Lake Sturgeon Biology in Rainy Lake, Minnesota and Ontario

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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Abstract

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Rainy Lake contains a native population of lake sturgeon *Acipenser fulvescens* that has gone largely unstudied. The objectives of this study were to document the population characteristics of lake sturgeon in Rainy Lake, determine spawning locations and generalized lake sturgeon movement patterns through the use of biotelemetry, and to relate climate, Namakan Lake discharge, and Rainy Lake water levels to year-class strength of lake sturgeon in Rainy Lake. Results of gill net efforts throughout the study indicate a substantial population of lake sturgeon in Rainy Lake. Based on body condition and growth, lake sturgeon in Rainy Lake were relatively plump and fast growing compared to a 32-population summary. Size structure analysis revealed a lack of smaller (<105 cm total length) and larger (>150 cm total length) lake sturgeon. Age-structure analysis indicated a similar trend, with few younger (<10 years) and older (>50 years) lake sturgeon, and a maximum age of 59 years. Of the 322 lake sturgeon captured or recaptured during this study, 217 were in the area adjacent to the Squirrel Falls Dam, indicating the importance of this location. Telemetry data reinforced the high utilization of the Squirrel Falls area by lake sturgeon, with 37% of the re-locations occurring in that area. Squirrel Falls was the only site at which spawning was confirmed by collection of

lake sturgeon eggs, although other spring aggregations in areas associated with Kettle Falls, the Pipestone River, and the Rat River could indicate spawning activity. Movement of lake sturgeon between the Seine River and the South Arm of Rainy Lake indicates the likelihood of one integrated population on the east end of the South Arm. The lack of re-locations in the Seine River during the months of September and October may have been due to lake sturgeon moving into deeper water areas of the Seine River and out of the range of telemetry gear or simply moving back into the South Arm. Few correlations existed between lake sturgeon year-class indices and both annual and monthly climate variables. The same was true for lake sturgeon year-class strength and Namakan Lake discharge. Correlation between Rainy Lake elevation and the lake sturgeon year-class strength indices across years yielded consistent, but weak correlations during the time period between late April and early June when spawning of lake sturgeon occurs. The lake sturgeon has historically been a resource of both cultural and economical importance to the Rainy Lake area. The unique biological characteristics of this species combined with the size of the system in which they live require biologists to utilize diverse management strategies. A proactive approach will allow lake sturgeon in this system to continue their role in the Voyageurs National Park aquatic ecosystem for many years to come.

Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

The lake sturgeon *Acipenser fulvescens* is one of North America's longest-lived fish species, with an evolutionary lineage that can be traced back 300 million years to the palaeonisciforms of the Devonian period (Schaeffer 1973; Gardiner 1984). The historic range for this fish includes large rivers and lakes in the Laurentian Great Lakes, Hudson-James Bay, and Mississippi River watersheds of eastern North America, extending as far south as the Tennessee River in Alabama and northern Mississippi (Harkness and Dymond 1961; Scott and Crossman 1973; Lee et al. 1980; Houston 1987; Ferguson and Duckworth 1997). Throughout this region, lake sturgeon populations presently represent only a fraction of their former numbers with 20 U.S. states and seven Canadian provinces categorizing them as threatened as of 1989 (Williams et al. 1989).

The unique biology of lake sturgeon should be considered and incorporated into management decisions made by fisheries biologists to restore and maintain healthy populations. One important aspect of lake sturgeon reproduction is age at sexual maturation. Mosindy and Rusak (1991) reported a mean age at maturity of 16.8 years for males and 25.8 years for females in the Lake of the Woods/Rainy River system, while lake sturgeon in northern Ontario were reported mature at >19 years for males and >22 years for females (Nowak and Jessop 1987). The interval between successive spawnings is thought to increase with latitude, ranging between 1 and 3 years for males and 4 and 6 years for females (Magnin 1966). Total lifespan of lake sturgeon may exceed 100 years

(Houston 1987), with individuals attaining weights over 136 kg (Scott and Crossman 1973).

Lake sturgeon population declines can be traced to the loss of spawning and rearing habitat due to pollution and hydroelectric dam development, and also to commercial fishing harvest (Harkness and Dymond 1961; Brousseau and Goodchild 1989; Rochard et al. 1990; Auer 1996). Payne (1987) suggested that water level fluctuations due to varying hydrologic regimes imparted by hydroelectric dams might have accounted for observed differences in populations of lake sturgeon at three different study sites in Ontario.

Within the native range of the lake sturgeon is the Winnipeg-Nelson drainage system, which encompasses Voyageurs National Park, Minnesota. Remnant populations of lake sturgeon exist in the major lakes within Voyageurs National Park and have long been important to the region for their economic and cultural value. Lake sturgeon have been valued for consumption as well as for various products derived from their bodies (Holzkamm et al. 1988). Three of these lakes (Rainy, Namakan, and Sand Point) are bi-national waters shared with the Canadian province of Ontario. In these waters, lake sturgeon have declined due to exploitation and habitat loss. The Minnesota Department of Natural Resources (MN DNR 2003) currently considers the lake sturgeon a state-listed species of special concern. This designation is given to species that, because of their rarity or specialized habitat requirements, merit close monitoring and research.

The population of lake sturgeon that still exists in Rainy Lake has gone largely unstudied over the years. McLeod (1999) conducted the only assessment of lake sturgeon in the Lower Seine River system, a primary tributary of Rainy Lake. However, biologists believe that lake sturgeon abundance in Rainy Lake has been reduced by commercial fishing and by dams built in the late 19th and early 20th centuries (Larry Kallemeyn, U.S. Geological Survey, personal communication). A hydroelectric dam at the outlet and two regulatory dams have controlled water levels in Rainy Lake since the early 1900's. Operation of the dams has removed much of the hydrologic variability that the lakes would experience under natural conditions by altering the magnitude and timing of water level fluctuations (Kallemeyn et al. 1993). These controlled water levels have been found to significantly limit habitat development and availability for many aquatic and semi-aquatic species, including fish, birds, and mammals (Kallemeyn 1987a, 1987b; Kallemeyn et al. 1988; Cohen and Radomski 1993). These three dams, along with a hydroelectric dam established in 1926 at Sturgeon Falls on the Seine River, may have contributed to the loss of critical spawning habitat and a decline in lake sturgeon populations.

Dams also prevent upstream movement of lake sturgeon, which has isolated the populations in the Rainy and Namakan reservoirs from each other and from known downstream populations in the Rainy River and Lake of the Woods (Mosindy and Rusak 1991). While commercial fishing for lake sturgeon was eliminated in Minnesota waters of Rainy Lake in 1940 (L. Kallemeyn, U.S. Geological Survey, personal communication) and Ontario waters in 1990 (D. Mcleod, Ontario Ministry of Natural Resources, personal communication), little can be done to increase opportunities for upstream fish migration in this system. While commercial catch records indicate that lake sturgeon populations have suffered a substantial decline, there are no estimates of the number of lake sturgeon remaining. Natural resource agencies in Minnesota and the province of Ontario have established angling harvest regulations to protect the lake sturgeon population in Rainy Lake. However, to properly ascertain harvest allocations, including those for Native American subsistence fisheries that remain active, baseline data on population dynamics and structure, relative abundance and characterization of spawning habitat in combination with existing hydrological and reservoir morphometric data are necessary for the development of water-specific management models. Without these baseline data, it is impossible to investigate the effect of the dam and reservoir operation or the impact of harvest restrictions on the lake sturgeon populations. These reservoir-operation models can then be presented to the International Joint Commission so they can be incorporated into their operating plan for Rainy Lake.

The aforementioned factors, combined with the late sexual maturity and infrequency of spawning that is characteristic for this species (Houston 1987), leave many gaps in our understanding of the biology of lake sturgeon in Rainy Lake. The Minnesota-Ontario Border Waters Technical Committee, a group of fisheries specialists from resource management agencies in both countries, identified the need for up-to-date information on the status of the lake sturgeon population and its habitat requirements as a high priority (MNDNR/OMNR 1998). Therefore, the objectives of this study were to 1) assess lake sturgeon population characteristics in Rainy Lake, 2) acquire generalized knowledge of seasonal movement patterns and spawning locations, and 3) assess the effects of reservoir water level on lake sturgeon recruitment.

Chapter 2. Study Site

Rainy Lake, located on the northern Minnesota-Ontario border, was selected as the study site due to a lack of baseline data for this lake sturgeon population. The lake consists of three main basins: the North Arm, Redgut Bay, and the South Arm, all of which are part of the Winnipeg-Nelson drainage system in the Lake Winnipeg primary watershed (Figure 2-1). The North Arm and Redgut Bay are both located entirely in Canada. The South Arm extends for 56 km along the border of the United States and Canada, with approximately 45% of the surface area in the United States. Of this area, 91% lies within Voyageurs National Park. The South Arm of Rainy Lake, along with a 40-km section of the Seine River, was the area of focus for my study. Much of my sampling and transmitter implantations occurred at specific locations on Rainy Lake. These locations have been summarized in Figure 2-2 so that readers can refer back to this map if questions arise concerning specific sites.

Rainy Lake has a total surface area of 92,000 ha, a maximum depth of 49.1 m, and a mean depth of 9.9 m. Of the three main lake basins, the South Arm has the greatest surface area at 49,200 ha, with 27,300 ha in Ontario and 21,900 ha in Minnesota. The South Arm also is the deepest basin with a mean depth of 9.9 m and a maximum depth of 49.1 m. The North Arm has a surface area of 34,570 ha, a mean depth of 8.0 m, and a maximum depth of 41.0 m. Redgut Bay has a surface area of 8,320 ha, a mean depth of 6.9 m and a maximum depth of 31.2 m.

