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EVALUATING MOVEMENTS OF LAKE STURGEON IN LAKE ST. CLAIR, MICHIGAN

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Introduction

Lake sturgeon *Acipenser fulvescens* were once widely distributed in rivers and lakes throughout North America. Their historic range includes the Mississippi, Hudson Bay and Great Lakes drainage basins (Mackay 1963; Scott and Crossman 1973). Although lake sturgeon are primarily a fresh water species, some populations are found in the brackish waters of the lower St Lawrence River, Hudson Bay, and James Bay (Harkness and Dymond 1961). Within the last century, lake sturgeon populations have been dramatically reduced or extirpated from much of their native range (Harkness and Dymond 1961; Brousseau 1987). In the 1800s and early 1900s, habitat degradation, over fishing, and intentional reduction were cited as the primary causes for their decline (Harkness and Dymond 1961; Brousseau and Goodrich 1989). Within the Lake St. Clair/Lake Erie system, commercial sturgeon harvest peaked at about 5 million pounds per year in 1885 and has declined to near zero since about 1910 (Tody 1974).

Life history traits such as longevity, large size, and late sexual maturity have made lake sturgeon particularly vulnerable to exploitation. Today most remaining populations are restricted from moving into and out of riverine systems by dams or navigation locks (Folz and Meyers 1985; Hay-Chmielewski 1987; Thuemler 1988; Rochard et al. 1990). To further slow the decline of the species, state governments in the United States and Provincial Governments in Canada have listed lake sturgeon as a protected species (Brousseau 1987; Johnson 1987). Within Michigan, lake sturgeon are currently listed as a threatened species, and a controlled harvest is allowed only in locations where the population is able to sustain itself (Lake St. Clair, Black Lake, and the Menominee River). Throughout other locations in the state fishing for sturgeon is illegal. However, sufficient data are lacking to make sound management decisions involving this important species.

Lake sturgeon movement patterns are complex because of the different habitats required at various life stages such as spawning, resting, foraging, and over-wintering areas. Evidence from mark-recapture experiments in Wisconsin reported that sturgeon in the Lake Winnebago system travel great distances up connecting rivers to spawn in the spring returning to a home range in lake environments post-spawning (Priegel and Wirth 1971). In systems where sturgeon are free to move out of rivers and into lakes post-spawning, most populations do (Priegel and Wirth 1971; Hay- Chimielewski 1987; Auer 1999). In the Wolf River, one of the main spawning rivers connected to Lake Winnebago, a unique population of sturgeon was detected that remained in the river year-round (Lyons and Kempinger 1992). In 41 Km^2 Black Lake, Michigan, radio and ultrasonic transmitters were used to follow movement patterns of sturgeon that spawn in the Black River (Hay-Chimielewski 1987). Post-spawned fish returned to the lake, moving distances of 1.5 to 2.5 Km daily during June, July, and August with no clear indication of home range detected (Hay-Chimielewski 1987). Radio telemetry research on Indian Lake, a closed system in Michigan, showed that sturgeon moved less than 2 km during an entire summer (Bassett 1982). In the Moose River, an open system in Ontario, sturgeon were reported to remain in a 5 Km reach of the river even though no physical barriers were present (Threader and Brousseau 1986). Tag recoveries from the Sturgeon River population in Michigan found sturgeon moving 70 to 280 Km from the spawning site out into Lake Superior (Auer 1999).

In order to better manage lake sturgeon it is essential that mangers have knowledge about habitat requirements and forage associated with those habitats. Harkness and Dymond (1961) provide one of the early descriptions of habitat requirements for lake sturgeon, and indicate that shallow-water (< 4.6 m) with mud substrates are the most common habitat. In the Mattagami and Groundhog rivers in northern Ontario, researchers found that sturgeon were most closely associated with substrates dominated by clay and sand. The dominant benthic organisms found in these substrates were Diptera, Hexagenia, and Trichoptera larvae, and depths in those locations ranged from 4.1 to 8.4 m (Chiasson et al. 1997). Research on Black Lake in Michigan lists Orconectes, Hexagenia, Hirudinea, and Chironomidae as preferred food, with muck being the preferred forage substrate (Hay-Chimielewski 1987). Research in the Hudson Bay drainage found similar results (Choudhury and Dick 1993). Due to the eutrophic nature of Lake Winnebago, Hexagenia are not present in sufficient numbers to make up an appreciable portion of lake sturgeon diet. Instead, tubificid, ologochaetes, and chironomid larvae are the primary food items (Choudhury 1996). These studies suggest that the availability of food and substrates associated with these food types may influence habitat selection.

Both sediment composition and the distribution of benthic organisms, two important habitat components for lake sturgeon, have been studied in Lake St. Clair, the St. Clair River and the Detroit River. Hiltunen (1980) identified 71 invertebrate taxa in Lake St. Clair, the St. Clair and Detroit rivers. The majority of these were included in nine taxonomic groups, Nematoda, Oligochaeta, Polychaeta, Amphopoda, Isopoda, Diptera, Ephemeroptera, Gastropoda, and Pelecypoda. Oligochaeta were found to be the dominant taxa in Lake St. Clair. Amphopods were present in high densities in Anchor Bay, but were scarce in other locations in the lake. Densities of native Gastropods and Pelecypods were found in high densities throughout Lake St. Clair prior to the invasion of Dreissena polymorpha in the late 1980s (Hiltunen 1980; Nalepa et al. 1996). Nalepa found that from its introduction until 1994 Dreissena polymorpha, has become the dominant mollusk in Lake St.Clair, increasing in density from 1,700 m^{-2} in 1990 to 3,200 m^{-2} in 1994, while total counts of Unionidae decreased from 248 to 6 during the same time period. Among the immature forms of insects collected Diptera, primarily Chironomidae, and Ephemeroptera, primarily Hexagenia were the dominant species (Hiltunen 1980; Hiltunen and Manny 1982). Although densities of Hexagenia a generally low relative to other invertebrates in the system, they are a significant part of the total fauna because the biomass of their population is greater than that of most other groups (Hiltunen 1980). According to Thornley (1985) the distribution of Hexagenia in Lake St. Clair was influenced by substrate type. He found that the center of the lake was composed of fine sand and silt and had higher number of Hexagenia while the shallower areas containing fewer nymphs was composed of coarser substrates. Average densities of Hexagenia in Lake St. Clair in 1977 and 1983 were 390 and 467 organisms m^{-2} (Hiltunen and Manny 1982; Thornley 1985).

Also important to lake sturgeon management are behaviors associated with migration to and from spawning areas. Both populations of riverine and lacustrine sturgeon migrate to and from spawning grounds on a seasonal basis. Fish in the Lake Winnebago system move into the Wolf or Fox rivers in the spring to spawn, returning to their respective lakes after spawning (Probst and Cooper 1955). Tagging and telemetry studies showed that males return to the same location every 1 to 2 years and females return every 3 to 6 years (Priegel and Wirth 1971,1978; Foltz and Meyers 1985). Tagging research by Lyons and Kempinger (1992) demonstrated strong homing instincts for sturgeon returning to spawning locations. An eight year tagging study on the Sturgeon River determined that spawning intervals for males was every 2 to 4 years and for females every 3 to 7 years (Auer 1999).

Until recently no studies have been conducted on lake sturgeon originating in the connecting waterways between the Great Lakes. Perhaps this is linked to the ability to find and capture sturgeon in these environments. In the St. Clair River between Lake Huron and Lake St. Clair, Thomas and Haas (1999) were able to collect lake sturgeon using setlines in this environment with swift currents, steep bottom contours, and depths > 18 m. They demonstrated that lake sturgeon could be consistently collected in the North Channel of the St. Clair River (Thomas and Haas 1998). This population of sturgeon was utilizing areas of the North Channel for spawning. However, it was unknown if adults spawning in the North Channel were residing in the St. Clair River or if they were migrating to the river from Lake Huron, Lake St. Clair, or even further away. In the Sturgeon River Auer (1999) was able to identify individuals by sight because virtually all of the tagged fish that returned to the spawning areas could be recaptured. The spawning sites were located downstream form a hydroelectric facility. The facility was able to alter flow in order to facilitate the research.

The Michigan lake sturgeon rehabilitation strategy (Hay-Chimielewski and Whelan 1997) lists limited habitat information as one of the primary difficulties in managing lake sturgeon. The lake sturgeon workshop sponsored by The Great Lakes Fishery Trust also concluded that more research is needed regarding habitat utilization by various life stages, habitat classification, and inventory of potential habitats in the Great Lakes (Holey et al. 2000). While numerous studies have evaluated the movement patterns and habitat requirements of lake sturgeon in different systems and other studies have looked at physical and biological parameters of Lake St. Clair no studies have been conducted to relate lake sturgeon movement patterns to habitat availability and forage abundance in the Lake St. Clair system. Information from other sturgeon research and past research on Lake St.Clair helped determine the objectives of this study. I decided that using radio and ultrasonic telemetry to track movement patterns of individual lake sturgeon would work best accomplish these objectives in the St. Clair system. Based on previous research I hypothesized that: (1) lake sturgeon collected in the St. Clair River during spring spawning runs have individual home ranges and probably reside in Lake St. Clair; (2) lake sturgeon select habitat in Lake St. Clair based on food type and abundance; (3) Hexagenia, a primary prey item of lake sturgeon, are negatively correlated with substrate size in Lake St. Clair.

