AN ASSESSMENT OF JUVENILE LAKE STURGEON MOVEMENT AND HABITAT USE IN THE NAMAKAN RIVER OF NORTHWESTERN ONTARIO

by

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ABSTRACT

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Key Words: *Acipenser fulvescens*, acoustic telemetry, aquatic habitat, lake sturgeon, Namakan River, resource selection

The Namakan River of Northwestern Ontario is home to a recovering population of lake sturgeon (*Acipenser fulvescens*). Although the adult portion of this population has been well studied in recent years, very little information has been available for the juvenile (< 61 cm) portion. This study was designed to gather baseline information focused primarily at locating "nursery areas" used by juvenile lake sturgeon. Netting at 5 locations returned catches ranging from 0.9 juveniles per net at the mouth of the Namakan River and Little Eva Lake to 4.1 juveniles per net in Bill Lake, about 14 km upstream from the river mouth. Movements of ten juvenile lake sturgeon caught in Bill Lake and later aged at 4-6 years were tracked and matched to local water depth and flow. Six acoustic receivers and two "synctags" (VEMCO, Amirix Systems Ltd., Halifax, NS) were stationed in a fixed array and the study fish were implanted with acoustic transmitters. Of these, two were not detected at any point by the receivers, while the remaining eight were each relocated by receivers an average of 6,913 (range = 3,470 to 11,442) times. Areas with relatively lower (6-8 cm/s) or greater (14-16 cm/s) water velocities were used more within the 95% Kernel Density Estimator home ranges of

each of the eight fish than would be expected by chance. Shallow areas (< 6 m) of the Namakan River at Bill Lake were also avoided, amounting to fewer than 2% of all detections. The most consistent peak in activity occurred with the onset of ice cover on Bill Lake. The habitats used within the Namakan River and Reservoir by juvenile lake sturgeon generally consist of deep (>10 m), flowing waters downstream of known spawning locations.

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INTRODUCTION

The lake sturgeon (*Acipenser fulvescens*) is one of eight species of sturgeons (Family Acipenseridae) found across North America and the only endemic to the Hudson Bay and Great Lakes drainages (Auer, 1996). As with other sturgeons, lake sturgeon are long lived, with females often not maturing until they are 20-25 years old and males 12-15 years old (Auer, 1996; Bruch, 1999; Bruch et al., 2001). Once mature, females generally spawn only once every 3-5 years, and males usually every other year (Bruch et al., 2001; Shaw et al., 2013). The combination of long life, late maturation and intermittent spawning results in a complex age structure in lake sturgeon populations, understood more completely by studying life history and habitat of juveniles separately from adults.

As an example of this complexity, adults inhabit lentic habitats and feed in shallow areas of a watershed, while the same is not true for individuals < 12 years old (Adams, 2006; Barth et al., 2009). The juvenile stages include larval lake sturgeon, which are found initially at spawning sites until they participate in what is called larval drift (Roseman et al., 2011). These larval drifts typically occur nocturnally approximately one month after hatching (Chiotti et al., 2008). After the larval stage, swimming occurs to a second set of areas, which are referred to in this thesis as “juvenile areas” or “nursery habitat.” At this second juvenile life stage, the fish inhabit these areas and behave in them differently from what it does at the adult stage. Adult lake sturgeon travel extensively, change their behaviour and location seasonally, and occupy large geographic areas over a variety of habitats, while juveniles occupy much smaller areas and typically range < 1 km (Adams, 2006; Shaw et al., 2013; Barth, 2011).

Insights gained from studying distribution and habitat use by juvenile lake sturgeon may provide valuable information for management and recovery of lake sturgeon populations by identifying critical areas to protect from future anthropogenic impacts which have depleted populations across their range (Birstein, 1993; Beamesderfer and Farr, 1997). In the Winnipeg and English rivers of northwestern Ontario, juvenile lake sturgeon (<61 cm total length, TL) are found in discrete areas characterized by water depths greater than 13.7 m, water velocities greater than 0.20 m s^{-1}, but over various substrate types (Barth et al., 2009). They exhibit high site fidelity and occupy small (< 2.5 river km) home ranges (Barth et al., 2011). In the St. Clair River, southern Ontario, a large and deep river similar to the Winnipeg and English rivers, juvenile (< 80 cm TL) lake sturgeon are found most often in deep (12-20 m) waters, rarely (< 5 % of detections) in water less than 9 m depth, and similarly exhibit a high degree of site fidelity (Lord, 2007). Similarly, in the Ottawa River, a large, altered, river system in southern Ontario, juvenile lake sturgeon (mean TL 69 cm) are captured more often in areas with water depths of 12-20 m than at depths >35 m (Haxton, 2011).

Each of the above studies casts doubt on a habitat suitability index that identifies juvenile lake sturgeon preference for water depths of 4-8 m and characterizes depths > 14 m as unsuitable (Threader et al., 1998). These same studies, meanwhile, support the growing understanding that juvenile lake sturgeon have varying life histories, which may depend on the location of spawning by adult lake sturgeon, sometimes in shallow rapids, often < 5 m depth (Chiotti et al., 2008); juvenile habitat may depend on where drifting lake sturgeon larvae settle after hatching, or possibly on a later downstream movement of young-of-the-year in search of suitable overwintering habitat (Barth et al., 2011). In sum, systematic investigation into the relationship of juvenile habitat, or nursery areas, with the spawning locations of lake sturgeon is rarely undertaken, even though this relationship may explain the considerable variation observed in juvenile habitat.

Broad-scale movements within and between preferred habitats have also been described for some populations of lake sturgeon, with few studies characterizing the home ranges and movement patterns of juvenile lake sturgeon (Auer 1996; Peterson et al., 2007; Barth et al., 2011). However, telemetry using acoustic positioning systems is relatively new allowing finer-scale information on habitat use than previous technologies, that have been used in describing movements related to feeding, resting, and overwintering (Smith and King, 2005; Lepage et al., 2003; Lord, 2007; Barth et al., 2011). Movements by juvenile lake sturgeon within large riverine systems have been typically described as small, with infrequent excursions from home ranges or core areas (Holtgren and Auer, 2004; Barth et al., 2011). Home ranges of juvenile lake sturgeon in the St. Clair River in Michigan are found to vary between 0.8 and 10.8 km^2 (Lord, 2007); in the Sturgeon-Portage rivers in Michigan they average 11.0 ± 9.9 km^2 (Holtgren and Auer, 2004), and in the Winnipeg River in Ontario over 90.8 percent of studied fish remained within a 2 km stretch of river during a mark-recapture study (Barth et al., 2011). Larval drift from initial spawning locations is another possible predictor for river reaches that may serve as nursery areas (Barth et al., 2011). Seasonal movements constitute a third phenomenon in both adult and juvenile lake sturgeon, especially fall migration to wintering locations (Barth et al., 2011; Shaw et al., 2013).

This study documents habitat use by juvenile lake sturgeon in the Namakan River in northwestern Ontario, identified as the primary spawning area for a shared stock of lake sturgeon in a system between Ontario and Minnesota (Shaw et al., 2012). The river is a large, complex and mesotrophic waterway with reaches of both lentic and lotic environments of varying depths (Kallemeyn et al., 2003), and recent investigations provide the locations of lake sturgeon spawning areas within it (Shaw, 2010; Ontario Ministry of Natural Resources, OMNR, unpublished data; Figure 1). As each of these spawning areas is upstream of a series of deep and shallow areas of the river, an opportunity is provided to test the hypothesis that juvenile lake sturgeon will more likely be found downstream of potential spawning locations than in any predictable depth ranges. Given the Namakan River's complex structure and variety of habitats, it is likely that suitable juvenile nursery habitats would be found within 5 km of spawning sites. The first objective of this study is to identify and describe juvenile lake sturgeon habitat within the Namakan River and its relationship to known spawning areas. The associated hypothesis is based on the larval drift mechanism of dispersal and the high site fidelity observed in juvenile lake sturgeon.

