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[Article]

Movement and Habitat Use of Yearling and Juvenile Lake Sturgeon in Black Lake, Michigan

KREGG M. SMITH*[1] AND DONNA K. KING

Central Michigan University, 155 Brooks Hall, Mount Pleasant, Michigan 48859, USA

Abstract.—Information about the distribution, movement, and home ranges of lake sturgeon *Acipenser fulvescens* was incomplete in the Great Lakes region; therefore, the objective for this study was to determine habitat selection and the extent of movement by two life stages of lake sturgeon in Black Lake, Michigan. Ultrasonic transmitters were surgically implanted into yearling (age-1) and juvenile (age-5–13) lake sturgeon. The yearling lake sturgeon implanted with transmitters averaged 36.04 cm total length (TL) and 207.2 g, while the juvenile lake sturgeon tracked during this survey averaged 97.23 cm TL. Previous studies of movements and habitat use by lake sturgeon have noted distinct areas of use by groups of adult lake sturgeon in riverine environments. In contrast to these findings, yearling and juvenile lake sturgeon in the present study used individual areas of activity. Comparisons between our study and studies conducted in lotic environments suggest that core areas of activity for groups of lake sturgeon may be more important for lake sturgeon inhabiting flowing environments. Two distinct mean depths (nearshore and deep offshore habitats) were used by yearlings, while juveniles utilized deep, flat-bottomed offshore habitat. Yearling lake sturgeon were associated significantly with sand and organic substrate types rather than clay or sand–organic substrate, while juveniles were associated with organic substrate types. Median distances moved between locations were significantly different between yearlings that used nearshore habitat and those that used offshore habitat. Juvenile lake sturgeon larger than 90 cm displayed longer median daily linear movements and occupied larger home ranges than did juveniles smaller than 90 cm. The findings from this study illustrate the different habitats used at various lake sturgeon life history stages in a lake environment.

Studies of the behavior of lake sturgeon *Acipenser fulvescens* have focused on adult movement and habitat use (Fortin et al. 1993; Rusak and Mosindy 1997; McKinley et al. 1998; Auer 1999). Early tagging studies showed that adults typically migrate out of lakes (including fluvial lakes) to spawn (migration movements end at barriers), after which they return to distinct foraging areas of lakes (Harkness and Dymond 1961; Lyons and Kempinger 1992; Rusak and Mosindy 1997). Other than their spawning migrations, information on the seasonal movement and wintering behavior of lake sturgeon is limited. Evidence from large rivers suggests that lake sturgeon use activity centers (Borkholder et al. 2002) or core areas (Knights et al. 2002), which indicates some selection of a home range. In fluvial lakes of the St. Lawrence and Ottawa rivers, Quebec, adult and subadult lake sturgeon are sedentary during nonspawning periods (Fortin et al. 1993).

* Corresponding author: smithkrm@michigan.gov

[1] Present address: Michigan Department of Natural Resources, 621 North 10th Street, Plainwell, Michigan 49080, USA.

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The spatial ecology and habitat use by lake sturgeon at different life stages are partially understood. Only a few studies have been conducted on the distribution patterns of lake sturgeon larvae (Kempinger 1988; Lahaye et al. 1992; D'Amours et al. 2000; Auer and Baker 2002; Smith and King 2005), and only limited information is available on the juvenile and subadult life stages (Thuemler 1988; Kempinger 1996; Haxton 2003). The rehabilitation of lake sturgeon populations throughout the Great Lakes has been hindered by this lack of life history knowledge.

Movement and habitat selection by lake sturgeon in previous studies have been documented for lotic habitats or for populations occupying large water bodies (Lyons and Kempinger 1992; Rusak and Mosindy 1997; McKinley et al. 1998). There have been few investigations of spatial ecology requirements for juvenile lake sturgeon, particularly within populations that have restricted movements (Thuemler 1988); even fewer studies have been conducted for inland lakes that have become isolated from the Great Lakes. Studies of isolated lake sturgeon populations will be important to the future management of the species because most populations are currently restricted to habitats that are smaller than they were historically. Moreover, behavioral differences in movement patterns may exist in genetically different populations. Consequently, information that documents the range and habitat use of juvenile lake sturgeon in systems with different available habitat types will be important for completing the knowledge of early life history requirements.

Black Lake, Michigan, offers an opportunity to study the habitat use and movement patterns of lake sturgeon because dams have restricted the population to a small, confined system. The movements of Black Lake adult lake sturgeon have already been documented (Hay-Chmielewski 1987); however, the movement patterns and habitat use of yearling and juvenile lake sturgeon are not well understood. Black Lake is appropriate for a study of habitat selection by lake sturgeon because of its diverse habitats, including water depths to 15.3 m, steep-sloped and flat-bottomed habitats, variable substrate types (clay, organic, silt, and sand), and vegetated plus nonvegetated areas. The lake sturgeon population of Black Lake has supported an economically and culturally valuable fishery for the last 54 years. Legal harvest of 486 lake sturgeon was reported for the years from 1974 to 2002 (Baker 1980; Michigan Department of Natural Resources [MDNR], unpublished data). An understanding of habitat requirements and behavior of additional lake sturgeon life history stages will provide critical ecological information on early life history and will allow fisheries managers to regulate the fishery. The objective for this study was to determine habitat selection and the extent of movement by two life stages of lake sturgeon in Black Lake.

Study Site

Black Lake, situated in Cheboygan and Presque Isle counties (Figure 1), is the eighth-largest inland lake in Michigan, possessing a surface area of 4,101 ha (Hay-Chmielewski 1987). The lake has two basins; the average depth of the entire lake is 7.5 m, and the maximum depth of 16.8 m occurs in the southern basin. The northern basin has a maximum depth less than 10 m. The maximum width of the lake is 4.8 km, and the maximum length is 9.6 km. The lake has a large, shallow, sandy perimeter that first gradually (1:0.0033) and then sharply (1:0.0615) slopes to a large, flat muck basin in the southern portion (Hay-Chmielewski 1987).

The Upper Black River from Kleber Dam to the confluence at Black Lake is the primary lotic habitat for the lake sturgeon population. The Upper Black River is 91.7 km long, but sturgeon migration is restricted by Kleber Dam, located 11 km from the river's confluence with Black Lake. The Lower Black River (16.4 km) is the only source of outflow from the lake and once was the conduit for lake sturgeon migration between Black Lake and Lake Huron. Alverno Dam, located on the Lower Black River 8 km downstream from the lake, was constructed in 1903 and now isolates Black Lake from Lake Huron.