Study Site

The St Clair System is unique to the Great Lakes Region both physically and biologically. This system along with the Detroit River forms the connecting waterway between Lake Huron Lake Erie (Figure 1). Water leaving Lake Huron travels 64 km in a southerly direction to Lake St. Clair and before the river enters Lake St. Clair it passes through the largest natural delta system in the Great Lakes. The upper reaches of the river are dominated by heavy industry on both sides of the border. In the southern reaches urbanization dominates the U.S. side while wetlands and some agriculture dominate the Canadian side. River velocities at the surface reach 3.2 km/hr with an average discharge rate of 5,121 m^3/s (Edsall et al. 1998). Once reaching the delta, flow is diverted between four main channels. Navigation-related dredging in the St. Clair system began as early as 1873 and continues to the present, a minimum depth of 8.3 meters maintained in the shipping lane. Within the river there are natural deep holes >24 m while in other areas deposition of sand has created extensive submerged bars that are < 1 m deep (Edsall et al. 1998).

Lake St. Clair is a heart-shaped lake with a mean depth of 3 m and a maximum natural depth of 6.4 m. Total surface area of Lake St. Clair is 1,114 km^2 (Bolsenga and Herdendrof 1993). The Lake St. Clair Basin receives 98% of its inflow from the St. Clair River, the remaining 2% comes from the smaller tributaries (Clinton, Thames, and Sydenham rivers) (Edsall et al. 1998). Schwab and Clites (1986) estimate the hydraulic retention of Lake St. Clair is between 2 and 30 days. Two distinct water masses have been identified in Lake St. Clair based on physical and chemical differences and differences in biological productivity (Leach 1980). The northwestern mass consists of primarily Lake Huron water and is considered less productive. The southeastern mass has a longer retention time in the lake due to currents mainly caused from prevailing winds during certain times of the year (Leach 1980). Nutrients from both urban shoreline development and intensive agriculture within the drainage results in greater biological productivity in the southeastern water mass (Leach 1972, 1973). For the purposes of this study research was restricted to the following areas of the St. Clair System: from the Blue water Bridge in Port Huron, all of the St. Clair River and it's connecting waterways, Lake St. Clair, and the Detroit River downstream to the Ambassador Bridge.

Methods

Sixteen lake sturgeon were captured in the North Channel of the St. Clair River during the spring spawning migration in 1997, 1998, and 1999. All fish were captured using setlines at a depth of about 10-15 m (Thomas and Haas 1999). All fish used in this study were fish in excess of 140 cm in length, it was assumed that fish this size would be fully mature.

After initial capture, sturgeon were placed in a livewell receiving continuous flowing water from the river to maintain constant temperature and dissolved oxygen. To further reduce stress, a dark tarp was placed over the livewell. Fish were then moved to the deck of the boat or to a worktable for collection of biological information, which included; total length (mm), girth (mm), weight (kg), lamprey attachment marks, sex and sexual maturity. Sexual maturity was determined by massaging the ventral surface of the fish pushing towards the vet and watching for the release of eggs or sperm. When that technique was unsuccessful, some females released eggs out of the incision made for the transmitters. The leading edge of the left pectoral fin ray was dissected from the fish for use in age interpretation (Roussow 1957; Rossiter et al. 1995). A small tissue sample from the fin ray was also archived for later genetic analysis. Individual monel tags were placed at the base of the posterior portion of the dorsal fin, and notes were taken on general appearance of each fish.

Transmitters were implanted into the body cavity of lake sturgeon using procedures described in Hay-Chmielewski (1987). The fish were restrained in a net stretcher with their heads covered with wet cloth to prevent trauma. In spring of 1997 the first four lake sturgeon captured were implanted with both radio and ultrasonic transmitters. With these four fish, two incisions were made in the abdominal cavity. The first incision, used to insert both transmitters, was 5-8 cm long and was located anterior of the vent. A second incision was used as an exit location for the whip antenna on the radio transmitter. This incision was located 3 cm posterior to the first, and was approximately 1 cm long. The two remaining fish implanted in 1997 and all other fish received only ultrasonic transmitters and required one incision. Fish were sutured with dissolvable nylon thread material and injected with oxytetracyline (55 μg/kg body weight) as an antibiotic. They were held in water until they were able to swim and then were released. Fish were out of the water no more than 10 minutes during implantation.

Individually coded ultrasonic transmitters were manufactured by Sonotronics Inc. (Tucson, Arizona), model CHP-87-L\MT. Tags operated at 75 KHz, were 18 mm in diameter and 100 mm long, weighed 38 g in air, and 13 g in water. The manufacture listed the battery life at 15 months. Radio tags were manufactured by Advanced Telemetry Systems (ATS Isanti, Minnesota), the model used was 2C 6V with trailing antenna. Tags operated in the 49 to 50 MHz range, pulse rate 55 ppm, pulse width 20 msec. Tags were 33 mm in diameter and 115 mm long, and weighed 140 g in air. The manufacture listed the battery life at 660 days. The combined weight of the transmitters amounted to less than two percent of total body mass of the fish.

In 1997 attempts were made to follow fish implanted with radio transmitters by boat and by helicopter, but they were unsuccessful. For the remainder of the study sturgeon were tracked by boat or from land using an ultrasonic receiver and a hand held directional hydrophone. A systematic grid of listening stations was used, and distance traveled between listening stations was dictated by weather conditions and sound attenuation caused by boat traffic or water surface disturbance. Typical detection ranges were greater than one nautical mile. Stations were generally separated by about 0.8 minutes latitude or 1.0 minute longitude. Using this method, large portions of the lake could be searched with relatively low likelihood that fish were in the area but not detected. It was possible to search all areas of the lake and most sections of the river in approximately 40 – 45 hours of effort when conditions were favorable. When fish were located some distance from the boat they were advanced upon until the transmitter signal exhibited equal strength in all directions. In the St Clair River and the connecting channels listening stations were determined by direction changes in the river when distances between listening stations were less than one nautical mile. The amount of error locating fish due to hydrophone limitations was estimated to be $\pm$ 10 meters. Fish locations and listening locations were recorded using Global Positioning System. When a fish was located, water depth and temperature were also recorded.

In order to facilitate analysis and to better manage tracking and sturgeon information a one-by-one minute latitude/longitude grid of Lake St. Clair was constructed (Figure 2). The grid and all other geographic analysis were done using ArcView Geographic Information Software (GIS) (ESRI Inc.). Lake sturgeon locations and listening stations were plotted from May 1997 through October 2000 on the gridded map.

Tracking data from May 1997 through December 1999 was used to determine areas of Lake St. Clair that were most frequented by lake sturgeon. To accomplish this, all listening stations were plotted and then each point was buffered with a one nautical mile radius. The buffered point represented the most likely listening area for each event. Listening episodes counted for each grid cell included listening episodes completely covering a cell and listening events from adjacent grid cells whose buffered area encompassed at least half of the cell.

The above information was used to produce a GIS theme depicting relative frequency of occurrence of adult lake sturgeon in different parts of Lake St. Clair. Overall frequency of occurrence for each grid cell was derived by dividing the total number of sturgeon found in a grid cell by the number of searches conducted in that grid in a given sampling season. Sampling season was defined from spring of one year until spring of the next year. Since each spring more fish with transmitters were added to the population, a correction was required to compare frequency of occurrence across years. The equation used was $F = (T_f / T_s) * 1/n$; where F is the relative frequency of occurrence of sturgeon in the cell, T_f is the total number of fish found, T_s is the total number of searches, and n is the potential number of fish tracked.

Relative frequency of occurrence data collected from May 1997 – December 1999 was used to separate Lake St. Clair into four strata. There were natural breaks in the data resulting in areas of no use ($F = 0$), low use ($F = 0.001 – 0.003$), moderate use ($F = 0.0031 – 0.009$), and high use (F = 0.0091 – 0.03). These areas were further separated into strata based on one-meter depth contours ranging from 1 to 7 m. The frequency of location and depth strata were then used to design sampling schemes for other habitat data. Habitat sampling stations were randomly chosen within each depth contour and within cells of high, moderate, low and no use. Three locations, two primaries and one alternate, were chosen for each stratum for a total of 48 grids. Because of irregular sturgeon locations, not all relative frequency of occurrence strata were represented within each depth contour.

On 25-27 May 2000 three samples of benthic invertebrates and three samples of sediment were collected at each sampling station. Samples were collected using Ponar with a 232 cm^2 jaw opening, cleaned in a standard #30 (0.65 mm) benthos bucket and preserved in a 70% ethanol/rose bengal solution. Samples were taken back to the lab and analyzed within six months for benthic invertebrates. At the lab benthic samples were placed in a twelve-inch glass pie pan and hand sorted. Organisms were separated down to the level of order or family and counted to determine number of organisms per square meter.

