A Population Estimate of Lake Sturgeon in Little Eva Lake, Ontario 2007

Darryl M[c]Leod
Ontario Ministry of Natural Resources
Fort Frances, Ontario

October, 2008

Ministry of Natural Resources
Ontario

Fort Frances District Report Series No. 79

ABSTRACT

A population estimate of adult lake sturgeon was completed in fall 2007 on Little Eva Lake, a small 281 hectare lake located approximately 80 km southeast of Fort Frances, Ontario. The lake is situated between two proposed hydroelectric generating facilities at High Falls and Hay Rapids on the Namakan River, approximately 7 km upstream of Namakan Lake. In October 2006, 101 sturgeon were captured of which 97 fish were tagged as part of an initial sampling effort. In October 2007, 157 fish including 9 recaptures were caught using the same large mesh gill nets, with a total of 140 fish exceeding 1,000 mm total length. Mean size of all fish that were biologically sampled (n=249) was 1,224 mm (774-1,630 mm) total length, 11,692 g (2,300-33,700 g) round weight, and 448 mm (286-711 mm) girth. Mean age was 24.6 years (9-41 years). A simple Peterson estimate of fish >1,000 mm was 3,352 (1,315-13,410, 95% CI) and a Chapman adjusted Peterson estimate of 2,729 fish (1,218-6,824, 95% CI) were derived from this single mark-recapture event. Several other estimates of population size in 2007 were generated using multiple mark-recapture methods including Schumacher, Schnabel and Modified Schnabel. These estimates ranged from 2,225 to 2,967 fish >1,000 mm total length, representing a population density in the range of 7.9 to 11.9 adult fish/ha.

Table of Contents

	Page
Abstract	1
List of Figures	3
List of Tables	3
Introduction	4
Study Area	7
Methods	9
Results	11
Discussion	16
Acknowledgements	20
References	21
Appendices	24

List of Figures

Figure 1: Location of Little Eva Lake on the Namakan River, Ontario.

Figure 2: Sampling stratification and net locations on Little Eva Lake on the Namakan River, Ontario in October 2007.

Figure 3: Girth of lake sturgeon (including mean, quartiles and range) by mesh size of capture in Little Eva Lake, 2007.

Figure 4: Total length of lake sturgeon (including mean, quartiles and range) by mesh size of capture in Little Eva Lake, 2007.

Figure 5: Girth and total length relationship for lake sturgeon captured in large mesh gill nets in Little Eva Lake, 2007.

List of Tables

Table 1: Physical and chemical characteristics of Little Eva Lake, Ontario.

Table 2: Summary of effort and catch of lake sturgeon by mesh size from multifilament gill nets in Little Eva Lake, 2006.

Table 3: Summary of effort and catch of lake sturgeon by mesh size from multifilament gill nets in Little Eva Lake, 2007.

Table 4: Summary of cumulative catch of tagged and untagged lake sturgeon in Little Eva Lake, 2007.

Table 5: Summary of lake sturgeon population and density estimates (fish > 1,000 mm total length) for Little Eva Lake, October 2007.

APPENDICES

Appendix I: A comparison of lake sturgeon population, density and biomass estimates for Little Eva Lake to similar studies in other waters and jurisdictions.

INTRODUCTION

A proposal to develop two hydro-electric generation sites at Hay Rapids and High Falls on the Namakan River lead to the preparation of a Environmental Field Study Plan (OPEG, 2006) and commencement of an Environmental Screening process in 2006. An assessment of the lake sturgeon population(s) was identified in this study plan as part of a larger fisheries data collection effort, including telemetry, tagging, genetics and habitat evaluation. The specific objective of this study was to estimate the fall (over-winter) population size and density of lake sturgeon *(Acipenser fulvescens)*, and contribute to the assessment of potential impacts of hydro-electric development on the Namakan River. This population estimate also provides valuable baseline data for the development of water management plans and long-term monitoring efforts, particularly if development proposals are approved.

Lake sturgeon are known to occur in Little Eva Lake, which is part of the Namakan River system. They also occur throughout the Namakan River from Lac La Croix downstream to Namakan Reservoir. The lake is located approximately 80 km southeast of Fort Frances, Ontario. Water levels in both Namakan River and Little Eva Lake fluctuate naturally and are currently unregulated. The Namakan River drains close to 8,860 km^2 in Ontario and represents approximately 75% of the inflow to Namakan Reservoir; and contributes the largest single source of inflow with a mean discharge of 109 m3/sec (Kallemeyn et al., 2003). Downstream water levels in Namakan Reservoir are regulated by the International Joint Commission (IJC) through the International Rainy Lake Board of Control (IRLBC). Two water control dams at Kettle and Squirrel Falls regulate water levels on Namakan Reservoir based on a "rule curve". Recent changes to water regulation in 2000 lead to the development of a long-term monitoring strategy to evaluate aquatic ecosystem impacts;

in which a lake sturgeon inventory and assessment program was included (IRLBC, 1999; USGS, 2000; Adams et al, 2006a; 2006b).

The Ontario-Minnesota Fisheries Committee established a Border Waters Lake Sturgeon Management Committee, which recommended that additional studies be completed on sturgeon populations where little or no information currently exists (OMNR and MDNR, 1995). Previous investigations have already occurred on the South Arm of Rainy Lake (Adams et al., 2006a; 2006b) and on the Rainy River (Stewig, 2005). The biology of the fish, the early and intense exploitation, and the effects of dams and pollution on the ability of the species to reproduce have all contributed to low levels of lake sturgeon populations elsewhere in Canada (Scott and Crossman, 1998). In the Great Lakes, the decline in lake sturgeon populations has been attributed to three factors: physical impacts on spawning and nursery habitat, barriers to migration and over-fishing (Auer, 1999).

Lake sturgeon are currently designated as a species of Special Concern in Ontario and regulated under the Endangered Species Act (S.O. 2007). A similar designation exists in Minnesota, but the legal context may differ. In Canada, the species is under review by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) for possible designation under the Species At Risk Act (S.C. 2002). From an international perspective, lake sturgeon are also regulated through the Convention on International Trade in Endangered Species of Fauna and Flora (CITES – Appendix II). Conservation status is listed as Vulnerable by the American Fisheries Society (AFS, 2008), while global status is G3-Vulnerable and provincial status is S3-Vulnerable (NatureServe, 2005).