Methods

Capture, tagging, and tracking of lake sturgeon.—We raised lake sturgeon larvae to the yearling stage so that ultrasonic transmitters could be inserted into the fish during the spring of 2002. During previous research, it became evident that capturing juvenile lake sturgeon required an enormous amount of effort but that larval drift sampling was an ideal means to collect and rear fish (Smith and King 2005). In addition, the use of larvae collected from the wild population allowed us to use fish that would exhibit genetically predetermined behaviors reflective of the wild fish from the Black Lake system. In 2001, lake sturgeon larvae collected from drift-net samples in the Upper Black River (Smith and King 2005) were transferred to an on-site holding facility used to rear larvae to the yearling stage. The holding facility consisted of two 95-L, circular fiberglass tanks housed inside a stationary building adjacent to the river. A constant flow of water was pumped into the tanks directly from the river. Each lake sturgeon larva was reared on 1,000 brine shrimp *Artemia* spp. nauplii for 3–5 d. The brine shrimp were hatched out in an 18-L, cone-shaped glass tank for 24 h and then were placed into a drip bucket that was suspended above each holding tank. The larvae were held throughout each discrete drift event and were later transferred to the MDNR's Wolf Lake Hatchery for rearing to the yearling stage.

Juvenile lake sturgeon were captured during two different sampling efforts: a population estimate survey conducted in 2002, and netting surveys conducted in 2000–2002 in which the sampling effort was allocated equally among grids within a grid system of Black Lake. We used three gear types. Monofilament gill nets (stretch-mesh sizes = 10.2, 15.2, 20.3, and 25.4 cm) were used during June, July, and August of 2000–2002. Nets were checked every 2–3 h. A Smith-Root electroshocking boat and a backpack electroshocking unit were used to capture juvenile lake sturgeon in the lake

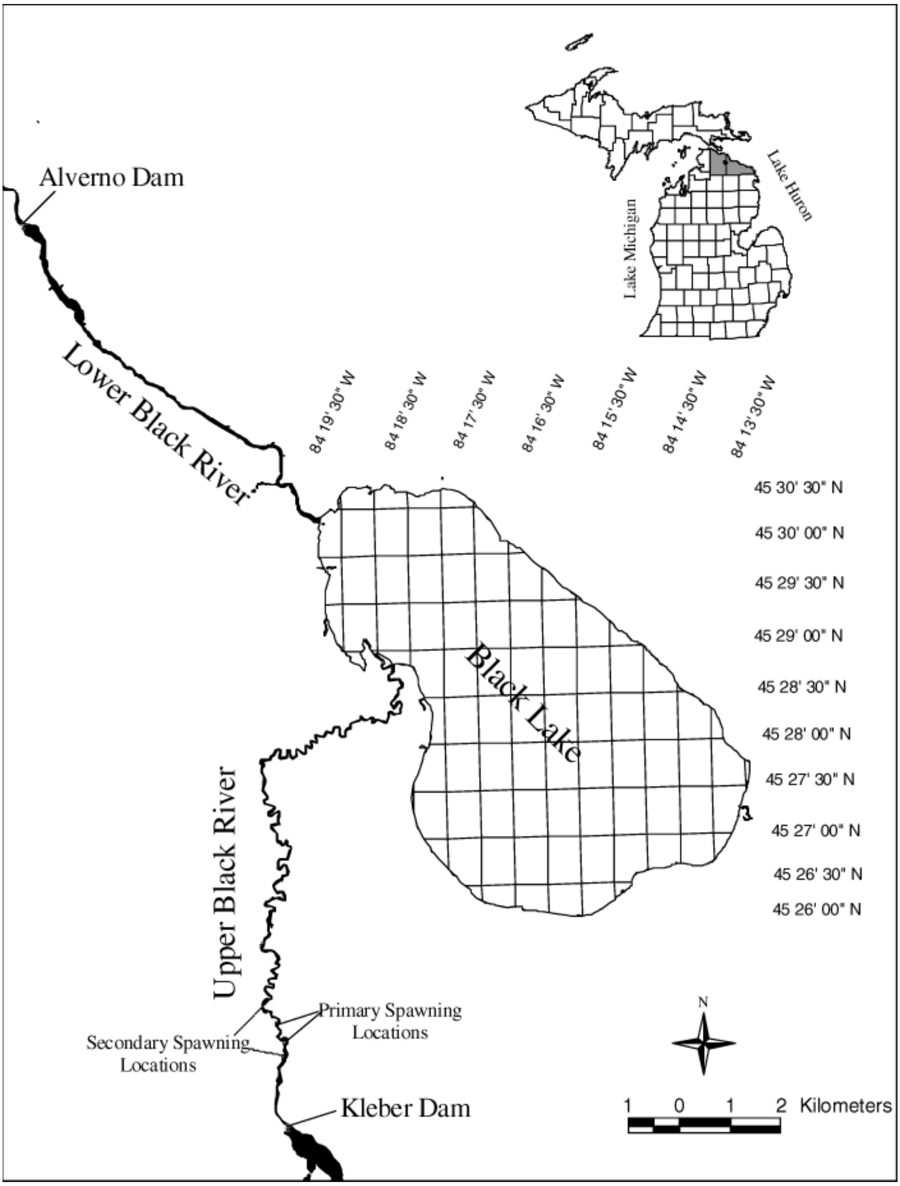

FIGURE 1.—Map of the Black Lake, Michigan, study site, showing the 0.5-min × 0.5-min grid system used for the tracking of lake sturgeon implanted with ultrasonic transmitters. The inset in the upper right-hand corner is the state of Michigan; Black Lake is located centrally within the two gray-shaded counties (Cheboygan and Presque Isle).

and Upper Black River at depths less than 2.0 m. Boom electroshocker settings included a frequency of 240 Hz at a 25% duty cycle and a voltage gradient of 0.5 V/cm. Backpack electroshocker settings included a frequency of 60–80 Hz at a 10% duty cycle and a voltage gradient of 0.3 V/cm. Trawling (semiballoon trawl with a 4.6-m headrope) at a speed of approximately 4.8 km/h was done in Black Lake to capture lake sturgeon of ages 0–5. The net was made of 19.0-mm bar mesh in the body and 6.35-mm bar mesh liner in the cod end. Total length (TL), fork length, weight, and girth were recorded for all lake sturgeon captured. Each captured lake sturgeon was tagged externally with a t-bar anchor tag (Floy model) placed in the dorsal fin. Each fish was also internally tagged with a passive integrated transponder (PIT) tag placed under the fourth dorsal scute.