A 40 ml sub sample of sediment was collected from each of the ponar samples to determine the percent organic carbon, sand silt and clay at each sampling location. In the field sediment samples were placed in a 40 ml plastic vial and stored on ice in a cooler. After being transferred to the lab, they were frozen until sediment analysis was conducted. Sediment samples were analyzed one year after collection. Samples were thawed then poured into 100 ml aluminum drying tins. Samples were placed in a drying oven at 104^0 C for 24 hours. Samples were then placed in a desiccation chamber until cool. To determine percent organic carbon approximately 1 g of material was removed from each sample then placed in a new 100 ml drying tin weights were taken (to 0.001 g) (Rand et al. Eds. 1975). The 1 g sub samples were burned at 550^0 C for three hours. Sub samples were then placed in a desiccation chamber until cool and burned weights (to 0.001 g) were taken. The equation used for % organic carbon was $C = [(W_d - W_b) / W_d] * 100$, where C is % organic carbon, W_d is dry weight, and W_b is burned weight. The remainder of the sample was used in a hydrometric procedure to determine substrate particle size (Gee and Bauder 1986). Samples were removed from the desiccation chamber and passed through 2 mm sieve to remove large particles then weighed (to 0.001 g). The sediment was placed into a 250 ml Erlenmeyer flask. Tap water, warmed to room temperature, was added to completely wet the sample. Then 100 ml of sodium hexametaphosphate (dispersing agent) was added, samples were sealed with parafilm and mixed for 5 min. Mixtures were placed in a metal blender cup tap water was added to fill it half full and blended for 5 min. Samples were transferred to 1 L glass sediment cylinders filled to 1 L with tap water. A metal plunger was used to thoroughly suspend the sediment into solution, plunger was removed and a hydrometer was inserted into the cylinder. After forty seconds and after 2 hours specific gravity readings were taken and recorded. Since specific gravity is affected by temperature and the dispersing agent a blank containing 100 ml of sodium hexametaphosphate and filled to 1 L was used for a correction. The equation used for percent sand was $S = [1 - ((H_1 - H_3) / W)] * 100$, where S equals percent sand, H_1 equals the forty second specific gravity reading, H_3 equals the specific gravity reading for the blank, and W equals dry weight of the sample. The equation used for percent clay was $C = [1 - ((H_2 - H_3) / W)] * 100$, where C equals percent clay, H_2 equals the 2 hour specific gravity reading, H_3 equals the specific gravity reading for the blank, and W equals the dry weight of sample. Percent silt was determined by subtracting percent sand and percent clay from 100.

Additional information collected at each habitat sampling site included depth of the site, secchi depth, temperature, and dissolved oxygen profile of the water column. Temperature and dissolved oxygen profiles were also taken at random locations in Lake St. Clair in 1999 during the months of July, August, and September. Temperature and dissolved oxygen was measured using Yellow Springs Instrument (YSI) dissolved oxygen meter.

Statistical analysis was completed using SPSS statistical software (Norusis 1993). Multiple analysis of variance (MANOVA) was used to test for differences between areas of high, moderate, low, and no use grids and to test for differences due to depth. If differences were detected Scheffe's test was used to detect which differences were significant. One-way analysis of variance (ANOVA) was used to test for significant differences between areas where Hexagenia were presence and absent with substrate type and percent organic carbon as factors. ANOVA was also used to test for significant differences between areas where sturgeon were present and absent with invertebrate categories, substrate types as factors. ANOVA was used to detect differences in depth distributions among individual sturgeon. Results for all statistical tests were considered significant at $P \leq 0.5$. All numerical data are shown with $\pm$ one standard deviation.

Results

Sixteen adult lake sturgeon were implanted with ultrasonic transmitters during the course of this study (Table 1). While Sonotronics listed the battery life of the transmitters used in this study at 15 months, they lasted 42 months with a noticeable decrease in reception on or about month 36. In total, fish were searched for on 182 different days starting on 30 May 1997 and ending on 20 October 2000 (Figure 3). A total of 2,758 listening locations were used, with 349 different fish locations being identified in Lake St. Clair and the St. Clair River.

Lake sturgeon were most often found at depths of 4 to 6 m in Lake St. Clair. More than 50% of the fish observations were at 5 m, and eleven of the sixteen fish used in this study were observed at this depth (Figure 4). Only one fish was found in areas of the lake with depths less than 3 m, and no fish were found at depths greater than 7m. In the St. Clair River fish were found at depths ranging from 4 to 24 m. Depths where at least three unique individuals could be found ranged from 9 to 18, and 24 m (Figure 5). Sturgeon were not found in areas of the river where depths were less than 3 meters. No sturgeon were found in the shipping lane.

Temperature and dissolved oxygen profiles collected in 1999 (July, August, and September) and 2000 (May) indicate that Lake St. Clair did not stratify. Water temperatures differed by $1.5 \pm 1.3\ ^0C$ between the surface and the bottom. Dissolved oxygen in the water column averaged 95.8% $\pm$ 5.5% saturation between the surface and the bottom of the lake.

The spring spawning period began when water temperatures in the North Channel reached 10 ^0C and ended at 14 ^0C (Thomas and Haas 1998). In 1997 the spawning period occurred from 23 May to 1 June, in 1998 from 1 May to 18 May, in 1999 from 4 May to 6 June, and in 2000 from 6 May to 7 June. Surface water temperatures for the St. Clair River were obtained from the Algonac City, Michigan, water plant.

During this study a number of problems were encountered while trying to locate individual sturgeon. Fish 1, implanted in May 1997, could not be located and was thought to have moved out of the system or to have suffered transmitter failure. In August 1999 it was located near the mouth of the Detroit River. During consecutive visits up to a year later, fish 1 could be found in the same location. I assumed that the fish had either died or had passed the tag. One transmitter malfunctioned and the pulse code changed after implantation. When a transmitter malfunctions, it automatically reverts back to a factory pulse code setting of 15 - 15 - 15. By process of elimination I eventually determined that the transmitter in question was in fish 11.

Fish 12 and 15 both could not be relocated shortly after implantation. Fish 12 was only located one time on 29 June 1999 near Algonac. After implantation on 3 June 1999, fish 15 moved out into the finger of the North Channel that extends out into Anchor Bay, then within one week was found moving upriver towards Lake Huron. Both fish were presumed to have moved into Lake Huron.

The remaining 13 lake sturgeon were located for 15 to 42 months throughout Lake St. Clair and the St. Clair River. Two general patterns of movement emerged. After the spawning season most sturgeon (fish 2-10 and 14) moved out into Lake St. Clair. A subgroup of these fish (2, 4, 5, 6, 7, 9, 10, and 14) moved to a region off of the St. Clair River Delta. The delta region can be described as a large depositional area extending 2 to 4 kilometers into the lake with depths less than 1 m. Following this shallow area the bottom gradient slopes to 3 m deep within a few hundred meters. The fish were found just past the 3 m depth contour through an area extending approximately 12 Kilometers in a west-southwest direction into deeper water. The southern boundary was the shipping lane that cuts across the lake also in a west-southwest direction. Mean range of this subgroup of sturgeon was $11.5 \pm 1.6\ Km^2$. Fish 10 had the largest range (18.1 Km^2) and fish 4 had the smallest range (4.8 Km^2). Calculations for range did not include fish locations of individuals migrating to the North Channel in the spring or migrating from the river shortly after the spawning period. The other subgroup (fish 3, 8, and 11) moved into the delta region but also traveled across the shipping lane and could be found in the southern basin during multiple years. These fish did not localize in any specific areas but were in waters 3 m or deeper and traveled over a much larger area of the lake. Mean range for this subgroup was 26.3 ± 1.2 Km^2. Fish 11 had the largest range (27.9 Km^2) and fish 3 had the smallest range (24.0 Km^2). Fish 6 and 10 were the only other fish to be located south of the shipping lane but both fish were only found on one occasion in this area.

Three fish (4, 13, and 16) remained in the river or returned to the river during non-spawning periods. Fish 4, implanted in June 1997, moved to the Delta region after river temperatures increased above 14^0 C. The fish returned to the North Channel in December 1997 and remained there for the next 19 months. The fish was located a total of 33 times in the river. In February 1998 this fish was captured by an angler, the external monel tag on the dorsal fin prompted the angler to notified MDNR personnel. They examined the fish on location, took pictures, and released it. The sturgeon was in excellent condition, other than having lost some weight most likely due to spawning. While in the St. Clair River fish 4 was found on 15 separate occasions off of Pt. Aux Chenes in the North Channel. This portion is characterized by a sharp bend in the river with depths greater than 20 m. The sharp bend followed by a deep hole provides an eddy where the substrate is dominated by soft substrates and organic debris is deposited, video footage, taken by MDNR personnel, confirmed this (Mike Thomas, MDNR personal communication). Fish 13 moved out into Anchor Bay following implantation in June 1999 but returned to the North Channel by August and remained in the River until June 2000. This fish also was found off of Pt. Aux Chenes on 3 occasions. Fish 16 remained in the North Channel after implantation and was located on 18 occasions from June 1999 through September 2000. Mean range for river resident sturgeon was 12.0 ± 1.1 Km, with fish 4 having the largest range (14.0 Km) and fish 16 having the smallest range (10.1 Km).

