18

Movements and Habitat Use by Lake Sturgeon (*Acipenser fulvescens*) in an Unperturbed Environment: A Small Boreal Lake in the Canadian Shield

Terry A. Dick[1], D. Block[2] and Dale Webber[3]
[1]*Department of Biological Sciences, University of Manitoba, Winnipeg, Manitoba*
[2]*Department of Highways, Province of Manitoba*
[3]*Vemco, Division of Amirix, Halifax Nova Scotia*
Canada

1. Introduction

The order Acipenseriformes, belonging to a group of basal Acthopterygian fishes (Choudhury and Dick 1998), has two living families (Acipenseridae and Polyodontidae), 6 genera, and 26 species worldwide (Nelson and Paetz, 1992; Nelson 1994). The Acipenseridae are old with the fossil record of sturgeon like fish dating back 100 million years to the upper Cretaceous (Harkness and Dymond 1961, Fogle 1975, Pearce 1986, Mecozzi 1988, Choudhury and Dick 1998). Fossils of an extinct family, the chondrosteidae, are dated from the lower Jurassic to the lower Cretaceous (Scott and Crossman 1998). Other authors state that sturgeon species are primitive relicts of the Devonian period 300 million years ago (Glover 1961, Ono et al. 1983, Houston 1987). Choudhury and Dick (1998) suggest that acipenserids diversified within a narrow time frame and lapsed into a subsequent long period of morphologica1 stasis.

The lake sturgeon has the most local names of al1 North American sturgeon species. These names include: rock, common, red, ruddy, Ohio, stone, shell-back, bony, freshwater, smooth-back, rubbernose, black, dogface, bull-nosed and Great Lakes sturgeon (Harkness and Dymond 1961, Williams and Vondett 1962, Scott and Crossman 1998), Pearce 1986, Mecozzi 1988).

The decline of sturgeon populations throughout the world (Bemis and Findeis, 1994) and in North America is well documented. Population numbers plummeted around the turn of the 20th century as a result of over-fishing (Prince, 1905, Dick et al. 1998). The continued decline of populations across Canada is due to a variety of factors including habitat loss, continued fishing pressure in the form of commercial, sport, and subsistence fisheries. Consequently, the Committee on the Status on Wildlife in Canada (COSEWIC) raised major concerns on the status of the species and a report was written for Canada by Dick et al. (2006a). Considerable effort has gone into sturgeon research over the past two decades and since then the understanding of lake sturgeon biology and habitat use has improved, facilitating the possible rehabilitation of some populations. The Manitoba records on lake sturgeon population declines are relatively complete because there are good historical records for lake sturgeon harvests from commercial fisheries (Prince, 1905; Bajkov and Neave, 1930; Baldwin et al. 1979, Choudhury et al. 1990), and the aboriginal communities have a strong knowledge base and a long fishing and cultural connection to sturgeon **(**Holzkamm and Wilson, 1988; Dick et al. 2002).

Information on lake sturgeon (*Acipenser fulvescens*) in North America was first compiled by Dick and Choudhury (1992). A considerable amount of new data has been accumulated since the early 1990s on lake sturgeon in North America and in Canada **(**Dick et al. 2006b). This document clearly shows that the national trends for lake sturgeon populations are a general decrease in numbers with some of the decline attributed to environmental perturbation. However, not all declines are due to environmental perturbations, for example, the recent decision by the Province of Quebec to reduce the commercial fishery quota on what was considered viable stocks indicates that commercial fishing still has a major impact on a few sturgeon populations **(**Dick et al. 2006a**)**. Furthermore, continued fishing of any sort on numerous sturgeon stocks across Canada will have a detrimental affect on their chances of survival. According to current information there are atleast six distinct genetic stocks across Canada, therefore rehabilitation programs will be limited by restrictions on the transfer of stocks across major watersheds (Ferguson and Duckworth, 1997; Ferguson et al. 1993).

Today, a substantial amount of information is available on the general state of most lake sturgeon populations across Canada and the United States, the natural fragmentation of sturgeon populations, and how to retrospectively view lake sturgeon distributions. We also have some idea of what constitutes "good" sturgeon habitat, the habitat by juvenile sturgeon in natural systems (Chiasson et al. 1997; Barth et al. 2009), and new information on genetic diversity and rare phenotypes of lake sturgeon in a Canadian contex (Ferguson and Duckworth 1997; Ferguson et al. 1993).

The objectives of this study were to develop methods to study movements and habitat use by lake sturgeon, especially subadults and juveniles and develop tags that provide data on specific activities such as feeding. This study was designed to collect data on lake sturgeon movements and then to attempt to define habitat by describing substrate and currents in the vicinity of their movements. The Pigeon River was chosen because there was a relatively confined population in Round Lake, which would allow for fine scale movements to be assessed without the complications of immigration and emigration. Most of the data on which this chapter is based is from research conducted in Round Lake, Manitoba, Canada and from the laboratory of T. Dick at the University of Manitoba. No attempt was made in this chapter to provide a complete literature review of lake sturgeon as this has been published elsewhere (Dick et al. 2006b).

*Round Lake study area***:** Round Lake is located on the Pigeon River which flows from Family Lake to Lake Winnipeg (Fig. 1). It is a small isolated lake in eastern Manitoba, Canada that was never commercially fished and consequently has remained a relatively unperturbed and an important reference lake for lake sturgeon studies. The study area included the Pigeon River in the vicinity of Round Lake, areas upstream from the lake to the first set of falls, Grant Falls, and downstream of the lake to the first set of falls. Round Lake has a typical boreal lake fish species compositions plus lake sturgeon. The fish species composition in Round Lake is illustrated in Fig. 2**.** Diets of fish species collected from Round Lake are presented in (Fig. 3) and lake sturgeon consumed mostly mayflies, clams and amphipods (based on the gavage method, see Dick (2004). Lake sturgeons are about 10% of the fish community based on catch per unit effort.

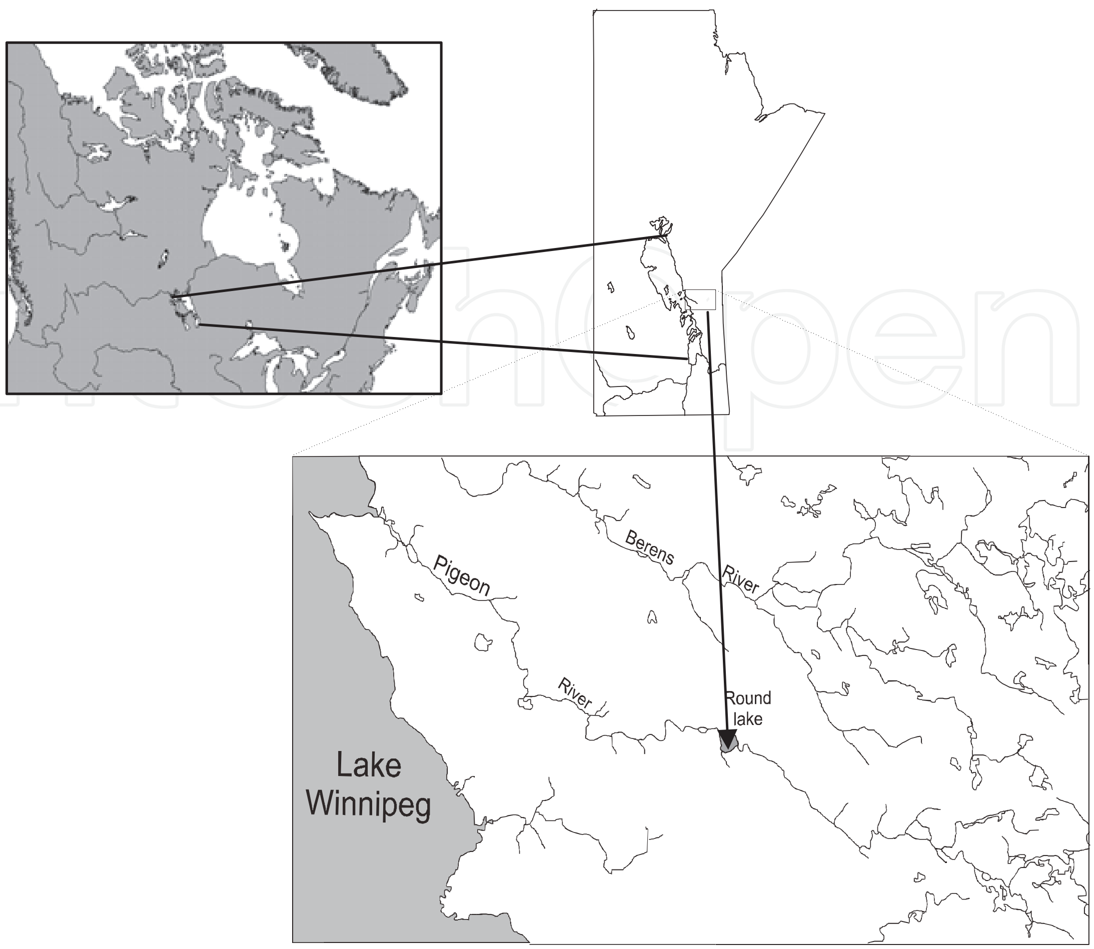


Fig. 1. Map of the Pigeon River, from Family Lake to Lake Winnipeg.

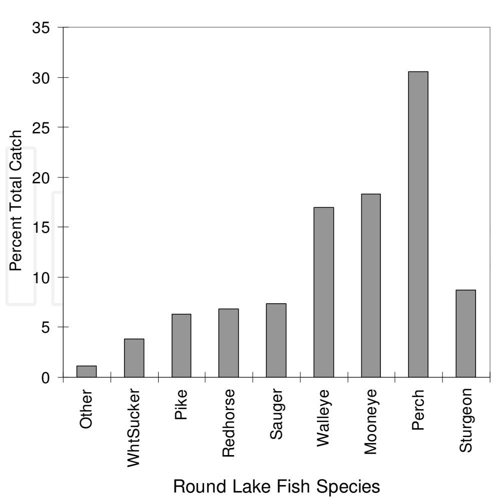


Fig. 2. The composition of fish species in Round Lake.

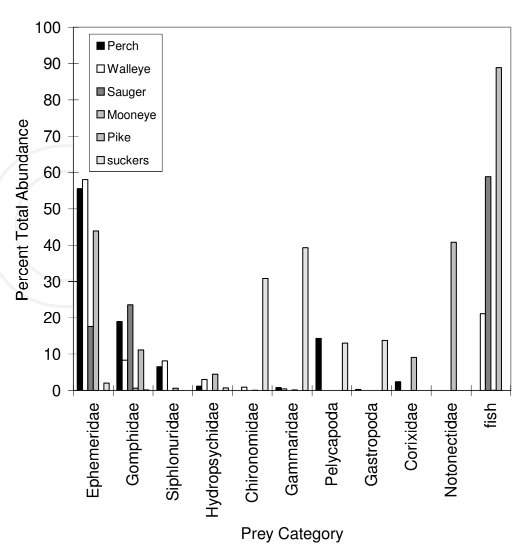


Fig. 3. The abundance of prey items in the stomach contents of each individual species of fish in Round Lake.

2. Telemetry technologies

2.1 Comparison of radio and acoustic tag technologies

Radio and acoustic telemetry were the two methods used to study animal movements but there are differences in their applications and the type of data acquired. Acoustic signals must be received underwater while radio signals are received in the air. Data from radio tags can be received from boats, airplanes and through the ice and is best for large scale studies where animals move considerable distances but is usually less precise in terms of location and is also labour intensive, especially the way we applied it. Both types of tags provide repeat data. Acoustic receivers are more precise (especially the VRAP system of Vemco Ltd.) and tags can measure variables such as depth and temperature, and are good for fine scale studies. Initially acoustic tags were large and the equipment was expensive and cumbersome to handle due to bulk and weight. More recently tags and receivers have been constructed that are reduced in size and the life of the tags has increased. Both radio and acoustic tags can be detected with mobile receivers but precision in locating animals is lower, for both systems, and there are usually fewer observations.

Gill nets were used to capture all lake sturgeon. Three different nets were used: 30 cm stretched mesh, 22.5 cm stretched mesh and a standard gang with six panels (3.1, 5, 6.9, 8.8, 10.6, 12.5 cm stretched mesh). Fish were brought to shore and placed on a damp canvas sheet. Weight, length was recorded and on a few fish a pectoral fin ray was removed to establish a size to age relationship.

This following section deals with a comparison between the two technologies. Both radio and acoustic tags were attached externally to the dorsal fin. For short term studies over days or a few months, external tags are adequate but for longer term studies of several years internally implanted tags are necessary. Radio tags were obtained from Lotek, Missassauga, Ontario, Canada and the acoustic tags were obtained from Vemco Ltd. (Halifax, Nova Scotia). Two types of acoustic tags were used. Large fish were tagged with V16 pressure tags, the remaining fish were tagged with V8 position tags. Pressure tags transmitted information on swimming depth as well as positional information. The V8 tags transmitted positional data. The tag weight to body weight ratio for both radio and acoustic telemetry was less than 1% for all fish. A piece of neoprene was placed between the tag and the dorsal fin and a piece of neoprene was placed on the opposite side of the fin for support of the attachment wires. Two hypodermic needles, spaced apart the length of the tag, were pushed through the neoprene backing and then through the dorsal fin of the fish. The attachment wires were fed through the tag, through the second piece of neoprene, and then through the needles. The needles were then pulled out pulling the attachment wires through the fin and the neoprene on the opposite side of the fin. The attachment wires were pulled snug and several knots were tied to secure the tag. Excess wire was removed using wire cutters. Later, a 40 gauge neoprene was used between the tag and the fin instead of the foam and neoprene also replaced the foam and plastic backing on the opposite side. This method gave a tighter fit for the tag when tested by hand, however there was no tag loss using either method. The radio tags were manufactured by Lotek Engineering, Missassauga, Ontario, Canada. All tools were sterilized before use and salt was applied to the tagged area after the procedure to reduce infection. Lake sturgeons, after attaching external tags, were held in a holding net placed in the lake at a depth of 2.0 meters. Fish remained inactive for periods of 20 to 40 minutes but as soon as normal swimming behaviour was observed they were released.