The watershed associated with Rainy Lake encompasses over 37,500 km^2 and can be divided into two sub-basins, including a 19,270-km^2 area above the outlet of Namakan Reservoir at Kettle Falls and Squirrel Falls and a 19,320-km^2 area below Kettle Falls and Squirrel Falls that drains directly to Rainy Lake. Overflows between Namakan Reservoir and Rainy Lake also occur at Bear Portage and Gold Portage. Below Kettle Falls and Squirrel Falls there are two principal tributaries that enter Rainy Lake, the Turtle River with a mean discharge of 37 m^3/sec and the Seine River with a mean discharge of 48 m^3/sec. Smaller, ungauged tributaries into the South Arm of Rainy Lake include the Rat and Pipestone rivers, both of which may be used by lake sturgeon for spawning. Along with these tributaries, there is outflow from 13 interior lakes within Voyageurs National Park. Three chains or series of interior lakes discharge into Rainy Lake: Loiten, Quill, War Club, and Locater; Little Shoepack and Shoepack; and Oslo, Brown, and Peary. Changes in flow initiated at the headwaters take about 21 d to reach the outlet of Rainy Lake under normal flow conditions with the water dropping about 135 m in the 338 km between these two points (International Rainy Lake Board of Control/International Lake of the Woods Control Board 1984). Long-term flow records indicate that approximately 8.3 billion m^3 of water move through the Rainy Lake watershed annually (Ericson et al. 1976).

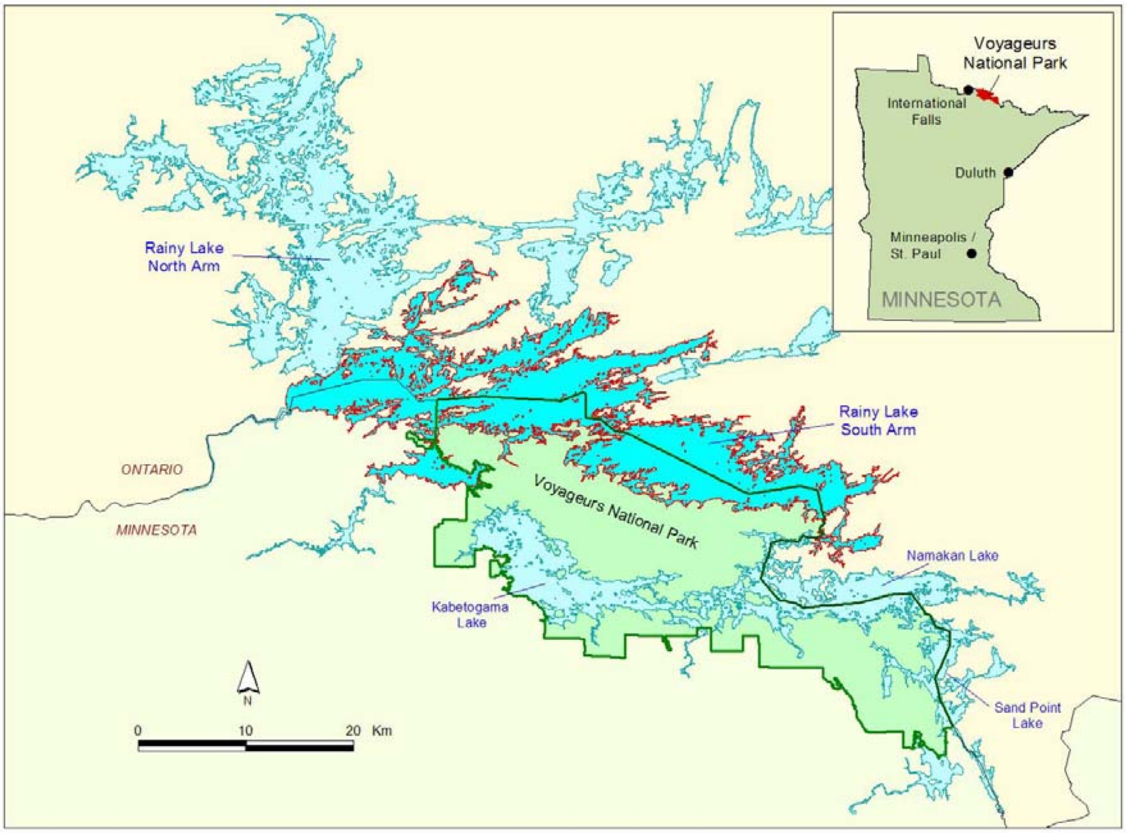


Figure 2.1. Location of study area, Rainy Lake, Minnesota, United States and Ontario, Canada.

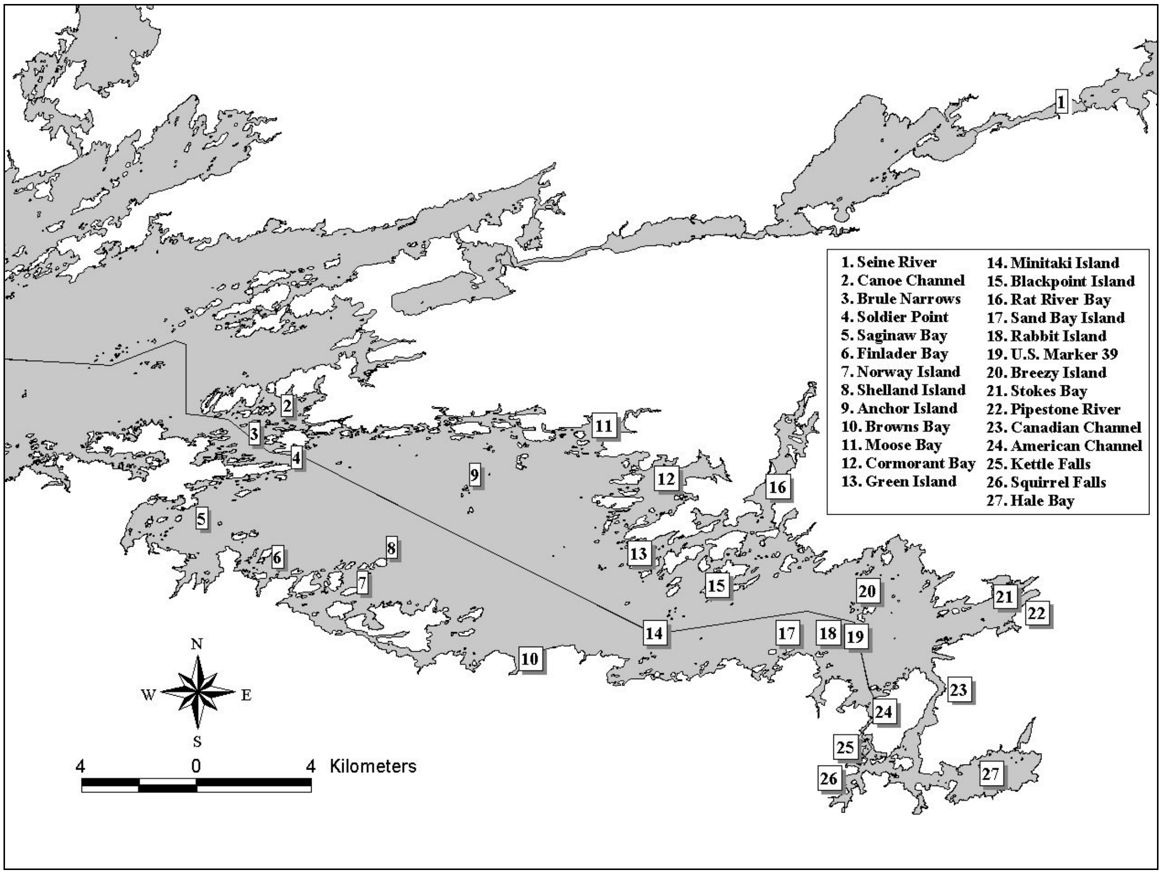


Figure 2-2. Locations of sampling and transmitter implantation sites on Rainy Lake, 2002-2004.

Chapter 3. Lake Sturgeon Population Characteristics in Rainy Lake

Introduction

Although the lake sturgeon is a Minnesota state-listed Species of Special Concern, biologists currently have little information on the population characteristics of this fish in Rainy Lake (Larry W. Kallemeyn, U.S. Geological Survey, personal communication). The limited information is especially of concern because females of this species typically do not mature until they are at least age 20 (Scott and Crossman 1973) and may spawn only once every 4-6 years (Magnin 1966).

Once abundant, lake sturgeon populations were reduced by commercial fishing and dams built in the early 20th century. Dams constructed on the outlets of Rainy and Namakan lakes prevent the upstream movement of lake sturgeon and have isolated the populations in the Rainy and Namakan reservoirs from each other and from known downstream populations in the Rainy River and Lake of the Woods (Mosindy and Rusak 1991). Commercial fishing was allowed on the U.S. side of Rainy Lake through 1940 and on the Canadian side through 1990, although natural resource agencies in Minnesota and the province of Ontario have now established harvest regulations to protect the lake sturgeon (Larry W. Kallemeyn, U.S. Geological Survey, personal communication).

The objective of this chapter is to document the population characteristics of lake sturgeon in Rainy Lake. Specifically, I determined lake sturgeon population size structure, weight-length relation, condition, age structure, mortality, and growth.

Methods

Lake sturgeon were collected using multifilament gill nets having mesh sizes (bar measure) of 102, 114, 127, 152, and 178 mm. Effort was not equally distributed among meshes, and effort by mesh was not consistently recorded by the variety of biologists involved in fish collection. Net lengths varied between 30 and 273 m, with all nets having a height of 1.83 m. Lake sturgeon were collected during May and October of 2002; May, June, August, and October of 2003; and May, June, and August of 2004. Despite known seasonal changes in fish vulnerability to capture and body condition (Pope and Willis 1996), I combined all lake sturgeon caught during the 3-year period to attain a sufficient sample size for fish population analysis for Rainy Lake.