Four females (fish 2, 5, 14, and 16) and three males (fish 4, 8, and 11) were in the North Channel during the spawning period after implantation. Fish 2 returned from the lake after 3 years. Fish 4 returned the year following implantation then remained in the river for the next spawning period. Fish 5 returned two and three years after implantation. Fish 8 returned after two years. Fish 13 returned to the river from Anchor Bay in the fall following implantation and was in the North Channel the following spring. Fish 16 remained in the river after implantation through the next spawning period.

Pre-spawning and post-spawning migration data for fish in this study is sketchy. Fish 5 was located in Anchor Bay on 5 May 1999 when water temperatures were at 12.0 ^{0}C. On 6 June 1999 it was located in the river, water temperatures were at 13.0 ^{0}C. The fish could be located in the river until water temperatures reached 16.0 ^{0}C. Fish 8 and 9 moved out of the river in 1998 shortly after water temperatures reached 15.0 ^{0}C. Fish 8 was first located in 2000 on 15 May. The fish was located in the finger on thee North Channel that extends out into Anchor Bay on that date water temperatures were 11.2 ^{0}C. Due to the lack of data it is not possible to confirm if the fish was in the river earlier than 15 May. Fish 11 remained in the North Channel until water temperatures reached 13.6 ^{0}C then one week later on 10 June 1999 was located in the Lake, water temperatures in the river had increased to 16.0 ^{0}C. Fish locations during the spring migration to the North Channel or return migrations to Lake St. Clair post-spawning is limited but suggests that lake sturgeon use Anchor Bay and the North Channel as a migration corridor.

Occasionally sturgeon were located upriver from where the North Channel splits from the rest of the channels. However, no fish were located in any of the other channels that lead to Lake St. Clair. Three fish were found in the main channel of the St. Clair River. The last location for fish 5 was near Chenal Ecarte in the main channel. The last two locations for fish 5 were on 2 June and 6 June 2000 (at the end of the spawning period) near Pine River. This was the furthest upriver migration recorded, approximately 25 km form the North Channel. Fish 8 was located during the peak spawning period near Fawn Island. Anecdotal evidence from anglers suggests that this may be a lake sturgeon spawning site (Mike Thomas, MDNR, personal communication)

A total of 1,185 identifiable macroinvertebrates (Table 2) were collected during 2000 from the 134 Ponar samples collected at the 48 habitat sampling locations (Figure 6). Organisms from the phyla Nematoda and Annelida were fragmented during processing and were not used in the analysis. Dreissena polymorpha values are listed in grams wet weight. Dreissena polymorpha was the dominant taxonomic group followed by Chironomidae, Hexagenia, and Gammarus fasciatus. Hirudinea, Isopoda, Ephemeroptera (other than Hexagenia), Odonata, Trichoptera, Diptera (other than Chironomidae), and Mollusca (other than Dreissena polymorpha) were sparse and consequently omitted from further analysis.

Hexagenia densities differed due to substrate type (t-test P = 0.011). Mean percentage of silt at the sampling locations where Hexagenia were present was significantly higher (44.12 ± 4.41) than at locations without Hexagenia (24.32 ± 6.14). Tests for percent clay resulted in no significant differences between locations. Mean differences were not significantly higher (t-test P = 0.062) at locations where Hexagenia were present (2.15 g ± 0.21) than at sampling locations without Hexagenia (1.46 g ± 0.30). Simple linear regression showed that sand and silt were negatively correlated ($R^2 = 0.97$) so only silt was used for analysis.

Invertebrate densities varied slightly among the four relative frequency of occurrence categories with no significant differences detected. Mean densities of Dreissena polymorpha, Chironomidae, Gammarus fasciatus and Hexagenia were compared to sturgeon relative frequency of occurrence categories. Mean densities of Hexagenia in the high use categories was $158.0 * m^{-2} \pm 65.1$ while mean densities of Hexagenia in the zero use categories was $44.9 * m^{-2} \pm 11.6$ however, the differences were not significant (Scheffe's test P = 0.07). No significant differences were detected comparing silt clay and carbon content of the substrate in areas of zero, low, moderate, and high relative frequency of occurrence. When sturgeon relative frequency of occurrence data were converted into a binary format of presence or absence of sturgeon and analysis was recalculated results were similar. Dreissena polymorpha, Chironomidae, and Hexagenia means were higher in the locations where sturgeon were present. However, only Hexagenia was significantly higher (P = 0.035). Mean for Gammarus fasciatus was lower in locations where sturgeon were present but not significantly lower.

Discussion

The results from this study show that adult lake sturgeon follow unique movement patterns and habitat selection may be related to these movements. Following implantation, most of the 16 sturgeon traveled downstream to Lake St. Clair and resided there for some period of time. Some of the fish returning to the lake moved to a region off of the St. Clair River Delta and were consistently located in this region for periods of up to three years. Some individuals traveled more extensively throughout the lake and were located on several occasions in the southern basin of the lake. Unique to open systems, this study found some individuals that either remained in the St. Clair River or returned to the river and resided there for an extended period. Fish that resided in the river returned to the spawning area the following spring. Some individuals that moved to the lake also exhibited homing behavior and returned to the spawning area in subsequent years. Migration to the spawning area in the spring and movement away from the spawning area was closely related to water temperature. Within Lake St. Clair, areas where adult sturgeon were found had a significantly higher number of Hexagenia. While areas where Hexagenia were present were composed primarily of silt substrates, there was no correlation between substrate type and the relative frequency of occurrence of sturgeon.

The first objective of this study was to establish the movement patterns of adult lake sturgeon spawning in the North Channel of the St. Clair River. I hypothesized that sturgeon collected during spawning were coming from Lake St. Clair. However, what was found were three general patterns of movement, sturgeon moved into Lake St. Clair following spawning, remained in the river, or I believe moved out of the study area. Twelve of the sixteen fish used in this study returned to Lake St. Clair and remained there for an extended period of time. Eight fish moved to a region off of the St. Clair River Delta. The greatest area cover by fish in the delta region was 18.1 Km^2. Three fish traveled throughout Lake St. Clair crossing into the southern portion of the lake encompassing areas up to 27.9 Km^2. In systems without physical barriers restricting fish movement, the distances traveled by sturgeon varies greatly. Fish from the Sturgeon River traveled between 70 and 280 Km (Auer 1999). While fish from the Moose River remain in a localized area traveling less than 5 Km (Threader and Brousseau 1986). Two fish I believe moved into Lake Huron so it is possible that the extent of fish movement was greater than what was observed in Lake St. Clair.

The second objective of this study was to use the movement data to establish what areas of the lake were being used by lake sturgeon and to determine forage abundance in those areas. I hypothesized that sturgeon selected habitat in Lake St. Clair based on forage abundance and type. I found that the mean densities of the dominant taxa found in this study (Dreissena polymorpha, Chironomidae, and Hexagenia limbata) were not significantly correlated with sturgeon relative frequency of occurrence. However, when all areas of the lake were classified as sturgeon present or absent Hexagenia limbata densities were significantly higher in areas where sturgeon were present. Gastric lavage techniques were not perfected when this study began so sturgeon diets were not taken. Because of this, it is unclear what macroinvertebrates are important forage items for sturgeon in Lake St. Clair. It is known that adult lake sturgeon feed primarily on benthic macroinvertebrates, with some variation in diet depending on species availability (Magnin and Harper 1970; Hay-Chmielewski 1987; Chiasson et al. 1997). Hay-Chmielewski (1987) found that crayfish and Hexagenia were the primary forage items of adult sturgeon. While other studies found Hexagenia made up 86.3% of the diet and when combined with Diptera and Trichoptera made up 96.1% of the diet (D.L.G. Noakes, A. Rossiter, and F.W.H. Beamish unpublished data *in* Chiasson et al. 1997). Based on research by others I assumed that Hexagenia and Diptera the two dominant native species, and the exotic species Dreissena polymorpha, because it was so abundant in the lake, would make up the forage of adult lake sturgeon. Results were not conclusive but I believe that sturgeon were selecting habitat based on forage abundance and type. Sampling more sites and collecting more samples would reduce variation in the data and should provide more conclusive results in future research.

Lake sturgeon residing in Lake St. Clair seemed to have preferred depths. Both groups of fish that resided in Lake St. Clair were found at depths between 4 and 6 m greater than 98 % of the time. Approximately 57 % of the lake is between 4 and 6 m deep with 42 % $\leq$ 3 m. At depths between 4 and 6 m, substrates were composed primarily of silt. Considering that much of the lake is within the preferred depths, and silt substrates dominate the deeper portions of the lake, it is not clear to me why sturgeon could be consistently found in areas off of the delta region but were not found in other similar areas of the lake. Also, with 42 % of the lake $\leq$ 3 m it is unclear why sturgeon were only rarely located in shallow areas such as Anchor Bay. One benthic study found that the total number of taxa in Anchor Bay was similar to the rest of the lake but densities were significantly higher (Hiltunen and Manny 1982). In fact, Hiltunen and Manny found that Hexagenia densities were 1.5 times higher and Diptera larvae were almost three times higher in the bay than in the open lake and that the bay is composed of primarily silt and sand. One explanation may be that plant growth in shallower areas is higher and this may prevent sturgeon from foraging efficiently. It is also possible that sturgeon were foraging in Anchor Bay during the evenings and returning to the refuge provided by the deep channel that extends out into Anchor Bay. Many fish resided in this location of the North Channel for extended periods of time. However, research in Black Lake revealed that there were no differences between day and night movement patterns (Hay-Chimielewski 1987). Diel patterns of activity could not be established because fish were not tracked over a 24-hour period in this study.