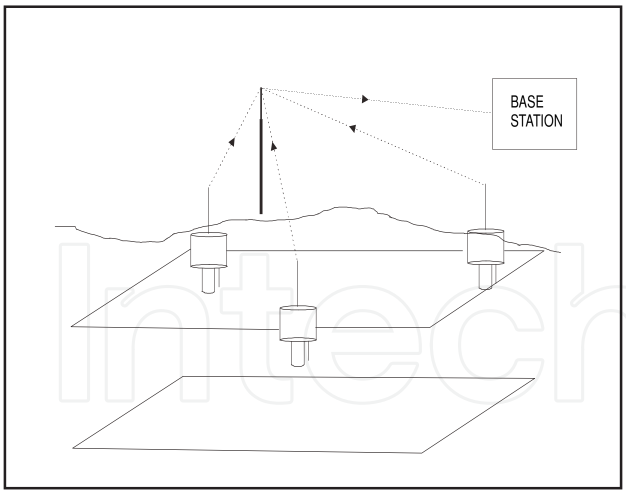


Fig 4. Diagram of the Vemco (VRAP) system.

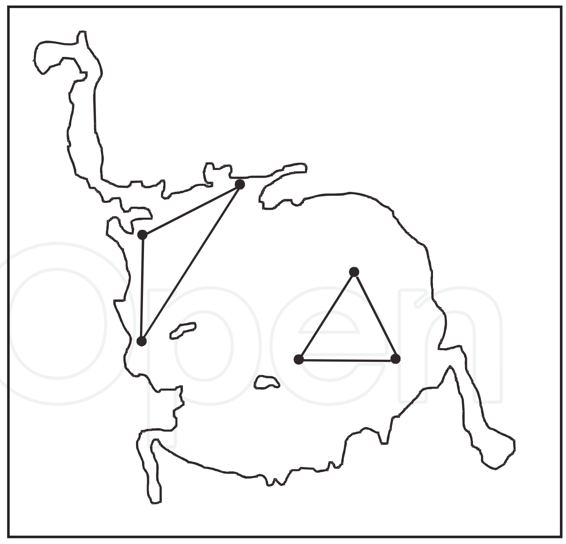


Fig. 5. Location of the two acoustic arrays in Round Lake.

Precise positioning of lake sturgeon was done using two radio linked acoustic positioning arrays (VRAP, Vemco Ltd.). Each array consisted of a base station which communicated with each of three buoys anchored in the lake (Fig. 4). Each buoy contained an acoustic transmitter, an omnidirectional hydrophone, and a VHF modem.

Buoy location was determined using survey techniques and having an understanding of the lake morphometry so that there was a clean line of site between receivers so that a tag signal was picked up by atleast two receivers. Test tags determined if a signal could not be picked up by a receiver due to an under water obstruction, such as a boulder, and if the receiver was obstructed it was re-positioned. The chosen positions covered 80% of the surface area of the lake. Figure 5 shows the distribution of the two 3-receiver arrays.

2.2 Telemetry data

Telemetry data analysis and presentation was done using Idrisi for Windows (Clark University, MA). Some maps were created in Idrisi for Windows. Acoustic telemetry data was imported from the VEMCO system program.

Determination of depth selection and substrate selection was done by hand. Seven days were selected for analysis. Selection was based on movements to include the widest possible range of movement patterns. Days 206 and 221 were selected for sturgeon 4014. Days 210 and 222 were selected for sturgeon 4015. Days 206, 211 and 219 were selected for sturgeon 4017. For each location on each day bottom depth was determined.

Swimming depth minus bottom depth was calculated to determine all locations in which the fish was in contact with the substrate. All values of 1 or less were included. All figures and comments pertaining to substrate selection only include locations in which a fish was in contact with the bottom. Other location statements and figures used all the positional data available.

Radio tags: These tags were attached externally to the dorsal fin. Initially, a piece of foam was placed between the tag and the dorsal fin and a piece of foam and a plastic backing were placed on the opposite side of the fin for support of the attachment wires. Details on tag attachment are outlined above.

A total of 20 radio tags were used and lake sturgeons were tracked periodically by boat (Table 1). When a signal was received the exact location of the fish was determined by circling the area until the signal was strong enough to trigger the code on the receiver. The locations were plotted on a map of the lake by visual triangulation with known points on land. A GPS location was recorded. Fig. 6A shows the total movements of all lake sturgeon in Round Lake fitted with radio tags. Twenty lake sturgeons were monitored over a three year period. The main patterns of movements over the deeper areas of the lake related to the flow of the river through the lake.

ID	Total (cm)	Fork(cm)	Weight(g)	Age
code 33	140	129	21000	-
code 31	129	121	13200	-
code 64	144	138	25970	-
code 63	132	122	14900	-
code 75	123	110	10185	-
code 65	122	112	9870	-
code 60	47	41	499	-
code 66	47	42	485	-
code 68	55	49	734	5
code 70	62	55	1202	7
code 72	50	45	551	-
code 32	114	106	8700	-
code 56	107	98.5	7120	34
code 51	66	60.5	2272	-
code 41	99	91	5350	-
code 42	114	109	9945	-
code 43	119	112	11596	-
code 40	135	122	14470	-
code 55	124	116	12840	
code 45	104	99	7920	

Table 1. Biological data for the radio tagged lake sturgeon.

Acoustic telemetry: Figure 6B illustrates the overall movements of nine tagged lake sturgeon in Round Lake in July and August 1997 using acoustic telemetry and provides details on each tagged fish (Table 2). Figs. 4 and 5 illustrate an array configuration and the base station (VRAP system) and the relative positions of two arrays. The main patterns trends are related to the deeper areas of the lake and related to the flow of the river into, through and out of the lake. Since stationary receivers were used we had the opportunity to run transects to determine if boat activity influenced lakes sturgeon movements as there have been concerns that boat activity may affect lake sturgeon movements.

Fig. 6. A) Total movements of lake sturgeon in Round Lake using radio telemetry,
B) Total movements of lake sturgeon in Round Lake Round Lake using acoustic telemetry

A series of transects were run at the same time each day on the acoustic tagged sturgeon to test the hypothesis that boat activity affected lake sturgeon movements. The results showed that movements of lake sturgeon during periods when boat transects were run do not differ from the sturgeon movements when no boat was on the water (Fig. 5**)**. Lake sturgeon 4014 was located at the inlet and in the middle of the lake with and without boat activity. Lake sturgeon 4015 was located at the inlet with and without boat activity. Lake sturgeon 4017 was located generally in the area of the outlet with and without boat activity.The swimming depth of lake sturgeon during periods when the boat was on the water did not change from depths of lake sturgeon directly prior to when the boat was on the water **(**Figs.7 and 8). Lake sturgeon swimming depth changed often but was not correlated with presence or absence of boat activity. Mean depths were similar for times when boat transects were being run and times immediately prior to boat activity. We conclude that boat activity had no impact on lake sturgeon movements in our study and the lack of correlation between boat activity and lake sturgeon movements may relate to lake depth. By contrast, the application of radio tags and a mobile receiver in a shallow (2-3m) prairie river did affect lake sturgeon movements (Dick, unpubl. data). Clearly the type of aquatic system one is working in needs to be assessed, for impacts of boats and other anthropogenic activities, to be certain that abnormal sturgeon movements are not being recorded.

Number	**Total length(cm)**	**Fork Length(cm)**	**Weight(g)**	**Age**
4010	54	48	632	-
4013	49	44	572	-
4011	49	45	562	-
4012	48	43	506	4
4014	143	128	16900	-
4015	125	117	13250	-
4016	138	126	14750	31
4017	119	113	11620	-
4009	101	95	6790	22

Table 2. Lake sturgeon data for the acoustic tagged fish.

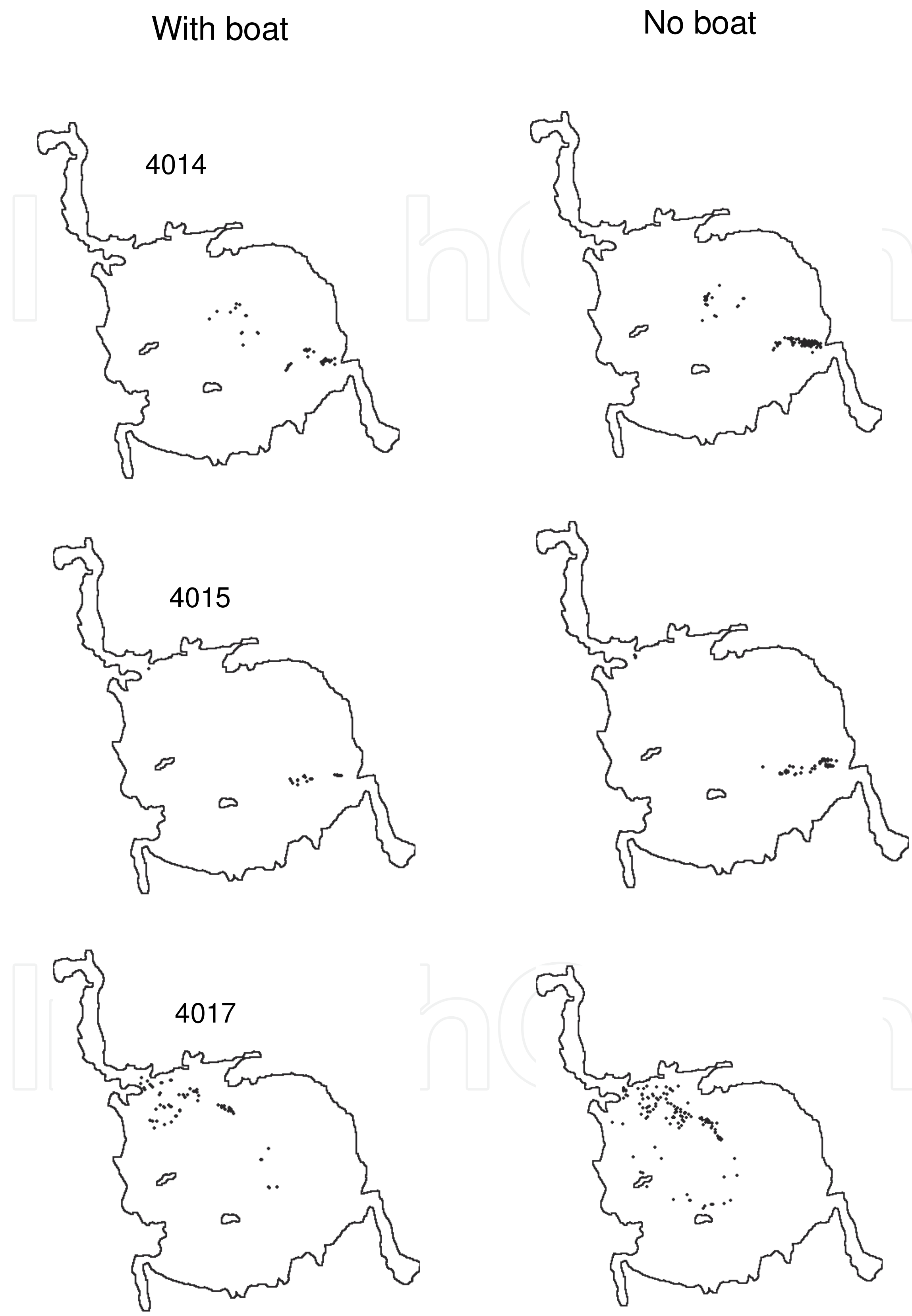


Fig. 7. Movement of lake sturgeon during movements of the boat and during times when no boat was on the lake

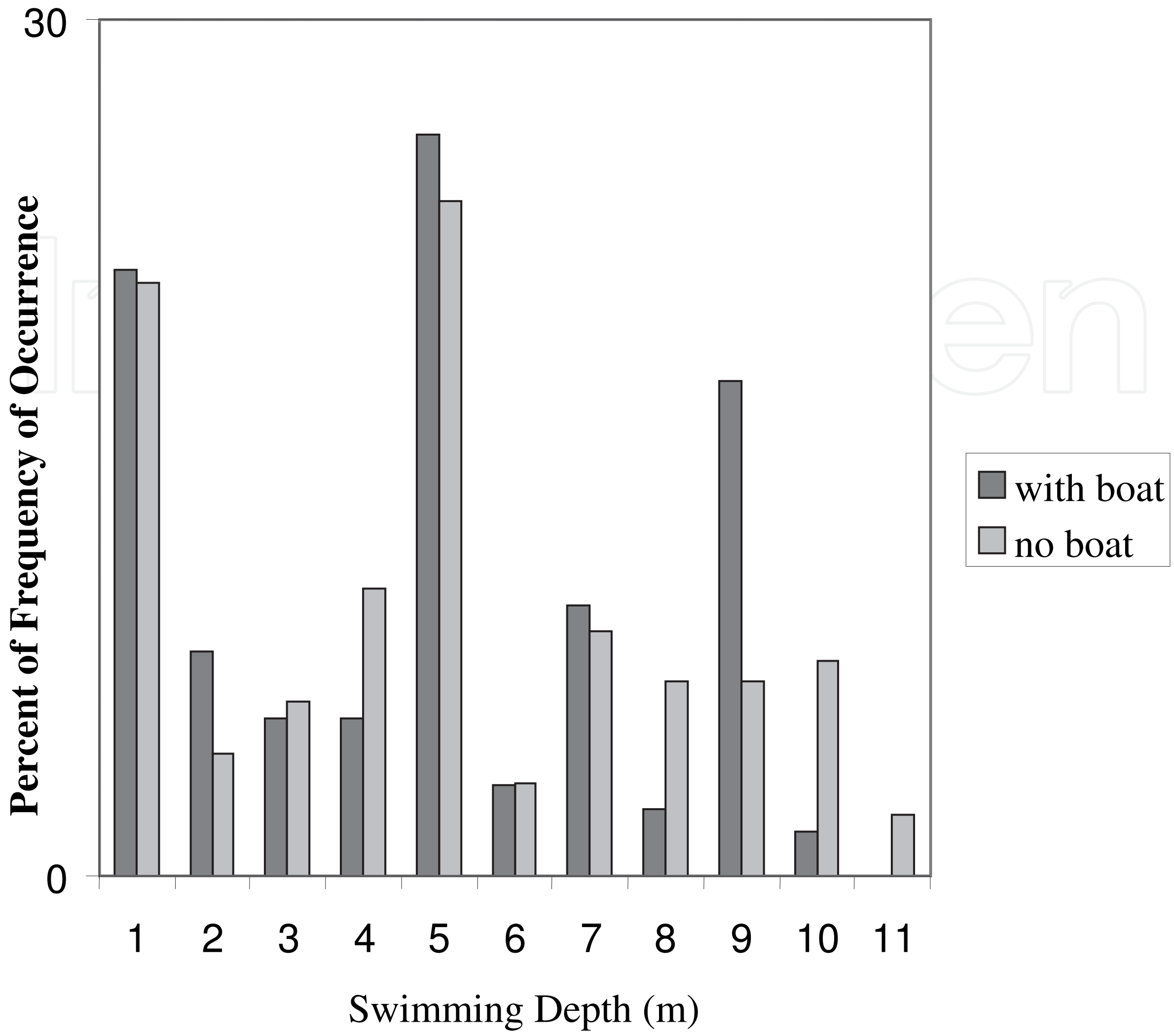


Fig. 8. Depth selection of lake sturgeon with and without boat activity

The major difference between radio and acoustic telemetry in freshwater is the receiving systems for the radio system can be above the surface of the water while acoustic telemetry receivers requires the more dense water to transmit the signal. This allows the former to be detected by aircraft as well as on the water surface but is labour intensive. A weakness of the acoustic system is bubbles in the water column interfere with transmission of the signal while a major advantage is that repeated collection of signals by well placed receivers can save considerable time and provide a much better indication of frequency of use of an area. Acoustic tags can also provide depth data.