A second objective of this study is to observe the use by juvenile lake sturgeon of the range of depth and water velocities within identified nursery areas. Movements within nursery areas are predicted to be small, based on reported site fidelity, although seasonal migration in preparation for overwintering activities is also likely to occur, as it has been observed among adult lake sturgeon in the Namakan River (Shaw et al., 2012), and suggested to occur among juveniles generally (Barth et al., 2011).

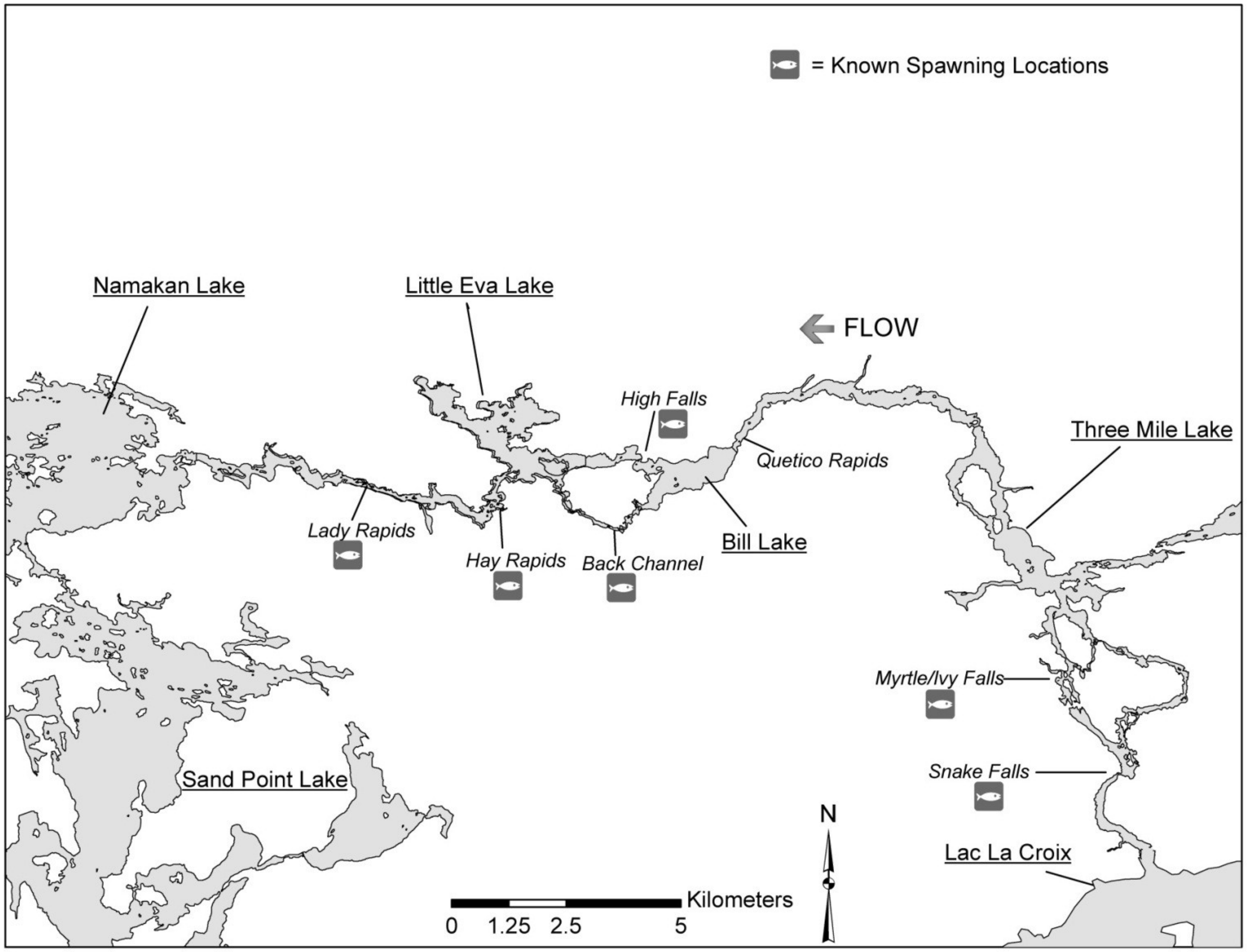

Figure 1. Map of the Namakan River showing falls, rapids, lakes, and known sturgeon spawning locations.

METHODOLOGY

Study Area

The Namakan River is located immediately downstream of Lac La Croix and upstream of the Namakan Reservoir (Figure 1). This mesotrophic river is found in the southern range of the boreal forest in North America, and is typical of Canadian Shield lakes and rivers, having soft water and sparse, submerged aquatic vegetation (McLeod and Debruyne, 2009). The Namakan River drains a watershed of close to 8,860 km^2 with an elevation drop of 19.2 m over a distance of 30.5 km from Lac La Croix to the Namakan Reservoir (OPEG, 2007). It provides approximately 75% of the inflow to the Namakan Reservoir and contributes the largest single source of inflow with a mean discharge of 109 m^3/s (Kallemeyn et al., 2003). Three separate, smaller lakes are situated along the Namakan River: Little Eva Lake (281 ha), Bill Lake (134 ha), and Three Mile Lake (399 ha). Each of these lakes is situated below probable spawning areas in the Back Channel and High Falls, both of which flow into Little Eva Lake (Figure 1). Spawning in the Back Channel likely occurs at locations ranging from directly at the downstream channel entrance upstream, approximately 3 km to the head end of the channel. High Falls is situated directly at the head end of Little Eva Lake. Bill Lake is defined at the head end by the Quetico Rapids, a likely spawning location, downstream of a reach of approximately 6 km of shallow (<10 m) flowing water. Three Mile Lake is the furthest upstream of the lakes and is defined at the head end by both Ivy and Myrtle Falls, known spawning locations, and 2 km below Snake Falls, the furthest upstream spawning location in the Namakan River.

Study Population

The lake sturgeon population in the Namakan River and an associated reservoir is part of the Lake of the Woods-Rainy River Designatable Unit, classified as "threatened" by the Committee on the Status of Species at Risk in Ontario (COSSARO), and therefore given protection under the Ontario Endangered Species Act. It is also given protection as a state-listed species of special concern, managed by the Minnesota Department of Natural Resources with limited harvest. This population has experienced negative impacts similar to other populations across the species range. A dam was created at the outlet to Rainy Lake in the early 1900s, isolating the population and preventing upstream migration into the Namakan Reservoir (Mosindy et al., 1991). The population has also been subject to overfishing, with commercial harvest underway by the 1890s (Pearson, 1963). Commercial licenses were issued for the Namakan Reservoir from 1916 to 2001, with a mean annual sturgeon harvest of 435 kg from 1924 to 1999 (McLeod and Debruyne, 2009). The Namakan population has otherwise not experienced negative impacts, such as water pollution or habitat destruction, as has been observed in other populations.