Although there is no history of commercial fishing on Little Eva Lake, low to moderate levels of non-resident angling and First Nation subsistence fishing are known to occur. Commercial fishing for lake sturgeon previously existed downstream in Namakan Lake from 1916 to 2001; and upstream on Lac La Croix from 1959 to 1966. No creel surveys have been completed to evaluate angling effort and harvest. Little or no sturgeon angling has been observed in Little Eva Lake or the Namakan River. Exploitation is likely incidental and similar to Namakan Lake where the majority of angler effort is generated by non-residents (99%) and directed at walleye (85 %) (Elder, 2001).

From 1994-1999, non-resident anglers were restricted to catch and release angling only for all fish species, unless staying overnight at an Ontario tourist establishment, houseboat, recreational fishing site, parcel of land or provincial park as described in the regulations. Pending a NAFTA trade challenge by the U.S., more general regulations were put in place across the border waters area in 2000 to limit harvest by all non-resident anglers. Effective July 1, 2008, the catch and possession limit for recreational angling of lake sturgeon was changed from one to zero for all anglers. Prior to this change, the daily catch and possession limit included a minimum size limit, whereby only fish greater than 190 cm (74.8”) total length could be retained. Prior to January 1, 2008, there was no size restriction on Little Eva Lake and other portions of the Namakan River. The open season for angling of lake sturgeon was June 30 to May 15 each year until 2008, when it was changed to July 1 to April 30.

STUDY AREA

Little Eva Lake is located immediately downstream of High Falls and upstream of Hay Rapids on the Namakan River (Figures 1 and 2). This 281 ha, mesotrophic lake is found in the southern range of the boreal forest in North America, and is typical of Canadian Shield lakes and rivers with soft water and little submerged aquatic vegetation. Table 1 provides of summary of known physical and chemical characteristics of the lake.

Little fisheries information is available and no aquatic habitat inventory (lake survey) has been completed. No other fisheries investigations have been completed on Little Eva Lake except for a Fall Walleye Index Netting (FWIN) survey in 2006. A diverse coolwater fish community with 13 species was found to be present (McLeod and Rob, 2008), while a total of 43 fish species are known to occur immediately downstream in the Namakan Reservoir (McLeod and Trembath, 2007).

Development on the shoreline of Little Eva Lake consists of one private cottage/outpost camp, three commercial boat caches and several recreational boats. Portage trails exist from the Gustav Road, Hay Rapids and High Falls (Bill Lake).

Table 1: Physical and chemical characteristics of Little Eva Lake, Ontario.

Parameter	Little Eva Lake
Surface Area (ha)	281
Mean Depth (m)	5.1
Maximum Depth (m)	18.1
Mean Summer Secchi Depth (m)	2.5
Perimeter Shoreline (km)	25.5
Island Shoreline (km)	4.0
T.D.S. (mg/L)	45
M.E.I.	8.82

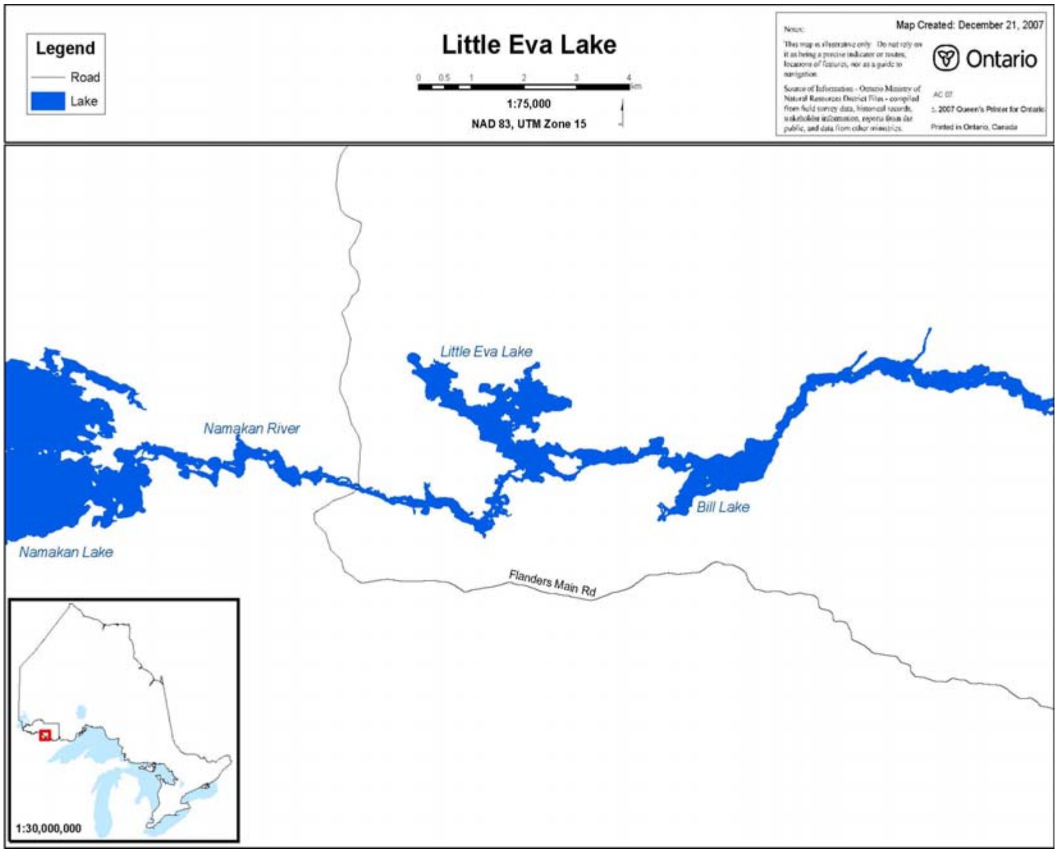

Figure 1: Location of Little Eva Lake on the Namakan River, Ontario.