We conclude that while there is a place for both types of tags, radio tags work best below rapids and waterfalls where there are usually plenty of air bubbles and in small stretches of rivers where there are dramatic current shifts, some air bubbles and up welling currents. Acoustic technology allows repeated measures but is scale limited due to the distance that the signal can be received. However, the Vemco VRAP system it is highly useful for relatively small aquatic systems with well defined boundaries, little or no emigration from the system and where accuracy to a few metres is important to describe habitat use, especially when pressure sensors are used to collect depth data on individual fish.

3. Sturgeon habitat assessment

3.1 Lake substrates

There are two main types of equipment now available for bottom classification but reviewers differ on the quality of bottom categorisation. The RoxAnn classification is based on energy calculations for first and second echosounder returns and the QTC view (version 5) calculates first echo shape parameters. QTC view provides automatic classifications and confidence estimates, while the RoxAnn relies on arbitrary manual calibration. The QTC bottom classes generally have consistent grain size and texture properties and follow grain size trends but RoxAnn classes are difficult to define. Both the RoxAnn and two versions of the QTC –View, series 5 were used to assess substrate.

Depth and Substrate Hardness: Substratum information was collected using an American Pioneer V digital sonar system and a Trimble Pro XR submeter Global Positioning System. Sonar data was collected using a 120 kHz - 12 degree transducer. Information collected included depth, bottom hardness, and roughness. Bottom hardness is an interval measure of the magnitude of the sonar ping return signal. Larger byte range values indicate a harder substrate.

The QTC-View Series 5 classification system is based on the principle that the shape of an echo sounder's first echo discriminates seabeds or substrates. For example, the acoustical signal of a smooth, simple, muddy seabed absorbs a high amount of energy and exhibits a low degree of backscatter resulting in an echo trace with a relatively narrow peak and no tail. Energy reflected from a rough, complicated, gravel seabed exhibits a high degree of backscatter. This results in an echo with a wide peak and a tail. The QTC-View series collected all echos and then post-processes the data in QTC IMPACT. The echo and GPS data is merged and the poor quality echos are filtered out. After echo digitization and preprocessing, the datum is analyzed by algorithms which characterize the waveform by using energy and spectral components to generate a digital string of over 100 shape descriptors. This series of numbers constitutes a description of the echo shape. Statistical analysis determines the most useful elements or series of elements to best discriminate echo shape.

The depth and substrate was collected and calculation of available habitat was done on Idrisi for windows. A frequency distribution was created using the data from each pixel on the hardness and depth images. For most of the mapping ArcMap, digital elevation models and/or kriging were used.

Sediment Analysis: Thirty-seven sediment grabs were collected so that comparisons could be made between sonar data and the sediment type. A substrate type; silt, sand, cobble, etc., could be related to hardness values, ranging from 90-145. Sampling sites were selected so that all possible substrate types were collected. Transects were run across the depth gradient in the lake running from the shallow sandy areas to the deeper silt/clay areas. Current was considered when selecting sample sites. Areas of high and low current were sampled (see section on current profiles).

Buoys were placed at the spot to be sampled. The location of each sample was recorded using a GPS unit. An Eckman dredge was dropped at the buoyed site and the sample retrieved. The sample was placed in a bag and kept cool until it could be tested in the laboratory.

The total sample at each site was divided into three parts. 100 ml was taken for particle size analysis, 100 ml was taken for invertebrate sampling and the remaining portion (if any) was frozen.

Laboratory analyses: Gravel and larger particle sizes were separated individually by hand, sieve analysis was used to separate the portion of the sample in the very fine sand to gravel categories, and settling velocity was used for silt and clay particle sizes.

The sample was placed in a tray and mixed thoroughly. The sample was added to water and dispersent (Calgon-sodium hexametaphosphate), mixed, and let sit overnight. The sample was then mixed, frozen, thawed and mixed again. The process was repeated a second time to ensure that the particles were completely separated. After the sample was separated thoroughly by the above mentioned process the silt and clay particles were removed from the sand and gravel particles. The sample was wet sieved through a 4 phi sieve to remove the silt and clay from the sample. The sediment left in the 4 phi sieve was placed in a beaker and the sediment falling through the sieve was stored in a separate container. The fine particles and larger particles were then treated separately.

Sand samples were placed into a pyrite beaker and allowed to dry in the oven until the sample was completely dry. A pestle and mortar were used to break up any chunks formed by the drying process. The total sample was weighed and placed in the top of a series of sieves ranging from -1.5 phi to 4 phi (0.5 phi intervals). The sieves were then placed into a Ro-tap shaker and then shaken for ten minutes. The material left in each sieve was weighed and recorded.

Silt/clay samples were placed in a 4000 ml graduated cylinder. Water was added to the cylinder to make the total solution 4000 ml. The solution was then shaken thoroughly and allowed to settle for the appropriate amount of time necessary to separate silt from clay. Five phi (1/32 mm) particles are the largest size category and were removed first. Five phi particles fall at a rate of 4 mm/second. The 4000 ml suspension is 500 mm high therefore the suspension was allowed to settle for 6 minutes and 15 seconds to allow all 1/32 mm particles to fall the full length of the cylinder. The supernatant (water and particles smaller than 1/32 mm) was siphoned off and saved. The process was repeated twice more to remove any smaller particles that would settle from the bottom portion of the cylinder. The remaining precipitant after the third siphon was dried and weighed as the silt category. The siphoned water was also dried and weighed as the clay category.

The particle size classification used was Cummins (1962) modification of the Wentworth Scale. Thirty-seven sediment grabs were taken and analysed from Round Lake. GPS locations for the sediment grabs were compared to hardness values from the Round Lake map at the same GPS location to obtain a system of classifying hardness values obtained by sonar.

Telemetry data analysis: Data was presented in maps using Idrisi for Windows (Clark University, MA). Some maps were created in Idrisi for Windows. Acoustic telemetry data was imported from the Vemco system program.

Determination of depth selection and substrate selection was done by hand. Seven days were selected for analysis. Selection was based on movements to include the widest possible range of movement patterns. Days 206 and 221 were selected for sturgeon 4014.

Days 210 and 222 were selected for sturgeon 4015. Days 206, 211 and 219 were selected for sturgeon 4017 (Table 2). For each location on each day bottom depth was determined. Swimming depth minus bottom depth was calculated to determine all locations in which the fish was in contact with the substrate. All values of 1 or less were included. All figures and comments pertaining to substrate selection only include locations in which the fish was in contact with the bottom. Other location statements and figures use all positional data available.

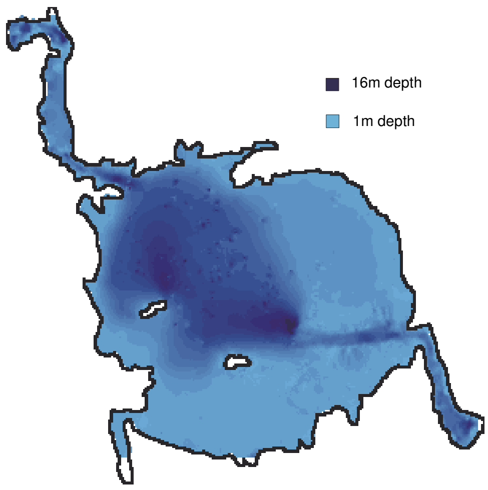


Fig. 9. Digital elevation model of Round Lake.

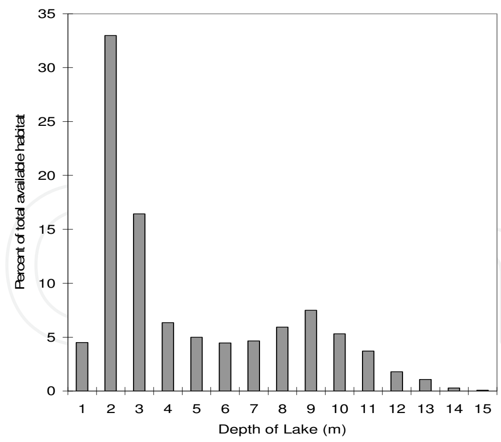


Fig. 10. Depth availability in Round Lake

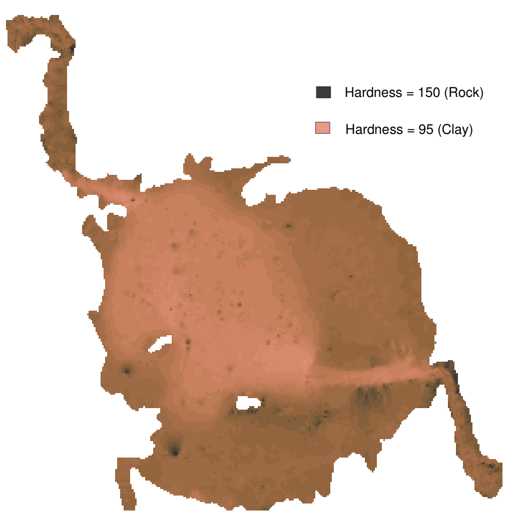


Fig. 11. Hardness map of Pigeon River at Round Lake obtained from sonar data.

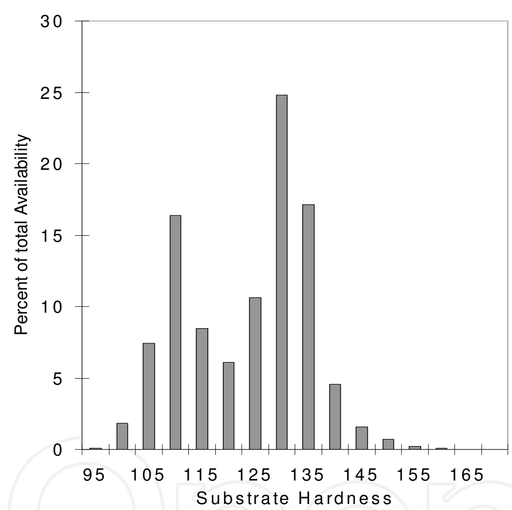


Fig. 12. Hardness (substrate) availability in Round Lake.

Substrate and Depth: Maximum depth of Round Lake is 16m. A depth map of Round Lake is shown in Fig. 9. Two deep holes, one off the Northeast corner of each island, are found in the lake. The general structure is bowl shaped. Depth availability is shown in Fig. 10. Two and three meters depths are available 33 and 16% respectively. Seven, 8, and 9 meter depths are available 5, 6, and 8% respectively.

Substrate hardness of the lake is shown in Fig. 11. Substrate was generally related to depth. The deeper areas of the lake had softer substrates with a high percentage of silt. The shallow sections along the shoreline to about 10m depth had sandy substrates. Cobble and rock substrate predominated in areas of high flow at the inlet and outlet. Availability of substrate hardness was 11, 25, and 17 percent for hardness values of 125 (coarse sand), 130 (gravel), and 135 (medium sand) respectively (Fig. 12). Substrate hardness of 110 (fine sand) had a frequency of 16 percent.

Phi	Particle Size (mm)	Category	Hardness
9	<0.0039	clay	95
5,6,7,8	0.0039 – 0.0625	silt	100
4	0.00625 - 0.125	Very fine sand	105
3	0.125 – 0.25	Fine sand	110
2	0.25 – 0.5	Medium sand	115
1	0.5 - 1	Coarse sand	120
0	1 – 2	very coarse sand	125
-1,-2,-3	2 – 16	gravel	130
-4,-5	16 - 64	Pebble	135
-6,-7	64 - 256	Cobble	140
-8	>256	Boulder	145

Table 3. Sediment classification scheme for Round Lake.

Thirty–seven sediment grabs were taken to compare with the hardness values obtained from the sonic data. Table 3 lists the substrate classification given to each range of hardness values. Hardness values range from 95 (clay) to 150 (rock, see Fig. 11).

4. Lake sturgeon movements

The biological data for the nine lake sturgeon tagged with acoustic tags are listed in Table 2. The nine fish were tracked for 27 days and 15,446 locations were obtained. Movements ranged from individuals that were mostly sedentary to highly mobile individuals. Daily movements were variable between fish as well as by the same fish on different days. Figure 13 shows the locations of fish 4015 on four separate days. Movement was confined to the inlet to Round Lake on day 210. Movement increased on days 211 and 212 and covered most of the lake. Movement on day 220 was restricted to the river outlet.

A comparison of the movements of juvenile and adult lake sturgeon is shown in Fig. 14. Movements of the juvenile fish were focused at the inlet and outlet and in the deep hole (~16 m). Movements of the subadult and adult lake sturgeon were also associated with the inlet and outlet but the movements were more widespread around the lake. The channel where water entered the lake was a preferred site as was the outlet from the lake. Figure 15 shows the swimming depth of sturgeon 4014 on day 206 relative to the bottom depth. Note the day 206 is based on January 1 being day 1. Sturgeon 4014 was on the bottom 30% of all locations on day 206. During the hours from midnight to 5 AM sturgeon 4014 was in the water column the majority of the time. From 5 AM to 11 PM more time was spent on the bottom. After 11 PM lakes sturgeon movements shifted to the water column. Figure 16 shows sturgeon 4015 on day 221 where 53% of all locations were on the bottom on day 221. Sturgeon 4017 on day 211 was on the bottom for the entire day but periodically swam to the surface (Fig. 17**).** Figure 18 shows the overall distribution of each lake sturgeon fitted with a pressure tag and the total distribution of all fish on the bottom and in the water column.