Stream temperature was recorded at 1-h intervals by use of two Onset Stowaway XT1 temperature loggers (Onset Computer Corp., Bourne, Massachusetts) located between the spawning locations and at the river mouth. Current velocity readings were taken with a Flo-Mate 2000 current meter (Marsh-McBirney, Inc., Frederick, Maryland). The cross-sectional area of the channel was measured and the mean velocity was recorded at 3-m transects to calculate discharge during each night of sampling. To verify calculations, we obtained hourly streamflow data from the U.S. Geological Survey recording station at Kleber Dam in Tower, Michigan.

In the spring of 2002, ultrasonic transmitters were inserted into 20 yearling (age-1), hatchery-reared lake sturgeon; only 12 yearlings were able to hold the transmitters without rejecting them after insertion. Juvenile lake sturgeon (ages 5–13; mean TL = 97.23 cm) were captured in Black Lake, and ultrasonic transmitters were surgically implanted into eight individuals. Age estimation was determined from pectoral fin ray counts. The ultrasonic transmitters (IBT96-2 model; Sonotronics, Inc.) were designed to activate for three consecutive days and turn off for 4 d. The expected life of these transmitters was 60 d; however, because of the special design of these transmitters, the actual longevity was 90 d. Transmitters were 28 mm long and 9.5 mm in diameter and weighed 2.5 g. The range of these transmitters was 500 m. Transmitters were surgically implanted into the body cavity by cutting a 3-cm incision at the midventral region in the pelvic girdle. Oxytetracycline (0.1 mL/kg body weight) was injected into the body cavity to prevent infection. The incision was closed in an interrupted suture pattern with absorbable sutures (Ethicon-coated vicryl; 2-0 cutting CP-1 needle); the surgical area was dried, and Nexabond surgical glue was applied to each incision. Hatchery fish remained in holding tanks for 7 d so that we could monitor survival after surgery; juveniles captured in Black Lake were held in a water bath until operculum beats returned to presurgery condition.

Tracking (ultrasonic receiver Model USR-5W with an ultrasonic cone hydrophone) was conducted throughout Black Lake from 0600 to 1900 hours each day for the 3 d that the transmitters were active. Our searching strategy to document the habitat use of lake sturgeon involved applying a 0.5-min-latitude × 0.5-min-longitude grid system (Figure 1). Each grid was categorized as near shore (if the grid encompassed a portion of the shoreline) or off shore (if the shoreline was not present in the grid). We searched in a linear north–south direction in the lake and stopped at a location every 500 m. The Lower and Upper Black rivers were assessed for fish presence every other week by stopping at each outside bend in the river so that a signal could be heard upstream and downstream of the station. Location of fish was determined by the homing method described by White and Garrott (1990). Fish locations (latitude/longitude coordinates) were recorded by use of a Garmin GPS 12.

At each fish location, water depth (m), vegetation, and substrate type were documented. Presence or absence of vegetation was assessed by use of an Aqua-vu MC2X underwater camera at one station done for each fish location. A substrate sample was obtained by an Eckman dredge at each fish location, and substrate particle size was classified according to the Wentworth scale (Cummins 1962). Benthic invertebrates were separated from substrate samples with a Wildco bucket sieve (0.64-mm mesh). Invertebrates were preserved with 70% ethanol and were later identified to taxonomic family classification. The number of organisms per square meter was calculated for each substrate type and for water depth zones of 1.5 m.

Data analysis.—We used analysis of variance (ANOVA) to examine differences in mean length and weight between hatchery-reared yearlings that received transmitters and yearlings that could not hold transmitters.

Latitude and longitude coordinates were entered into ArcView (Environmental Systems Research Institute), and point coverages were created to show the distribution of fish locations. Geographic units were re-projected into X and Y units by use of MI-GeoRef projection. Measurements for linear distance traveled (km) were determined by using the distance calculation feature in the ArcView Animal Movement Analysis Extension (AMAE; Hooge et al. 2000). Total linear distance was calculated by summing all straight-line distances between consecutive fixed locations. Movement rates were calculated as the log-transformed linear distance between consecutive fixed locations divided by the number of elapsed days. Differences in movement rates were then tested by use of one-way ANOVAs. Spearman's rank correlation test was used to test for associations between fish length and movement parameters, minimum convex polygon (MCP) home range, and 50% kernel home range size (described below). An ANOVA was conducted on $\log_{10}$ transformed distance data to ascertain if movement differed among fish and between periods (May versus June for yearlings; July versus August for juveniles).

The MCP home range (Mohr 1947; Harris et al. 1990; White and Garrott 1990) was calculated for each yearling and juvenile lake sturgeon by use of the AMAE, where outermost locations were connected to form a convex polygon. The MCP home range (ha) was calculated with 95% of the locations to reduce the outliers effect (White and Garrott 1990) associated with the initial locations of yearlings (as they moved out of the river) and the initial capture of juveniles. Preliminary analyses regarding each home range model were conducted prior to retaining valid home range sizes. First, site fidelity was tested by use of the Monte Carlo random walk test within the AMAE. In this analysis, the mean square distance (MSD) from the center of activity was compared to 100 randomly generated paths. If actual paths were lower than the lower bound of the 95% confidence interval of the random MSDs, then site fidelity by the individual fish was indicated. Second, stability analysis was conducted by plotting the area used against the sample sizes of individual fish locations to identify how many locations were required for the home range size to reach an asymptote (Harris et al. 1990; White and Garrott 1990). Sample sizes for the MCP home range size were examined by a bootstrap test within the AMAE. Probabilistic techniques to evaluate the use of an area within each lake sturgeon's home range were examined by use of a kernel home range estimator. Output contours for the kernel estimator included a 95% contour that estimated the maximum area of use, a 75% contour, and a 50% contour as the core area of activity. Statistical comparisons between individual lake sturgeon were performed with the 50% contour estimate.