All fish captured were measured for total (TL) and fork (FL) lengths (mm) and weight (kg). An anterior, proximal portion of the pectoral fin ray was taken from each fish for age determination. Each fish was tagged by attaching a numbered yellow oval disc tag to the dorsal fin to allow biologists to determine if fish were recaptured. Sex was determined when possible by examination of ovaries or testes during telemetry tag implantation surgery or by visual inspection of sperm or eggs exiting the body cavity during sampling process.

Precision of standardized gill-net samples

During 2003 and 2004, multifilament gill nets were utilized to establish estimates of precision for mean catch per unit effort (CPUE), which were used to determine units of effort needed for a standardized sampling regime. Net dimensions were 273 m X 1.83 m, with each net consisting of 91 m each of 102, 127, and 152 mm mesh (bar measure). During 2003, sampling consisted of 21 net nights, while in 2004, sampling was terminated after 11 net nights due to the lack of fish being captured. These nets were set at stratified-random locations, with the stratification based on biotelemetry data. Strata included depths of <9.1 m, 9.1-21.3 m, and 21.3-30.4 m. Random sites were then selected within each stratum using Arcview (Environmental Systems Research Institute 1999).

Units of effort required for various levels of precision were calculated using the following equation:

$$N = \frac{(t^2)(S^2)}{[(a)(x)]^2}$$

where: N= sample size required

t= t-value obtained from a t-table at n-1 degrees of freedom for a desired significance level

s^2= variance

a= accuracy desired in describing the mean, and

x= mean CPUE.

Size structure

Lake sturgeon size structure was qualitatively assessed by inspection of length-frequency histograms. Histograms were constructed for lengths pooled by sex, as well as for males and females. However, small sample sizes limited the utility of the assessment of size structure by sex. Because most fish were measured for total length and fork length, I assessed the relationship between these two variables.

Weight-length relation and body condition

The total length (mm) and weight (kg) relationship was assessed for this population using logarithmic transformation (base 10) of both variables to linearize the relation (Lagler 1956). Fortin et al. (1996) provided a method by which to compare condition (i.e., plumpness) of lake sturgeon. They calculated mean weights of 1,000-mm (TL; sexes pooled) lake sturgeon from 32 lakes or river sectors across the distribution of the species in the United States and Canada. For comparison, I predicted mean weight of 1,000-mm lake sturgeon from Rainy Lake using the $\log_{10}$-transformed weight-length regression that I developed.

Age structure and mortality

Pectoral fin rays were allowed to dry for a minimum of 3 weeks prior to sectioning. Two sections were cut from each fin ray sample with each having a thickness of approximately 0.5 mm. Sections were cut using an Isomet model 11-1280-160 saw, and aged by viewing using an Olympus Model SZH1D 0.7-7.0 microscope.

Age structure analysis was conducted on pooled data for the three years, and thus was done by year class rather than age group. Catch curve analysis was used to analyze total annual mortality (Ricker 1975). The 1986 year class was selected as that first recruited to the sampling gear because all younger cohorts were less abundant, and the

1965 year class was the last year class for which a minimum of five lake sturgeon were sampled. To complete the catch curve, ages had to be assigned to each year class, so I simply assigned ages based on an assumption that 2004 was the year of capture (e.g., fish hatched in 1984 were assigned to age group 20).

Growth

Growth was first summarized as mean length at time of capture by age group. A weakness of this technique is that individual fish within a cohort may have been captured any time between May and October, and growth obviously could occur during that growing season. However, given the long lifespan of these fish and small sample size, this technique probably provides the best estimation of growth rate. Growth was calculated separately for pooled sexes, males, and females. However, the small sample sizes for fish that were sexed probably limits the reliability of those growth data.

To compare growth with other lake sturgeon populations, I used the method of Fortin et al. (1996), who compared growth rates among 32 lake sturgeon populations from the United States and Canada using the mean of mean total lengths at ages 23-27 (sexes pooled). The von Bertalanffy growth functions were also fit to the Rainy Lake lake sturgeon data set using the Fishery Analyses and Simulation Tools (FAST; Slipke and Maceina 2000).

Results and Discussion

Three hundred twenty-two lake sturgeon were captured (272) or recaptured (50) during the duration of this study. Of these, 217 (67.4%) were collected below the Squirrel Falls Dam (Table 3-1). Other frequent collection locations included Kettle Falls Dam (40; 12.4%), the Seine River (19; 5.9%), Canadian Channel (13; 4.0%), and Stokes Bay (10; 3.1%).

Precision of standardized gill-net samples

Eleven lake sturgeon were collected during random sampling conducted in 2003, with five of the 21 nets capturing fish (maximum = 5, minimum = 0) (Table 3-2). Mean CPUE was 0.524 with a variance (s^2) of 1.462 and a standard error of 0.264.

Based on the 2003 random gill-net sample, I estimated that 580 net nights would be required to estimate, within 20%, the mean catch per unit effort at the 95% confidence level. More realistically, 93 net nights would be required to estimate, within 50%, the mean catch per unit effort at the 95% confidence level. These results indicate that using a completely random sampling design would not be time or cost effective. An alternative would be to utilize a sampling design that would target areas of known lake sturgeon congregation (e.g., Kettle and Squirrel Falls during spawning season). If units of effort and locations were consistent from year to year, trends in lake sturgeon populations would become evident over time.

Size structure

Two hundred eighty-three lake sturgeon were collected over the three year period for which total length measurements were taken (Figure 3-1). These fish ranged from 83 to 166 cm, with most from 110 to 150 cm. The limited number of fish shorter than 110 cm is probably due to the 103-cm mesh being the smallest used for my sampling; smaller lake sturgeon would swim right through these nets. However, based on other studies (e.g., Fortin et al. 1993; Bruch 1999), I expected to collect more lake sturgeon from 165 to 185 cm. Most fish were collected in the 103-152 mm meshes; perhaps the 178 mesh would have collected more of the larger fish if it had been used to a greater extent. I actually captured longer lake sturgeon in the 152-mm mesh than the few caught in the 178-mm mesh (Figure 3-2).

Of the 283 lake sturgeon collected, 59 were sexed. The 17 females that I did identify ranged and averaged longer than the 42 males (Figure 3-3).

Based on 275 lake sturgeon for which both total length and fork length measurements were obtained, the two measures were highly correlated (Figure 3-4; $r = 0.988$, $P = 0.001$). Thus, when necessary, total length could be predicted when only fork length was recorded for a particular fish (or vice versa) using the equation:

$$TL = 48.26 + 1.06\ (FL),$$

where TL and FL are in mm. Fortin et al. (1996) also reported a slope of 1.06 for this relationship, but a Y-intercept of 35.97.

Weight-length relation and body condition

Total length (mm) and weight (kg) measurements for 271 lake sturgeon exhibited the expected curvilinear relation between weight and length (Figure 3-5). Logarithmic transformation ($\log_{10}$) linearized the relationship (Figure 3-6; r = 0.94, P = 0.0001).

Based on $\log_{10}(\text{Weight}) = -8.323 + 3.033(\log_{10}\text{TL})$, where weight is in kg and total length is in mm (r = 0.94, N = 271), the predicted weight of a 1,000-mm lake sturgeon from Rainy Lake would be 5,970 g (5.97 kg). Fortin et al. (1996) provided a summary of mean weights for 1,000-mm (TL; sexes pooled) lake sturgeon from 32 lakes or rivers sectors across the distribution of the species in the United States and Canada and only 11 of those 32 means were higher than the Rainy Lake mean weight of 5,970 g. The mean weight of 1,000-mm lake sturgeon in nearby (i.e., downstream from Rainy Lake) Lake of the Woods/Rainy River system was 6,119 g with only 9 of the 32 means ranking higher.

Age structure and mortality

Pectoral fin rays were removed from 259 lake sturgeon for aging purposes. Fish were assigned to year classes ranging from 1945 to 1995 (Figure 3-7). As mentioned previously for size structure, I captured few younger fish, likely because the 103-mm mesh was the smallest mesh size used in sampling efforts. The age structure for the Rainy Lake population was quite similar to that for Lake St. Clair (Thomas and Haas 2002), especially for the 1955 to 1985 year classes. These authors used a combination of set lines and trawls to capture lake sturgeon, and reported that setlines in the St. Clair

River captured significantly longer and older lake sturgeon than the otter trawl in Lake St. Clair. A limited commercial fishery remained for lake sturgeon in the Ontario waters of the St. Clair system through 2000. Thus, the commercial harvest allowed on the Canadian side of both Rainy Lake and the St. Clair system may explain the similarities in age structure.

Maximum age for my lake sturgeon population sample from Rainy Lake was 59. Fortin et al. (1993) reported lake sturgeon maximum ages of 25 years (131 cm) from Lac des Deux Montagnes, 97 years (187 cm) from Lac Saint-Louis, and 49 years (162 cm) from Lac Saint-Pierre, Quebec. Rusak and Mosindy (1997) reported a maximum age of 37 years for radio-tagged fish from the Lake of the Woods/Rainy River system.

Catch-curve analysis indicated that instantaneous total mortality (Z) was 0.0481 (Figure 3-8). Total annual mortality (A) for lake sturgeon from 1984 back to 1965 was calculated to be 4.7%, thus indicating annual survival (S) of 95.3%. Total annual mortality for lake sturgeon in the St. Mary's River system, Michigan was estimated at 4.6% for ages 5-55 (T. Sutton, Purdue University, personal communication).

Growth

Two hundred thirty-seven lake sturgeon were aged to provide a growth summary for the Rainy Lake population (Table 3-2). The Rainy Lake population mean of mean lengths for ages 23-27 was 1,289 mm (sexes pooled), which exceeded 26 of the 32 populations summarized by Fortin et al. (1996) from the United States and Canada. Too few data were available to assess growth rates by sex, as only eight females were aged and identified to sex, while 28 males were both aged and sexed. However, means for females exceeded the means for pooled sexes in all but one case, while means for males were similar to those for the pooled means (Table 3-2).