Lake sturgeon generally do not mature until they are at least 12 years old and(or) greater than 61 cm in length (Noakes et al., 1999; Block, 2001). Thus, for this study, lake sturgeon with a total length less than 61 cm were considered juvenile fish.

Lake Sturgeon Collection

Fish were captured using either monofilament or multifilament nylon gillnets (38, 51, 64, and 76 mm BAR) and setlines, both 30 m in length. The nets were selectively placed for a maximum duration of 20 hours in habitats of varying depths and flows to ensure each depth and water velocity classification would be sampled. Nets were positioned at a 45° angle to water flow in areas of visible current. Any nets that were intentionally placed in locations with no detectable flow were positioned perpendicular to the shoreline. Setlines consisted of 13.6 m of 27.2 kg braided nylon line with a total of 14 drop lines spaced 2 m apart. The drop lines, connected to the main line with snap swivels, were made of both 4.5 kg monofilament and 13.6 kg nylon line 0.5 m in length. A 6/0 circle hook was attached to each drop line and baited with earthworms. Each end of the main line was anchored by 15 kg weights marked with buoys. Similar setlines have proved effective for sturgeon capture with very low mortality (Elliott and Beamesderfer, 1990; Thomas and Haas, 1999; Lord, 2007; Wanner et al., 2007).

Topographic maps of the Namakan River at 1:50,000 were used to identify narrow waterways within the system with likely higher water flows, and bathymetric maps with 5-m contour intervals were used to discern areas of deep (>10 m) water. This coarse-scale set of maps guided site selection throughout the system. The baited setlines, as well as the gillnets, were placed in five general locations (Figure 2), within which a minimum of six sets were positioned to allow for varying depth and flow. Fishing effort was reallocated during the sampling period (31 May to 15 July, 2010) to areas where the nets produced at least one fish, in order to maximize juvenile lake sturgeon capture. This focused effort was designed to aid in assuring the best chances of collecting fish, i.e. in deep, fast-flowing areas of the reservoir and the river, while at the same time offering a survey of a range of potential habitats (Barth et al., 2011). Sampling and handling of lake sturgeon and by-catch followed Animal Use Protocol 19 09-10, approved in 2010 by the Lakehead University Animal Care Committee, and were consistent with guidelines of the Canadian Council on Animal Care and the OMNR.

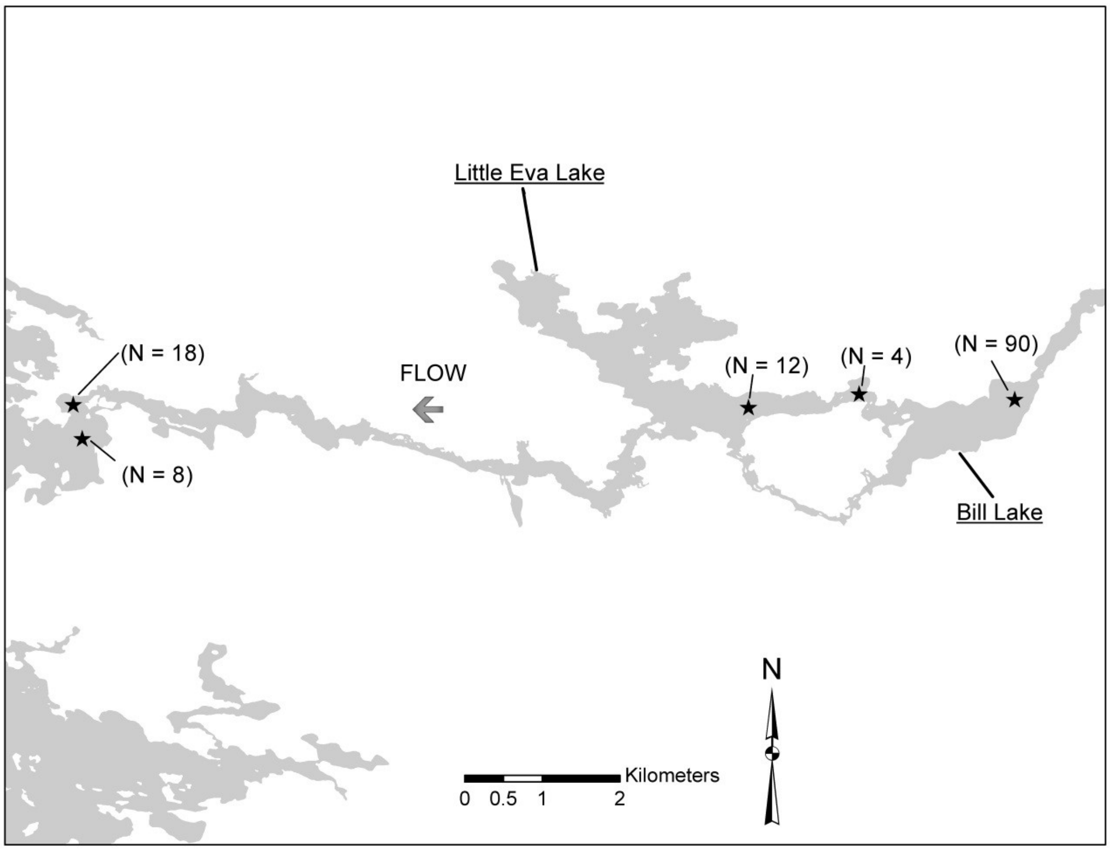

Figure 2. Map of Namakan River showing location of juvenile lake sturgeon set locations as indicated by stars. Numbers in parentheses represent total number of fish captured at each site.

Fish Handling

All captured fish were placed immediately in a 950-litre holding tank and brought to shore for processing before being released near their capture location. Each lake sturgeon was weighed (g), and its TL was measured to the nearest mm. All lake sturgeon between 30 to 61 cm were marked with a small, individually numbered Carlin disk dangler tag attached immediately below the center of the dorsal fin with 0.5 mm stainless steel wire (McLeod and DeBruyne, 2009; Shaw et al., 2012).

A subsample of fish representing different year classes was selected for age analysis by removing of a portion of the pectoral fin spine. I attempted to include a minimum of two fish per year class based on field-estimated length measurements and known size-at-age of Namakan lake sturgeon (Shaw 2010). All fish that were implanted with acoustic transmitters were similarly sampled for pectoral fin spines. All fin-ray sections were sent for age determination and validation to the OMNR Northwest Regional Fish Aging Facility in Dryden, Ontario.

A total of 18 of the captured juvenile lake sturgeon, ranging in weight from 0.6 to 3.0 kg, were selected for implantation of acoustic transmitters (V-13, Vemco – Amirix Systems Inc., Halifax, Nova Scotia). The minimum weight in this sample was chosen to ensure that a transmitter did not exceed 2% of the body weight of any of the monitored individuals (Winter, 1983). The transmitters were implanted in fish in both the Namakan River (Bill Lake, n=10 and Little Eva Lake, n=4) and at the mouth of the Namakan River at the Namakan Reservoir (n=4). Fish that were fitted with acoustic transmitters were anesthetized and implanted using procedures described in Adams et al. (2006), McLeod and Debruyne (2009) and Neely et al. (2009), as modified from Hart and Summerfelt (1975). The implantation technique was also consistent with Animal Use Protocol 19 09-10, Lakehead University.