Lake sturgeon habitat use was estimated by evaluating the proportion of ultrasonic transmitter locations within the six habitat categories (deep offshore, shallow nearshore, sloped, flat-bottomed, vegetated, and nonvegetated habitats) and four dominant soil types (clay, sand, organic, and sand–organic) of Black Lake. Habitat use for each lake sturgeon was defined as the proportion of utilized habitat in each individual's home range (95% kernel) with respect to the habitat's relative availability in the lake. Habitat selection was determined by compositional analysis, comparing log-ratio-transformed use and availability data for each lake sturgeon with a likelihood ratio statistic Λ (Aebischer et al. 1993). The AMAE implements a version of the compositional analysis that uses the utilization distribution of the fish rather than its point locations to determine habitat selection. Depth was recorded at each lake sturgeon location, and the data were used to determine whether there was a difference in depth use between individuals. Individual locations of lake sturgeon were overlayed onto a bathymetry map to evaluate the habitat selection based on depth zones. The log-likelihood ratio goodness-of-fit test was used to evaluate the fish's observed frequency of occurrence in a given habitat with respect to that habitat's availability.

Results

Capture, Tagging, and Tracking

Larval drift-net sampling over 4 weeks yielded 2,814 larvae. These individuals were transported to the hatchery in three discrete batches (1,173, 730, and 911 larvae); a total of 915 larvae survived (33%) to the end of September. On 27 September 2001, 890 fingerling (4–5 month posthatch) lake sturgeon had coded wire tags inserted into the cartilage of the snout and were released into the Upper Black River below Kleber Dam (Figure 1). Stocked fish averaged 14.7 cm TL. The remaining yearling lake sturgeon were held at the hatchery and were reared until May 2002.

Ultrasonic transmitters were implanted into 20 yearling lake sturgeon, and all fish were PIT-tagged. After 1 week, only 12 yearlings were able to handle the transmitter without physically pushing it out of the incision. Yearling lake sturgeon implanted with ultrasonic transmitters measured 33.0–39.0 cm TL (mean = 36.04 cm, SD = 2.21) and weighed 156.8–272.9 g (mean = 207.2 g, SD = 42.91). Internal ultrasonic transmitters ranged from 0.92% to 1.59% (mean = 1.25%, SD = 0.25) of body weight. Fish that rejected transmitters measured 29.3–34.4 cm TL (mean = 32.025 cm, SD = 1.68) and weighed 108.5–180.7 g (mean = 143.6 g, SD = 22.3; Figure 2). There was a significant difference in mean length and weight between fish inserted with transmitters and fish that were unable to retain their transmitters ($F_{11,33}$ = 14.18, $P < 0.002$).

Yearling lake sturgeon were released at the Redbridge site in the Upper Black River (Figure 1). Signals from three fish were only received intermittently throughout the study and were not used for home range analysis because of low sample

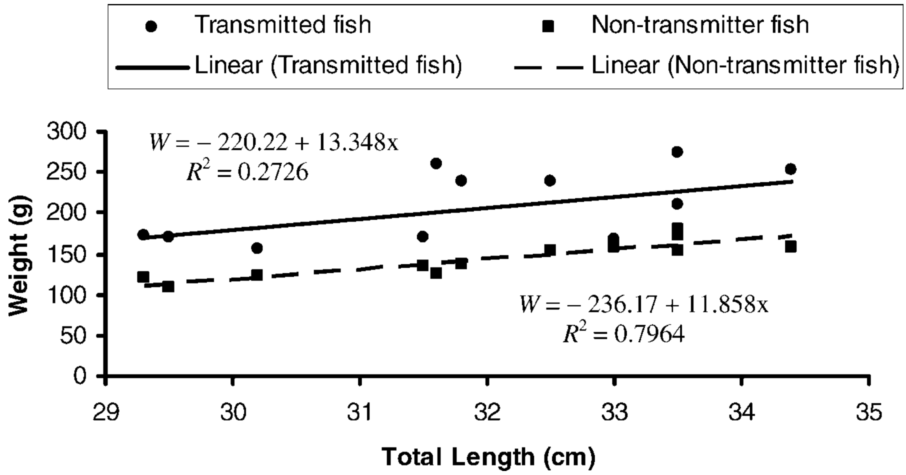

FIGURE 2.—Length–weight relationships for yearling lake sturgeon that received ultrasonic transmitters and those that rejected their transmitters during a study of fish movement in Black Lake, Michigan, in 2002.

size. Signals from one lake sturgeon became stationary after the first location within the river and was excluded from movement and habitat use analyses. The remaining eight fish moved out of the Upper Black River within 7 d after release at a mean water temperature of 11.07°C (SD = 0.71) and a mean discharge of 6.82 m^3/s (SD = 0.39). All eight fish were then initially found in the north basin of Black Lake and proceeded to disperse to different individual locations, generally to the southern basin, as the summer progressed.

Fixed locations of eight yearling lake sturgeon (a total of 167 contacts) were recorded from 24 May to 19 July, 2002, in Black Lake; thereafter, signals from ultrasonic transmitters implanted in yearlings were not detected. We concluded that the transmitter battery life had ended, and no yearlings were relocated after this time. The number of times each yearling was located ranged from 10 to 24 occasions (Table 1). For juvenile lake sturgeon (mean TL = 97.23 cm, SD = 17.5; n = 7 fish), 136 fixed locations were recorded from 10 July to 1 October 2002. The number of times each fish was located ranged between 14 and 23 occasions (Table 2).

Electrofishing in the Upper Black River was conducted to collect data for estimating the survival and river residency of age-0 lake sturgeon. Six age-0 lake sturgeon were captured during 14 h of sampling effort in 2000. Lake sturgeon ranged from 175 to 198 mm TL, weighed 24–30 g, and were captured between 0.32 and 0.45 km upstream from the river mouth. Ten lake sturgeon (175–188 mm TL; 24–27 g) were captured on 22 August 2001 during 6.5 h of sampling in the same sampling locations used in 2000. Twelve age-0 lake sturgeon were captured in 2002. These fish ranged in length from 166 to 193 mm TL and weighed

TABLE 1.—Measurements of distance traveled by yearling lake sturgeon in Black Lake, Michigan, during May–July 2002. An asterisk denotes that the number of contacts was not large enough to reach an asymptote for home range. Calculations for the minimum convex polygon (MCP), 95% kernel, and 50% kernel home ranges are described in the Methods.

Fish number	Total linear distance (km)	Median linear distance (km)	Home range MCP (km^2)	Home range 95% kernel	Home range 50% kernel	TL (cm)	Number of contacts
345	12.02	0.44	4.60	9.66	2.21	33.0	20
445	9.96	0.21	1.10	4.25	0.70	34.0	21
467	7.04	0.13	0.74	1.58	0.58	34.5	24
447*	6.1	0.12				34.5	10
459	3.98	0.08	0.95	3.35	0.70	35.5	23
558	15.4	0.55	5.98	12.65	3.82	38.0	21
489	6.82	0.22	1.59	3.81	1.04	38.5	24
577	16.2	0.42	2.49	5.36	1.19	38.5	24

TABLE 2.—Measurements of distance traveled by juvenile lake sturgeon (ages 5–13; mean TL = 97.23 cm) in Black Lake, Michigan, during July–October 2002. Asterisks denote that the number of contacts was not large enough to reach an asymptote. Calculations for the minimum convex polygon (MCP), 95% kernel, and 50% kernel home ranges are described in the Methods.