Although invertabrate densities had high variation in Lake St. Clair, the abundance of Hexagenia was not random but linked to substrate type. I hypothesized that substrate size in Lake St. Clair would be negatively correlated with Hexagenia. As expected, Hexagenia limbata, the second most abundant macroinvertebrate found in samples, were most common in locations dominated by silt substrates, these areas also tended to located in the deeper portions of the lake not in shallow areas near shore. Thornley results were similar (1985), in that study the abundance of Hexagenia was linked to substrate size with the greater densities of Hexagenia being found in the deeper areas. There was no significant difference in clay or carbon content of the substrates between areas with Hexagenia and areas without Hexagenia. This organism typically lives in U-shaped tubes in the substrate, they require sediments soft enough for burrowing and firm enough to maintain the integrity of the tube (Edmonds et al. 1976). Because of this I expected both silt and clay content to be higher in areas where Hexagenia were present. I had hoped to relate sturgeon relative frequency of occurrence to substrate type and carbon abundance. However, the comparisons were inconclusive. In spite of the results I believe Hexagenia abundance is an important factor determining where sturgeon can be found in a system.

Individual lake sturgeon were able to home to the spawning site in the North Channel. Due to the extended life of the transmitters in this study it was possible to follow most of the fish over three spawning periods. From the group of fish that moved back to Lake St. Clair following implantation, 6 returned to the North Channel spawning site in subsequent years, while the three fish defined as river resident fish, also returned to the spawning area. Based on this evidence it appears that homing occurs in this population. Homing behavior has been demonstrated in other lake sturgeon studies (Folz and Meyers 1985; Lyons and Kempinger 1992; and Auer 1999). In the Lake Winnebago system, estimates of 10% to 20% of sturgeon do not return to their home river location to spawn (Lyons and Kempinger 1992). Lyons and Kempinger describe this adaptation beneficial to the fish because elimination of a spawning site could eliminate a population. In this study some individuals were located in other suspected spawning areas located in other parts of the St. Clair River during peak spawning temperatures. If in fact only one main spawning area exists for this population, it would seem that this population would be at great risk if a disaster were to happen to that area.

Spawning migrations to the North Channel and patterns of out-migration seem to be dependent on water temperature. From the time fish first started appearing in the river until fish moved back to the lake averaged about 43 days. The fish used in this study were collected in the North Channel when river temperatures were between 10 and 14 ^{0}C with most sturgeon moving away from the spawning areas as temperatures increased above 14 ^{0}C and moving out of the river when water temperatures reached 16 ^{0}C. Based on limited information available from the two fish locations recorded prior to spawning, fish returned to the North Channel when temperatures were between 11 and 12 ^{0}C. Results from a MDNR study support most of these findings (Thomas and Haas 1998). The MDNR study was being conducted concurrently with this study. They used setlines to collect sturgeon from the North Channel in the spring and found that low numbers of sturgeon began being captured on setlines when water temperatures were as low as 7.0 ^{0}C. These early captures may be river resident fish and not individuals that are spawning. They collected sexually ripe individuals at temperatures ranging from 12 to 14 ^{0}C (Thomas and Haas 1999). In other studies lake sturgeon spawning occurs in rivers during the spring with water temperatures usually between 13.0 and 18.0 ^{0}C (Scott and Crossman 1973; Foltz and Myers 1985; LaHaye et al. 1992). Some studies indicate spawning behavior begins at lower water temperatures, Baker (1980) reported spawning at temperatures from 11.2 – 11.7 ^{0}C, Auer (1999) found spawning began in the Sturgeon River, Michigan, shortly after temperatures reached 9 ^{0}C and Ottawa River populations spawned at temperatures as low as 9 ^{0}C (Roussow 1957). Other studies indicate spawning occurs at high temperatures. At sites in the Wolf River, Wisconsin, water temperatures were as high as 23.3 ^{0}C (Kempinger 1988) and LaHaye et al. (1992) recorded temperatures up to 21.5 ^{0}C in L'Assomption River, Quebec.

Other channels in the delta were sampled during spring migrations to determine if sturgeon used these areas as migration corridors. During the course of this study no fish were found in the connecting channels leading to Lake St. Clair. However, fish were found upriver from the point where the North Channel splits off from the main channel. Why fish were only found moving through the North Channel is not clear. If sturgeon have the ability to imprint and home to specific historic sites to spawn (Lyons and Kempinger 1992), then sturgeon returning to the North Channel may only be able to detect the spawning site from water coming out of the North Channel. Avoidance of the South Channel may be related to shipping traffic and the fact that the South Channel has been dredged. It is also possible that fish were using these other channels but were not detected.

Spawning periodicity was not easily determined from this population. The limited data in this study suggested that males spawned every 1 to 2 years and females spawned every 1 to 3 years. Early research in other systems suggested that spawning periodicity for either sex of lake sturgeon did not occur annually (Harkness and Dymond 1961). More recent research has documented males spawning at biennial intervals (Priegel and Wirth 1974; Mosindy and Ruzak 1991) and in some populations males spawn annually (Lyons and Kempinger 1992). Males from the Sturgeon River population returned to spawn every 2 to 6 years while females returned to spawn every 3 to 7 years (Auer 1999). Three studies of the Lake Winnebago system found females returning every 4 to 6 years (Priegel and Wirth 1977), or every 3 to 4 years (Folz and Meyers 1985; Lyons and Kempinger 1992). It was not possible to capture the individuals with transmitters and check their sexual condition each time they returned to the spawning site. Because of this, spawning periodicity was based on the assumption that sturgeon located at the spawning site when river temperatures were between 10 and 14 ^{0}C were spawning. The assumption would not be valid if individual sturgeon, defined as river-resident fish, were attracted to the spawning fish but do not actually spawn, or if individuals migrated from the lake to the river and did not spawn.

Some sturgeon remained in the North Channel for an extended period of time post-spawning. Three fish (two males and one female) from the St. Clair River population exhibited this behavior. Both males moved to the lake following implantation, one returned to the river in August the other in December. Both fish over-wintered in the river then moved to the spawning area in the spring. It is unclear if these fish move back to the spawning site to spawn or if it is behavior related to the larger school that congregates at the spawning site each spring. One fish was not located post-spawning the other fish remained in the river for the next 19 months. The female remained in the river following implantation, and post-spawning moved 2 to 3 Km from the spawning location. The following spring the fish returned to the spawning site, and again moved away from the site post-spawning. Known river-resident behavior is not unique to this study but the behavior is unusual. In most studies where sturgeon have access to lacustrine habitats, post-spawning fish move downstream out of the river shortly after the spawning period ends (Baker 1980; Hay-Chmielewski 1987; and Auer 1999). Studies on the Lake Winnebago system, Wisconsin, also recorded the downstream migration following spawning (Priegel and Wirth 1977). However, a more recent tagging study on the Winnebago system found that substantial numbers of adult lake sturgeon could be found in fall in the Wolf River, the same river that they spawn in (Lyons and Kempinger 1992). Information from that study was not sufficient to determine if fish were in the river during the winter or the summer, because of this they were not certain if the fish were permanent residents of the river. They suggest that the fish move from the lake into the river in fall, reside there for winter, spawn in the spring, then return to the lake. Auer (1999) suggests that movement out of spawning rivers may be related to survival adaptations. This behavior prevents stranding, exposure to sunlight and avoidance of predators. These behaviors may not be applicable to rivers like the St. Clair River or other large rivers forming connecting waterways between the Great Lakes. In the St. Clair River the diversity of microhabitats may provide abundant foraging opportunities (Edsall et al. 1991; Schloesser et al. 1991), and locations for resting. Adults feeding in the same river need to be separated from recently deposited eggs and newly-hatched fish (Auer 1999). Fish that remained in the North Channel post-spawning moved upriver and downriver from the known spawning site. Two locations that best typify this are the deep hole at Pt. Aux Chenes and the finger of the North Channel that extends out into Anchor Bay both locations were frequented by different fish over many months. Sturgeon have been collected by setlines at Pt. Aux Chenes during the spring spawning periods. It is unlikely that this is a habitat conducive for spawning due to the nature of the substrate (fine sediments) and lower flow velocities near the bottom (Thomas and Haas 1998). The fish that were captured there were collected on baited setlines so it is assumed that they were feeding. It is possible that the close proximity to the spawning site provides a resting site or a staging area until water temperatures are optimum, or perhaps fish collected form locations like this are fish that are river-resident and not spawning.