A V-shaped wooden table wrapped with foam and soaked with water held and stabilized the fish for surgery. Fish were placed ventral side up with a continuous flow of water over the gills provided by a 12-volt water pump and hose. The water flow was made less direct by filtering it through a clean cloth before passing it into the mouth, providing a more efficient “flooding” of the mouth and gills. A small (15-25 mm) incision was made through the ventral body wall 15-20 mm adjacent and parallel to the linea alba about 4 cm anterior to the pelvic fins. The transmitter (length, 36 mm; weight, 11 g) was then inserted into the abdominal cavity through the incision using minimal pressure to prevent any internal injury. The incision was closed using a single interrupted layer of absorbable surgical sutures. All surgical instruments and the transmitter to be implanted were sterilized by soaking for 10 min in a benzalkonium chloride solution (Germaphine) prepared at a ratio of 50 mL germicide to 4 L distilled water before being rinsed with sterile saline solution prior to the operational procedure. Fish were held momentarily (5-10 min) in fresh water to allow recovery and confirm responsiveness, then released back to their original capture location.

Acoustic Positioning System

An array consisting of six acoustic receivers (Vemco VR2W) and two synchronizing reference position transmitters (Vemco V16; “synctags”) were determined by Vemco factory representatives as being sufficient to cover the area likely occupied by lake sturgeon caught at the site with the highest capture rates (i.e., Bill Lake, Figure 3). The Vemco VR2W receivers record acoustic signals transmitted from both the Vemco V16 and V13 transmitters and time-stamp the detection to the nearest millisecond. The V16 “synctags” are placed in a known location and transmit an acoustic signal on a programmed interval of 5 min to allow synchronization of the data by correcting time drift among the individual receiver’s internal clocks. Each fish or synctag signal detected was triangulated via the time differences that the signal was recoded at the receiver through a post-processing of the data by Vemco using proprietary software, returning .kmz files for importing to GIS applications. The receivers were tied to shore with 0.75-cm lead core rope, anchored in place with a 10-kg concrete anchor, and suspended above the lake bottom with a 22.5-cm buoy. Locations for each of the transmitters were obtained using Geographic Positioning System (GPS) units (Garmin eTrex Legend®, Garmin International, Inc., Olathe, KS). The transmitters operated at 69 kHz and were programmed to emit a uniquely coded signal on a random interval from 180-240 seconds. The resulting location data were downloaded from the receivers onto a Panasonic Toughbook laptop computer through a Bluetooth wireless connection.

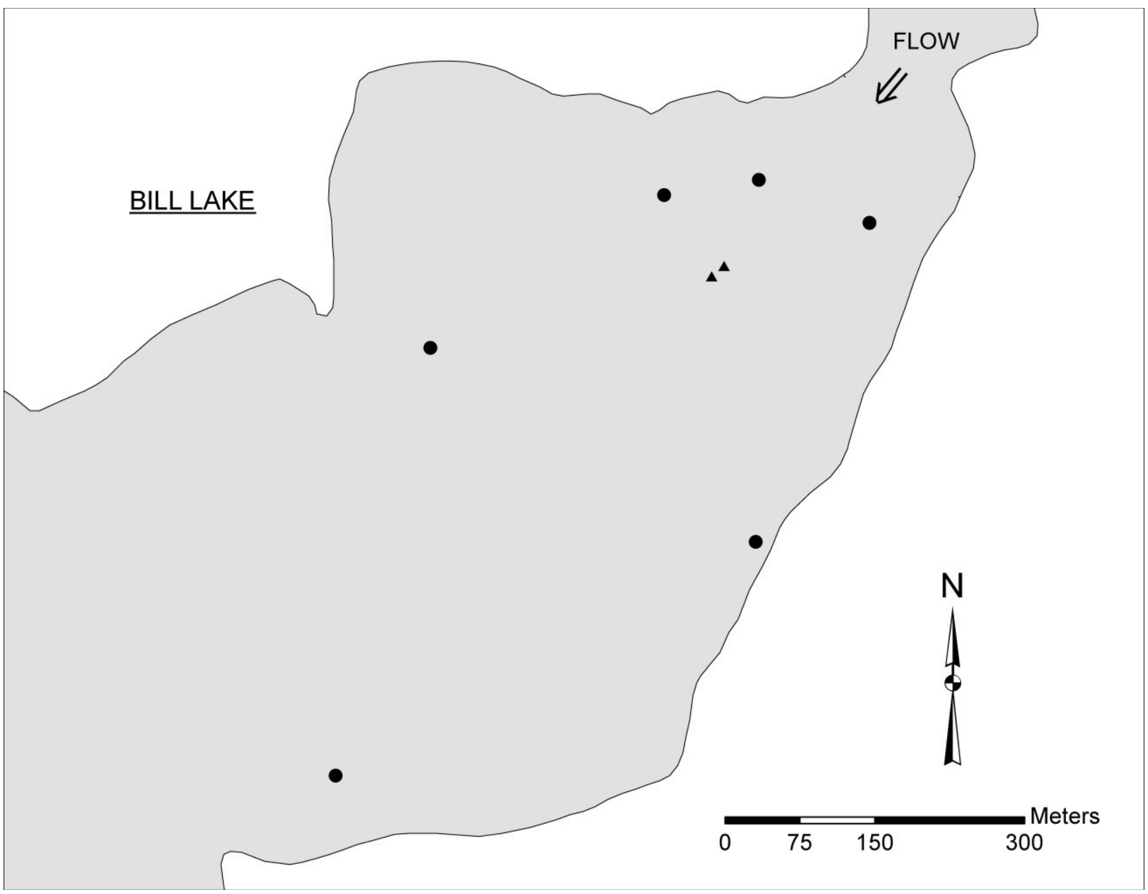

Figure 3. Map of Bill Lake on the Namakan River, Ontario showing the position of the acoustic telemetry receivers (n=6; circles) and synctags (n=2; triangles).

Habitat Classification

For the fine scale habitat mapping in the area where the juvenile lake sturgeon were monitored in Bill Lake, a Sontek River Surveyor Acoustic Doppler Profiler (ADP) was used in conjunction with a differentially corrected Trimble Ag GPS to collect a single depth and water velocity profile of Bill Lake on 12 September 2011. The ADP was mounted to the front of a 12′ boat propelled by an 8-hp outboard motor. A 1000 Watt portable generator supplied power to the ADP unit, GPS, and data logging computer. Transects were then run at approximately 50-m intervals from shore to shore and perpendicular to the current.

Data Analysis

Home ranges of the lake sturgeon with transmitters were calculated using a GIS-based Kernel Density Estimator (KDE) in ArcMap, using the spatial ecology extension Hawths Tools (Beyer H, Spatial Ecology LLC). Both 50% and 95% KDE polygons were calculated, the 50% KDE used to define core areas within the larger home ranges. Time and distance intervals between consecutive detections were calculated using Microsoft Excel.

Habitat availability was summarized by classification of each of the 95% KDE home ranges by depth from the ADP data into four classes as follows: (i) 6 to <10 m, (ii) 10 to <14 m, (iii) 14 to <18 m, and (iv) 18 to 22 m from the surface. Classification by water velocity was also in four classes as follows: (i) 8 to <10 cm/s, (ii) 10 to <12 cm/s, (iii) 12 to <14 cm/s, (iv) 14 to 16 cm/s. The cell values from the habitat raster grids were extracted and joined as matrices to the individual fish location point files, creating two matrices of "habitat use," one by depth and the second by water velocity, for each of the fish. Locations in depths < 6 m were excluded, as they accounted for < 2% of the dataset. Excluding locations in this class strengthened the ability of resource selection functions (RSFs) to differentiate among the other depth classes in a data exploration phase.