Fish number	Total linear distance (km)	Median linear distance (km)	Home range			TL (cm) (age)	Number of contacts
			MCP (km^2)	95% kernel	50% kernel		
347	13.60	0.50	6.27	12.34	2.38	78.5 (5)	21
367*	9.06	0.33				79.5 (5)	14
444	17.10	0.38	5.0	7.22	0.98	90.0 (6)	20
366	22.56	0.65	7.27	17.80	2.91	91.0 (7)	20
355*	16.54	0.37				97.5 (7)	17
333	16.40	0.80	4.79	10.97	4.28	107.0 (10)	23
359	21.27	0.37	6.48	20.28	3.88	113.5 (12)	21

26–34 g. All juvenile lake sturgeon were captured over sand substrate in the middle portion of the river channel.

Movement Patterns

Ultrasonic telemetry data indicated two distinct movement patterns by individual yearling lake sturgeon. Median distances moved between locations for yearlings were significantly different between individuals that used nearshore habitat and those that used offshore habitat ($F_{1,5}$ = 9.37, P = 0.028). The average distance between locations for fish located in nearshore habitat was 0.23 km/d, while the average for fish located in offshore habitat was 0.68 km/d. Median movement distance was not related to fish length (r = 0.14, df = 7, P = 0.75). Yearling movement distance was not different between May and June ($F_{1,86}$ = 2.02, P = 0.16). Three fish (numbers 467, 489, and 459) exhibited single, long, linear movements during May (mean = 1.2 km/d) and short, linear movements during June and July (mean = 0.08 km/d). Two yearlings (558 and 345) exhibited longer median daily movements and used larger home ranges than the other fish but were often found in the deep offshore habitat of the lake. The median movement distance of yearlings was not related to water temperature (r = 0.23, df = 2, P = 0.67).

Movements made by juvenile lake sturgeon during our study were complex. Some individuals moved substantial distances, as indicated by the extent of movement for fish 366, which was relocated 6.8 km from the capture site on the day after surgery. Juvenile movement distance was linearly related to fish length (R^2 = 0.97, P = 0.037). Specifically, we found that juveniles larger than 90 cm exhibited longer travel distances between contacts than did juveniles smaller than 90 cm. The average distance between contacts for juveniles larger than 90 cm was 1.43 km/d. Juvenile movement in July was not significantly different from movement in August ($F_{1,74}$ = 0.65, P = 0.42).

Seven of the eight yearling lake sturgeon exhibited site fidelity during the study. The MCP home ranges for these yearlings ranged from 0.74 to 5.98 km^2 (Table 1) and were significantly different between fish that used nearshore habitat and those that used offshore habitat ($F_{1,6}$ = 12.52, P = 0.016). The core home range (50% kernel) ranged from 0.58 to 3.82 km^2 (Table 1) and was significantly different between fish that used nearshore habitat and those that used offshore habitat ($F_{1,6}$ = 24.0, P = 0.004; Figure 3). Yearling fish length was not related to either the MCP home range (r = 0.16, P = 0.85) or the core home range (r = 0.24, P = 0.72). Movement distance was positively related to both the MCP (r = 0.64, P = 0.028) and core home ranges (r = 0.72, P = 0.001). There was no evidence for distinct areas of use by groups of yearling lake sturgeon.

Five of seven juvenile lake sturgeon displayed site fidelity during the study. Juvenile MCP home ranges ranged from 4.79 to 7.27 km^2 and were significantly different between fish larger than 90 cm and those smaller than 90 cm ($F_{1,5}$ = 16.43, P = 0.02). The core home range varied between individuals (0.98–4.28 km^2) and was significantly different between juveniles larger than 90 cm and those smaller than 90 cm ($F_{1,5}$ = 13.65, P = 0.03). Movement distances were positively related to the MCP (r = 0.51, P = 0.03) and core home ranges (r = 0.39, P = 0.04). Juvenile lake sturgeon displayed longer movement distances ($F_{1,10}$ = 12.02, P = 0.006) and home ranges ($F_{1,10}$ = 6.15, P = 0.032) than did yearling lake sturgeon.

Habitat Use

Yearling lake sturgeon were associated significantly with sand (χ^2 = 33.13, P < 0.001) and