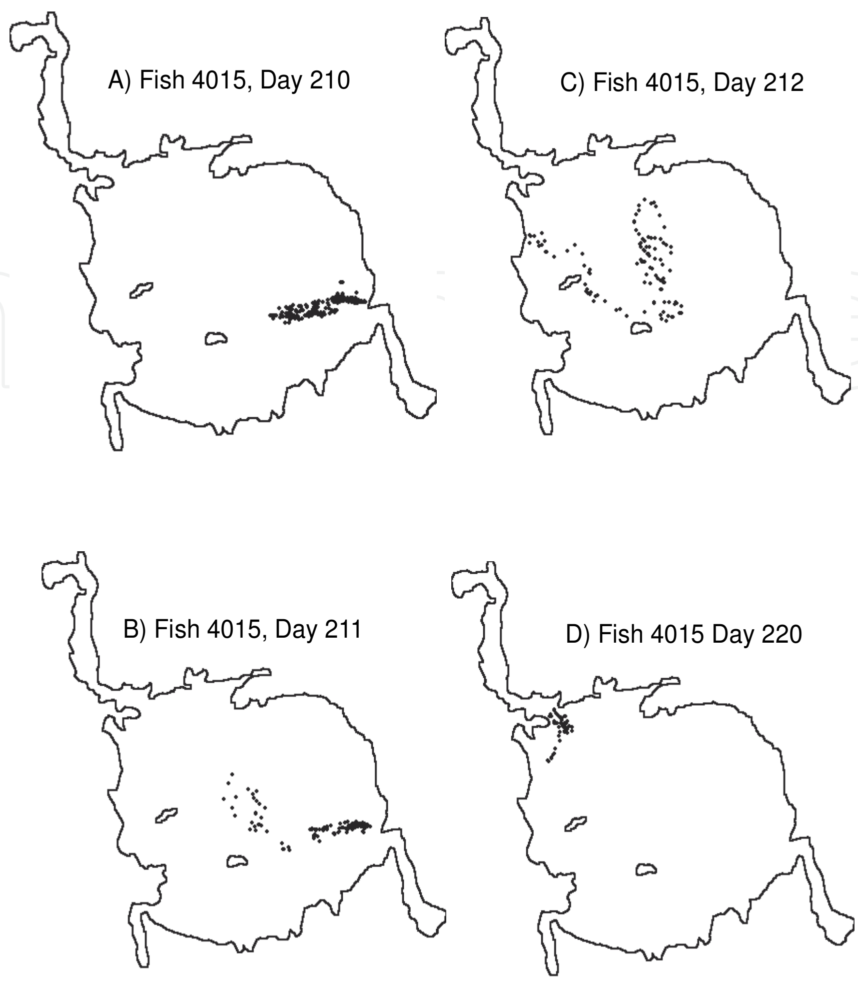


Fig. 13. Movements of lake sturgeon 4015 on four separate days.

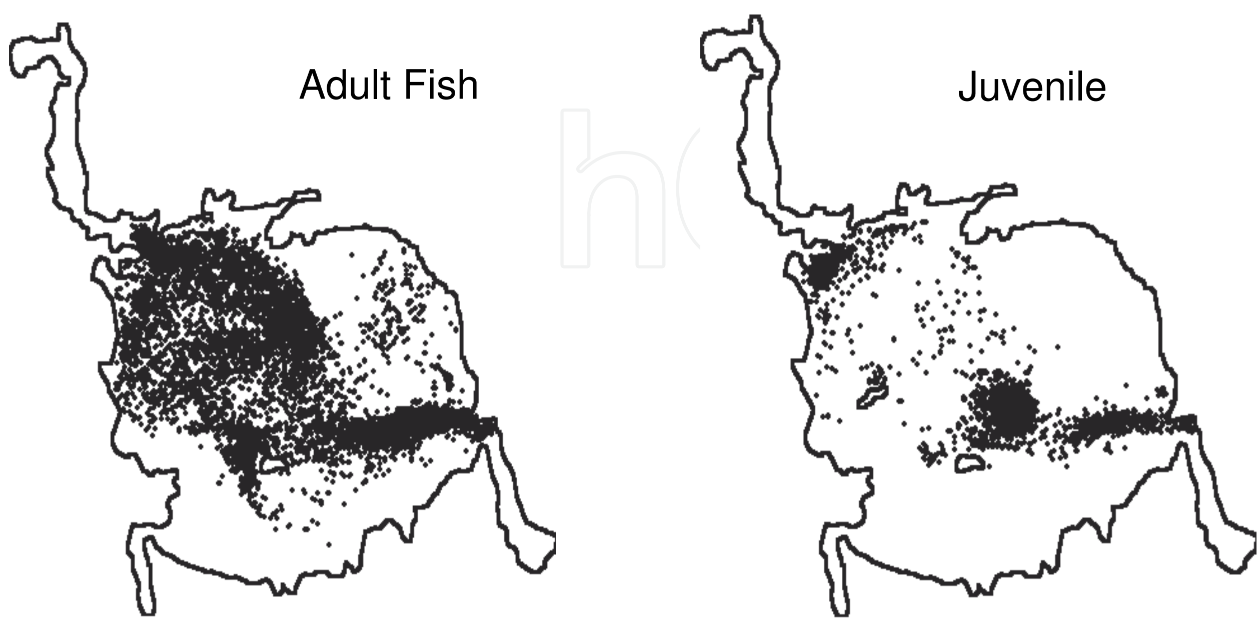


Fig. 14. Comparison of the movements of adult and juvenile sturgeon in Round Lake

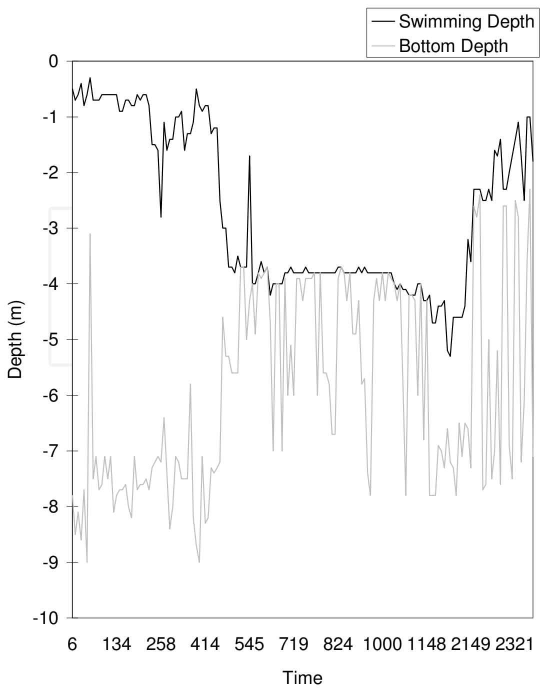


Fig. 15. A comparison of swimming depth and bottom depth of the lake for sturgeon 4014 on day 206.

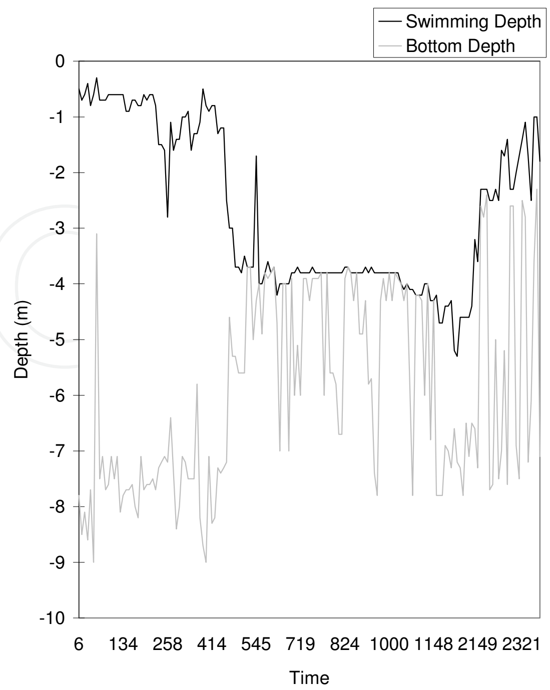


Fig. 16. A comparison of swimming depth and bottom depth of the lake for sturgeon 4014 on day 221.

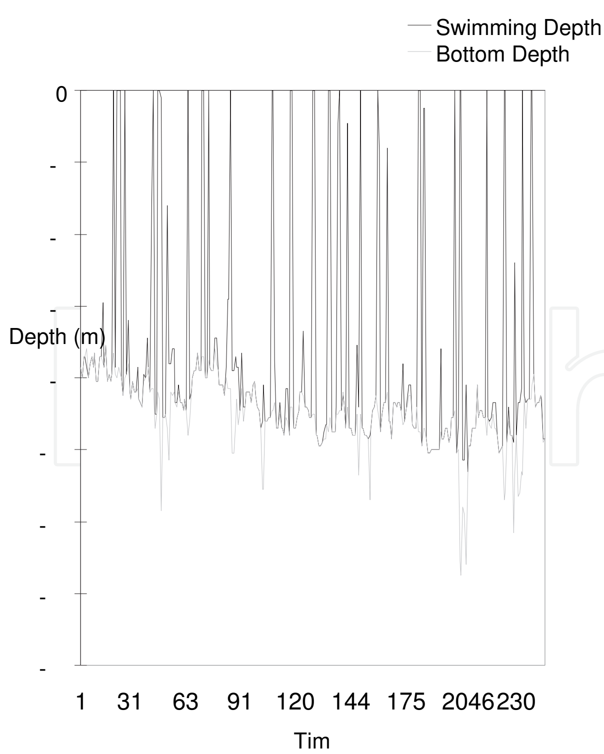


Fig. 17. A comparison of swimming depth and bottom depth of the lake for sturgeon 4017 on day 211.

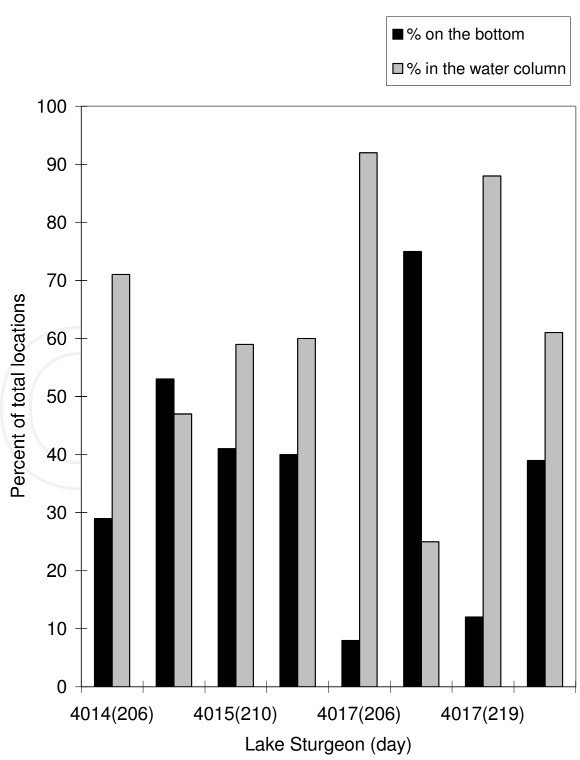


Fig. 18. Time spent in the water column and on the lake bottom for sturgeon 4014, 4015 and 4017 combined total.

Figure 20 shows substrate selection of sturgeon 4014, 4015, 4017 from the 7 day sample. Substrate with a hardness value of 110 was selected 53% of all locations.

Overall, lake sturgeons were located on the bottom 39% and in the water column 61% of the locations on the 7 day sample (day 215 based on January 1 being day 1).

The amount of time spent at the surface varied with time of day. The majority of locations < 1m occurred between the hours of 8 PM and 8 AM (Fig. 19).

The selection of depth was analysed from two perspectives**.** Figure 21 shows the overall depth selection of the three lake sturgeon tagged with depth tags. Thirty percent of all locations were less than two meters. Sixty-six percent were less than four meters. Figure 22 shows the depth selection of the three lake sturgeon including only the locations in which they were in contact with the substrate during the 7 day sample. Seven, 8, and 9 meter depths were selected 11, 31, and 21 percent respectively. Figure 23 shows movements of lake sturgeon 4014. It spent 70% of the time in the water column at the inlet on day 206 and on day 221 lake sturgeon 4014 spent 47% of the time in the water column.

Figure 24 shows movements of lake sturgeon 4015 on day 210. It spent 59% of its time in the water column at the inlet of the river. Lake sturgeon 4017 (Fig. 25) spent 60% of the time in the water column on days 206 and 222, 25% on day 211, and 88% on day 219. On days 211 and 219, sturgeon 4017 covered most of lake, including areas around the inlet and outlet.

The use of depth tags eliminates the guess work of whether a fish was on the bottom or in the water column at each position. Comparisons were made in this study among telemetry position, depth and substrate using data from depth tags. Substrate, depth and current were the three primary environmental variables measured.

Lake sturgeon movements ranged from sedentary to highly active. Movements in the areas of the inlet and outlet, areas of higher flow rate were quite common as well as movements in the deeper areas and along the natural flow of the river. Movements along the shorelines were rare. Along the shorelines the water is shallow, there is little flow, and the substrate is primarily sandy. Movements of smaller and larger fish were similar but larger fish moved greater distances. Nevertheless, juvenile fish appear to use most of the same habitat as the larger fish. Movements for both were related to the inlet and outlet and the deeper part of the lake.

The larger lake sturgeon spent a significant amount of time in the water column and at the surface. We do not know what juveniles were doing concerning depth selection because they were too small to be fitted with tags with pressure sensors. The amount of time in the water column by the larger fish suggests these fish were feeding on organisms drifting with the current. A majority of the records on movement were near the inlet and outlet where drift nets recovered insects and the occasional small fish.. Extensive lake sturgeon activity was noted where insects were carried by the current, were floating on the surface, or were emerging i.e. mayflies. High sturgeon activity in some areas was also correlated with clam beds.

The timing of movements in the water column and at the surface was correlated to light intensity. Lake sturgeon spent more time at the surface at night than during the day, when more time was spent on the bottom.

Based on the comparison of substrate selection and substrate availability lake sturgeon were found over fine sand, cobble, and rock substrate at higher frequencies than the proportion of this substrate in the lake. Coarse sand and gravel substrates were selected at a lower frequency than their proportions in the lake.

