnal behavior of juvenile sturgeons. Therefore, the nocturnal activity of age-0 lake sturgeon may be a strategy to facilitate predator avoidance and more effectively forage for macroinvertebrate prey.

The seasonal movements of age-0 lake sturgeon have been examined on a limited basis throughout their geographic distribution. Long-term movement patterns and rates of movement for age-0 lake sturgeon in the lower Peshtigo River were highly variable, with fish moving up to 4,625 m/d before entering Green Bay. Most of these longer movements occurred during fall months, as fish began moving downstream coincident with declining water temperatures. The rate of downstream movements was much greater in 2002 than in 2003, possibly because of the higher river discharge in 2002. Age-0 lake sturgeon in the Sturgeon River were found to move long distances and exhibited rapid daily movements during late summer and early fall when fish moved from the river into deeper waters of Portage Lake (Holtgren and Auer 2004). In the Menominee River, stocked juvenile lake sturgeon also exhibited different rates of downstream movement between study years (Thuemler 1988). However, it is unknown why movement patterns differed between years or whether fish remained in the river. In the Wolf River, Kempinger (1996) hypothesized that age-0 lake sturgeon migrated downstream in the fall to deeper waters of the river or into one of the downstream impoundments. Telemetry studies conducted on age-0 Gulf of Mexico sturgeon in the Suwannee River, Florida, found that fish remained in the river until water temperatures declined during fall months and then moved into estuaries (Carr et al. 1996; Sulak and Clugston 1998). Older (ages 2 through 6) juvenile Gulf of Mexico sturgeon were also found in the Suwannee River during most of the year, but wintered in nearby estuarine areas (Sulak and Clugston 1999). Therefore, movements of age-0 sturgeons to deeper or downstream waters that are more protected from winter conditions appear to be coincident with declining water temperatures during fall months.

Based on this research, nursery habitats of age-0 lake sturgeon in the lower Peshtigo River were characterized by predominantly sand substrates in areas with low current velocities that supported a macroinvertebrate assemblage dominated by dipteran larvae. Daily movements indicated that this life stage was more active at night than during the day, possibly to avoid predators and forage more effectively. Declining water temperatures during fall months may cue fish to move downstream in search of warmer, deeper waters. As a result, areas in Great Lakes tributaries with spawning populations of lake sturgeon and having habitat characteristics similar to the lower Peshtigo River should be protected as nursery areas to facilitate recruitment and restoration efforts throughout the basin. Additional research should focus on winter habitat use and movement patterns of age-0 fish after they leave tributaries and move into receiving waters.

Acknowledgments

We thank S. Donabauer, T. Bacula, P. Wilson, P. DeHaan, B. Gunderman, K. Konyn, S. Kuchenberg, A. Hinickle, J. Simon, S. Reed, K. Maravilla, and L. Lindley for their assistance in the field and laboratory. Constructive comments on an earlier draft by J. Dunning, B. Fisher, D. DeVries, and five anonymous reviewers improved this manuscript. The experimental procedures used in this research were approved by the Purdue University Animal Care and Use Committee as protocol 01–058. Support for this research was provided by the Great Lakes Fishery Trust and the Department of Forestry and Natural Resources at Purdue University. This research was approved for publication as manuscript 17492 by the Purdue University Agricultural Research Program.

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