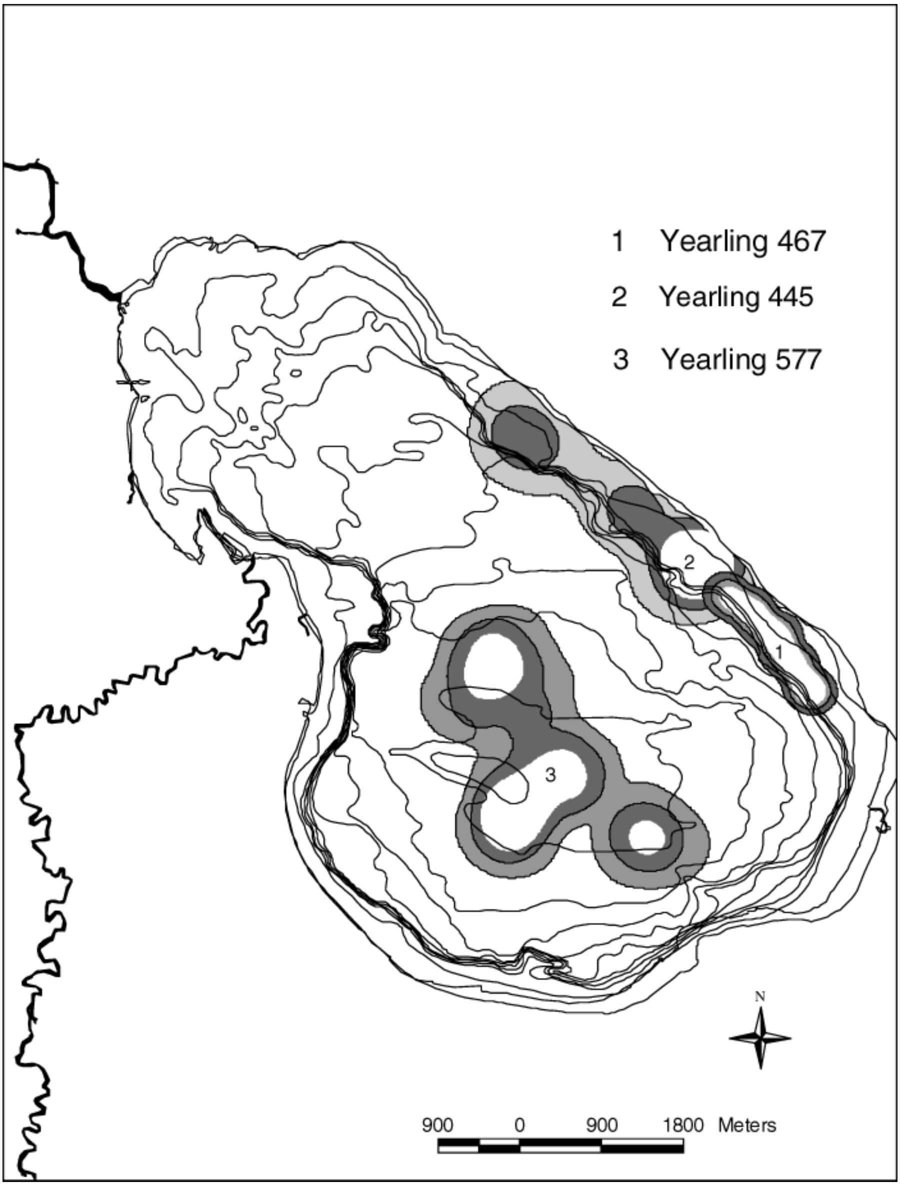

FIGURE 3.—Depth contour map of Black Lake, Michigan, showing kernel home range estimates for three representative yearling lake sturgeon tracked in 2002. The inner circle represents the 50% probability contour, the middle circle represents the 75% probability contour, and the outer circle represents the 95% probability contour.

organic substrate types ($\chi^2 = 20.14$, $P < 0.01$) but not with clay or sand–organic substrate. No yearlings were observed over clay substrate, despite the estimated habitat area of 123.9 ha in the lake. Two distinct mean depth parameters (nearshore and offshore habitats) were used by individual yearling lake sturgeon. Depth zones most selected by yearling lake sturgeon (Figure 4) were within the 1.5- and 12.2–13.7-m contours ($F_{9,16} = 3.0$, $P = 0.026$). Three yearlings (fish numbers 445, 467, and 447) were often found in shallow nearshore habitat at mean depths of 2.04 (SD = 1.48), 2.67 (SD = 2.45), and 3.23 m (SD = 9.56). The other five yearling lake sturgeon (459, 489, 577, 558, and 345) were located in deep offshore habitat at mean depths of 9.3 (SD = 12.08), 9.5 (SD = 9.11), 12.2 (SD = 5.05), 12.9 (SD = 4.02), and 13.4 m (SD = 1.24). Yearling habitat use within the home

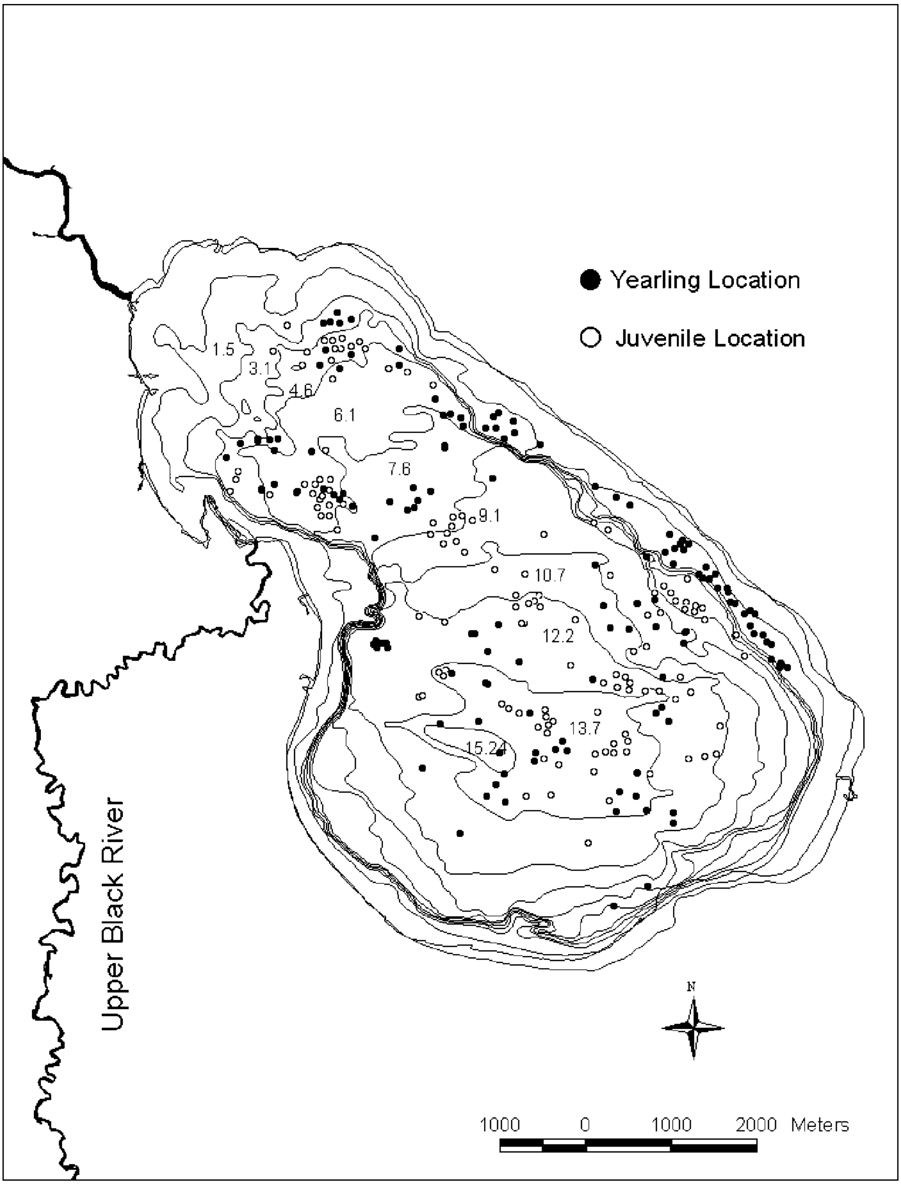

FIGURE 4.—Bathymetry map of Black Lake, Michigan, showing contact locations in relation to depth (contour) zones for yearling and juvenile sturgeon fitted with ultrasonic transmitters and tracked in 2002.

ranges differed significantly ($\Lambda = 0.256$, $\chi^2 = 16.7$, $P = 0.003$). Selection analysis indicated the following rankings for yearling lake sturgeon habitat use (from most selected to least selected): deep offshore, shallow nearshore, flat-bottomed, nonvegetated, and vegetated habitats; there was no detectable difference between the use of deep offshore and shallow nearshore habitats (Figure 5). Vegetated habitat was used significantly less often than the other habitat types. Sloped habitat types were not used by yearlings, based on a comparison of the proportions of locations within each habitat type and the proportions available in the home ranges; thus, this habitat type was dropped from analysis.