Three fish were last recoded moving upriver and presumed to have moved into Lake Huron. Two fish implanted in 1999 were last located moving towards Lake Huron. The fish could not be located during follow up searches of the River from Port Huron to Lake St. Clair and searches throughout Lake St. Clair in 1999 and 2000. The third fish was implanted in the North Channel in June 1997, moved to Lake St. Clair then returned to the river in the spring of 1999 and 2000. The last two recorded locations for fish 5, were taken at the furthest point upriver at the end of the spawning period, water temperatures were 13 ^{0}C. These results may support findings by the MDNR mark-recapture study that a small percentage of sturgeon are moving into southern Lake Huron (Thomas and Haas 1998). In that study, four sturgeon tagged at the North Channel Spawning site were captured approximately 70 Km away by commercial trap-net fisheries in southern Lake Huron. This evidence suggests that sturgeon spawning in the North Channel may be coming from different populations located in other areas of the Great Lakes, analysis of the genetic information collected from the fish should help answer this (Thomas Haas 1998).

Multiple assumptions were made in this study. The first one was stated earlier, sturgeon that were located at the spawning site during peak spawning temperatures were spawning. Unlike other spawning studies with adult lake sturgeon, (Priegel and Wirth 1971; Hay-Chimielewski 1987; Auer 1999) spawning locations in the North Channel are located in deeper water (> 9 m) so it was not possible to capture all fish and visually confirm if adult lake sturgeon were spawning. Evidence of spawning could only be confirmed from the small percentage of fish that were captured on setlines and visually checking for sexual readiness (Thomas and Haas 1998). If this assumption were not true then sturgeon males do not spawn every 1 to 2 years and females do not spawn every 1 to 3 years. Other studies do not support annual spawning for either sex (Harkness and Dymond 1961; Priegel and Wirth 1974; Mosindy and Ruzak 1991; Auer 1999). The likelihood that sturgeon were actually spawning each time they migrated to the spawning area is low. Another problem was the assumption related to the size of system being studied and the goal of trying to search all areas systematically. All fish could not be located on a regular basis and as a result I assumed that fish remained in the same general area between location periods. An error in this assumption would probably result in much larger areas of Lake St. Clair and the St. Clair River being defined as sturgeon habitat and the range of each individual fish would probably increase. The probability that fish remained in the same location between sampling events is low. To further compound the problem fish were assumed to be on the bottom and that each location where the fish was found was important habitat. Fish were often seen rolling at the surface and fish may have been passing through an area and not necessarily selecting bottom habitats at that location. In spite of these assumptions, using telemetry is still a valid way of determining movement patterns and establishing what areas are possible required habitats. Partitioning a lake the size of Lake St. Clair into manageable size areas is an effective way to compare locations. However, the problem with working on systems this size, (one-minute latitude by one-minute longitude) is finding a balance between collecting enough data to make sound conclusions and the logistical constraints of time and money. I assumed that these areas were homogenous which is unlikely. Errors in this assumption probably resulted in increased variance between the means of my benthic and sediment samples and resulted in an over simplification of the habitat in the lake. In future analysis increasing the number of sites and the number of samples collected at each site would help alleviate this problem.

The extent of sturgeon movements are complex and may be dependent on a number of factors such as habitat requirements at various life stages, migrations related to spawning, forage abundance, areas required for over-wintering, and available area. Extent of movement is further hampered by study design, for example telemetry studies typically do not track movements over great distances or time and movement patterns may be based on a few individuals. As was demonstrated in this study individual movement patterns are complex and only generalizations should be made about the larger population based on telemetry findings. Tagging studies provide other pieces of information such as population age and growth, sex ratios, estimates of the population size, and are able to cover a larger area for a longer period of time (Lyons and Kempinger 1992; Thomas and Haas 1998; Auer 1999) Using both telemetry and tagging together is probably the most effective way to gain knowledge about sturgeon in a particular system.

Management implications

Future management should recognize the need to protect critical habitats used by lake sturgeon for spawning, migration, and foraging. Management priorities should first protect locations where groups of sturgeon congregate and migration corridors. The known spawning site in the North Channel represents one of these locations. The shoreline next to the spawning site is classified as residential. The site is located in 9 and 12 m of water with a substrate composed of coal cinders ranging in size from < 25 to over 200 mm in diameter (Thomas and Hass 1998). It covers an area 25 by 54 m and roughly parallels the shoreline. This area needs to be protected from poachers, and disturbance especially during the spring when sturgeon are spawning. One disaster in this area could dramatically alter the population of sturgeon in Lake St. Clair. Dredging or alterations to the bottom could severely impact sturgeon in this area. Two other areas of the St. Clair River that management needs to focus on is the finger of the North Channel that extends out into Anchor Bay and the deep hole at Pt. Aux Chenes. On multiple occasions sturgeon were located in these areas and remained in these areas for extended periods. It is unclear if sturgeon other than those used in this study use those locations but I assume that they are. If sport anglers focus effort in areas where sturgeon congregate or along migration corridors remaining stocks may be quickly reduce.

While lake sturgeon are listed as a threatened species in Michigan and steps were taken to prevent over-harvesting, Ontario has much more liberal fishing laws and still allows a limited number of sturgeon to be harvested by commercial fishers in both Lake St. Clair and southern Lake Huron. The mark-recapture study being conducted by MDNR should provide some insight on the lake sturgeon population size in Lake St. Clair (Thomas and Haas 1998). Movement patterns that were determined from this study and estimates of population size should provide baseline information for managing this species in Lake St. Clair. If decreases in the population are detected in the future arguments for closing or further restricting the commercial fishery can be justified.

Lake St. Clair and the connecting waterways need to be protected from pollution and disaster caused by people. Research from in this study and others has documented sufficient bottom substrates that can support critical forage items (Hexagenia, Diptera, and Mollusca) are important habitat requirements for lake sturgeon (Harkness and Dymond 1961; Priegel and Wirth 1971; Hay-Chimielewski 1987; Chaisson et al. 1997). In Lake St. Clair and the connecting waterways pollution and the introduction of exotic species has impacted the abundance of these species in the past (Nalepa and Gauvin 1988; Edsall et al. 1991; Schloesser 1991; Nalepa et al. 1996). Steps must be taken to prevent pollution in the future and to prevent the introduction of other exotic species.

Throughout the Great Lakes region plans are being proposed and implemented to rehabilitate sturgeon to their native ranges. As I stated in the introduction to this study knowledge about the habitat requirements, habitat utilization during various life stages, and identification and protection of critical habitat was key to rehabilitating this species (Hay-Chimielewski and Whelan 1997; Holey et al. 2000). Information from this study should be helpful for the rehabilitation of lake sturgeon throughout the Great Lakes.

Future research

Expanding future research to include greater portions of the lake will help verify conclusions derived from this study. Due to the size of the lake and the limited resources available only 48 locations in the lake were sampled. Increasing the number of sampling locations, replications within a station, and including locations in the Detroit and St. Clair rivers would help ensure that results from this study are applicable to other locations throughout the Great Lakes.

Changes are taking place in the Great Lakes because of the introduction of such exotic species like zebra mussels. Stomach samples were not taken in this study so there was some uncertainty as to the preferred food of adult sturgeon. Future research should address foraging behavior of adult lake sturgeon and the importance of such prey items in their diet.

While movement patterns of adult lake sturgeon has been established for fish spawning in the North Channel of the St. Clair River. Future research should target both juvenile populations and other suspected spawning populations in other areas of the St. Clair River as well as the Detroit River. Movement patterns associated with these populations may require different management strategies than those discussed in this paper.

Table 1. Length, weight, age and tracking statistics for 16 adult lake sturgeon used in this study.

Fish Number	Sex	Total Length (mm)	Total Weight (Kg)	Estimated Age	Date Implanted	Date Last Located
1	F	1524	33.0	-	05/30/97	05/30/97
2	F	1524	31.5	-	05/30/97	08/23/00
3	F	1575	31.0	36	06/02/97	12/13/99
4	M	1762	45.5	42	06/02/97	07/15/99
5	F	1397	17.1	26	06/05/97	06/06/00
6	M	1461	19.0	28	06/05/97	08/28/00
7	M	1455	20.5	29	05/19/98	06/08/00
8	M	1544	30.4	31	05/19/98	10/20/00
9	-	1448	21.2	25	05/19/98	08/28/00
10	M	1422	18.5	17	05/19/98	10/20/00
11	M	1537	21.3	25	05/26/99	08/28/00
12	M	1412	18.4	26	05/26/99	05/29/99
13	M	1852	25.8	38	05/26/99	06/20/00
14	F	1435	18.8	28	05/26/99	08/23/00
15	F	1816	49.5	62	06/03/99	06/11/99
16	F	1537	31.0	44	06/03/99	09/27/00

Table 2. Macroinvertebrates identified from Ponar dredge samples. Invertebrates were identified to order, family or genus. Asterisks indicate categories used for analysis.