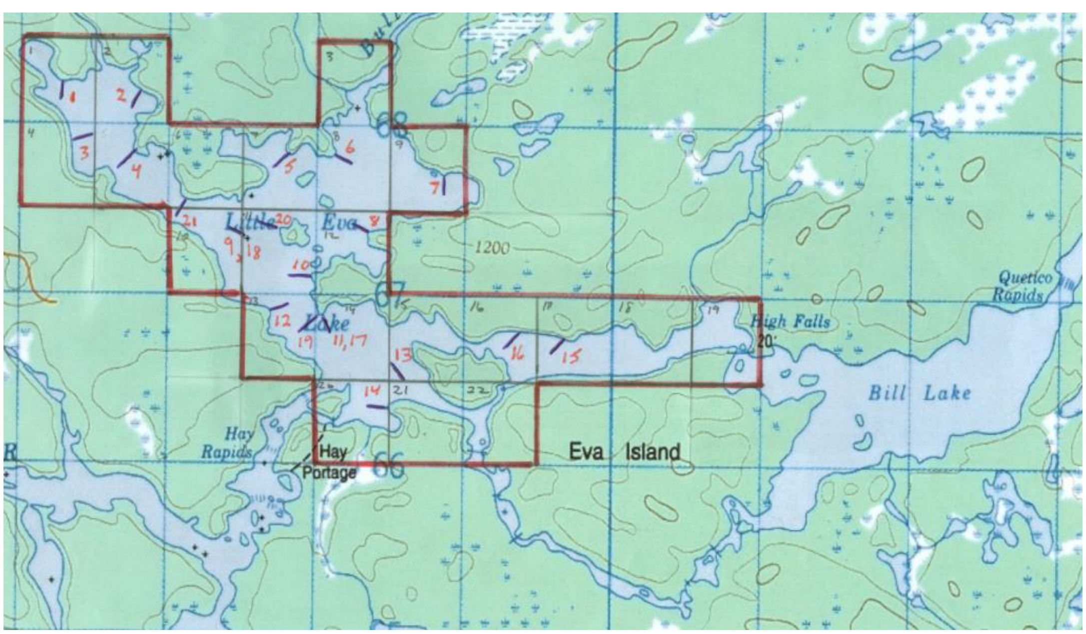

Figure 2: Sampling stratification and net locations on Little Eva Lake on the Namakan River, Ontario in October 2007.

METHODS

Lake sturgeon were first captured and sampled in Little Eva Lake using large mesh, assessment gill nets during the period of October 10-11, 2006. Fish were captured using 203 mm (8"), 230 mm (9"), 254 mm (10") and 305 mm (12") stretched mesh, multifilament gill nets. Each net panel was 91 m (300') long and 2.8 m (9') high. Eight net lifts occurred at eight different sample locations, and included a random selection of mesh sizes. Nets were set as close to perpendicular (90^o) from shore as each net site would allow.

Lake sturgeon were also captured and sampled during the period of October 9-19, 2007, using the same large mesh, multifilament gill nets. For the purpose of this mark-recapture study, the lake was stratified into 0.25 km^2 sampling grids. A topographic map (1:50,000) with existing one km UTM grid lines was used to define the sample cells (Figure 2). At least one gill net was individually and randomly deployed perpendicular to shore in 17 of the 22 potential grid cells. The remaining 5 cells could not be sampled due to high water flows at the time of sampling. A total of 4 cells were repeat sampled near the end of the sampling period. Twenty-one net lifts occurred in 2007, and included a random selection of mesh sizes. In both years, nets were set over-night with durations ranging from 17.5 to 24.5 hours.

Immediately upon capture, all fish were examined for external tags and pectoral fin ray clips. Fish with existing tags were released at the capture location after recording the individual tag number, while all other fish were temporarily retained in large plastic transportation bins filled with ambient lake water. As needed, fish were placed in a single compartment (12 m^3) holding net with a floating plastic frame anchored to shore near the daily sample location.

All lake sturgeon were sampled for total and fork length (mm), girth (mm) and round weight (g); tagged with an individually numbered Carlin disk dangler tag; and live released. Yellow OMNR tags were attached immediately below the centre of the dorsal fin with 0.5 mm stainless steel wire following methods outlined by Minnesota DNR (Stewig, 2005). A section of the large, marginal ray of the left pectoral fin was removed for age determination, and provided a secondary mark. The only exception to this methodology was in 2006, where full biological sampling (including length, weight, girth and age) was only completed on a sub-sample of fish. The remaining fish were sampled for total length only, tagged and immediately released due to inclement weather and unexpected high numbers in the catch. All aging structures were assessed by the OMNR Northwest Regional Aging Facility in Dryden, Ontario. Data were compiled and analyzed using FISHNET2 (Lester and Korver, 1996) and Fishnet Lite.

A simple Peterson index (Ricker, 1975; Bagenal, 1978) was used to estimate the population size of sturgeon over 1000 mm total length, as outlined in Stewig (2005). The marking phase was completed in October 2006, with the recapture phase completed one year later in October, 2007. The equation $N = MC/R$ was used, where N is the estimated population size, M is the number of fish initially marked and released, C is the number of fish collected and examined for marks in the second sample period, and R is the number of recaptures (i.e. previously marked fish) found in C. Since sampling during the recapture period was done without replacement, Chapman's modification was incorporated into the adjusted Peterson equation: $N = [(M+1)(C+1)/(R+1)]–1$, using the same variables described above. Due to the low number of recaptures, a 95% confidence interval was derived using a Poisson distribution table from Ricker (1975).

Additional estimates of population size were generated based on a cumulative (multiple) mark-recapture designs, using catch data from October, 2007 only. Schumacher, Schnabel and Modified Schnabel estimates (Ricker, 1975) were generated using statistical software and analysis completed at Northwest Science and Information, Thunder Bay (K. Armstrong, pers.comm.).

RESULTS

In October 2006, 101 sturgeon were captured of which 97 were tagged and released, including 90 fish exceeding 1,000 mm total length (Table 2). Water temperatures ranged from 9-10°C. Catches from a single gill net ranged from 2 to 29 fish. There was no incidental catch observed, and survival of captured sturgeon was very high. Only one large sturgeon died prior to release as a result of gill damage and bleeding during capture.

In October 2007, 157 sturgeon were captured (Table 3). A total of 148 unmarked sturgeon were tagged and released, including 140 fish >1000 mm total length. Nine tagged fish were recaptured, including 4 from October, 2006; 2 from May, 2007; and 3 from October, 2007 sampling. Water temperatures ranged from 10-11°C. Catches from a single gill net ranged from 1 to 23 fish. No incidental catch or mortality was observed in 2007.