The von Bertalanffy model provided a reasonable fit to the lake sturgeon growth data (r^2 = 0.806)(Figure 3-9). Ultimate length ($L\infty$; also termed asymptotic size) was 1,403.8 mm, the Brody growth coefficient (K) was -0.11, and the hypothetical age at which the fish were 0 mm (t_0) was -0.56. In comparison, Mosindy (1987) reported $L\infty$ of 1,421 mm, K of –0.085, and a t_0 of -0.0306 for the Lake of the Woods/Rainy River system. Although I captured several lake sturgeon longer than $L\infty$, ultimate length is a mathematical calculation and such underestimates are common. I hope that these von Bertalanffy data may prove useful for comparisons by biologists in the future and in population models (e.g., modeling the effects of potential regulations using FAST [Slipke and Maceina 2000]).

Table 3-1. Sampling locations for 322 lake sturgeon captured from Rainy Lake, 2002-2004. Refer to Figure 2-2 for geographical locations of sampling sites.

Sampling location	Number	Percent
Squirrel Falls Dam	217	67.4%
Kettle Falls Dam	40	12.4%
Seine River	19	5.9%
Canadian Channel	13	4.0%
Stokes Bay	10	3.1%
Rat River Bay	6	1.9%
Hale Bay	5	1.6%
Brule Narrows	4	1.2%
Moose Bay	2	0.6%
American Channel	1	0.3%
Breezy Island	1	0.3%
Canoe Channel	1	0.3%
Island southeast of Rabbit Island	1	0.3%
Norway Island	1	0.3%
U.S. Marker 39	1	0.3%

Table 3-2. Sampling locations for 11 lake sturgeon captured from Rainy Lake during the 2003 random sampling exercise.

Sampling location	Number
Canoe Channel (Brule Narrows)	0
Brule Narrows	0
Breezy Island	1
Cormorant Bay	0
NE of Anchor Island	0
Stokes Bay	2
Mouth of American Channel	0
Moose Bay	2
Mouth of Rat River Bay	5
Norway Island	1
Saginaw Bay	0
Shelland Island	0
Finlander Island	0
East of Brule Narrows	0
North of Anchor Island	0
Sand Bay Island	0
Anchor Island	0
Browns Bay	0
Green Island	0
Minitaki Island	0
Black Point Island	0

Table 3-3. Mean total length (TL; mm) at time of capture by age group for lake sturgeon collected from Rainy Lake, 2002-2004.

	Sexes pooled			Male			Female		
Age	N	TL (mm)	SE	N	TL (mm)	SE	N	TL (mm)	SE
8	1	865							
9	1	838							
10	0								
11	1	925							
12	1	1090							
13	5	1148	29						
14	5	1181	29						
15	6	1165	38						
16	5	1287	24	1	1265				
17	7	1156	29	1	1223				
18	12	1245	25	3	1265	23			
19	12	1249	32	1	1382				
20	8	1233	26	2	1203	3			
21	12	1306	39	3	1239	82			
22	5	1347	43	0			2	1398	63
23	13	1304	33	1	1125		1	1280	
24	10	1250	31	1	1335		0		
25	10	1273	38	1	1272		0		
26	11	1322	31	1	1305		0		
27	13	1298	30	2	1201	43	1	1505	
28	7	1313	27	1	1281		0		
29	16	1286	27	1	1477		1	1444	
30	6	1334	40	0			1	1425	
31	10	1291	39	0			0		
32	12	1329	38	4	1249	32	0		
33	7	1402	38	2	1304	25	0		
34	3	1281	64	1	1202		0		
35	7	1442	50	2	1394	16			
36	2	1285	87	0			0		
37	2	1302	40	0			0		
38	5	1351	53	0			0		

Table 3-3. Continued.

	Sexes pooled			Male			Female		
Age	N	TL (mm)	SE	N	TL (mm)	SE	N	TL (mm)	SE
39	5	1406	31	0			0		
40	1	1433		0			0		
41	2	1400	17	0			0		
42	2	1349	33	0			0		
43	2	1312	88	0			0		
44	2	1536	39	0			0		
45	0								
46	0								
47	3	1534	68	0			2	1598	
48	0								
49	0								
50	2	1399	42	0			0		
51	0								
52	0								
53	0								
54	0								
55	1	1506		0			0		
56	0								
57	1	1396		0			0		
58	0								
59	1	1403		0			0		

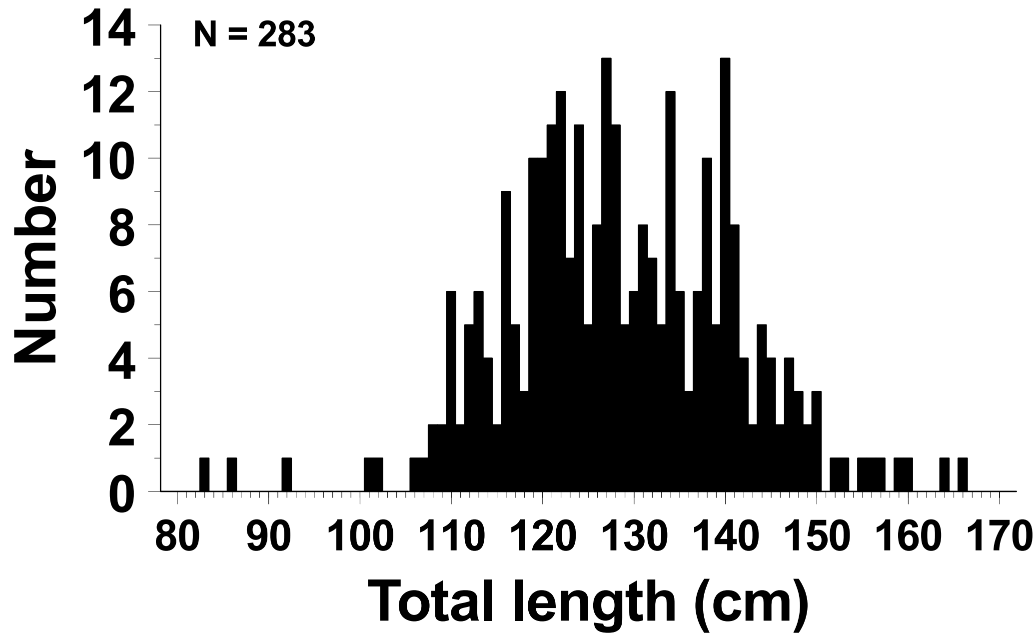


Figure 3-1. Length frequency for lake sturgeon collected with gill nets from Rainy Lake, 2002-2004.

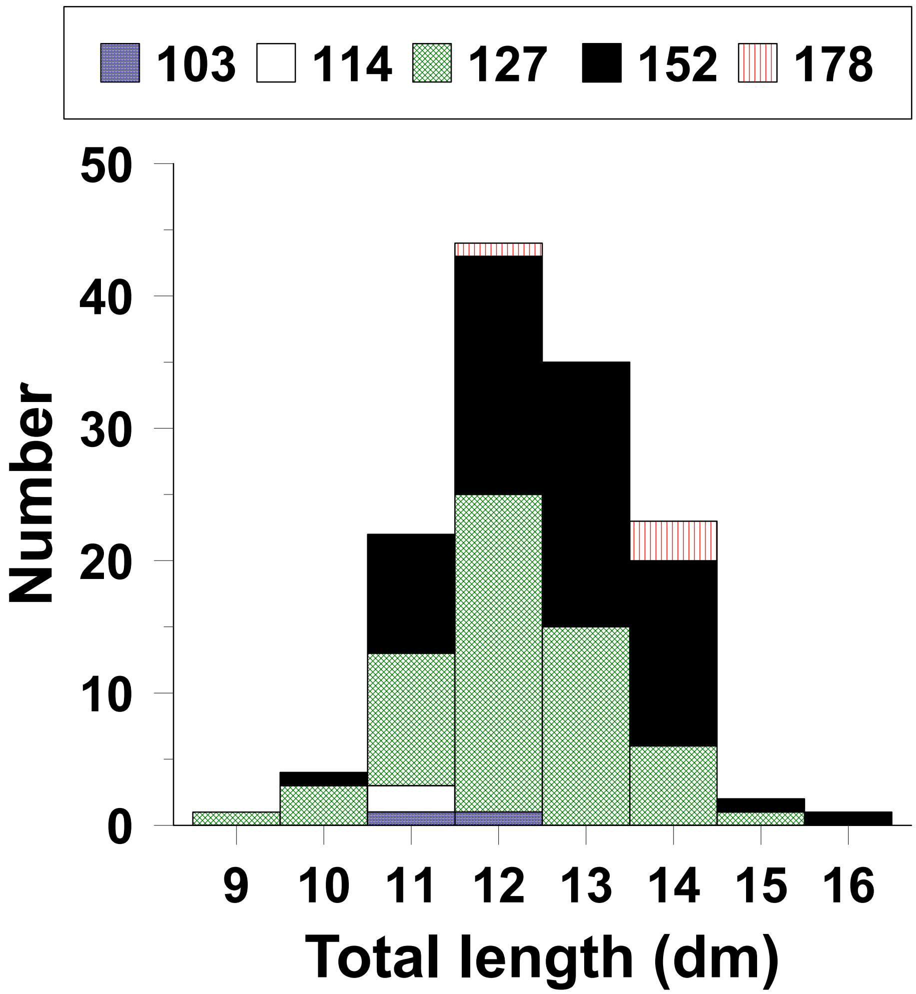


Figure 3-2. Total lengths of lake sturgeon captured from Rainy Lake by gill-net mesh size, 2002-2004. Mesh sizes are bar measure (mm).