Data collected from the ADP was processed in Sontek ViewADP to identify the water depth and bottom water flow velocities corresponding to each surface geographic location collected by the GPS. This matrix of values was exported into Microsoft Excel and then imported into ESRI ArcMap 9.3.1 as a point feature for further processing. The ESRI Spatial Analyst extension was used to interpolate the depth and water velocity data from the points to create two raster grids using the kriging method with default settings. The output raster size in both cases was set to 3 m × 3 m cells and clipped to a water surface polygon obtained from the OMNR.

To standardize the comparison of habitat use to habitat availability for both depth and water velocity, their ratios for class (iii), an arbitrarily defined reference class in both cases, was set as 1.00, following Manly et al. (2002). The number of locations for each fish in each depth and water velocity class, relative to the total number of locations for the same fish, was then compared to the expected relative frequency of locations for the class, based on its area relative to the total area of the 95% KDE home range for the same fish. Across all fish, the result was separate RSFs for depth and for water velocity, allowing variation to be described among fish (with one fish serving as the reference in both cases) and across any temporal periods which separated the location data. The RSF in both cases were modeled as log-linear functions in the Statistical Package for the Social Sciences (SPSS), version 16, IBM Corporation, Armonk, New York. Also following Manly et al. (2002), the RSFs included (i) a set of one–factor models representing selection by depth and by water velocity only, (ii) a second set of two-factor models extending the first set with factors representing any temporal changes in selection, (iii) a third set of three-factor models adding a factor representing variation in selection by individual fish according to either depth or water velocity, and (iv) a fourth set of models with a full set of factors including variation in selection by individual fish and any temporal changes in selection. Model sets were compared using differences in Akaike's Information Criteria for each model. Classes of depth and water velocity used more than expected by chance were determined to be those in the RSF model with $p < 0.10$, a conservative figure allowing for habitat preferences to be described.

RESULTS

Fish Captures

A total of 133 juvenile lake sturgeon were captured in 56 net sets (Figure 2). The majority (85%, N=90) of captures occurred within Bill Lake, a small (134 ha) and deep (>20 m) lake along the river's upper watershed, which represented just 39% of the total sets. Bill Lake also had the highest catch per unit effort (CPUE) with 4.1 juvenile lake sturgeon caught per net set. At Little Eva Lake, just downstream from Bill Lake, and at the mouth of the Namakan River, CPUE was similar at 0.9 juveniles caught per net set. Set lines failed to capture any juvenile lake sturgeon in 10 sets.

Fish implanted with acoustic tags ranged in age from 4 to 6 years as determined by aging the fin ray sections. The remainder of fish classified as juveniles spanned 1 to 6 years of age.

<u>Juvenile Lake Sturgeon Activity</u>

The acoustic receivers and transmitters produced data from 23 July through 21 December, 2010 and recorded a total of 2,132,464 detections from eight of the implanted juvenile fish at Bill Lake. Two implanted juveniles at Bill Lake were never detected by the acoustic receivers.

The remaining eight juveniles with transmitters were also not detected within the acoustic receiver telemetry array, but were monitored by single receivers in fixed locations that detected presence or absence of the transmitters. Six of these eight fish remained within 500 m of their original capture locations. The exceptions were two of the fish captured in Little Eva Lake, which made one-time movements each of ca. 3 km. One traveled from a deep lotic pool directly downstream of a large set of rapids (High Falls) to another deep lotic pool just inside the main portion of Little Eva Lake. The other did the reverse, traveling from a deep portion of Little Eva Lake to the pool below High Falls. Among those captured at Bill Lake, two travelled outside the general capture area to an area upstream above the small Quetico Rapids (< 2 m height) at the head of Bill Lake. They were detected by a receiver above these rapids for approximately two weeks in August, and then returned to Bill Lake. The number of detections of each fish monitored at Bill Lake ranged from 3,470 to 11,442, with a mean of 6,913 detections. The majority of these points (83.2%) were collected < 15 min of the previous detection for the same fish, while in all cases < 5 % of consecutive locations spanned > 1 h. The majority (56%) of distances between detection locations was < 5 m, while distances between consecutive locations of greater than 50 m occurred in < 5 % of observations.

Daily average distances travelled by juvenile lake sturgeon ranged from 440 to 1,030 m, and averaged 710 m among the eight fish monitored. This daily average was derived from the combined (minimum) straight line distance measured between detection points. Variation in daily distances travelled was high, with only one consistent decline late in November through early December, corresponding to cooling water temperatures and ice formation on Bill Lake (Figure 4). I also observed peaks in daily movement during mid-September to early-October and just at the onset of ice formation on about 23 November 2010.

Available habitat in the area of Bill Lake used by most of the juvenile lake sturgeon ranged from 2 to 22 m in depth (Figure 5); water flow ranged from 6 to 18 cm per second (Figure 6).

Home Ranges

The 95% KDE home ranges varied among individuals from 3.0 to 6.3 km^2 with an average of 4.6 km^2 (Figure 7). The 50% KDE core areas are considerably smaller (Figure 8), comprising an average of 15% of the home ranges.

Habitat Use Within the Home Ranges

As the only consistent change in activity of the monitored juvenile lake sturgeon appeared to be with the onset of ice in Bill Lake, the RSFs were constructed to compare two periods, one before and one after the onset of ice, arbitrarily set at 23 November 2010, a date based on local observations. Habitat use was similar across all fish with respect to water velocity, but changed following ice-up (Table 1). Fish used both highest water velocity (14 to 16 cm/s) areas more than expected by chance, and after ice-up, they