The total catch over two study years was 258 sturgeon of which 9 were recaptured fish. Of these fish, 244 fish were biologically sampled for length and age, while weight and girth information was obtained from 213 fish. Mean total length of fish captured was 1,224 mm (774-1,630 mm), while mean round weight was 11,962 g (2,300-33,700 g), and mean girth was 448 mm (286-711 mm). Mean age of these fish was 24.6 years, with a range of 9-41 years.

Table 2: Summary of effort and catch of lake sturgeon by mesh size from multifilament gill nets in Little Eva Lake, 2006.

Mesh Size mm (inches)	Effort meters (feet)	# Sturgeon Captured	C.U.E #/100 m (#/100 ft)
203 (8”)	91 (300)	7	7.7 (2.3)
230 (9")	273 (900)	57	20.9 (6.3)
254 (10”)	273 (900)	35	12.8 (3.9)
305 (12”)	91 (300)	2	2.2 (0.7)
Total	**728 (2,400)**	**101**	**13.9 (4.2)**

Table 3: Summary of effort and catch of lake sturgeon by mesh size from multifilament gill nets in Little Eva Lake, 2007.

Mesh Size mm (inches)	Effort Meters (feet)	# Sturgeon Captured	C.U.E #/100 m (#/100 ft)
203 (8”)	455 (1,500)	35	7.7 (2.3)
230 (9")	546 (1,800)	57	10.4 (3.2)
254 (10”)	273 (900)	40	14.7 (4.4)
305 (12”)	637 (2,100)	25	3.9 (1.2)
Total	**1,911 (6,300)**	**157**	**8.2 (2.5)**

To evaluate size selectivity and vulnerability to capture in large mesh gill nets, the girth and total length of individual fish was compared to the mesh size of capture (Figure 3 and 4 respectively). Results suggest that fish were likely fully recruited to the sampling gear at a mean girth of 402 mm, which coincided with a total length of approximately 1,175 mm (Figure 5). The minimum girth of fish captured in the smallest mesh size of 203 mm (8”) was 286 mm and the lower quartile (25%) was 369 mm (Figure 2). By comparison, the minimum total length of fish captured in the smallest mesh size of 203 mm (8”) was 885 mm and the lower quartile (25%) was 1,043 mm (Figure 3). These results were compared to length frequency data and net selectivity graphs prepared for Rainy River/Lake of the Woods (Stewig, 2005), and similarly a total length of 1,000 mm was selected for

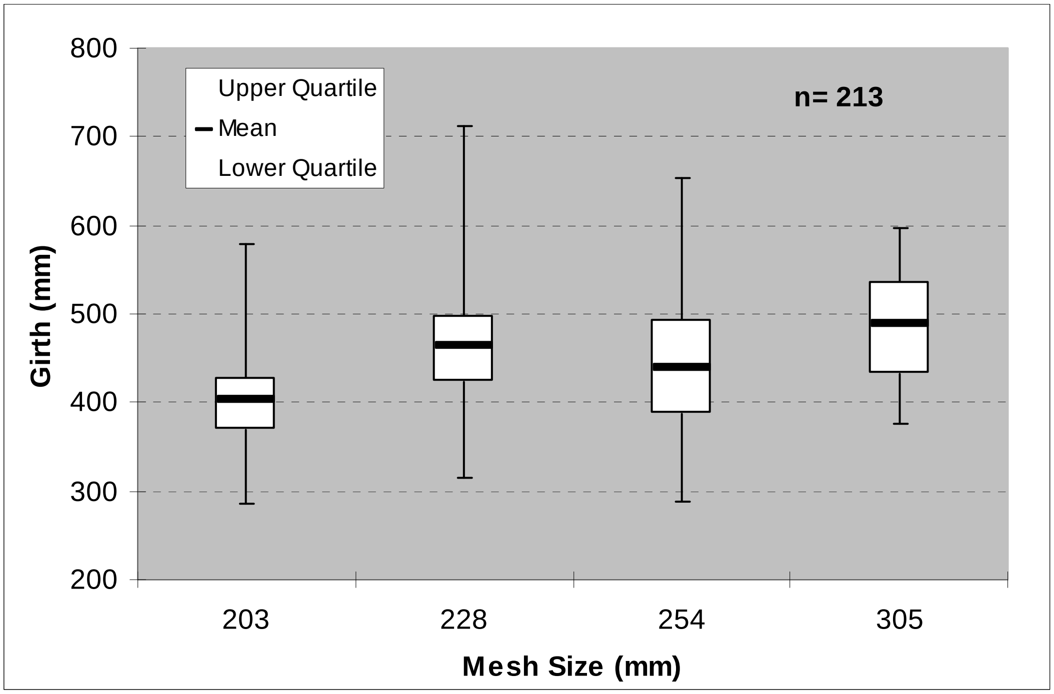

Figure 3: Girth of lake sturgeon (including mean, quartiles, range) by mesh size of capture in Little Eva Lake, 2007.