Juvenile lake sturgeon were associated with organic substrate (51% of locations); however, this was not significantly greater than the expected value because 55% of the bottom substrate of the lake was estimated to be organic ($\chi^2 = 0.65$, $P = 0.99$).

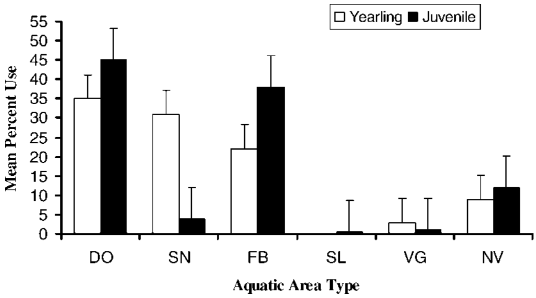

FIGURE 5.—Mean (+SE) habitat use of aquatic area types by yearling and juvenile lake sturgeon fitted with ultrasonic transmitters and tracked in Black Lake, Michigan, during 2002 (DO = deep offshore; SN = shallow nearshore; FB = flat bottomed; SL = sloped; VG = vegetated; NV = nonvegetated).

Juvenile lake sturgeon were randomly associated with sand and sand–organic substrate types, and no juveniles were observed over clay. There was a significantly higher occurrence of juvenile lake sturgeon within the east–central section of the lake ($P < 0.05$) and a significantly lower occurrence within the northwest section ($P < 0.025$), where only three contacts were received. Juvenile lake sturgeon used a total depth range from 5.4 to 13.4 m, and the overall mean depth used was 9.2 m. Depth zones most selected by juvenile lake sturgeon (Figure 4) were within the 13.7- and 6.1-m contours ($F_{9,19} = 3.01$, $P = 0.022$). Juvenile habitat use within their home ranges differed significantly ($\Lambda = 0.467$, $\chi^2 = 11.2$, $P = 0.025$). Selection analysis indicated that juvenile lake sturgeon habitat use ranked as follows (from most selected to least selected): deep offshore, flat-bottomed, nonvegetated, shallow nearshore, and vegetated habitats (Figure 5). Vegetated habitat was used significantly less often than the other habitat types; sloped habitat was dropped from analysis because only two locations were observed over that habitat type.

Sediment particle size composition changed according to depth in Black Lake. Nearshore depths (<3.0 m) had proportionally higher coarse material (>70% sand) than did deep offshore habitat (>84% silt). The shallow nearshore benthos community was dominated by Chironomidae (325 individuals/m^2), Baetidae (209 individuals/m^2), Sphaeridae (157 individuals/m^2), and Unionidae (67 individuals/m^2). The deep offshore benthos community was composed of Chironomidae (278 individuals/m^2), the mayfly *Hexagenia limbata* (165 individuals/m^2), oligochaetes (154 individuals/m^2), and Unionidae (35 individuals/m^2).

Discussion

The determination of habitat use and movement patterns by early life stages of lake sturgeon has been identified as necessary for the species' rehabilitation (Holey et al. 2000). The yearling lake sturgeon we tracked to determine habitat use and selection were collected as wild, drifting larvae and were representative of the natural genetic spawning stock within the Black Lake population. In contrast to the results by Thuemler (1988), who used stocked yearlings from two source populations and found distinct genetic differences in movement patterns between these two sources, results for lake sturgeon in the present study should have been more reflective of the behavior of the wild population.

Transmitter size and attachment position have been shown to affect growth rates and swimming performance of small fish (Stasko and Pincock 1977; Winter 1996; Counihan and Frost 1999). The ultrasonic transmitters used during this study averaged 1.25% of yearling lake sturgeon body weight and were cylindrical in shape. Laboratory studies with lake sturgeon and white sturgeon *A. transmontanus* have indicated that external transmitters should not exceed 1.25% of body weight and should be cylindrical (Counihan and Frost 1999; Sutton and Benson 2003). Although Counihan and Frost (1999) suggested that externally attached ultrasonic transmitters affected the swimming performance of white sturgeon, the internal use of the ultrasonic transmitters in our study may have lessened the transmitter effects on the fish's hydrodynamic properties. Ultrasonic telemetry provided an important assessment tool for the determination of habitat use, movement patterns, and variable depths used by lake sturgeon during various life stages in Black Lake.

Results from our study indicate that fish size affected the ability to handle the 2.5-g ultrasonic transmitter. The 12 fish that received transmitters averaged 36.04 cm TL and 207.2 g. Those that expelled their transmitters averaged 32.03 cm TL and had an average weight of 143.6 g. Yearling lake sturgeon used in this study were similar in size to those used by Thuemler (1988), who successfully implanted radio transmitters into juveniles ranging in size from 28 to 32 cm TL and weighing 96–167 g. Thuemler (1988) reported no mortalities and no visible changes in behavior over a period of 10–14 d after surgery. Lake sturgeon used in Thuemler's study were 18 months of age and were released in October, whereas the lake sturgeon we used averaged 12 months of age, were released in May, and exhibited no reported mortalities over a period of 7 d after surgery. This information suggests that body condition may be more important than age for successful transmitter implantation into the body cavity.