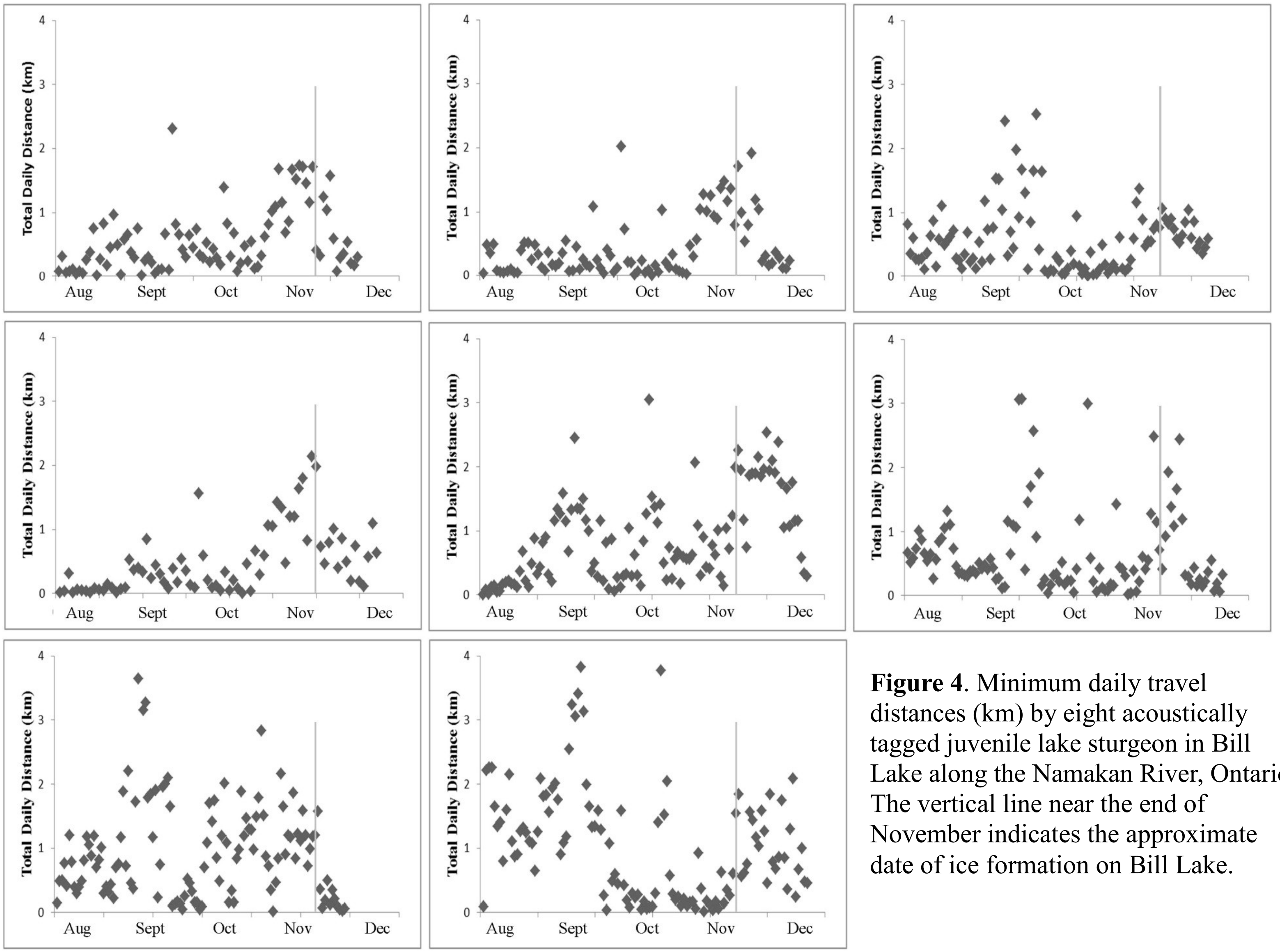

Figure 4. Minimum daily travel distances (km) by eight acoustically tagged juvenile lake sturgeon in Bill Lake along the Namakan River, Ontario. The vertical line near the end of November indicates the approximate date of ice formation on Bill Lake.

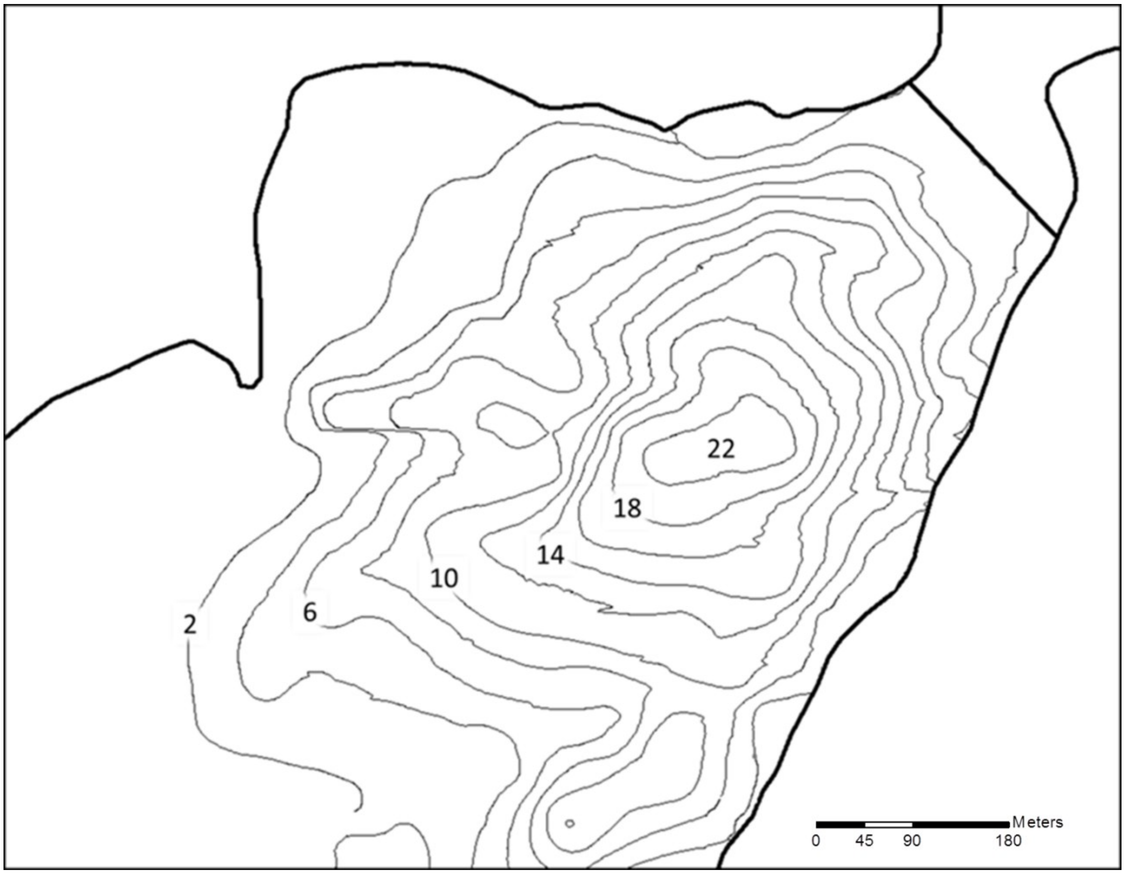

Figure 5. Depth contour map of Bill Lake, a small lake within the Namakan River in Northwestern Ontario. The depth contour lines are in 2 m intervals, with labels every 4 m beginning at 2 m depth.

also used areas with the lowest velocity class (8 to < 10 cm/s) more than expected by chance (Tables 2 & 3).

Habitat use according to depth also varied significantly before and after ice-up (Table 4). However, there was significant variation in use of areas of different depth among the sample fish (Table 5). For four fish (including the reference fish), no variation in use of habitat according to depth occurred. One fish used an intermediate (10 to <14 m) depth class less than expected before ice formation, and another less than expected throughout the monitoring period. The remaining two fish always used the shallowest (6 to < 10 m) areas of their ranges less than expected by chance.