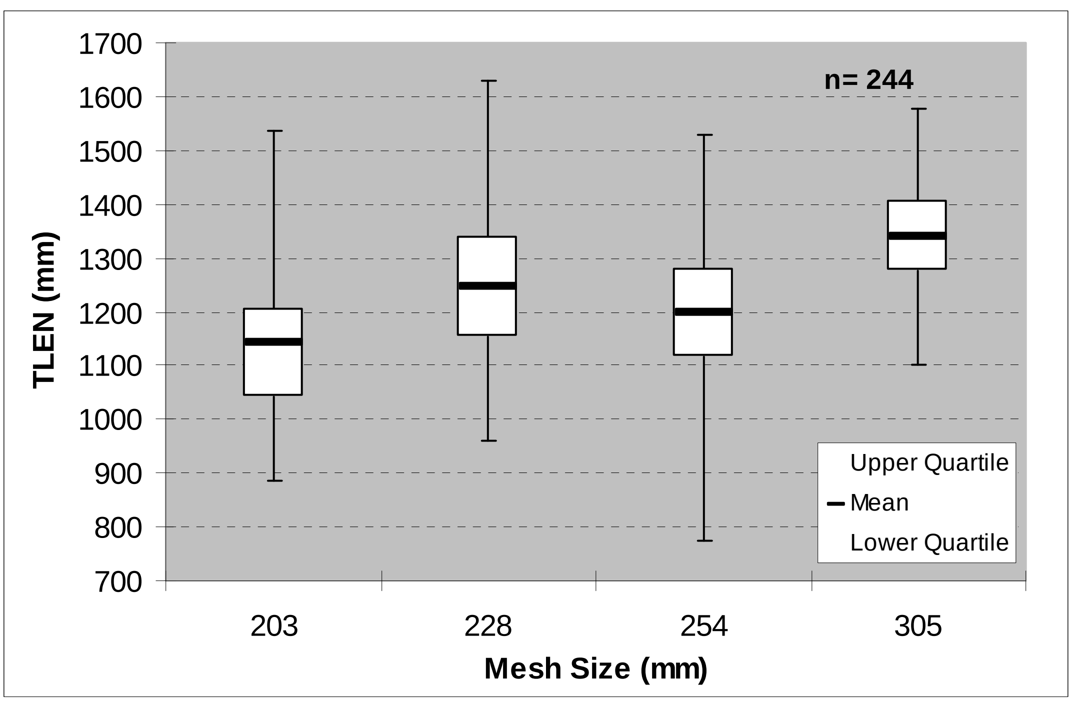

Figure 4: Total length of lake sturgeon (including mean, quartiles, range) by mesh size of capture in Little Eva Lake, 2007.

the minimum size in determining population estimates. Based on the regression equation from Figure 5, a total length of 1,000 mm represents an estimated mean girth of 337 mm in Little Eva Lake.

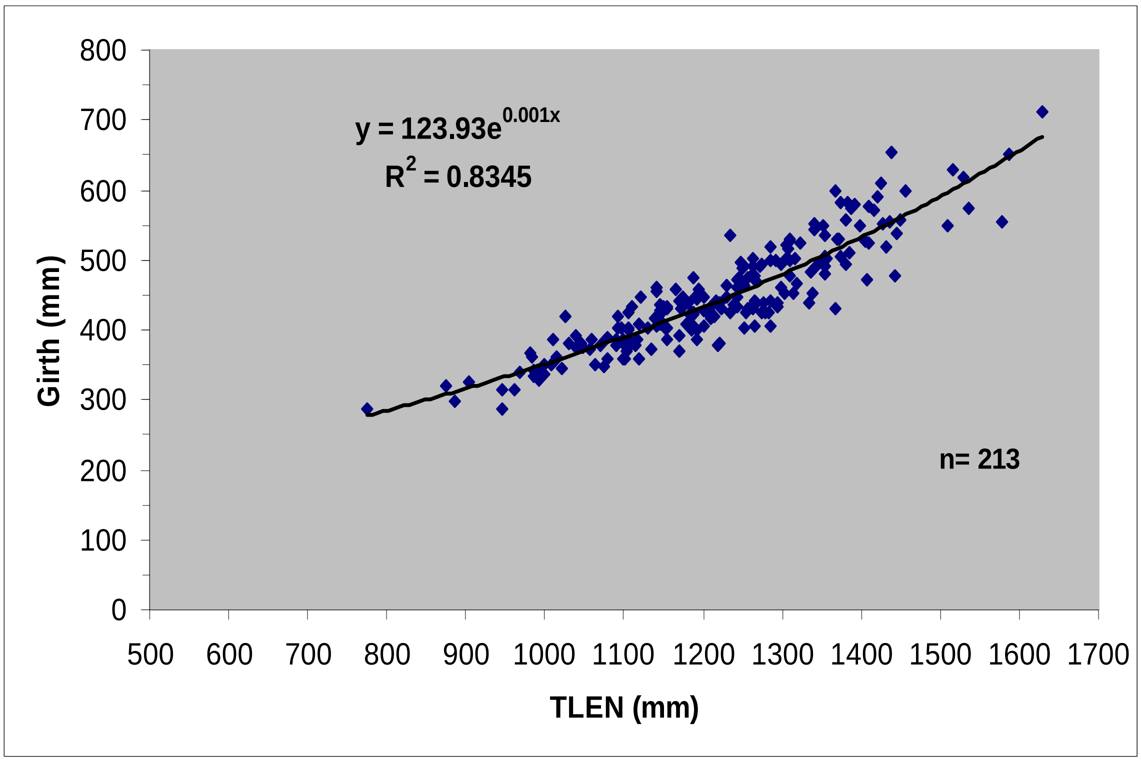

Figure 5: Girth and total length relationship for lake sturgeon captured in large mesh gill nets in Little Eva Lake, 2007.

The cumulative results of the 2007 multiple mark-recapture study are provided in Table 4, with a separate summary for all fish captured and for fish greater than 1,000 mm total length. Total catch over the 6 sample days (21 nets) was 157 fish (149 fish >1,000 mm) with 3 recaptures. The highest daily catch of 44 fish occurred on the final day of netting in 2007. This data was used to estimate population size following Schumacher, Schnabel and Modified Schnabel sampling designs, and compared to the single census (Peterson and Adjusted Peterson) designs (Table 5).

Table 4: Summary of cumulative catch of tagged and untagged lake sturgeon in Little Eva Lake, 2007.

All Fish

Sample	Date	Catch	Recaptures	Unmarked Catch
1	Oct. 10/07	18	0	18
2	Oct. 11/07	15	0	15
3	Oct. 12/07	30	0	30
4	Oct. 16/07	32	1	31
5	Oct. 17/07	18	0	18
6	Oct. 18/07	44	2	42
Total		**157**	**3**	**154**

Fish >1000 mm

Sample	Date	Catch	Recaptures	Unmarked Catch
1	Oct. 10/07	18	0	18
2	Oct. 11/07	14	0	14
3	Oct. 12/07	28	0	28
4	Oct. 16/07	31	1	30
5	Oct. 17/07	16	0	16
6	Oct. 18/07	42	2	40
Total		**149**	**3**	**146**

Table 5: Summary of lake sturgeon population and density estimates (fish > 1,000 mm total length) for Little Eva Lake, October 2007.