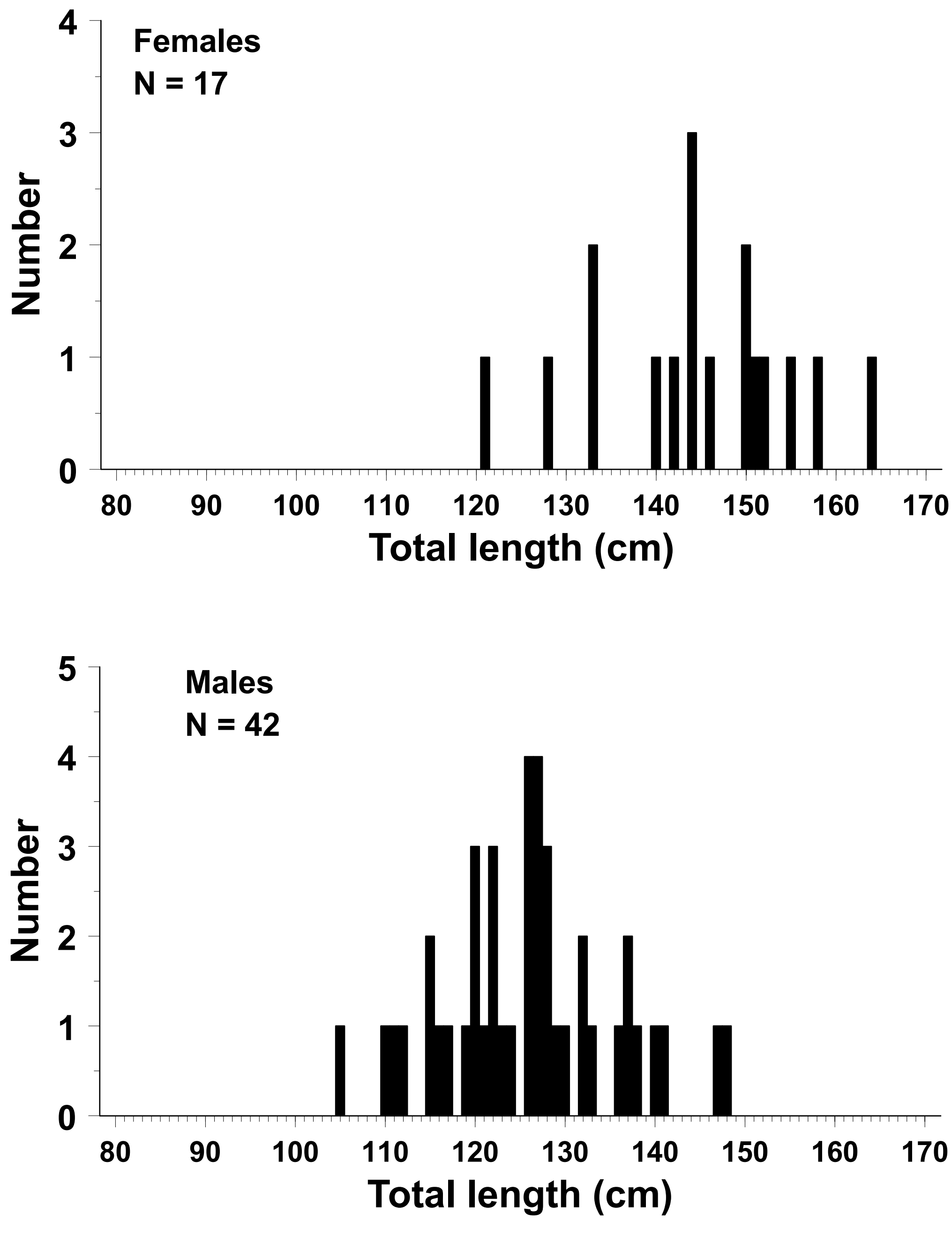


Figure 3-3. Length frequency for female (top) and male (bottom) lake sturgeon collected from Rainy Lake, 2002-2004.

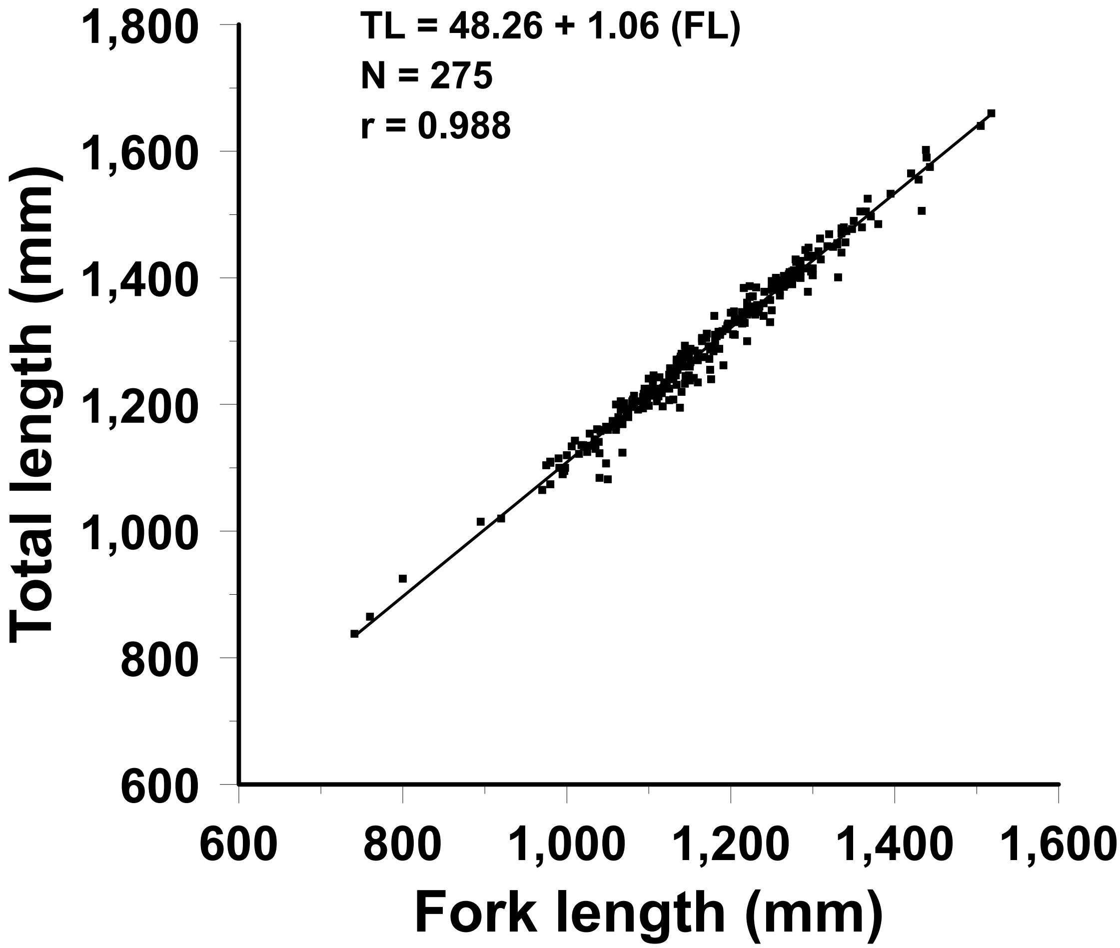


Figure 3-4. Relation between total length and fork length for 275 lake sturgeon collected from Rainy Lake, 2002-2004.

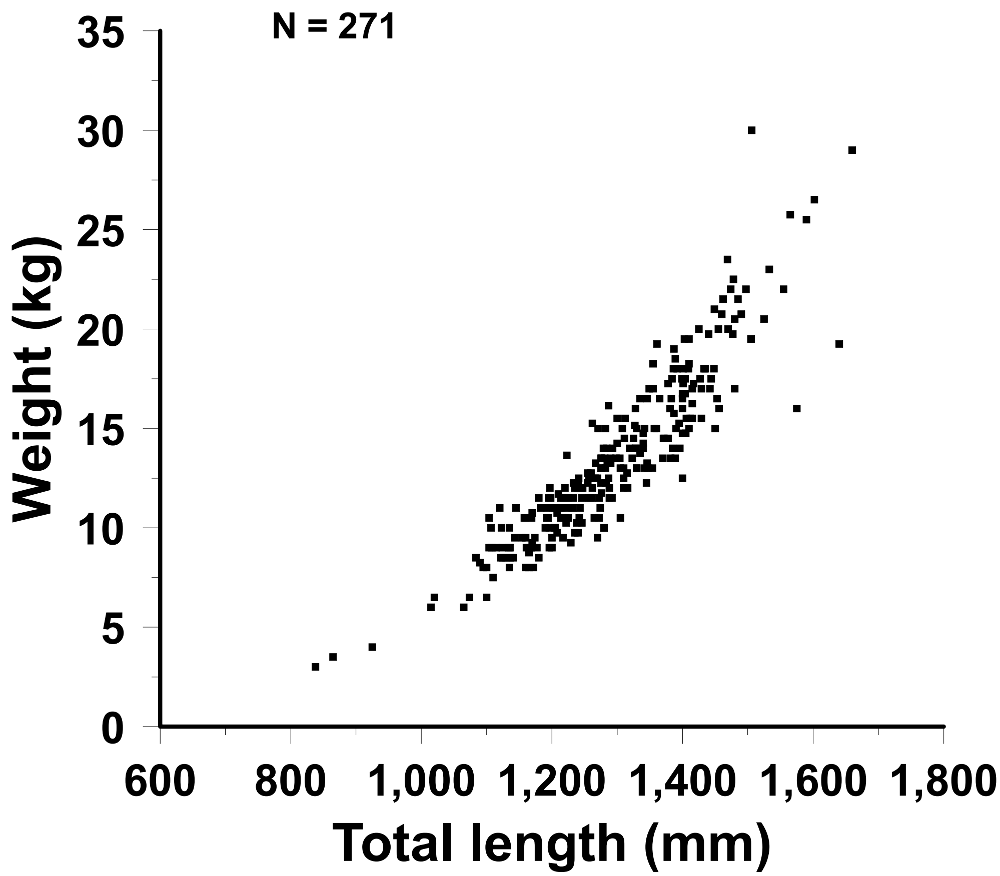


Figure 3-5. Relationship between weight and total length for 271 lake sturgeon collected from Rainy Lake, 2002-2004.