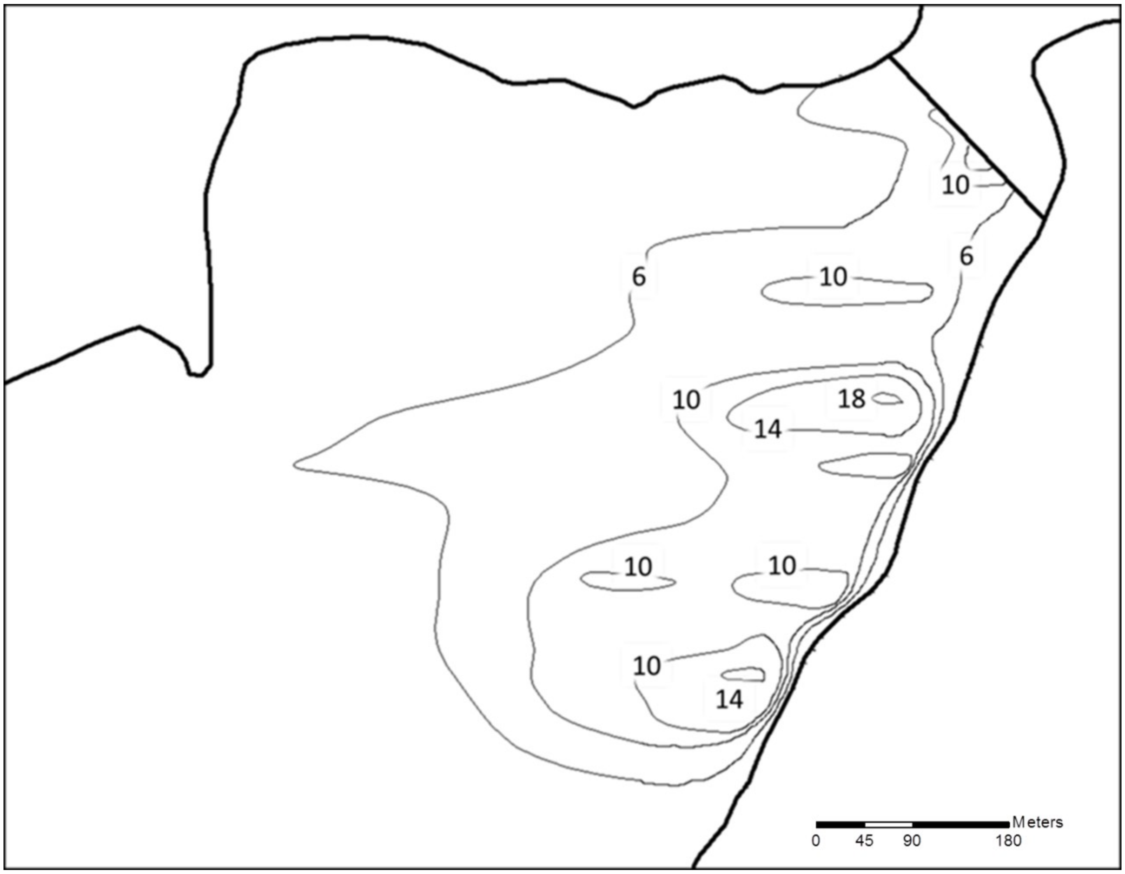

Figure 6. Lake bottom water velocity contour map of Bill Lake, a small lake within the Namakan River in Northwestern Ontario. The velocity contour lines are in 4 cm per second flow intervals, beginning at 6 cm per second, and correspond to 1 m above the bottom of the lake.

DISCUSSION

The habitats used within the Namakan River by juvenile lake sturgeon consist of deep (>10 m) and lotic waters downstream of identified spawning areas, but individuals varied considerably in their use of such nursery areas with respect to local depths. The distances downstream from spawning locations where juvenile lake sturgeon were observed ranged from 0.25 to 5.5 km. The highest capture rates were associated with the farthest upstream sampling location. This location is also the first deep pool to occur downstream of a spawning area, and it occurs after water flows through a reach of several kilometres of shallow water. This latter observation matches descriptions of nursery areas in the Winnipeg River (Barth et al., 2011). Thus, the association of nursery areas with spawning areas is consistent with studies of other populations in similar large complex river systems (Holtgren and Auer, 2004; Barth et al., 2009). Locations further downstream, while similar in physical characteristics, do not support as high of numbers of juvenile lake sturgeon found in catches at Bill Lake.

Figure 7. Maps of Bill Lake, Ontario showing 95% kernel density estimate home ranges (shaded areas) of eight juvenile lake sturgeon monitored from August through December, 2010.

Figure 8. Maps of Bill Lake, Ontario showing 50% kernel density estimate core areas (shaded areas) used by eight juvenile lake sturgeon monitored from August through December, 2010.

The Namakan River population is similar to those found in large complex river systems in terms of use of nursery habitats. High site fidelity was observed with the average home range of 4.6 km^2 (range, 3.0 to 6.3) among the eight fish tracked with the acoustic positioning system. Home range size is comparable to sizes estimated for juvenile lake sturgeon in the Sturgeon River/Portage Lake system (mean 11.0 km^2), in the St. Clair River (range 0.8 to 10.8 km^2), and in Black Lake, (4.79 to 7.27 km^2), three Michigan populations. Movements of fish outside of their estimated home ranges did occur for the Namakan River; while the reason for this migration is unknown, it may have been a seasonal response to search for alternative foraging or wintering habitats. In each case the movement was less than two weeks in duration and the fish returned to Bill Lake each time.

Table 1. Analysis of deviance table for the log-linear models of habitat use by juvenile lake sturgeon according to water velocity in Bill Lake, Ontario. The model in boldface is the best-fit describing habitat use by all fish, according to the size of the difference in the corrected Akaike's Information Criteria, ΔAICc, for each model.

				Difference in models		
Model	**Deviance**	**df**	**AICc**	**Deviance**	**df**	**AICc**
No selection according to velocity	35790	52	36223			
Constant selection according to velocity	29403	48	29846	6387	4	6377
Velocity selection changes with ice-on	**7711**	**22**	**8318**	**21692**	**26**	**21528**
Velocity selection varies by individual fish and changes with ice-on	3323	16	4047	4388	6	4271
Velocity selection with the ice-on effect varying by fish	0	0	0	3323	16	4047

Table 2. Parameter estimates for the best-fit log-linear model of habitat use by juvenile lake sturgeon according to water velocity in Bill Lake, Ontario. Boldface indicates significant differences (i) between frequency of detections in a water velocity class and expected frequency from available area in each velocity class, and (ii) occurring with ice formation on the river at approximately 23 November 2010.

Coefficient	**Estimate**	**S.E.**	**Ratio**	**Wald's X^2**	***p*-value**
Constant	5.71	1.09	5.24	27.49	< 0.01
Velocity 8-10 cm/s	**2.22**	**0.86**	**2.58**	**6.74**	**0.01**
Velocity 10-12 cm/s	0.41	0.30	1.37	1.88	0.17
Velocity 14-16 cm/s	**0.92**	**0.47**	**1.96**	**3.78**	**0.05**
Ice-up	**0.85**	**0.43**	**1.98**	**4.00**	**0.05**
Ice-up × Velocity 8-10 cm/s	**-1.95**	**1.04**	**-1.88**	**3.51**	**0.06**
Ice-up × Velocity 10-12 cm/s	-0.30	0.53	-0.57	0.32	0.57
Ice-up × Velocity 14-16 cm/s	-0.03	0.86	-0.03	< 0.01	0.97

Table 3. Estimated odds ratios, based on the best-fit log-linear model in Table 2 for the use of areas of varying water velocity by juvenile lake sturgeon in the Namakan River at Bill Lake, Ontario. Ratios in boldface indicate greater odds of use of a range of water velocity than expected by chance.

Water Velocity	Ice-off August to 23 Nov.	Ice-up 23 Nov to 21 Dec
8-10 cm/s	1.31	**9.21**
10-12 cm/s	1.12	1.51
12-14 cm/s	1.00	1.00
14-16 cm/s	**2.44**	**2.51**

Table 4. Analysis of deviance table for the log-linear models of habitat use by juvenile lake sturgeon according to depth below the surface of Bill Lake, Ontario. The best-fit model (boldface) is one that shows significant variation in habitat use among individual fish according to depth and in the effect of ice formation.