Method	Population Estimate	95% CI (Poisson)	Density (fish /ha)	95% CI (Poisson)
Simple Peterson	3,352	1,315↔13,410	11.9	4.7↔47.7
Adjusted Peterson	2,729	1,218↔6,824	9.7	4.3↔24.3
Schumacher	2,744	1,699↔7,127	9.8	6.0↔25.4
Schnabel	2,967	-	10.6	-
Modified Schnabel	2,225	908↔5,563	7.9	7.9↔19.8

DISCUSSION

The five methods of analysis used in this mark-recapture investigation suggest that the fall population of lake sturgeon in Little Eva Lake is high in both relative abundance and density when compared to other populations (Appendix I). Population size was estimated in the range of 2,225 to 3,352 adult fish (>1,000 mm) with a density of 7.9 to 11.9 fish/ha. As recommended by Pine et al. (2003), this study compared the results from several different mark-recapture models used to analyze the same data set. Consistent with other fish population estimates, several assumptions were made in this study, including: 1) marked fish do not lose their marks prior to the recapture period; 2) marked fish are not overlooked in the recapture sample; 3) marked and unmarked fish are equally vulnerable to capture during the recapture period; 4) marked and unmarked fish have equal mortality rates during the interval between the marking and recapture periods; 5) following release, marked fish randomly mix with unmarked fish; and 6) there are no additions to the population during the study interval (Stewig, 2005; Van den Avyle and Hayward, 1999; Bagenal, 1978; Ricker, 1975).

The Chapman modification or adjusted Peterson estimate was used since the simple Peterson method tends to over-estimate the true population (Ricker, 1975). This method provided the narrowest 95% confidence limits using a Poisson distribution, and appeared to be a more reliable estimate than the simple Peterson. However, sample size of recaptured fish was low (n=4) in both methods used. Additional population estimates were also derived in this study using a multiple mark-recapture design, including Schumacher, Schnabel and Modified Schnabel. These designs were considered since the number of marks released or recaptured in the single mark-recapture experiment is often insufficient to estimate population number to the desired level of precision and accuracy (Bagenal, 1978).

Ricker (1975) indicated that the minimum number of recaptures should preferably be 3 or 4 fish, to avoid the statistical bias and sampling variability inherent in Peterson estimates. In this study, sample size was at minimum levels with 4 fish recaptured in the single census (Peterson) and 3 fish in the cumulative or multiple census (Schumacher; Schnabel; and Modified Schnabel).

Although recruitment and mortality may be negligible or low for a species (i.e. lake sturgeon) over a period longer than a few days or a season, movement into or out of the study area often precludes the use of closed population models (Pine et al., 2003). In this study, some movement of both tagged and telemetered lake sturgeon in and out of Little Eva Lake was documented between the 2006 and 2007 sampling periods. However, the number of fish moving to and from the lake was considered small. Low flow or drought conditions existed in the system until early October, 2007 and likely precluded any extensive immigration or emigration of fish from Little Eva Lake during the study period. A closed population was therefore assumed for the simple Peterson and adjusted Peterson estimates, which compared well to the cumulative or multiple mark-recapture methods applied to the 2007 sampling. Pine et al. (2003) recommend using closed population models (e.g. Lincoln-Peterson) to estimate population size for short term studies where the closure assumption can be met.

Open models could be considered in future studies to alleviate this concern. The Jolly-Seber model is appealing because it is "open" to population changes due to movement, mortality and recruitment (Pine et al., 2003). Use of pilot studies such as this one and simulation analysis to assess precision of estimates is also recommended to improve our understanding and management of fish populations.

Stewig (2005) evaluated tag loss and delayed mortality of both angler-caught and gill netted lake sturgeon in the Rainy River, and reported no evidence of tag loss or mortality after 72 hours. A similar sampling and tagging protocol was followed in Little Eva Lake, and it was assumed that tag loss and delayed mortality were low to non-existent over the short study duration. Bagenal (1978) also noted that if different size classes of fish have different vulnerability to the sampling gear, then the population number based on all size classes combined is not valid. For this reason, we chose only to estimate the population size for fish greater than 1,000 mm total length. This approach is consistent to that used on the Rainy River and Lake of the Woods (Stewig, 2005).

Estimates of biomass were very high in Little Eva Lake and ranged from 103 to 114 kg/ha in 2007. Fish were concentrated in the lake in fall and this estimate may not reflect the biomass of lake sturgeon throughout the entire Namakan River or the reservoir downstream. Other investigations have also estimated the biomass of sturgeon in weight of fish per hectare of surface area. Reported densities vary from 1-2 kg/ha in the Mattagami River to 68 kg/ha on the Menominee River (Block, 2001). The Winnipeg River had a density estimate of 41 kg/ha below the Slave Falls dam, but the overall estimate for the entire section of river was 10 kg/ha. Additional estimates included 3-14 kg/ha in the Kenogami River (Sandilands, 1987), 14-22 kg/ha on the Fredrick House River and 7 kg/ha in the Abitibi River (Payne, 1987), and 16-68 kg/ha in the Menominee River (Thuemler, 1997).

This initial study on the Namakan River suggests that lake sturgeon density and biomass is high in Little Eva Lake in comparison to other waters in Ontario and elsewhere in North America. However, the Namakan River is currently unimpounded and undeveloped, and is believed to have very low levels of harvest. Because of these factors, it may not be directly comparable to other populations where water level regulation, exploitation or changes to habitat have altered historical population levels. Haxton and Findlay (2008) and Haxton (2002) reported that the relative abundance of lake sturgeon was greater in natural, unimpounded reaches than in impounded reaches, and that water power management appears to the primary stressor for lake sturgeon in the Ottawa River.

The purpose of this study was to determine the population size and density of lake sturgeon in Little Eva Lake between Hay Rapids and High Falls. In combination with other investigations on movement, habitat use and population health, this information would help evaluate possible consequences of proposed hydroelectric development. Single, point in time population estimates can be difficult to interpret due to natural fluctuations in recruitment and habitat conditions based on water levels and flows. The longevity of species, along with delayed maturation and skipped spawning, are also important considerations when monitoring lake sturgeon populations. An on-going assessment program is recommended in order to evaluate long-term trends in population size, especially if any future development proposals are approved.