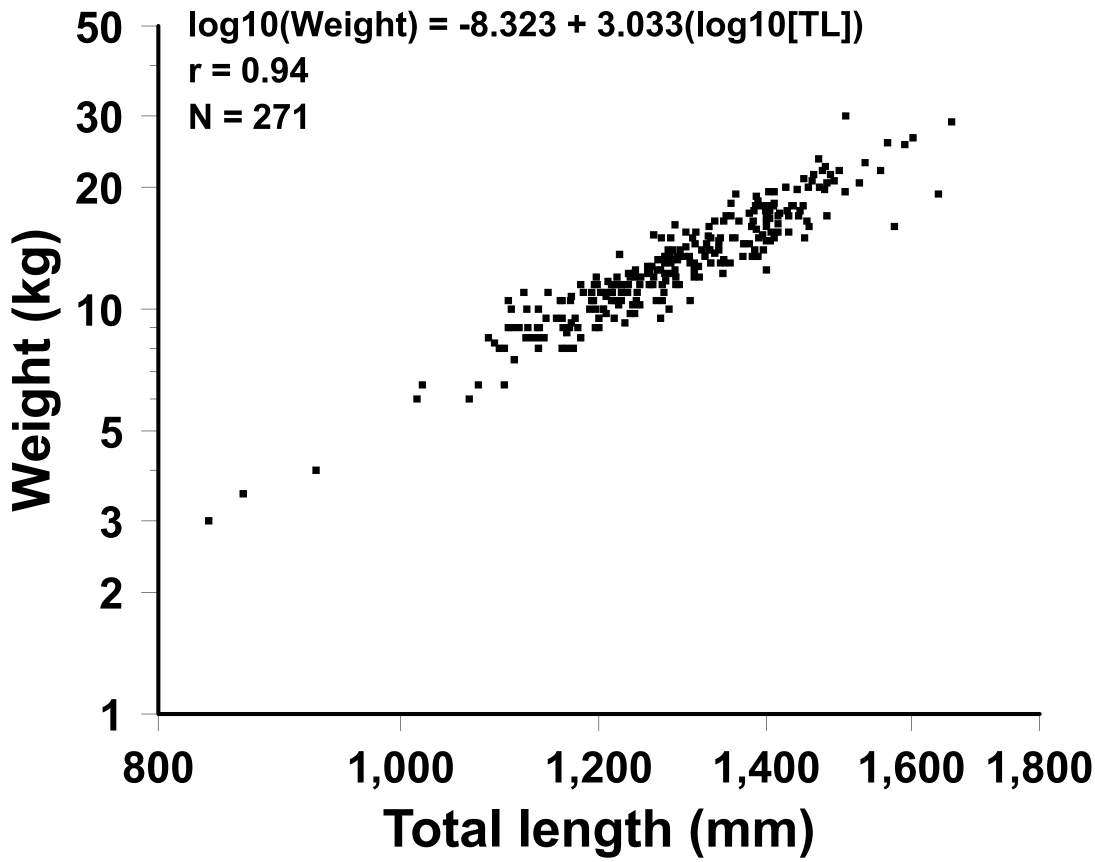


Figure 3-6. Logarithmic (base 10) relationship between weight and total length (TL) for 271 lake sturgeon collected from Rainy Lake, 2002-2004.

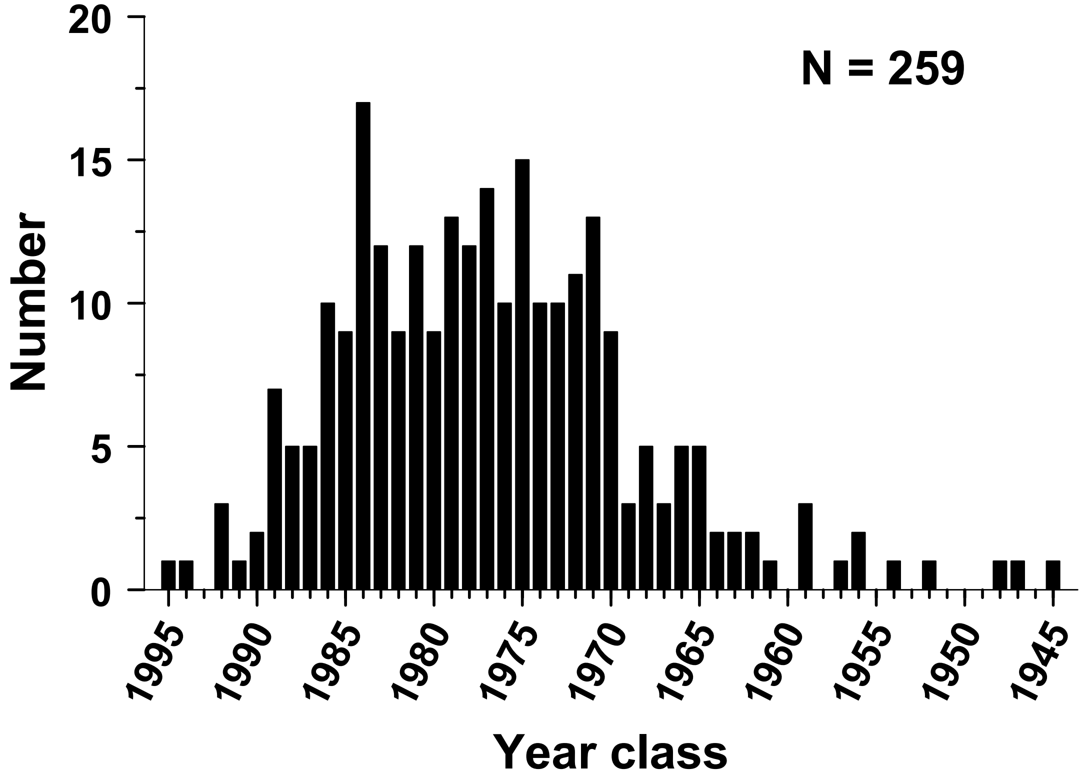


Figure 3-7. Age structure for 259 lake sturgeon collected from Rainy Lake, 2002-2004.

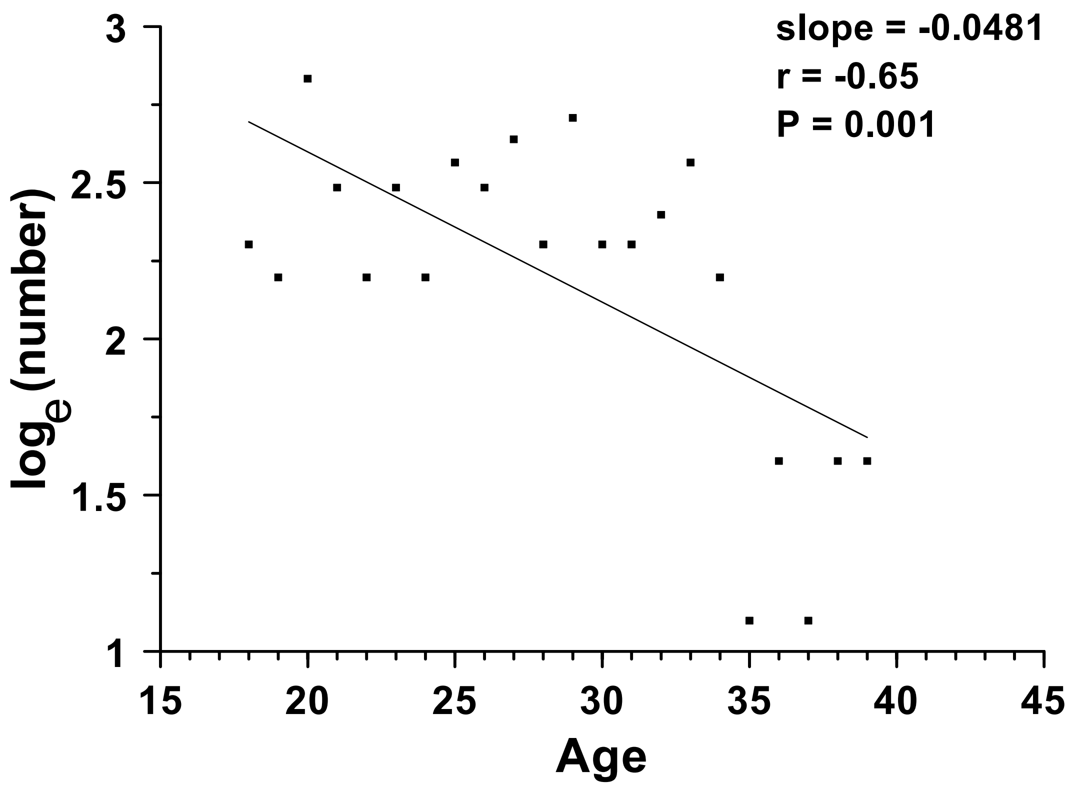


Figure 3-8. Catch curve for lake sturgeon from the 1986 (age group 18) to 1965 (assigned age group 39) year classes in Rainy Lake.