Benthic organisms			Number
Nematoda			[a]
Annelida			[a]
Oligochaeta			
Hirudinea			16
Arthropoda			
Amphipoda	Gammaridae	Gammarus fasciatus *	118
Isopoda			2
Insecta			
Ephemeroptera	Ephemeridae	Hexagenia limbata *	243
	Potamanthidae		1
	Caenidae		2
Odonata	Coenagrionidae	Enallagma sp.	1
Trichoptera			28
Diptera	Chironomidae *		698
Diptera	(Other)		32
Mollusca			
Gastropoda			14
Plecypoda	Unionidae		30
		Dreissena polymorpha *	484[b]

[a]Number not counted.
[b]Wet weight in grams.

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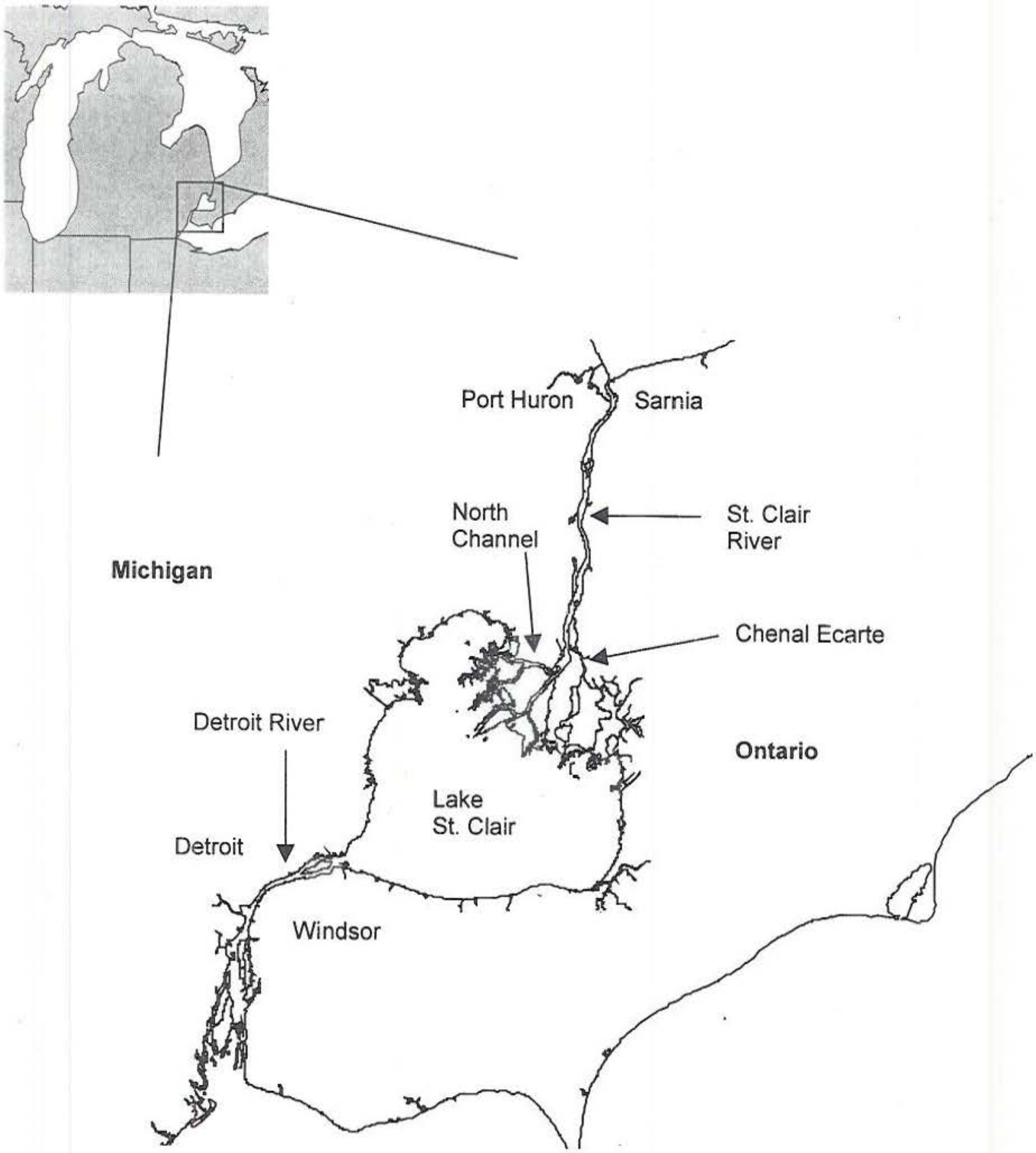

Figure 1. Lake St. Clair and the connecting waterways.

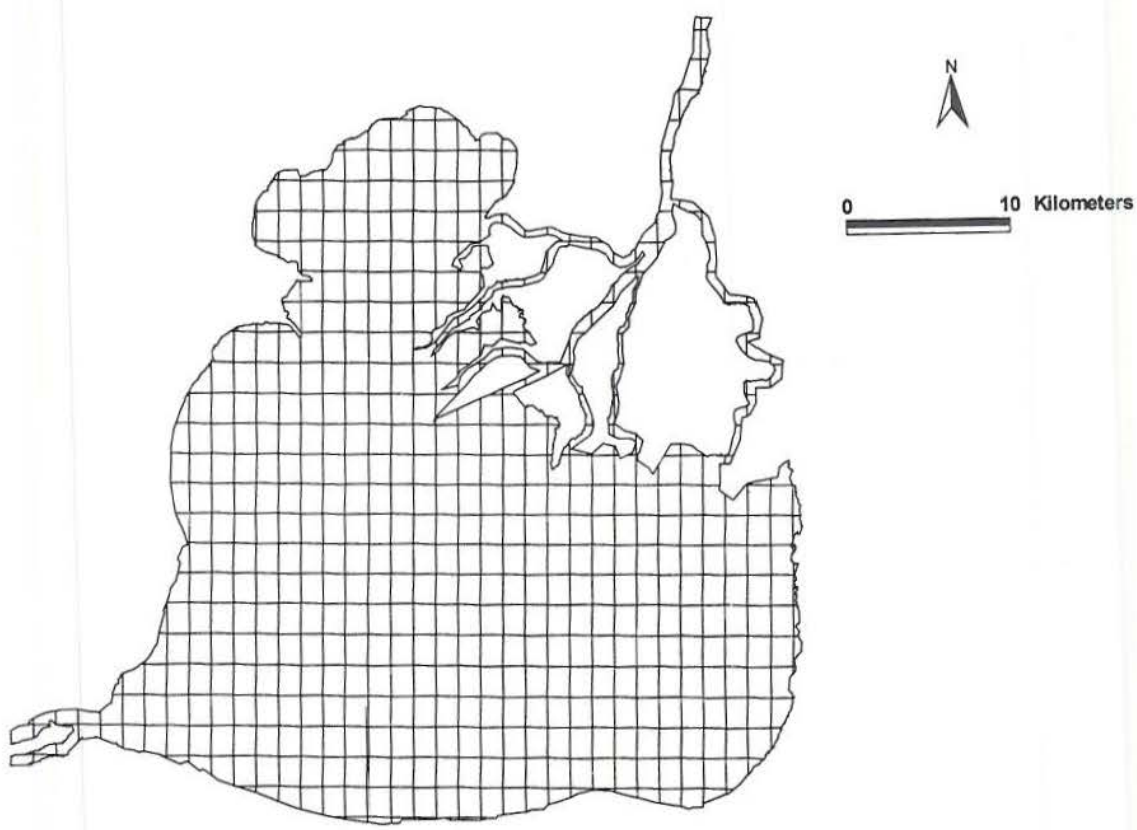

Figure 2. One-minute latitude by one-minute longitude grid of Lake St. Clair.

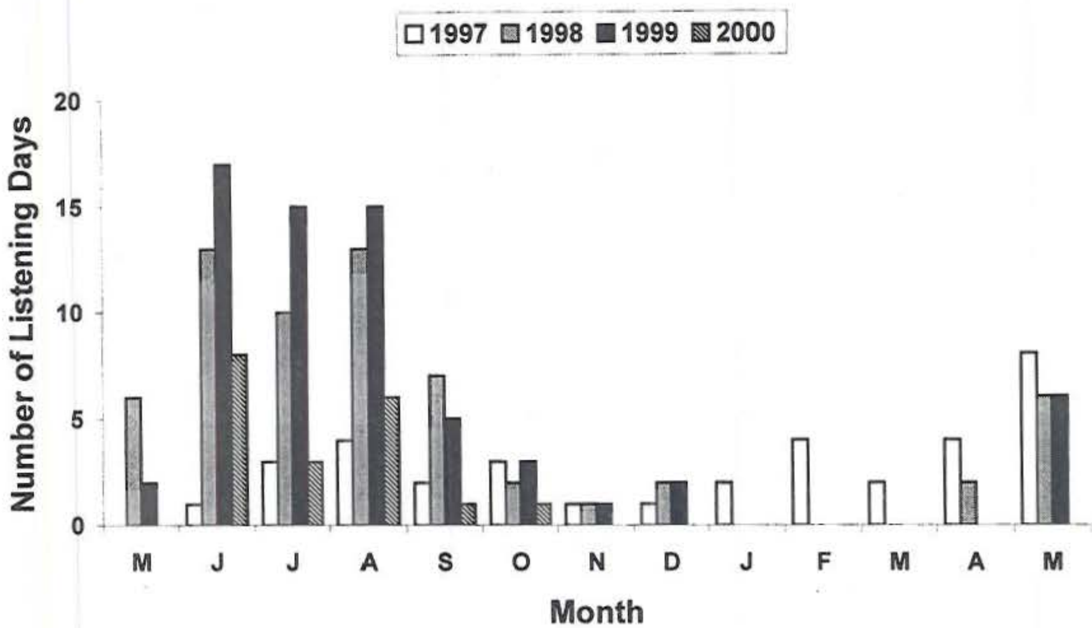

Figure 3. Number of listening days during each month, from May 1997 - October 2000.