ACKNOWLEDGEMENTS

I would like to acknowledge MNR staff from the Fort Frances Area who contributed to this mark-recapture study, namely Linda Chepil, Janet Fedoruk, Dan Fox, Dan McMahon, Alyson Rob, Rachel Hill, and Lisa Solomon (Quetico Provincial Park). In addition, Randy Geyshick, Gordie Geyshick and Andrew Jourdain of Lac La Croix First Nation; and Gord Persson (Bio-Consulting) assisted with the project. Alyson Rob also assisted with data summary and analysis. Kim Armstrong (Northwest Science and Information, Thunder Bay) provided the computer generated population estimates, and reviewed the final report. John Vandenbroeck and Mike Friday also reviewed the final draft of this report. Additional thanks to Ron Bruch, Steve Chipps, Mike Friday, Tim Haxton, Charles Hendry, Don MacDonald, Tom Mosindy and Joe Stewig for providing information from other waters and jurisdictions.

REFERENCES

Adams, W.E., Jr., L.W. Kallemeyn, and D.W. Willis. 2006a. Lake sturgeon, *Acipenser fulvescens*, movements in Rainy Lake, Minnesota and Ontario. Canadian Field-Naturalist. 120(1):71-82.

Adams, W.E., Jr., L.W. Kallemeyn, and D.W. Willis. 2006b. Lake sturgeon population characteristics in Rainy Lake, Minnesota and Ontario. J. Applied Ichthyology. 22: 97-102.

Auer, N.A. 1999. Lake Sturgeon: A Unique and Imperilled Species in the Great Lakes. Pages 515-534 *In* C.P. Ferreri and W.W. Taylor, editors. Great Lakes Fisheries Policy and Management – A Binational Perspective, Michigan State University Press.

Bagenal, T. 1978. Methods for Assessment of Fish Production in Fresh Waters. IBP Handbook No. 3. Blackwell Scientific Publications. 365 p.

Baker, E.A. and D.J. Borgeson. 1999. Lake sturgeon abundance and harvest in Black Lake, Michigan, 1975-1999. Trans. Am. Fish. Soc. 19(4):1080-1088.

Block, D. 2001. Growth estimates, habitat use and ecology of the lake sturgeon from Round Lake and mature reservoirs in the Winnipeg River. M.Sc. Thesis. University of Manitoba.162 p.

Brousseau, C. S. 1987. The lake sturgeon (*Acipenser fulvescens*) in Ontario. Pages 2-9 *in* C.H. Oliver, editor. Proceedings of a workshop on the lake sturgeon (*Acipenser fulvescens*). Ontario Ministry of Natural Resources, Fisheries Technical Report Series No. 23.

Elder, D. 2001. Creel survey of Namakan Lake and Sand Point Lake, Ontario – 1998. Ontario Ministry of Natural Resources. Fort Frances District Report Series No. 48. 51 p.

Galarowicz, T. 2003. Conservation assessment of lake sturgeon (*Acipenser fulvescens*). USDA Forest Service. Ph.D. Central Michigan University.

Haxton, T.J. and C.S. Findlay. 2008. Variation in lake sturgeon (*Acipenser fulvescens*) abundance and growth among river reaches in a large regulated river. Can. J. Fish. Aquat. Sci. 65:645-657.

Haxton, T.J. 2006. Characteristics of a lake sturgeon spawning population sampled a half century apart. Journal of Great Lakes Research. 32: 124-130.

Haxton, T.J. 2002. An assessment of lake sturgeon (Acipenser fulvescens) in various reaches of the Ottawa River. J. Appl. Ichthyol. 18: 449-454.

Kallemeyn, L.W., K. Holmberg, J.A. Perry and B.Y. Odde. 2003. Aquatic Synthesis for Voyageurs National Park. U.S. Geological Survey. Information and Technology Report 2003-0001. 95 p.

Kallemeyn, L.W. 2000. Proceedings of the Rainy Lake – Namakan Reservoir Ecological Monitoring Workshop: A Report to the International Joint Commission. U.S. Geological Survey. International Falls Biological Station. Service Order 1761-900422. 60 p.

Lallaman, J.J., R.A. Demstra and T.L. Galarowicz. 2008. Population assessment and movement patterns of lake sturgeon (*Acipenser fulvescens*) in the Manistee River, Michigan, USA. Journal of Applied Ichthyology. 24(1):1-6.

Lester, N.P., and R.M. Korver. 1996. FISHNET 2.0 analyses of index fishing and creel surveys. Part B. Fish statistics. Ontario Ministry of Natural Resources, Maple, Ontario. 23 p.

McLeod, D.T. and A. Rob. 2008. Fall Walleye Index Netting on Little Eva Lake, Ontario, 2006. Ontario Ministry of Natural Resources. Fort Frances District Report Series No. 73. 43 p.

McLeod, D.T. and C. Trembath. 2007. Fall Walleye Index Netting on Namakan Lake, Ontario, 2005. Ontario Ministry of Natural Resources. Fort Frances District Report Series No. 70. 50 p.

Nowak, A.M. and C.S. Jessop. 1987. Biology and management of the lake sturgeon (*Acipenser fulvescens*) in the Groundhog and Mattagami Rivers, Ontario. Pages 20-32 *In* C.H. Oliver, editor. Proceedings of a workshop on the lake sturgeon (*Acipenser fulvescens*). Ontario Ministry of Natural Resources, Fisheries Technical Report Series No. 23.

OMNR. 1999. Lake Sturgeon in Lake Superior. Ontario Ministry of Natural Resources. Lake Superior Management Unit. Unpublished Report. 4 p.

OMNR and MDNR. 1995. Report of the Border Waters Lake Sturgeon Management Committee. Ontario Ministry of Natural Resources. Unpublished Report. 13 p.

OPEG. 2007. Environmental Field Study Plan: Namakan River Hydro Development Project. Ojibway Power and Energy Group. 43 p.

Payne, D.A. 1987. Biology and population dynamics of lake sturgeon (*Acipenser fulvescens*) from the Fredrick House, Abitibi and Mattagami Rivers, Ontario. Pages 10-19 *In* C.H. Oliver, editor. Proceedings of a workshop on the lake sturgeon (*Acipenser fulvescens*). Ontario Ministry of Natural Resources, Fisheries Technical Report Series No. 23.