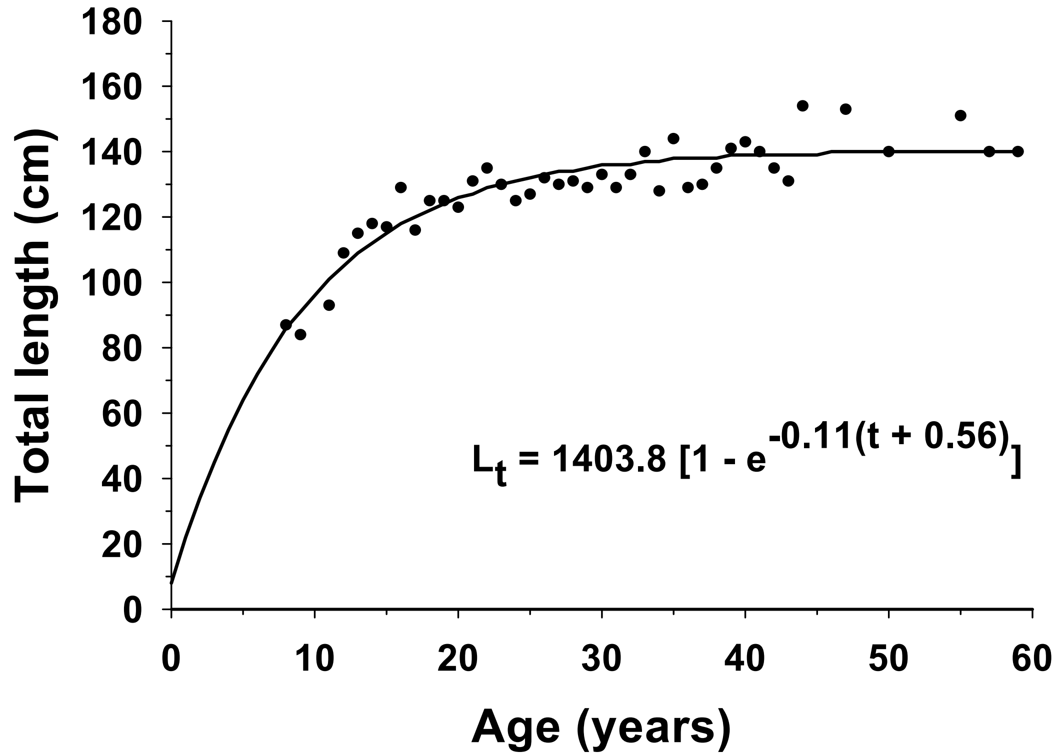


Figure 3-9. The von Bertalanffy growth function for lake sturgeon collected from Rainy Lake, 2002-2004. Sample sizes and SE for each mean can be found in Table 3-1.

Chapter 4. Spawning locations and movements of lake sturgeon in Rainy Lake

Introduction

Movement patterns of lake sturgeon were relatively unstudied through the early 1970's (Scott and Crossman 1973). However, in the past decade, lake sturgeon movements have been studied at an increasing rate and throughout much of the species range (Rusak and Mosindy 1997; McKinley et al. 1998; Auer 1999; Borkholder et al. 2002; Knights et al. 2002).

Auer (1999) found that lake sturgeon left the spawning grounds in the Sturgeon River, Michigan, and dispersed 70-280 km throughout southern Lake Superior with males and females utilizing different locations. Lake sturgeon in the upper Mississippi River system moved throughout a large geographic area, but extensively utilized two core areas with only one fish located in both core areas (Knights et al. 2002). Lake sturgeon began their upstream (spawning) migration as early as January in the Mattaggami River in northern Ontario, with the pattern continuing through May and fish dispersing downstream as water temperatures approached 13º C (Mckinley et al. 1998). Two distinct populations of lake sturgeon were found in the Lake of the Woods/Rainy River system, with "lake" fish overwintering in Lake of the Woods and making spawning migrations into the Rainy River while "river" fish remained in the Rainy River throughout the entire year (Rusak and Mosindy 1997).

The objective of this chapter was to determine spawning locations and generalized lake sturgeon movement patterns through the use of biotelemetry. Movement data obtained from tagged lake sturgeon were analyzed using a geographic information system (GIS) and used to identify seasonal movement patterns, spawning migrations, and spawning locations.

Methods

Lake sturgeon tagging

Biotelemetry was utilized in the identification and characterization of lake sturgeon spawning locations along with spawning movements and seasonal movement patterns in Rainy Lake. Areas of known lake sturgeon utilization were test netted in the spring of 2002 to locate areas within Rainy Lake where it was feasible to capture an adequate number of fish for the study. Lake sturgeon were captured in October of 2002 and May, June, and October of 2003 at the mouths of tributaries reportedly used for spawning. Large mesh multifilament gill nets with mesh sizes of 103, 114, 127, 152, and 178 mm (bar measure) were used to capture fish. Net lengths varied from 30 to 91 m, with all nets having a height of 1.83 m.

A 350-L fish holding tank was filled with clean lake water (300 L) and 1.5 kg of NaCl was dissolved in the water. Lake sturgeon were held in a cradle and water was continually flushed over the gills of the fish during surgery. Lake sturgeon were not anesthetized. A 2% chlorohexidine diacetate disinfectant/distilled water solution was prepared for sterilization purposes with the instruments involved in the procedure as well as the particular tag designated for implantation being bathed in the solution for approximately 15 min and subsequently rinsed with sterile saline solution prior to implantation.

Lotek Wireless combined acoustic/radio transmitters were surgically implanted into 41 lake sturgeon. Thus, only a single tag was implanted and used for both radio and acoustic tracking, with the radio portion of the tag allowing tracking of fish in shallow or turbulent habitats, while the ultrasonic portion of the tag was needed for tracking of lake sturgeon in deeper habitats (Winter 1996). Water depths in Rainy Lake commonly reach 30-40 m. Lotek CART 16-2 series tags were implanted in 33 lake sturgeon with the remaining eight fish receiving CART 16-1 series tags. Lotek CART 16-2 tags were 16 mm x 85 mm with a weight in air of 36 g, while Lotek CART 16-1 tags were 16 mm x 60 mm with a weight in air of 25.3 g.

Implanted CART tags did not exceed 2% of the total body weight of any given fish (Gallep and Magnuson 1972; McCleave and Stred 1975; Stasko and Pincock 1977; Moser et al. 1990;), although a recent study has suggested that implanted tags may be as much as 6-12% of the body weight of a fish without affecting swimming performance (Brown et al. 1999). Lake sturgeon implanted with CART tags had a mean fork length of 1217.4 mm (range 951-1505 mm), girth of 502.4 mm (range 372-639 mm), mass of 15.35 kg (range 7.5-30 kg), and age of 25.9 (range 15-55) (Table 4-1).

Along with radio/acoustic tags, eight lake sturgeon were also implanted with Lotek model LTD_1110 archival tags to help document depth (absolute pressure) and temperature data (Ishida et al. 2001). Tags were surgically placed in the body cavity through the same incision used for the radio/acoustic tags. To download data from archival tags, fish had to be recaptured with tags being surgically removed.

Surgical implantation procedures followed guidelines set by Hart and Summerfelt (1975). A 5 to 8-cm incision was made on the ventral fish surface approximately 3 cm off the midline and approximately 3 cm from the anterior end of the pelvic girdle. A 0.5-cm exit hole for the whip antenna was started with a scalpel on the midline approximately 3 cm posterior to the incision. A curved, 12-gauge catheter needle was passed through the hole and out through the incision with care taken to not penetrate or cut the viscera in any manner. The whip antenna projecting from the CART tag was then threaded though the end of the catheter needle that was protruding through the incision with the antenna being passed out of the peritoneal cavity through the antenna hole. The CART tag was next inserted into the peritoneal cavity with minimal pressure exerted on the internal organs. Along with the CART tags, eight of the fish also had archival tags implanted in the peritoneal cavity. A 20 to 25-cm segment of 22.7-kg monofilament fishing line was attached with epoxy to each archival tag to facilitate removal from the body cavity upon recapture. Implantation of these tags followed the same procedure as the CART tags with the same incision and antenna hole being utilized. The peritoneum was then closed with a continuous subcutical suture technique followed by five to eight simple interrupted sutures to close the incised skin. Ethicon PDS II monofilament (Polydioxanone) absorbable suture material was used for the closure of the peritoneum. Ethicon Ethilon monofilament nylon non-absorbable suture material was used for the closure of the incised skin. Fish were placed in a holding pen following implantation, if necessary. When full equilibrium was regained, fish were placed in the water at the site of capture and monitored until they vacated the area.

Lake sturgeon tracking

The receiver unit for the radio and acoustic tracking was a Lotek 4 MHz SRX_400 Receiver/Data logger. A boat/plane mounted H-antenna was used for radio tracking while an LHP_1 hydrophone with a DAB_45 45˚ Directional Adaptor was used for acoustic tracking. A Lotek UUCN-164 ultrasonic upconverter was used to allow the hydrophone to function with the SRX_400 Receiver/Data logger.

Radio and acoustic tracking equipment were tested during 2003 to establish signal ranges. A CART tag was lowered 2 to 20 m below a buoy by 2-m intervals. For the radio portion of the tag, the boat to be used for tracking throughout the two sampling seasons was then driven toward the tag until the signal was heard. For the acoustic portion of the tag, the boat was stopped at regular intervals and the acoustic hydrophone was lowered until the maximum detectable distance was determined.

Tracking of lake sturgeon took place at least once a week from the Voyageurs National Park airplane throughout the spring spawning season and summer months. Transects were flown covering the eastern half of the South Arm, with every flight including a 40-km stretch of the Seine River that flows into Rainy Lake (Figure 4-1). Transects were chosen to maximize area covered with the least amount of flight time. The remaining portion of the South Arm was flown at least once every two flights, time and weather permitting. The North Arm of Rainy Lake was flown once in the summer of 2003 in an attempt to locate a fish that could not be located in the South Arm.