				Difference in models		
Model	**Deviance**	**df**	**AICc**	**Deviance**	**df**	**AICc**
No selection according to depth	50042	52	50478			
Constant selection according to depth	45271	48	45717	4771	4	4761
Depth selection changes with ice-on	**13095**	**24**	**13678**	**32176**	**24**	**32039**
Depth selection varies by individual fish and changes with ice-on	7128	18	7806	5967	6	5872
Depth selection with the ice-on effect varying by fish	0	0	0	7128	18	7806

Fewer than two percent of all telemetry locations of juvenile lake sturgeon came from depths less than 6 m, consistent with the 5 percent of detections found in less than 9 m depth in the St. Clair River (Lord, 2007). Juvenile lake sturgeon in Bill Lake were found more often than expected by chance in the deepest areas of their home ranges, except after ice-up, when they were also more likely to use the shallowest areas more

Table 5. Parameter estimates for the best-fit log-linear model of habitat use by juvenile lake sturgeon according to water depth in Bill Lake, Ontario. Boldface indicates significant differences between frequency of detections in a depth class or with ice formation on the river at approximately 23 November 2010 and expected frequency from available area in each depth class shown separately for individual fish.

Coefficient	Estimate	S.E.	Ratio	Wald's X^2	*p*-value
Constant	5.92	10.03	0.59	0.35	0.56
Depth 6-10 m	0.45	0.80	0.56	0.32	0.57
Depth 10-14 m	0.02	0.62	0.03	< 0.01	0.97
Depth 18-20 m	-0.53	0.63	-0.84	0.72	0.40
Ice-up	0.25	0.40	0.63	0.39	0.53
47349	1.16	0.70	1.66	2.79	0.10
47350	**1.60**	**0.80**	**2.00**	**4.03**	**0.04**
47351	**2.64**	**1.37**	**1.93**	**3.72**	**0.05**
47353	**1.23**	**0.72**	**1.71**	**2.90**	**0.09**
62611	0.27	0.51	0.53	0.27	0.60
62612	**1.31**	**0.72**	**1.82**	**3.32**	**0.07**
62613	0.00	0.00	-	-	-
47349	No significant differences				
47350 × Depth 6-10 m	**-2.21**	**1.02**	**-2.17**	**4.65**	**0.03**
47351 × Depth 10-14 m	**-4.53**	**1.55**	**-2.92**	**8.48**	**< 0.01**
47351 × Ice-up	**2.14**	**0.96**	**2.23**	**4.97**	**0.03**
47353 × Depth 10-14 m	**-2.20**	**0.94**	**-2.34**	**5.49**	**0.02**
62611	No significant differences				
62612 × Depth 6-10 m	**-2.29**	**0.92**	**-2.49**	**6.17**	**0.01**
62613	No significant differences				

than expected by chance, the reason for which is unknown. Variation in water velocities used by juvenile lake sturgeon may reflect changes in feeding behavior. As opportunistic generalist foragers, juvenile lake sturgeon have been shown to position themselves with respect to water flow in order to capture drifting prey (Nilo et al., 2006); therefore, they may be using areas of higher flows while actively feeding and using areas of lower flows while resting.

A limitation of this study is that only a single depth and velocity profile was recorded during September 2010. This tracking of the fish transmitters occurred between July and December of that year, at a period when river water levels remained stable with depths varying < 1 m and flows varying less than they would earlier in the year. Higher resolution of this data would have perhaps better supported the existing findings, however, as the observed conditions of the river varied so slightly that it is unlikely that significant variation in behaviors could have been attributed to them.

Movement and habitat use by juvenile lake sturgeon in the Namakan reservoir system were similar to those reported for the Sturgeon River/Portage Lake system in Michigan, where daily total distances traveled by juvenile lake sturgeon ranged from 0.3 to 1.6 km (Holtgren and Auer, 2004). However, habitat use in Bill Lake varies from the Sturgeon River/Portage Lake study in that Holtgren and Auer (2004) observed the use of shallow (< 5 m) inshore areas, particularly at night, as a diel movement into the shallower areas. This study was not able to produce any indication of diel movements in the Namakan River population, possibly due to the variation in habitats between the study areas. The Sturgeon River/Portage Lake system has shallow areas of sandy substrates that likely provide good forage for the juvenile lake sturgeon there. The Namakan River, and Bill Lake in particular, lacks this nearshore sandy substrate, as the river carves through Canadian Shield rock and has primarily rough rocky near shore areas.

The increase in movement corresponding to the onset of ice cover is unique to this study, in that prior to the VPS capabilities, fish could only been tracked on a daily movement basis by active radio methodologies. The submerged receiver system allowed for continuous passive data collection, including under ice conditions. It is possible that the brief period of high activity with the onset of frazil ice, leading to ice cover, correlates to changes in habitat use as has been observed in other fish species (Simpkins et al., 2000). Increased activity levels after the initial onset of ice cover may be a function of a reduction of benthic prey availability, as lower light levels and cold temperatures potentially lead to lower invertebrate food resources (Vannote and Sweeney, 1980). Prey scarcity, as well as reduced light availability under ice and snow, may demand additional travel by foraging juveniles in order to meet their prey consumption requirements as has been observed in other fish species, such as rainbow trout (*Oncorhynchus mykiss*; Hiscock et al., 2002). Juvenile lake sturgeon may have similar behaviours to juveniles of other fish species, in that they employ individual strategies at ice-up depending on their body conditions. Fish in good physiological condition may reduce movement to conserve energy, while those without sufficient energy reserves may need to increase foraging activity to survive.

CONCLUSIONS

Juvenile lake sturgeon monitored in this study appeared to exhibit high site fidelity as evidenced by limited home range size and movement patterns. Because Bill Lake is a relatively small lake (134 ha) , it may provide a disproportionate amount of juvenile lake sturgeon rearing habitat, underscoring the importance of this area for continued recovery of lake sturgeon in the Namakan Reservoir system. As this study was only capable of focusing on a narrow stretch of the Namakan River, it is quite likely that other nursery sites exist within this system. Information presented here suggests that deep, lotic environments close to spawning areas would be likely places to search for additional nursery areas or perhaps a starting point for systems where they have not been previously documented. Specifically, portions of the Namakan Reservoir in St. Louis County, Minnesota (Crane Lake) may have the potential to contain juvenile lake sturgeon nursery habitat. The Vermillion River that flows into Crane Lake through a set of rapids is a confirmed lake sturgeon spawning area. Searches for deep lotic habitats downstream of the spawning site may provide documentation of these nursery areas.

The knowledge of habitat use and movement patterns of sturgeon during the juvenile stage is critical to the rehabilitation of this species (Boase, 2005). Information gathered during this study, which observed habitat selection and movement patterns in the Namakan River, will assist in strengthening lake sturgeon populations in this system as it has in others (Lord, 2007). Specifically, the identification of nursery areas and their association with spawning areas will provide guidance to future studies targeting juvenile lake sturgeon, and allow for natural resource management agencies to evaluate potential anthropogenic impacts to critical habitats of this protected species. The combined knowledge of the adult population of lake sturgeon within this system (Adams, 2006; Shaw, 2010; Shaw et al., 2012; Shaw et al., 2013) and this new information available on part of the juvenile cohort will provide a greater understanding for environmental managers in making sound ecological decisions. Additional investigations are warranted to build upon these findings and to better understand the initial observations of this study.

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