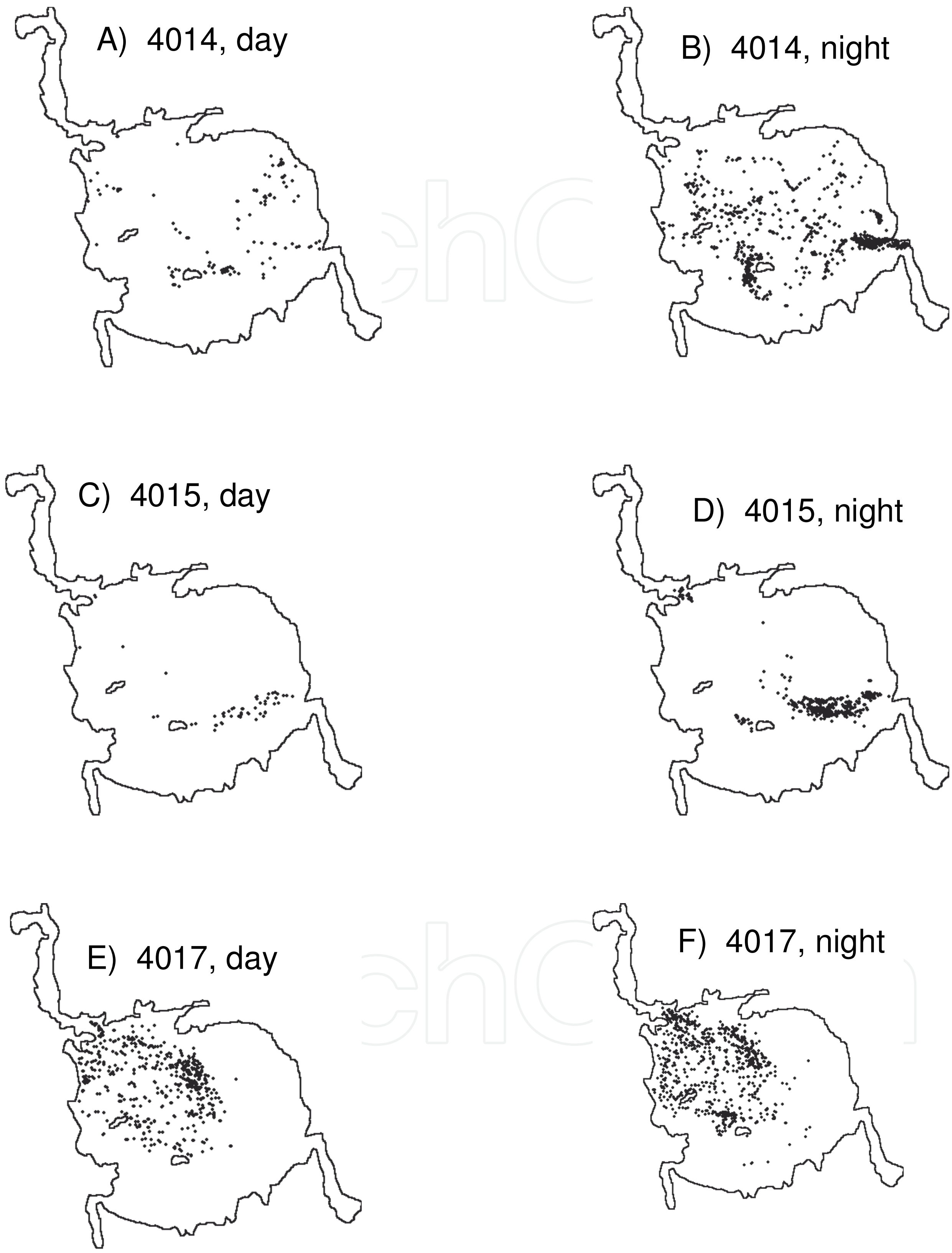


Fig. 19. Day and night comparison of time spent at the surface for sturgeon 4014, 4015, and 4017.

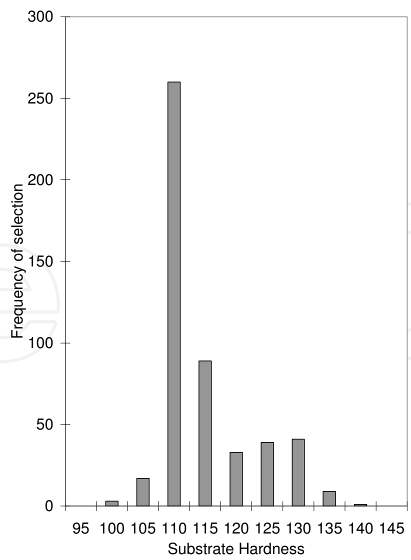


Fig. 20. Substrate selection by lake sturgeon in Round Lake (see Table 3)

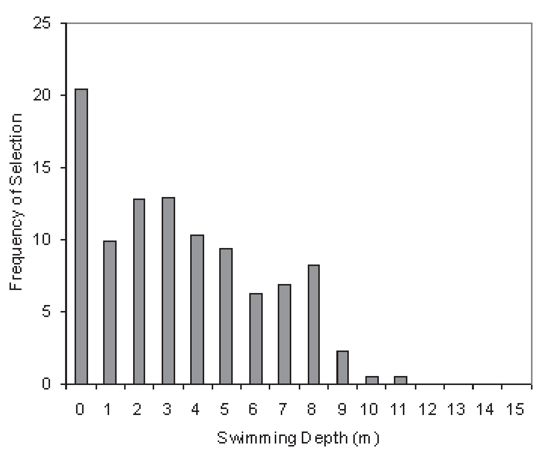


Fig. 21. Overall depth selection by lake sturgeon in Round Lake.

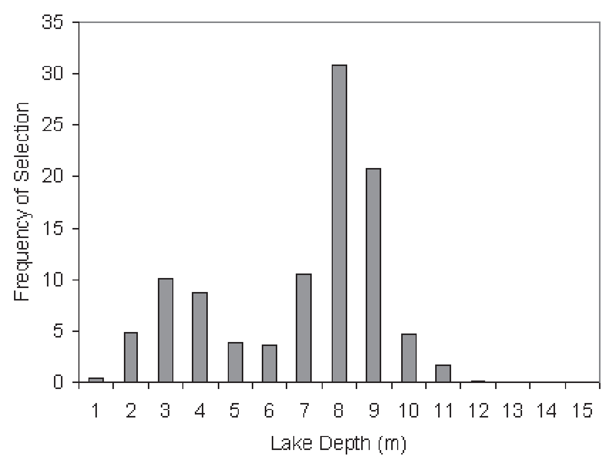


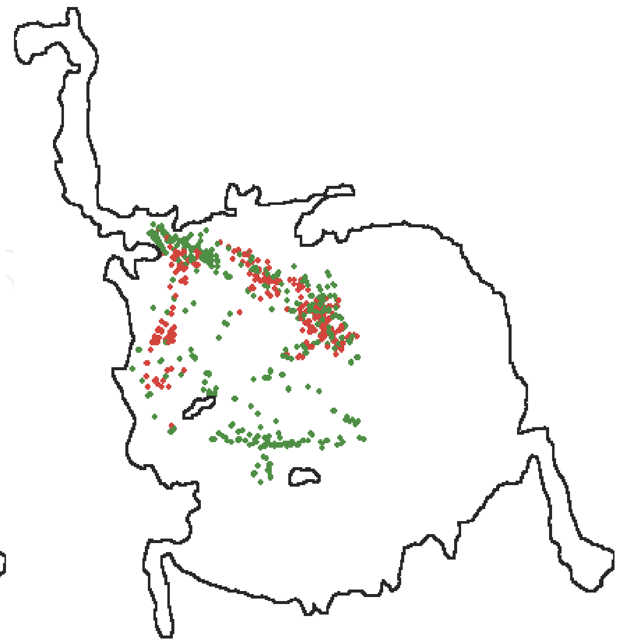
Fig. 22. Depth selection by lake sturgeon when in contact with the substrate.

Hexagenia (Ephemeridae) is a common prey item of lake sturgeon and silt and clay substrates are the preferred habitats. By contrast clams were often found in sandy substrates. While invertebrates were not common in the sieved substrates mayflies are a major food source for most fish species in the lake. Similarly, mayflies were a major food item of lake sturgeon, based on stomach contents which was verified by gavage. It appears in this system that mayflies are a major food source but competition for this food source by most fish species in the lake may make this food item a potentially limiting factor. Similar observations have been reported by others (Choudhury et al.. 1995; Chiasson et al. 1997).

The selection of depth based on horizontal and vertical movements of lake sturgeon seems to be related to current. Lake sturgeon tended to stay in the water column more often in areas of high flow such as the inlet and outlet. Since the study took place in mid summer and this activity was not related to spawning behaviours or movement related to fall/winter migrations the majority of movements are likely related to feeding behaviour.

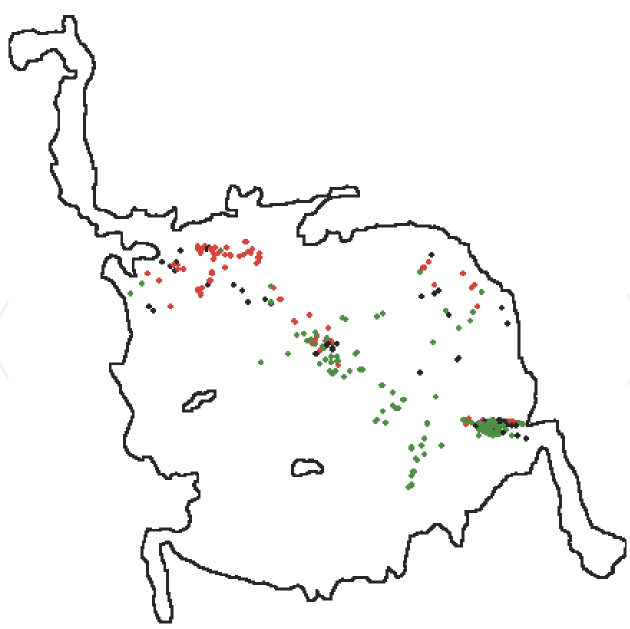
23

Fig. 23. Movements and depth selection of lake sturgeon 4014.



24

Fig. 24. Movements and depth selection of lake sturgeon 4015.



25

Fig. 25. Movements and depth selection of lake sturgeon 4017.

5. Current profiling

Since lake sturgeon movements and substrate were being evaluated in Round Lake and there was evidence that currents had a role in their distribution we evaluated current distribution in the lake. Figure 26A illustrates the cross sections of the river and lake where data was collected for current profiling and Fig. 26B identifies transects for which data was presented and discussed in the text.

Current profiling was done with the RDI Workhorse (Acoustic Doppler Current Profiler). This system was initially designed for stationary applications but its use was broadened to include total discharge measurements of streams and rivers and to measure currents in the areas where fish moved. This can be done from small moving boats.

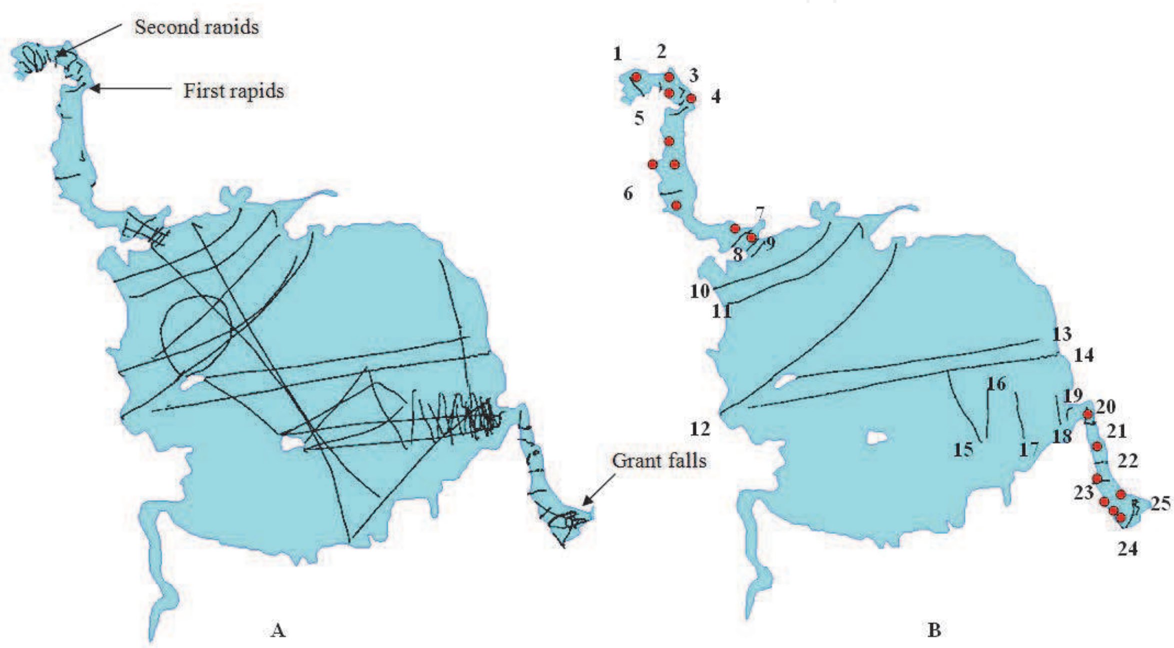


Fig. 26. Transects for the current profile measurements in the Pigeon River at Round Lake. A) all transects throughout the lake and B) includes transects where current profiles are presented in this report with additional transects and current profiles also shown tagged lake sturgeon where in these areas for extended periods of time. Red dots = location of radio tagged lake sturgeon

Data collection focused in the areas of greatest activity in the Pigeon River in and around Round Lake because lake sturgeon tagged with radio and sonar tags moved short distance upstream to Grant Falls and downstream to the second rapids (Fig. 26A).

Current profiles: Current profiles were taken in 1997, 2000, 2001. Movements of lake sturgeon in regions of the Pigeon River above and below Round Lake were determined with radio tags and sites where more transects were run are illustrated in Fig. 26A. Figure 26B outlines selected cross sections, some of which are discussed below. The current cross sections shown in Fig. 27 is above the second rapids on the Pigeon River downstream of Round Lake and the graph below the velocity magnitude is the boat or ship track that also indicates the direction and relative magnitude of the current. Note current is measured across a body of water and in the water column in units referred to as cells. The cells are coloured and represent the current in a cell. Each cell is coloured in the graph (see velocity magnitude) and is ~20 cm but cell size may vary depending on depth at the sampling point.