Originally, we thought that yearling fish released in the river would utilize the river for nursery habitat. In the Bad River, Wisconsin, young-of-the-year lake sturgeon inhabited the riverine environment for 8 months posthatch (H. Quinlan, U.S. Fish and Wildlife Service, personal communication). Kempinger (1996) found that juvenile lake sturgeon (89–221 mm TL) inhabited the Wolf River, Wisconsin, at 53–95 d posthatch. The knowledge of river residency of lake sturgeon in the Upper Black River during and after larval drift was obtained during this study and during previous larval drift sampling (Smith and King 2005). Findings from the electrofishing sampling effort in the Upper Black River indicated that young-of-the-year lake sturgeon occupied the lower reaches of the river at least until 86–112 d posthatch. Another possibility was that Black Lake historically provided the nursery habitat for lake sturgeon before the construction of Alverno Dam caused the population to be landlocked from Lake Huron. In the Lake Winnebago system, Wisconsin, length–weight relationships between the two basins indicated that the upriver lakes (Butte des Morts, Winneconne, and Poygan) provided nursery grounds, whereas fish moved to the larger Lake Winnebago when they attained larger sizes (Priegel and Wirth 1978; Bruch 1999). D'Amours et al. (2000) stated that lake sturgeon larvae traveled the 19-km stretch of the Des Prairies River, Quebec, during 6 h of nightly sampling. Therefore, we concluded that, because of the short migratory distance of the Upper Black River (11 km) and the immediate dispersal of yearling lake sturgeon from the river during this study, Black Lake provided critical habitats necessary for lake sturgeon older than age 1, and the lower sections of the river supported young-of-the-year fish between 86 and 112 d posthatch.

Previous studies of movements and habitat use by lake sturgeon have noted distinct areas of use by groups of adults (Fortin et al. 1993; Rusak and Mosindy 1997; Knights et al. 2002) and juveniles (Haxton 2003). In contrast to these findings, yearling and juvenile lake sturgeon in the present study used individual areas of activity. Auer (1996) stated that different lake sturgeon life history requirements allow a population to contain diverse life stages at any given time, therefore allowing habitat requirements and associated movement patterns to vary among individuals. Because of the lack of previous movement studies conducted on early life stages of lake sturgeon in lake environments, we were not able to make definitive observations or comparisons to movement patterns or life-stage-specific habitat use. However, information gathered from the isolated lake sturgeon population in Black Lake has shown that different habitat types and specific areas are used at various life history stages. Comparisons between this study and studies conducted in lotic environments suggest that core areas of activity for groups of lake sturgeon may be more important for lake sturgeon inhabiting flowing environments.

Seasonal patterns of movement have been documented in previous studies of adult lake sturgeon. Mosindy and Rusak (1991) found that movement rates were greatest during spawning and postspawning periods, when water temperatures increased. Other studies have indicated that lake sturgeon were sedentary during late summer (Mosindy and Rusak 1991) and winter (Hay-Chmielewski 1987; Borkholder et al. 2002). The limited life span of the transmitters used in this study prevented us from observing seasonal patterns of movement. While these inherent problems prevented seasonal interpretation of movement patterns, this study did reveal some details about movement rates and home range use between two early life history stages of lake sturgeon.

Median distances moved between locations for yearlings were significantly different between individuals that used nearshore habitat and those that used offshore habitat. Juvenile lake sturgeon larger than 90 cm displayed longer median daily linear movements and occupied larger home ranges than did smaller juveniles. We found no significant differences in movement patterns between months; therefore, we concluded that the differences observed were because of habitat selection and were not strictly attributable to seasonal differences between the two life history stages. Individual yearling and juvenile lake sturgeon that displayed the longest movements and largest home ranges were observed in the deep offshore habitat of the lake, while those individuals with short movements and small home ranges were observed in shallow nearshore habitat.

Distributions of food and habitat have been shown to be reasons for resource partitioning and the distinct movement patterns between life history stages. Hay-Chmielewski (1987) found that the areas most frequently used by adult lake sturgeon were those with the highest abundance of benthic organisms. The results of this study provide evidence that juvenile fish may occupy habitats different than those of adults to avoid competition with adults. The densities of chironomids were higher in the nearshore habitat than in offshore habitat. Chironomids were the most abundant food item throughout the lake, thereby allowing yearling and juvenile lake sturgeon to feed at various depth zones in the lake. Benthos samples indicated high densities of *H. limbata* in the deep, organic bottom areas of the lake. Smaller mayfly species were the second most-common food item in the shallow, sandy areas of the lake, where we observed active movement by three yearling lake sturgeon. Kempinger (1996) also found that Ephemeroptera nymphs and Diptera larvae were the two principal food items consumed by yearling lake sturgeon in the Lake Winnebago system. Contacts made with juvenile and yearling lake sturgeon in deeper water may also indicate that this area of Black Lake was a potential refuge from predatory interactions, as muskellunge *Esox masquinongy*, northern pike *E. lucius*, and walleyes *Sander vitreus* are common predators in Black Lake (MDNR, unpublished data).

The yearling and juvenile lake sturgeon tracked in this study occupied different depths and substrate types than did the adults tracked by Hay-Chmielewski (1987). Yearling lake sturgeon were associated significantly with sand and organic substrate types but not with clay or sand–organic substrate. Depth use (>9.2 m), substrate use (silt or organic), and general locality of juveniles favored the deep, flat, offshore portions of Black Lake, whereas yearlings were observed within the shallow nearshore (1.5-m contour) and deep offshore habitats (12.2–13.7-m contours). Chiasson et al. (1997) found that the largest concentrations of juvenile lake sturgeon in the Moose River drainage basin, Ontario, Canada, were adjacent to substrates dominated by sand and clay. We did not observe any fish located over clay substrate. Significant depth preferences by adult lake sturgeon within the lake were also shown by Hay-Chmielewski (1987): 7- and 10-m depths were more commonly utilized, while depths of 1, 2, 3, and 15 m were less common. Hay-Chmielewski (1987) found that adult lake sturgeon preferred muck substrate and rarely were found over the flat, deep part of Black Lake; 86% of the adults were located over the sloped regions. Yearling and juvenile lake sturgeon in our study did not use the sloped regions of the lake.

Reduced habitat availability has been identified as a cause of lake sturgeon population declines in the Great Lakes region. Most information known to date on the ecology of lake sturgeon was based on the adult life history stage, but the effect of reduced habitat availability may be greater at the larval or juvenile life stage. We found that in the confined system of Black Lake, yearling and juvenile fish were able to distribute throughout the environment and occupied different available habitat types than did adult lake sturgeon tracked in a previous study of the same system. Despite the fundamental problems we encountered (transmitter size limited ability to assess seasonal movements; the number of lake sturgeon tracked was small), we were able to present possible differences between habitat use by two life history stages of lake sturgeon, which points to the need for similar studies in lake and river environments.

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