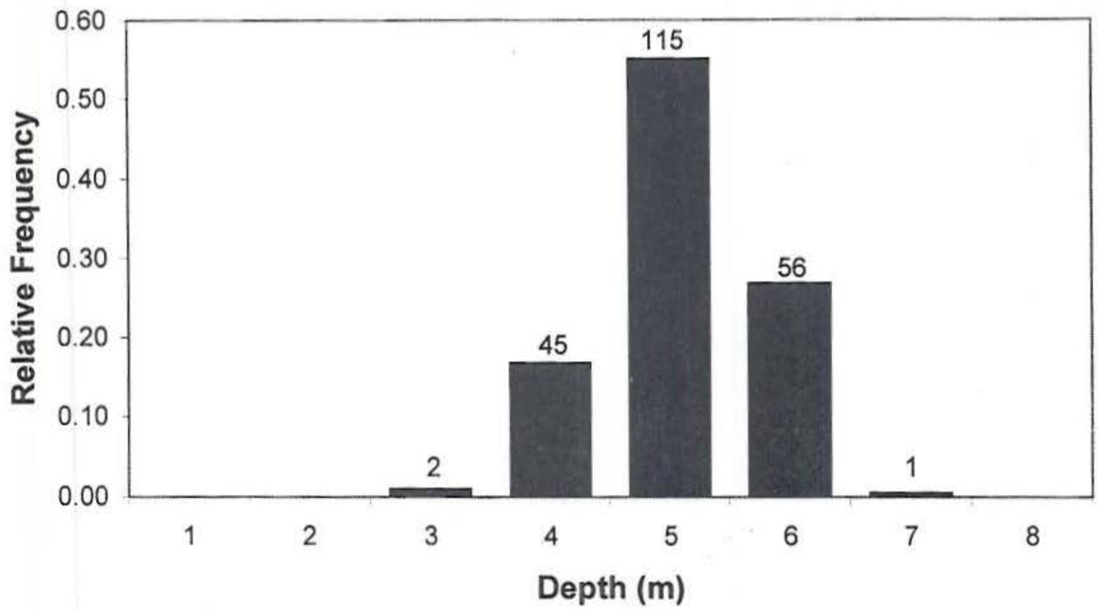

Figure 4. Relative frequency of lake sturgeon located at various depths in Lake St. Clair. Values above bars represent fish observations.

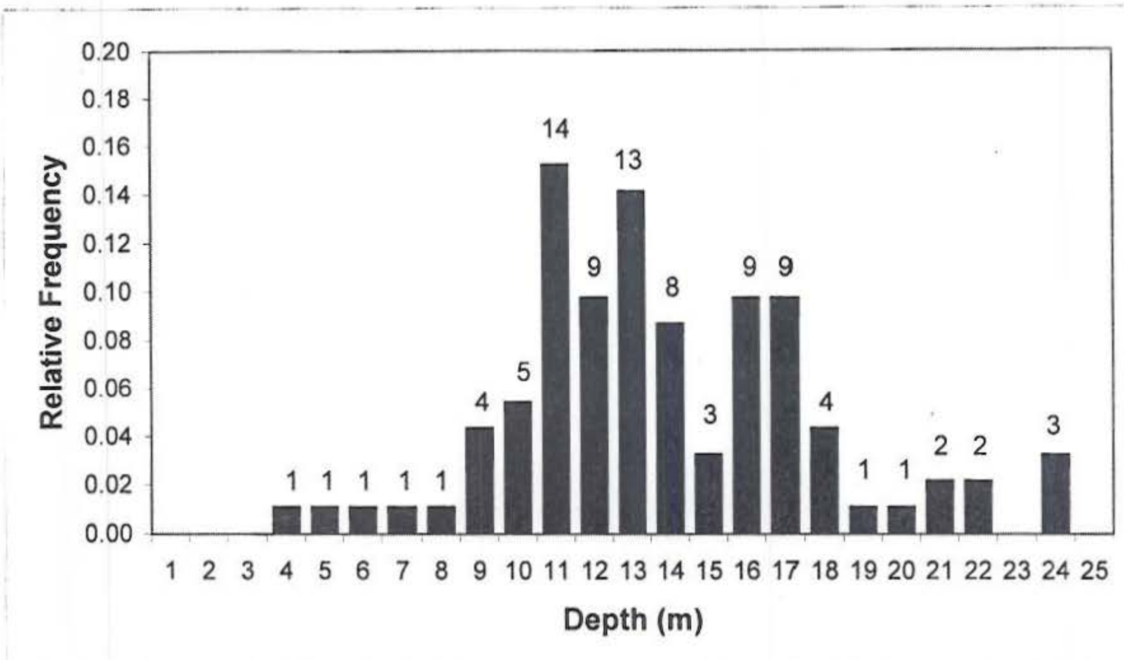

Figure 5. Relative frequency of lake sturgeon located at various depths in the St. Clair River. Values above bars represent fish observations.

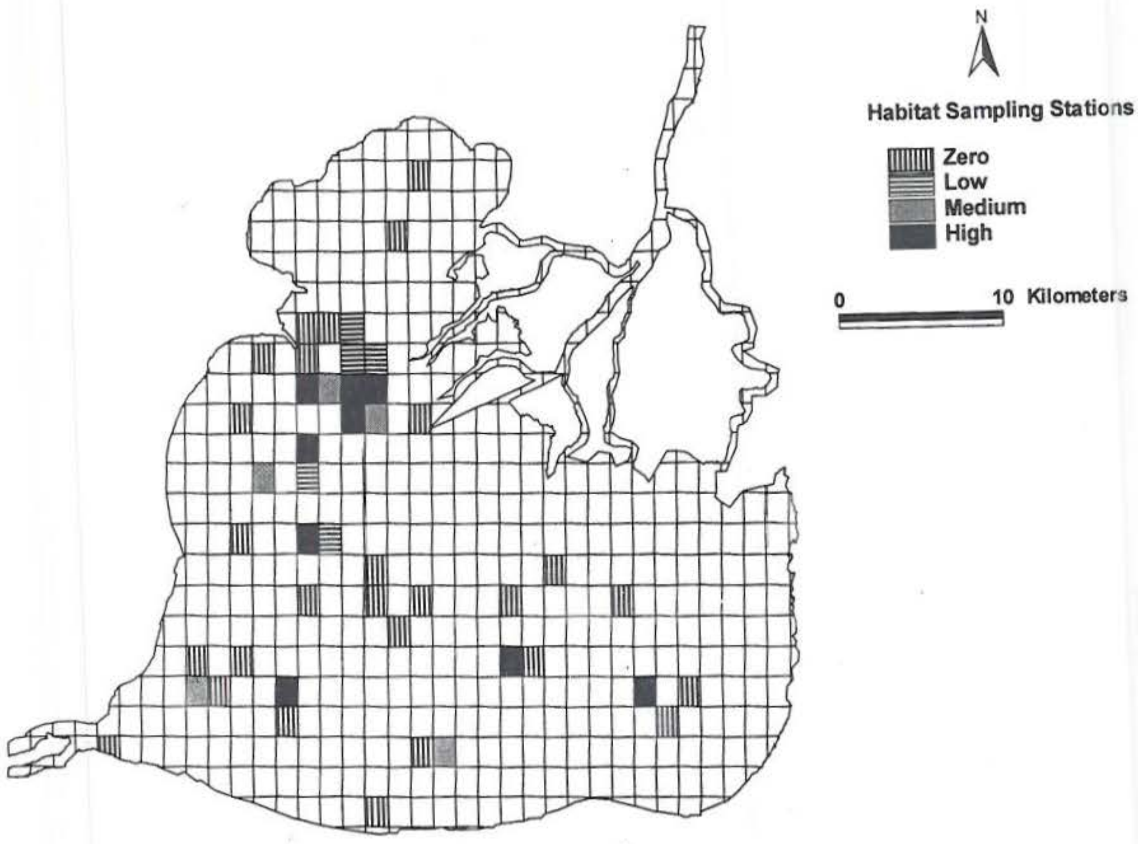

Figure 6. Location of the 48 grids that were sampled for sediment composition, benthic invertebrates, temperature, dissolved oxygen and secchi depth. Key depicts lake sturgeon relative frequency of occurrence values.