The stick ship tract directly below illustrates the ship tract across the river (red) and the blue lines shows relative current flows and direction along the transect. The top of the ship tract is the right side looking downstream, unless otherwise described. Figure 27 (transect 1**)** has a current ranging from 0.250-1.0 m/sec and while lake sturgeon moved through this area they spent most of their time on the right side in back eddies separated from the main flow by a ridge on the bottom. The current in this area was between 0.25 and 0.750 m/sec. In the area of transect 2 (Fig. 26B) lake sturgeon moved through this region but did not remain in the area. The strongest current encountered throughout this section of the Pigeon River was up to 2 m/sec. The river was shallow about 1.5 m at the narrowest section of the river with turbulence and air bubbles (the reason for the large numbers of blank spaces i e. no data).

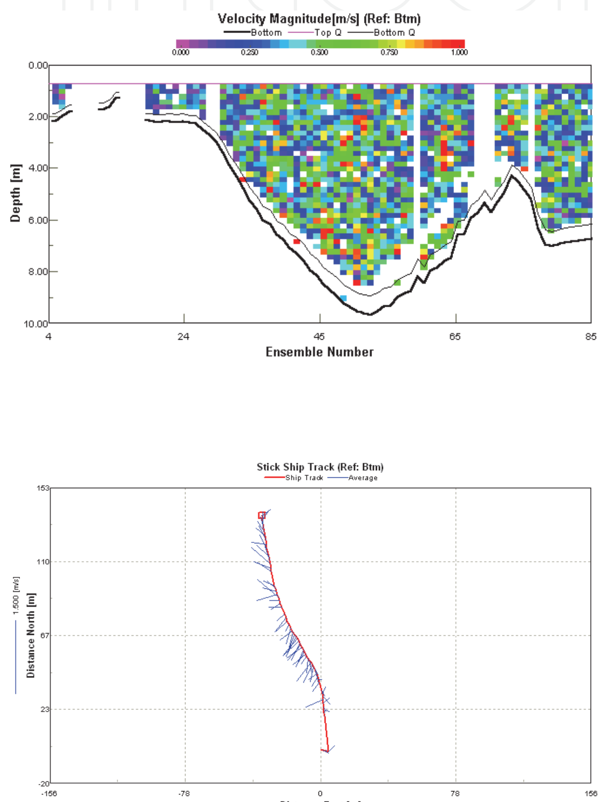


Fig. 27. Pigeon River ship transect 1 (see Fig. 26B).

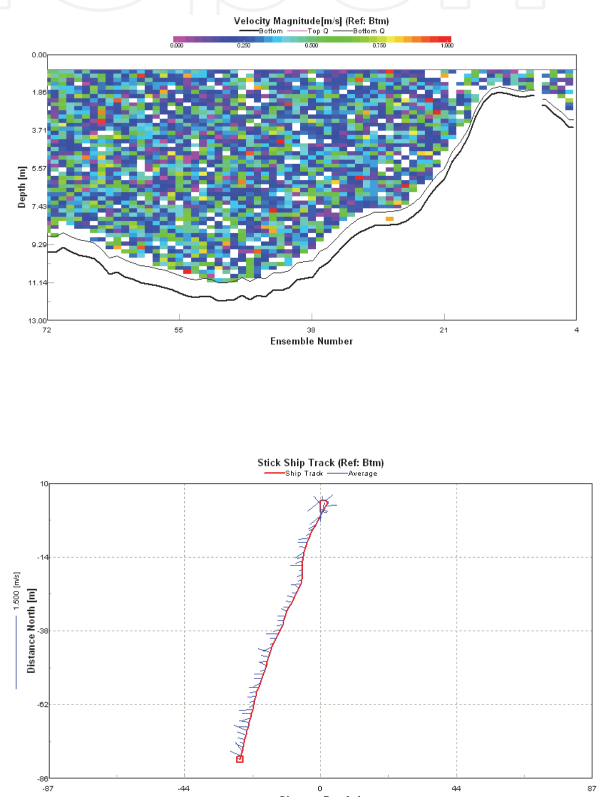


Fig. 28. Pigeon River ship transect 8 (see Fig. 26B).

The current was slightly lower on the left side (looking downstream) and deeper but this was off the main flow. Transects 7, 8 and 9 are from a region of the river where considerable lake sturgeon activity was recorded **(**Fig. 14). It is apparent from the boat track of Fig. 28 that a small back eddy occurs on the right side (looking downstream). From the acoustic tag data there was extensive movement throughout this area indicating that lake sturgeon movements in currents up to 1 m/sec were routine. Figure 29 illustrates a transect from a region of Round Lake with high lake sturgeon activity and where currents ranged from 0.00 to 0.250 m/sec. Transects 15 (Fig.26B) represents an area of Round Lake where flow from the river entering Round Lake starts to slow. Most of the current in the river bed is 0.5 m/sec. Figure 30 (transect 16) illustrates the river bottom and shallow area with macrophytes on the right side. Macrophytes have a similar affect on the equipment as air bubbles and as result the quality of the data is reduced. From the ship track in transect 16 the main flow of the river is becoming apparent and in Fig. 30 there is some evidence for a back eddy on the right side. This back eddy becomes more pronounced in transect 17 (not shown) but declines in transect 18 (Fig. 26B) and the current in both transect 17 and 18 increases to be predominantly 0.7 m/sec. Figure 31 (transect 19) illustrates that the strongest current occurs at the point the river enters the lake and the current across the entire river changes its direction as it passes over rocks on the right side. The majority of the current in Fig. 31 (transect 19**)** and transect 20 is between 0.7 and 1.0 m/sec. Transect 25 below Grant Falls has current ranging from 0.7 to 1.0 m/sec. This was also a region of the Pigeon River where spawning lake sturgeons were found.

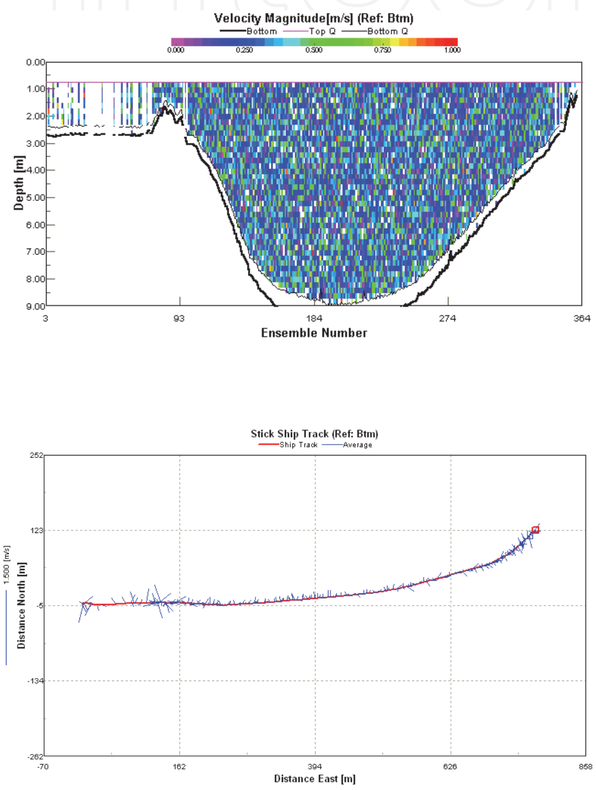


Fig. 29. Pigeon River ship transect 10 (see Fig. 26B).

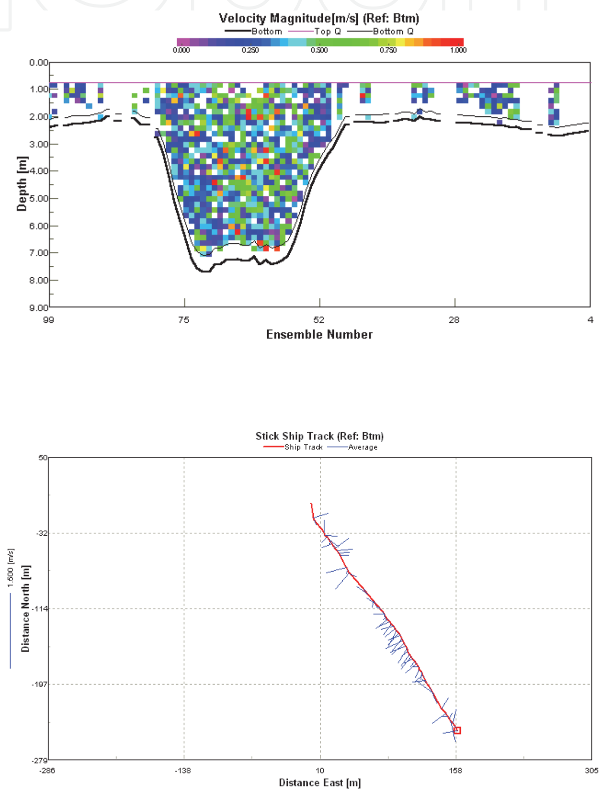


Fig. 30. Round Lake ship transect 16 (see 26B).

Correlation of lake sturgeon movements with current profiles: The overall frequency of movement of all acoustically tagged lake sturgeon is shown in Fig. 14 and it clearly indicates that activity is concentrated at the inlet and outlets to Round Lake. In the area of the inlet activity is concentrated in the main river channel as it enters the lake. The current at transect 19 (Fig. 26B) is up to 1.0 m/sec but this area is frequented by both large and small sturgeon (Fig. 14). It is worth noting that the current close to the contour of the river bed is < 1.0m/sec so lake sturgeon might be moving through these areas. Figure 14 shows that the smallest sturgeon also concentrated much of their activity in the deepest part of the lake and the main river channel entering the lake (Figs. 9 and 14**)**. By contrast the largest sturgeon spent proportionally less time in the deepest hole in the lake suggesting there may be some segregation of habitat, at the fine scale. It was also noteworthy that the smaller lake sturgeon frequented the area to the left of the outlet from Round Lake, again suggesting that there may be some differences in habitat use between small and large lake sturgeon **(**Fig. 14).

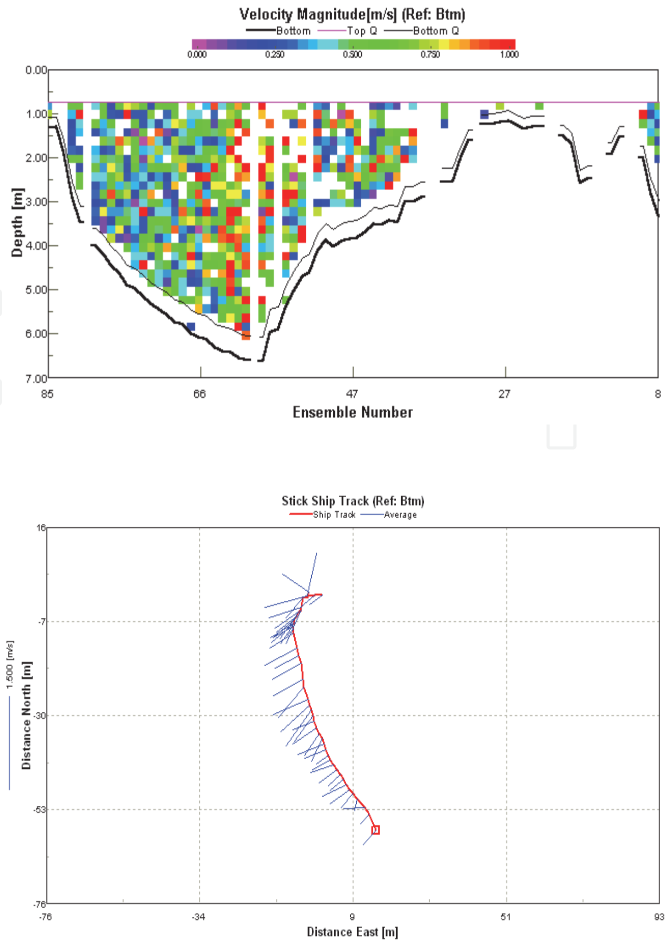


Fig. 31. Round Lake ship transect 19 (see 26B).

Interestingly while the larger sturgeon utilized this region they were more offshore. The larger sturgeon were concentrated at the outlet (Fig. 14**)** where currents were 0.25 to 0.5m/sec (Fig. 26B, transects 7, 8 and 9). These currents are below those noted for transect 9 at the inlet to Round Lake. Clearly there is more to the habitat requirements of juvenile lake sturgeon than a certain level of current. It is also apparent that the larger sturgeon frequented areas of the lake where currents were very low (Fig 26B, transect 12) but the ship track suggests a slight amount of counter flow (eddy) in this area. However, there was very little activity by smaller sturgeon in this area of the lake. The larger acoustically tagged lake sturgeon frequently ventured into the river, upstream and downstream from the lake but did not remain in these areas for extended periods of time as they always returned to the lake. None of the tagged lake sturgeon moved out of the area, either due to strong site fidelity or because this region of the Pigeon River is physically isolated due to rapids and small waterfalls.

Generally, the smallest lake sturgeon remained in slower flowing water and tended to frequent areas less used by large sturgeon in both deep and shallow regions of the lake. Unlike the larger sturgeon the small sturgeons were rarely located in water under 1 meter. Larger lake sturgeon can move through water with currents as high as 2m/sec but generally frequent areas with currents less than 1m/sec and if situated in the river tend to locate in the back eddies rather than in the main current. Current undoubtedly plays a role in defining lake sturgeon habitat but it is only one of several variables.

6. Sturgeon feeding tags

6.1 Background

Lake sturgeon movements in the field are readily identified using different tagging systems but establishing feeding behaviour is somewhat more complicated because one can not observe feeding directly as lake sturgeon generally do not feed at the surface. However, results reported in this chapter clearly revealed that lake sturgeon spend a significant proportion of time in the water column and were likely feeding on drift concentrated at the inlet and outlet of the lake, and emerging insects in the lake. Consequently a key question was could a sensor be developed to document lake sturgeon feeding? From previous studies on the histology of larval lake sturgeon we knew that there were extensive pressure receptors inside the mouth of lake sturgeon (Dick, unpubl. data). From other observations it was apparent that lake sturgeon utilized the branchial chamber to not only sense and feel the food but also to clean and to expel food with considerable force if the food was found to be unacceptable (Dick, unpubl. data). Furthermore, since lake sturgeons extend their mouth to feed we hypothesized that this may change the pressure inside the branchial chamber. We also knew that lake sturgeon extended the mouth with and without feeding.