Pine, W.E., K.H. Pollock, J.E. Histower, T.J. Kwak and J.A Rice. 2003. A review of tagging methods for estimating fish population size and components of mortality. Fisheries. 28(10):10-21.

Ricker, W.E.1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bulletin of the Fish. Res. Board of Canada. No. 191. Environment Canada. 381 p.

Sandilands, A.P. 1986. The biology of lake sturgeon (*Acipenser fulvescens*) in the Kenogami River. Ecologistics Ltd. Ontario Fisheries Technical Report Series. 62 p.

Scott, W.B., and E.J. Crossman. 1998. Freshwater Fishes of Canada. 4th edition. Galt House Publications, Oakville, ON.

Stewig, J.D. 2005. A population assessment of the lake sturgeon in Lake of the Woods and the Rainy River, 2004. Minnesota Department of Natural Resources. Division of Fisheries. Completion Report F-29-R(P)-24. 38p.

Threader, R.W. and C.S. Brousseau. 1986. Biology and management of lake sturgeon in the Moose River, Ontario. NAJFM. 6:383-390.

Thuemler, T.F. 1997. Lake sturgeon management in the Menominee River, a Wisconsin-Michigan boundary water. Environmental Biology of Fishes. 49:311-317.

Van den Avyle, M.J. and R.S. Hayward. 1999. Dynamics of exploited fish populations. Pages 127-166 *In* C.C Kohler and W.A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Maryland.

APPENDICES

Appendix I: A comparison of lake sturgeon population and density estimates for Little Eva Lake on the Namakan River, Ontario to similar studies in other waters and jurisdictions.

Lake	Year	Jurisdiction	Method	Population Estimate (95% CI)	Density (fish/ha)	Density (fish/km)	Reference
Little Eva (Namakan R.)	2007	Ontario	Adjusted Peterson	2,729 (1,218↔6,824)	9.7	-	McLeod (2008) – 181 ha
			Modified Schnabel	2,225 (908↔5,563)	7.9	-	McLeod (2008)
Rainy River/Lake of the Woods	2004	Ontario	Simple Peterson	59,050 (30,736↔121,372) (>1000 mm)	0.3	-	Stewig (2005) – 212,125 ha
Ottawa R. (Lac Deschênes)	2003	Ontario	Schnabel	202 (93↔378) (adults)	< 0.1	0.2	Haxton (2006) – 10,900 ha (40 km)
Kaministiquia R.	1998	Ontario	Schumacher-Eschmeyer	140 (77↔234)	1.2-5.0	3.0	OMNR (1999) – 47 km http://www.fws.gov/Midwest/sturgeon/omnrls_page.html
	2001		Modified Schnabel	188 (127↔289) (adults)	-	4.0	M. Friday (pers. comm.)
Mattagami R. (Little Long head pond)	1991	Ontario	Modified Schnabel	24,772 (16,359↔34,910)	3.5	-	Sheehan and McKinley (1992) – 7,167 ha
	2001		Modified Schnabel	12,395 (10,292↔14,924) (mature adults)	1.7	-	ESG International and Nassagaweya Environmental Consultants Ltd. (2002)
Mattagami R. (head ponds)	1985	Ontario	?	? (adults)	0.2 – 0.3	-	Nowak and Hortiguela (1986)
Kenogami R.	1985	Ontario	Schnabel	711 (660-767)	-	4.4	Sandilands (1986)
Moose R.	1985	Ontario		7,088 (5,774↔8,919) (≥ age 8)			Threader and Brousseau (1986)

Lake	Year	Jurisdiction	Method	Population Estimate (95% CI)	Density (fish/ha)	Density (fish/km)	Reference
Abitibi R.	1984	Ontario	Schnabel	994 (830↔1,213)	1.0	24.9	Payne (1987) – 40 km
Lower Groundhog/ Mattagami R.	1984	Ontario	Modified Schnabel	8,429 (6,260↔11,654) (>age 9)	7.2	187.0	Nowak and Jessop (1987) - 45 km
Frederick House R.	1984	Ontario	Modified Peterson	186 (spawning adults)	1.9	13.3	Nowak and Jessop (1987) - 14 km
Saskatchewan River	2006	Manitoba	Jolly-Seber	1,639 373↔16,342 (adults)	-	-	G. McVittie (2007) – MB border to Cedar Lake
Nelson R.	2000	Manitoba	Modified Peterson	692 (adults)	-	-	D. MacDonald – Kelsey GS to Sipiwesk Lake
Winnipeg R.	1999 1997	Manitoba	Jolly-Seber	10,571 2,998 (1,143↔13,101) 648 (356↔6,676)	- - -	- - -	D. Leroux – Seven Sisters to Slave Falls Block (2001) – Seven Sisters to Slave Falls Block (2001) – Slave Falls to Point du Bois
Round Lake	1998	Manitoba	Jolly-Seber	1,048 (562↔2,553)	-	-	Block (2001)
North Sask. R.	2000	Saskatchewan	Jolly-Seber (Bailey method)	200 (mature) 1,360 (>age 3)	- -	0.4 2.5	ASRD (2002) – 540 km
South Sask. R.	1986	Saskatchewan	Jolly-Seber (Bailey method)	510 (mature) 2,058 (>age 3)	- -	1.7 6.9	ASRD (2002) – 300 km
Kettle R.	2002	Minnesota	Schnabel	346 (309↔387)	-	-	www.dnr.state.mn.us/areas/fisheries/hinkley/rivers/sturgeonstudy.html
Manistee R.	2005 2001	Michigan	-	21↔66 46 (34↔65) (spawning adults)	- -	0.1 -	Lallaman et al. (2008) Galarowicz (2003)
Muskegon R.	2002	Michigan	Modified Schnabel	17 (mature)	-	-	Vecsei and Peterson (2002)

Lake	Year	Jurisdiction	Method	Population Estimate (95% CI)	Density (fish/ha)	Density (fish/km)	Reference
Black Lake	1997	Michigan	Schnabel	1,241 (>900 mm)	0.3	-	Baker and Borgeson (1999)
Lake Winnebago system	2008	Wisconsin	Modified Peterson	41,796 (35,536↔52,320) (adults)	0.5	-	R. Bruch (2008) – 80,940 ha (lakes and rivers combined) www.dnr.wi.gov/fish/sturgeon/lakewinnebago