Branchial pressure ranges from 50-150 pascals for restrained animals and no studies had attempted to relate branchial pressure to various levels of metabolic activity. We expect pressure to be correlated to oxygen consumption but our initial question was to determine if we could measure differences in the branchial chamber of lake sturgeon. Since lake sturgeon feed by sucking in prey and water this action should result in large pressure pulses interrupting rhythmic ventilation pressure pulses. It should be possible to distinguish mouth movements associated with feeding, coughing etc. The objective was to build a prototype tag to test the feasibility of a pressure tag to monitor branchial chamber pressure and use this as a measure of feeding activity. Previous reports by Webber et al. (2001a) and Webber et al. (2001b) describe the application of pressure tags to measure swimming speeds of fish.

6.2 Methods

Lake sturgeon used in this study were cultured at the University of Manitoba and subdued with tricaine methanol sulfonate (MS-222). The pressure sensor is a proprietary design with a cannula (PE 160) attached to the positive port, inserted under the tegument and into the parabranchial cavity under the opercular flap such that most of the cannula was not exposed to the environment. The tip of the cannula did not interfere with the movement of the gill filaments. The pressure sensors were powered by a standard bridge voltage (+10v), amplified and sampled at 69Hz. The pressure sensors were calibrated against a column of water of known density at the beginning and end of each experiment. Pressure signals were digitized by a MACLAB data acquisition system (AD Instruments Ltd.) and stored on disk. The resolution of the sensor was 1.85 pascals digital value^{-1} or 0.0189 cm freshwater at 4^{o}C. The prototype sensor was designed to be attached by wires to the receiver to obtain physiological data. The second sensor was designed to transit the signal directly to a receiver. The experimental setup for the study is shown in Fig. 32

6.3 Results

The original experiments utilized direct wiring from the sensor and the data are represented by the Analog to Digital conversion (A/D) of the A/D board in the PC (Fig. 33).

Fig. 32. Initial set up to collect data from sensor.

Fig. 33. Sensor on pectoral fin and cannula inserted into the branchial chamber with cannula visible.

Fig. 34. Flushing cannula with syringe to remove air bubbles.

Fig. 35. Branchial pressure at 15°C. Note occasional negative values.

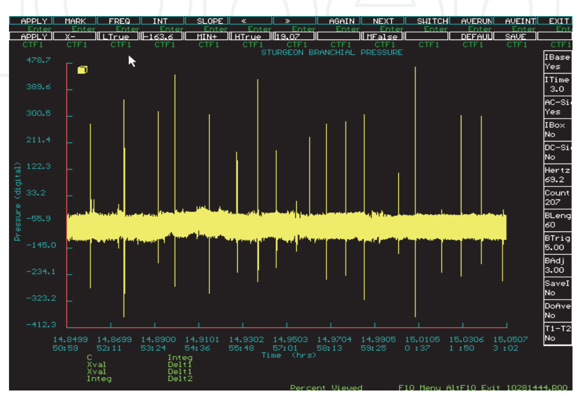


Fig. 36. Branchial pressure at 22°C.

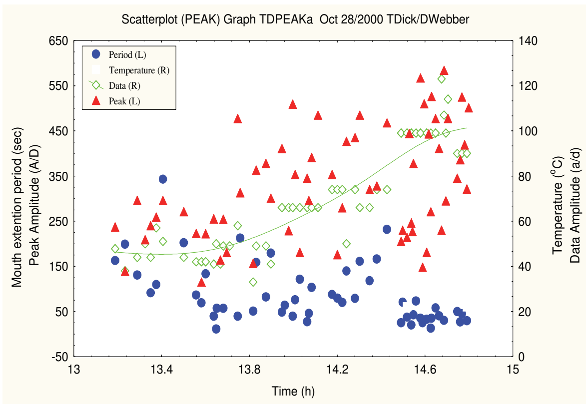


Fig. 37. Ability to rapidly alter branchial frequency.

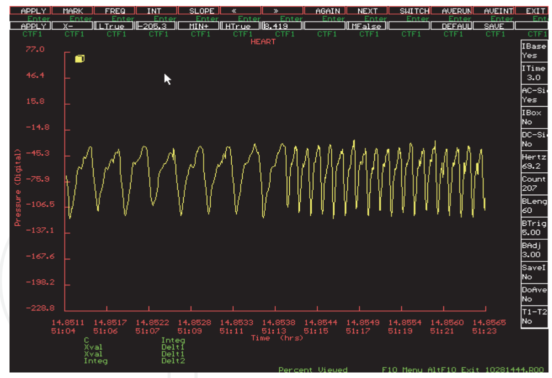


Fig. 38. Direct observation of changing frequency due to stress.

Approximately 1 cm of water pressure is equivalent to 40-50 A/D. The method to attach the wiring to the body wall is illustrated in Fig. 33. Figure 33 illustrates the sensor attached to the fish with the opercle lifted to observe the end of the cannula inside the branchial chamber. Figure 34 illustrates the priming of the cannula and the removal of air bubbles. For the majority of the time, data from the opercular cavity had a regular pattern exhibiting consistent amplitude and frequency (Figs. 35 and 36). However, peaks varied in amplitude in both positive and negative directions. Peak amplitude was approximately 5.5 cm (230 AD) at 15°C and increased to 9.5 cm (400 AD at 22°C) and the period ranged from 150 sec at 15°C to 40 sec at 22°C (Fig. 37). The peak amplitude and frequency increased with temperature (Fig. 35 at 15°C and Fig. 36 at 20°C). Figures 36 and 37 illustrate how quickly an individual can alter the opercular frequency in response to activity, metabolism and stress. Figure 38 demonstrates the changing opercular frequency of lake sturgeon as a result of stress. Figures 39 and 40 illustrate that immediately after a large pressure pulse (feeding peak) the regular breathing movements were larger than the preceding ones. Regular pulses increased in frequency and amplitude in response to temperature. Amplitude (green diamond) increased from 2 cm (45 AD) to 2.5 cm (110 AD) (Fig. 42).

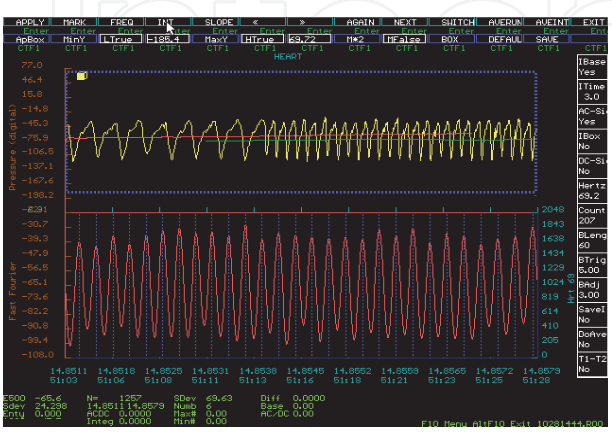


Fig. 39. Regular breathing movements are higher immediately after feeding.

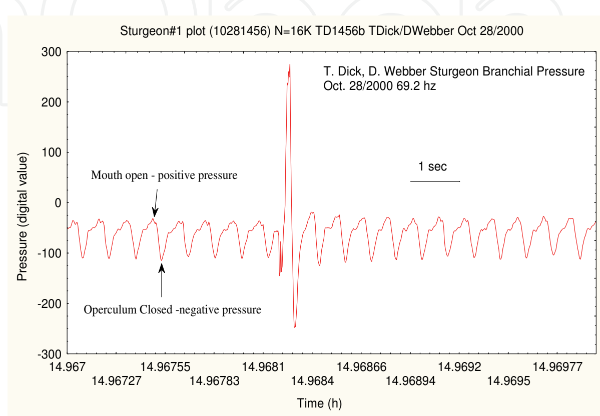
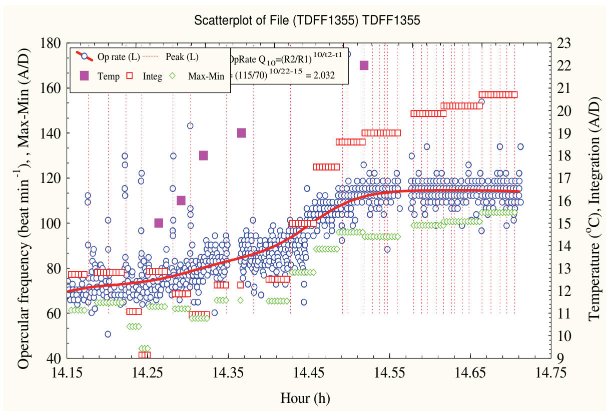


Fig. 40. Feeding pulse is followed by rapid change to normal pulse.



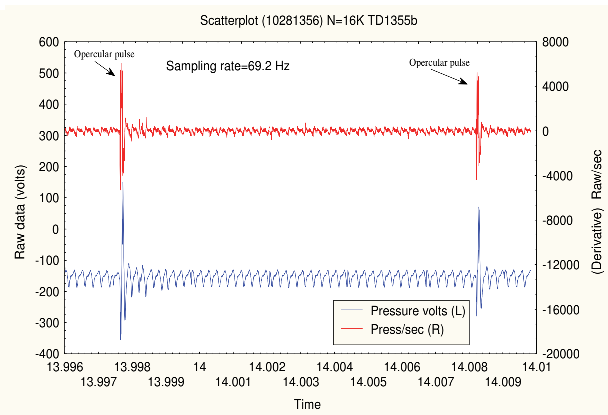
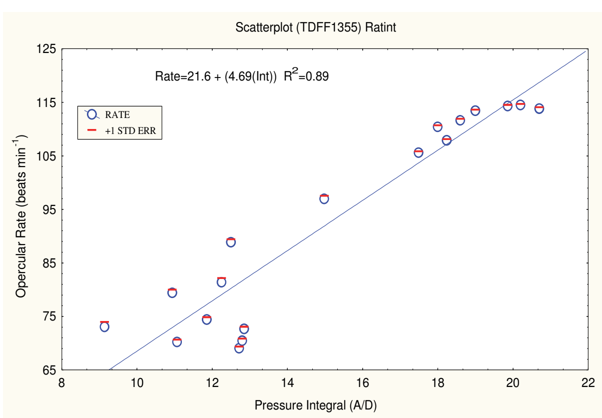


Fig. 41. Increase in frequency and amplitude due to temperature.

Fig. 42. High correlation between pressure and voltage changes.

It was decided to build a prototype tag to test the feasibility of a pressure tag to monitor branchial chamber pressure from 12 to 22ºC. Frequency (blue circles) increased from 70 to 115 opercular beats^{-1} (Fig. 42). The calculated Q_{10} for frequency was 2.03, which describes the general response of most metabolic processes with temperature. The increase in amplitude and frequency was due a metabolic increase in routine metabolic rate. There was a high correlation between pressure in the branchial chamber and voltage changes (Fig. 41). When the TELEPLAY.EXE was used to integrate branchial pressure waveform as an AC neg-pos-neg waveform the integration (red squares) was highly correlated to temperature. Frequency of pulses was highly correlated to both integration (Fig. 43) and amplitude (Fig. 44).



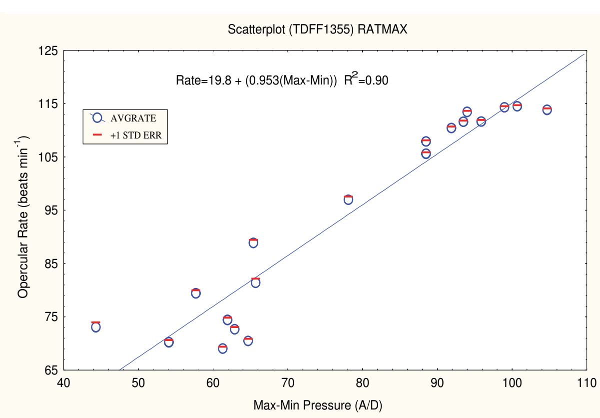


Fig. 43. Frequency of pulses correlated to integration.

Fig. 44. Frequency of pulses highly correlated to amplitude

The feeding pressure tag (Fig. 45) was tested under laboratory conditions (Fig. 46). A major challenge was determining how to stabilize the cannula and how to attach it to the lake sturgeon. Several methods to attach the tag were attempted, including drilling holes through the scutes and attaching to the dorsal surface of pectoral fin (Fig. 47) and attached to the pectoral fin (Fig. 48). Two methods were tested for placement of the cannula to monitor pressure, 1) attached to the tegument and under the opercle and 2) inserted through the cartilage at the base of the pectoral fin (Figs. 33 and 34).

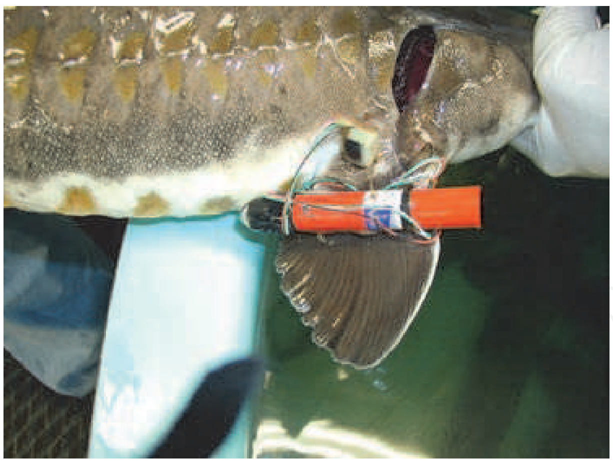


Fig. 45. Tag attached to pectoral fin.

Fig. 46. Collection of data from tag in tank.

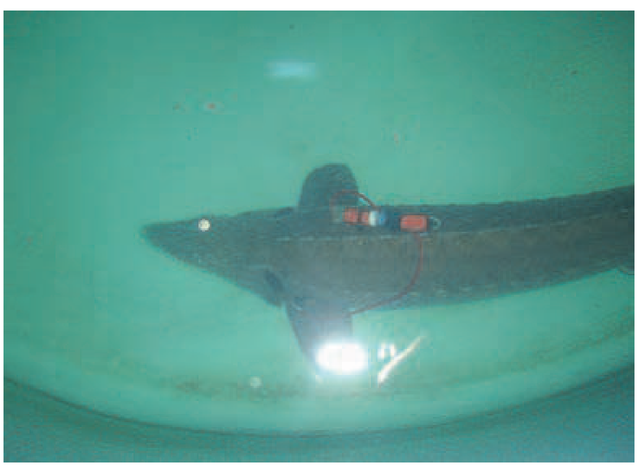


Fig. 47. Tag attached to dorsal scutes.

Fig. 48. Tag attached to right pectoral fin and connected to sensor situated on the left pectoral fin.

The feeding sensor pressure tag gave identical results to the data collected from the prototype experimental data. The major problem was attachment of the tag as the longest time for attachment was 12 days. The best location was on the surface of the pectoral fin and surprisingly there was little influence on normal use of the fin by lake sturgeon in a tank. Attaching the tag to the scutes was the least effective as the sharp boney scutes severed both wire and heavy fishing line with ease. Once the tag was not firmly attached the cannula was dislocated and either became clogged with mucous or was outside the branchial chamber and was unable to measure any pressure changes. There was no evidence of infection when the cannula was inserted through the tegument and the cartilage and once the cannula was removed there was no infection. The point at which the cannula was inserted was undetectable within 2 weeks of its removal.

6.4 Discussion

Ventilation was characterized by alternating positive and negative pressure pulses whose amplitude and frequency were very constant when activity and temperature were stable.

Positive pulses were always associated with opening of the mouth and negative pressure with closing of the mouth. Amplitude of these rhythmic pulses generally ranged from 50 to 100 pascals for all lake sturgeon. We also observed that all fish periodically made rapid mouth movements that resulted in considerably larger pressure pulses (800 pascals) compared to the rhythmic ventilations pulses described previously. These pulses were caused by the sudden projection of the jaw approximately 3-4 cm outward form the mouth. Pressure amplitude was often an order of magnitude greater when compared to ventilation pulse pressure. This is interpreted as instances of feeding or feeding attempts. Temperature influences all variables as integral and max-min pressure and frequency of ventilation on pulses increased with temperature. As well, amplitude and period of feeding pulses increased with temperature.

Although we did not measure MO_2 (oxygen consumption) directly the data on integration of branchial pressure and an AC waveform indicates that integration and amplitude can be used to predict MO_2 (energy budgets) sturgeon in nature. This information could be combined with temperature and feeding data to predict seasonal growth rates, etc.

We have developed a specialized feeding tag for lake sturgeon that functions under laboratory conditions. Inserting the cannula through the cartilage above the pectoral fins had a minimal affect on the fish; however, we have yet to find a satisfactory method to hold the tag securely to the fish for more than 12 days. Internal placement of the tag is not an option as the wires would then have to come from the tag through the body wall to the sensor. The prototype tag weighed 46 gm in air and the next stage of development will be to reduce the weight of the tag size considerably (we are already using depth tags that have a much lower weight than the V16s). Even the prototype tag can be attached to large lake sturgeon (over 25 kg) and the preferred attachment site will likely be the pectoral fin. The next tags will have to weigh less than 15 gm in air, be more streamed lined to reduce resistance and mode of attaching to the boney fins rays will need to accommodate self tightening strap.

7. Summary

Lake sturgeon (*Acipenser fulvescens*) in Canada in the early 1900s were reduced to remnant populations over most of their historic range and extirpated from much of the Great Lakes and Lake Winnipeg. Populations continued to decline over the next 100 years due to commercial fishing pressure, hydroelectric and other industrial developments. This led in the early 2000s to the Committee on the Status of Endangered Wildlife in Canada recommending that lake sturgeon be listed as threatened or endangered in various regions of Canada. Most of the current research on lake sturgeon is related to environmental assessment for hydroelectric developments from perturbed areas where populations are low. The purpose of this research was to study a lake sturgeon population in an unperturbed system, the Pigeon River at Round Lake on the west side of Lake Winnipeg, Manitoba, Canada. Round Lake is a small isolated lake with a typical fish community found in the boreal region of Canada. The size of the sturgeon population relative to other fish species in the lake was determined by randomly set standard gang gillnets and all sturgeon caught were tagged with external and PIT tags and returned to the wild. Lake sturgeon comprised about 10% of the total population of fish. The main food item of lake sturgeon was mayflies and a detailed stomach analyses indicates that mayflies are important food for several other fish species. Since we were interested in determining how lake sturgeon, from

juvenile to adults, utilized their environment a comprehensive study was undertaken. Round Lake was mapped using sonar technology to establish substrate types and current profiles were described at the inlet and outlet to the lake, and in the lake. The substrate map, based on roughness/smoothness and hardness/softness, were correlated with substrate types i.e. silt, fine sand, fine and coarse gravel, cobble, and rock.

Lake sturgeons were tagged using radio and acoustic tags. Radio tags were more useful to study movements in the river due to the high flows and air bubbles in the water but were limited because of the high labour input to track individual fish. Some of the acoustic tags had both temperature and pressure sensors and the application of the VRAP acoustic system (Vemco, Canada) enabled us to obtain 3-D positioning of individual fish in real time. Results from the lake sturgeon movement studies using acoustic tags showed that there was individual variation with some fish spending most of their time on the bottom while others spent up to 75% of their time in the water column. The amount of time spent in shallow and deep water and over substrate types was determined. The movements of large (over 5 kg) and small lake sturgeon (< 2 kg) often overlapped but there was a tendency to frequent different areas i.e. smaller lake sturgeon frequented the deeper parts of the lake but were also found in shallow sections near the main flow. The most frequently used sites by both groups of lake sturgeon were near the inlet and outlet from the lake where currents were up to 1m/sec. Larger lake sturgeon moved through regions of the river where currents were up to 2m/sec. Lake sturgeon were more active over substrates consisting of fine sand, cobble, and rock.

The conventional view is that lake sturgeons are primarily a bottom feeder. However, we noted that lake sturgeon fitted with pressure sensors moved up and down the water column and spent more time in the water column than previously thought based on a review of the literature. We noted that this movement was usually correlated with emerging mayflies and postulated we were likely observing a feeding event. This led to the development of a pressure tag with the potential to record feeding events in sturgeon by measuring branchial chamber pressure. The pressure sensor consists of a cannula (PE 160) attached to the positive port, inserted under the tegument and into the parabranchial cavity under the opercular flap such that most of the cannula was not exposed to the environment. The tip of the cannula did not interfere with the movement of the gill filaments. The resolution of the sensor was 1.85 pascals digital value^{-1} or 0.0189 cm freshwater at 4^{o}C. The prototype sensor was designed to be attached by wires to the receiver to obtain physiological data. The second sensor was designed to transit the signal directly to a receiver. The reason for providing this example of sensor development (feeding in this case) is that with 3-D movement studies, using a VRAP system or the more recent VPS (Vemco Ltd.), researchers are not only able to record fine scale fish movements but with new sensors like the pressure sensor can pose new questions and drive technology, especially sensor technology, in new directions.

8. Acknowledgments

T. Dick acknowledges financial support for these studies from a Natural Sciences and Engineering Council of Canada operating grant and from the Department of Fisheries and Oceans Canada, Environment Canada, Manitoba Hydro and Manitoba Model Forest. T. Dick also thanks elder Henry Letander, Sagkeeng First Nations, Fort Alexander, Manitoba for advice on lake sturgeon and companionship in the field. We thank Dr. M. Papst (Department of Fisheries and Oceans Canada) and Keith Kristopherson (Fisheries Branch, Province of Manitoba) for encouragement and logistical support. We thank Ph.D student Kate Gardiner for help with the illustrations. We also thank contractors Paul Coolie (substrate mapping) and Maria Begout (acoustic tag studies) for helping with the collection of data and some of the analysis.

9. References

Bajkov,A.D. and F. Neave. 1930. The sturgeon and sturgeon industry of Lake Winnipeg. *In*: Canadian Fisheries Manual. National Publications Ltd. Gardenville, Quebec. 43-47.

Baldwin, N.S., R.W. Saalfeld, M. A. Ross and H.J. Buettner. 1979. Commercial fish production in the Great Lakes 1867- 1977. pp. 6,30,31,70,84-85, 124-125, 158-159. IN: Gr. Lakes Fish. Comm. TGech. Rep. 3. Available from www.gflc.org/databases/commercial/commerc.php

Barth, C.C., S.J. Peake, P.J.Allen and W.G. Anderson. 2009. Habitat utilization of juvenile lake sturgeon, *Acipenser fulvescens,* in a large Canadian river J. Appl. Ichthyol. 215: 18-26.

Bemis, W.E. and E.K. Findeis. 1994. The sturgeons' plight. Nature 370: 602.

Chiasson, W.B., D.L.G. Noakes and F.W.H. Beamish.1997. Habitat, benthic prey and distribution of juvenile lake sturgeon (*Acipenser fulvescens*) in northern Ontario rivers. Can. J. Fish. Aquat. Sci. 54: 2866-2871.

Choudhury, A., R. Bruch, and T.A. Dick. 1995. Helminths and food habits of lake sturgeon, *Acipenser fulvescens* from the Lake Winnebago system, Wisconsin. The American Midland Naturalists 135: 274-282.

Choudhury, A. and T. A. Dick. 1998. Historical biogeography of sturgeons (Osteichthyes: Acipenseridae): a synthesis of phylogenetics, palaeontology and palaeography. Journal of Biogeography 25: 623-640.

Choudhury, Anindo, Terry A. Dick, Harry L. Holloway, and Chris Ottinger. 1990. The lake sturgeon - *Acipenser fulvescens* (Chondrostei, Acipenseridae) in Canada: Preliminary studies on parasitofauna and immunological parameters. 1990 Interbasin Biota Transfer Study Program Proceedings (Eds., J.A. Leitch and D. J. Christensen), North Dakota Water Resources Research Institute, Fargo, North Dakota, 121-133.

Cummins, K.W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. American Midland Naturalist, 67(2): 477-504.

Dick, T. A. R. R. Campbell, N. E. Mandrak, B. Cudmore, J. Reist, J. Rice, P. Bentzen and P. Dumont. 2006a. Update COSEWIC status report on lake sturgeon, *Acipenser fulvescens*. 154 p.

Dick, T. A., S.R. Jarvis, C.D. Swatzky and D.B. Stewart. 2006b. The lake sturgeon, An annotated bibliography. Can. Tech. Rep. Fish Aquat. Sci. iv + 252 p.

Dick, T.A. 2004. Lake sturgeon studies in the Pigeon and Winnipeg rivers and biota indicators. Report prepared for Manitoba Hydro and Manitoba Model Forest. 445p

Dick, Terry, Henry Letander, Kim Morriseau and Chris Paci. 1998. Namay an northern resource in crisis, In: Issues in the north (Eds. Jill Oakes and Rick Riewe), Canadian Polar Institute and Department of Native Studies, University of Manitoba, Vol. III: 181-190.

Dick, T.A. and A. Choudhury. 1992. The lake sturgeon *Acipenser fulvescens* (Chondrostei: Acipenseridae): annotated bibliography. Can. Tech. Report Fisheries and Aquatic Sciences No. 1861. 69p.

Dick, Terry A. and Bryan Macbeth. 2002. The importance of First Nations community participation in determining the status of species at risk. *In*: Native Voices in Research (*Eds*. J. Oakes, R. Riewe, K. Wilde, and A. Dubois), Native Studies Press, University of Manitoba, Winnipeg.
Ferguson, M.M. and G.A. Duckworth. 1997. The Status and Distribution of Lake Sturgeon, *Acipenser fulvescens*, in the Canadian Provinces of Manitoba, Ontario, and Quebec: a Genetic Perspective. Environmental Biology of Fishes, 48: 299-309.
Ferguson, M.M., L. Bernatchez, M. Gatt, B.R. Konkle, S. Lee, M. Malott and R.S McKinley. 1993. Distribution of mitochondrial DNA variation in lake sturgeon (*Acipenser fulvescens* from the Moose River basin, Ontario, Canada. J. Fish. Biol. 43: 91-101.
Fogle , N.E. 1975. Michigan's oldest fish. Mich. Nat. Res. 44(1): 32-33.
Glover, C.R. 1961. The sturgeon in Pennsylvania. Penn. Angler, Jan. 1961: 3.
Harkness, W.J.K., and J.R. Dymond. 1961. The lake sturgeon, the history of its fishery and problems of conservation. Ont. Dept Land. For. Fish Wildl. Br. 121p.
Houston, J.J. 1987. Status of the lake sturgeon, *Acipenser fulvescens*, in Canada. Can. Field Nat. 101(2): 171-185.
Holzkmann, T.E., and Wilson, Chief W. 1988. The sturgeon fishery of the Rainy River Ojibway Bands,. *In* Smithsonian Institution (ed.) Smithsonian Columbus Quincentenary Program "Seeds of the past" ("Raices del Pasado"). Smithsonian Institution, Washington. p. 1-10.
Holzkmann, T.E. 1987. Sturgeon utilization by the Rainy River Ojibwa Bands. *In* W. Cowan (ed.) Papers of the Eighteenth Algonquin Conference, Carlton University, Ottawa. p. 155-163
Mecozzi, M. 1988. Lake sturgeon (*Acipenser fulvescens*). Wis. Dept Nat. Res. Bur. Fish. Manage. PUBL-FM-704 88. 6p.
Nelson, J.S. and M.J. Paetz. 1992. The fishes of Alberta (2nd ed.). The University of Calgary Press and the University of Alberta Press, Canada. [Pagination unknown]
Nelson, J.S. 1994. Fishes of the World. 3rd edition. John Wiley and Sons Inc. New York. 600p.
Ono, R.D., J.D. Williams, and A. Wagner. 1983. p. 29-33 & 232-233. In Vanishing fishes of North America. Stone Wall Press Inc.
Pearce, W.A. 1986. Methuselah of freshwater fishes - the lake sturgeon. Conservationist 41(3): 10-13.
Prince, E.E. 1905. The Canadian sturgeon and caviare (sic) industruies. Can. Sess. Pap. 22: Spexc. Append. Rep.: liii-lxx.
Scott, W.B. and E.J. Crossman. 1998. Freshwater Fishes of Canada. Galt House Publications Ltd. Oakville, Ontario, 82-95.
Webber, D.M., Boutilier, R.G, Kerr, S.R., and Smale, S. M. (2001a) Caudal differential pressure as a predictor of swimming speed and power output of cod (Gadus morhua). J. Exp. Biol. 20, 3561-3570.
Webber, D.M., McKinnon, G.P., and Claireaux, G. (2001b) Calibrating differential pressure to swimming speed in the European sea bass, Dicentrarchus labrax. . In Electronic Tagging and Tracking in Marine Fishes. (eds. J. R. Sibert and J. L. Nielsen), pp.297-314. Kluwer Academic Publishers.
Williams, J.E., and H.J. Vondett. 1962. The lake sturgeon, Michigan's largest fish. Mich. Dept Conserv. Fish Div. Pamph. 35: 6p.