Radio tracking took place by boat on average two to three times per week depending upon weather conditions. Tracking was also dependent on time availability, with partial and full days devoted to boat tracking when possible. Tracking often coincided with other activities such as netting or setting of egg samplers. The Squirrel Falls/Kettle Falls location was sampled by boat during May and June due to extensive use by tagged lake sturgeon, which made recognition of individual signals difficult from the airplane. Distributional patterns of lake sturgeon were summarized by month during the spawning period (May and June) and by two-month periods throughout the rest of the summer (July/August and September/October). Movement rates were calculated as the linear distance between successive fixes divided by the number of elapsed days. Home ranges were determined by drawing convex polygons with Arcview by connecting peripheral locations.

Egg sampling

Lake sturgeon eggs were sampled during 2004 in an attempt to confirm spawning locations. Egg collectors were set weekly from June 7 through July 1 in areas of high lake sturgeon use. Collectors consisted of an 18-m mainline of vinyl-coated wire cable (4.8 x 6.4 mm) with cement blocks (203 x 406 x 102 mm) attached at 3-m intervals and wrapped in furnace filter material. Floats were attached to each end of the mainline and egg collectors were set in shallow water areas of 0.3 to 4.6-m depth. Egg collectors were checked once weekly during the entire time period in which they were deployed. A sample of all egg types present on the collectors was removed and transported back to laboratory facilities to be hatched and the fry subsequently identified.

Results and Discussion

Forty-one lake sturgeon were located 587 times throughout the study, with fish being tracked through September 2004 (Figure 4-2). In 2003 lake sturgeon were located 285 times (Figure 4-3) and in 2004 lake sturgeon were located 302 times (Figure 4-4). Individual lake sturgeon were re-located between 0 and 36 times (Table 4-2).

Lake sturgeon tagging and subsequent survival

Forty-one lake sturgeon were implanted with CART tags. No mortalities were positively identified. However, fish 99, implanted in October of 2003, was not located during the remainder of the study. Fish 30 was not located for 12 months after it was tagged and released, but then was subsequently located 11 times throughout the remainder of the study indicating that fish 99 may not necessarily be a mortality. Fish 106 was found at the same location, adjacent to the Seine River First Nations village on the Seine River, weekly for 11 weeks. I then learned that a gill net used in the Seine River First Nations subsistence fishery had been left on the bottom of the Seine River due to entanglement with the substrate. Fish 106 may have been captured in the gill net and subsequently perished. All other fish were located at least once throughout the study.

Of the eight fish implanted with archival tags, one (fish 30) was recaptured during the study. Surgery was performed and the archival tag was removed. Subsequent locations of the radio tag indicated survival. As previously indicated, fish 30 was not located during the time period in which the archival tag was recording data. The battery for this archival tag stopped functioning after approximately 4 months. I thus was able to obtain mean daily depth for the functioning period from late May through early September (Figure 4-5). While this is just one fish, there was no use of deep-water (>20 m) during mid- to late summer.

Lake sturgeon tracking

Acoustic equipment was tested during the spring of 2003. Tags were lowered at 2-m intervals between 2 and 20 m. The highest maximum detectable distance from the boat was 0.95 km when the CART tag was lowered to 6 m. The lowest maximum detectable distance of 0.53 km occurred at a tag depth of 18 m. The mean maximum detectable distance was 0.65 km with a standard error of 0.04. Limitations in the performance of the acoustic portion of the tag led to the discontinuation of acoustic telemetry from the study beginning during the summer of 2003. No fish locations were recorded with the acoustic equipment despite attempts on 10 dates between May 15 and June 15, 2003. The complexity of the bottom contours of Rainy Lake may have been the most likely reason for the lack of reception of the directional acoustic signal.

Radio telemetry equipment was also tested. The highest maximum detectable distance from the boat was 0.47 km when the CART tag was lowered to 2 m. The lowest maximum detectable distance of 0.017 km occurred at a tag depth of 20 m. The mean maximum detectable distance was 0.21 km with a standard deviation of 0.17. The maximum detectable distance by airplane with the tag lowered to 8.77 m was 0.55 km with a standard error of 38.5.

Lake sturgeon utilized Squirrel Falls/Kettle Falls and adjacent areas (Canadian Channel, Hale Bay) extensively throughout the study (37% of total locations, including both spawning and non-spawning seasons, Figure 4-2). The Squirrel Falls Dam is one of the areas thought to be a spawning site for lake sturgeon in Rainy Lake (L. Kallemeyn, U.S. Geological Survey, personal communication). The number of lake sturgeon locations at Squirrel Falls Dam increased from 12 in 2003 to 56 in 2004. The more extensive use may have been due to an extended spawning season with mean daily air temperatures lower during 2004 than 2003 (Figure 4-6). Other sites with spawning habitat characteristics listed by Scott and Crossman (1978) (i.e., 0.61 - 4.6 m depth, swift current, below falls) for lake sturgeon include the Kettle Falls Dam, Pipestone River, Rat River, and the Seine River (Crilly Dam and Highway 11 Bridge). Lake sturgeon were located at all of these sites throughout the study including during the spawning season. However, lake sturgeon were not tracked on the Seine River during May due to malfunctions of airplane tracking equipment.

The majority of May locations (89%) for both 2003 (85%) and 2004 (90%) were associated with the current area directly below Kettle Falls, Squirrel Falls, and in the Canadian Channel (Figure 4-7). Of the other six locations not in these areas, four were associated with the Brule Narrows, also an area with consistent current.

A much lower percentage of locations in June were associated with the Kettle Falls/Squirrel Falls/Canadian Channel area (37%; Figure 4-8). Lake sturgeon were apparently leaving the spawning areas (Kettle Falls, Squirrel Falls) and dispersing throughout the lake. During this month, lake sturgeon locations in the Seine River were spread throughout Seine Bay and 36 km upriver. Mcleod (1999) stated that aggregations of spawning lake sturgeon have been observed in the tailwater area below the Crilly Dam on the Seine River. During my study, no lake sturgeon were located in the area of the Crilly Dam. The increased number of locations from 2003 to 2004 was due to the increased number of CART tagged lake sturgeon. Only four fish from the Seine River were tagged for 2003 tracking, while six additional fish were tagged for 2004 tracking.

Spawning migrations of lake sturgeon are often over 129 km and can exceed 402 km, beginning when ice cover is still present or shortly after ice-out (Vladykov 1955). In Rainy Lake, movement toward spawning areas likely begins in April, with lake sturgeon beginning post-spawn dispersal throughout the lake sometime during late June.

During the July/August period, the majority of lake sturgeon were found from the Brule Narrows eastward and in the Seine Bay/Seine River system, with only five locations found west of the Brule Narrows (Figure 4-9). Lake sturgeon were still located in the Kettle Falls/Squirrel Falls area during both years (15 locations and 35 locations, respectively). Locations in the main body of the South Arm were associated with the north shore more than the south shore during this time period (96% in 2003 and 84% in 2004). There are habitat differences between the two areas with the south shore consisting of a sharp drop-off into depths of over 30 m. Conversely, the north shore consists of rock reefs and depths shallower than 15 m. Either the fish were less likely to use the deeper water, or the lack of locations was due to limitations of the telemetry equipment with radio signals detected from depths no greater than 18 m. Further research will be needed to determine the use of deep-water habitats by lake sturgeon in Rainy Lake.

September locations were obtained during both 2003 and 2004 with October locations obtained only in 2003. Locations during this time period were distributed throughout the South Arm (Figure 4-10). Locations in the Seine River were few, with zero in 2003 and two in 2004. Fish 75 was tagged in the Seine River but located in the South Arm during this time period. Lake sturgeon were located on the south shore of the South Arm for the first time in September. One potential explanation is that lake sturgeon were staging at locations in the vicinity of winter habitats. Rusak and Mosindy (1997) found that lake sturgeon in the Lake of the Woods/Rainy River system demonstrated consistent preferences for specific areas in the main basin of Lake of the Woods during the winter. These areas were adjacent to the mouth of the Rainy River where the lake sturgeon would later spawn in the spring. Had my tracking continued through November, lake sturgeon in Rainy Lake may have continued to move toward the south shore on the east end of the South Arm.

Mean movement rates of lake sturgeon were calculated by month (Figure 4-11) for descriptive purposes. Movement rates increased from May to June during 2003 and 2004, with a maximum movement rate of 0.80 km/day in June of 2004 and a minimum movement rate of 0.17 km/day in May of 2003. Movement rates for lake sturgeon in the upper Mississippi River system were greatest during the spring with a mean movement rate of approximately 0.50 km/day (Knights et al. 2002). Lake sturgeon in Rainy Lake may have been dispersing into the lake away from spawning sites during the post-spawn period in June. Movement rates were dissimilar for the same months between years. Thus, further research will be needed to fully explore seasonal patterns in movement rates.

Movement west of the Brule Narrows was minimal with only a total of six locations. The most westerly location was fish 56, which was found at the mouth of Jackfish Bay (Figure 4-12). This fish also exhibited the largest one-time movement between successive fixes (52.36 km; 6/23/04 to 7/21/04). The last known location of this lake sturgeon was within 8 km of the North Arm of Rainy Lake and the riverine portion of the lake just above the outflow dam. An attempt was made in 2003 to capture lake sturgeon and implant tags in the area above the outflow dam, but no fish were captured at this location.

Movement of fish between the Seine River and the main body of the South Arm did occur but was minimal throughout the study. Locations in the Seine River were few with zero in 2003 and two in 2004. Rusak and Mosindy (1997) found that in the Lake of the Woods/Rainy River system, there was a separation in the population based primarily on winter habitat use. “River” fish spawned in the Rainy River and remained there throughout the winter months. “Lake” fish spawned in the Rainy River but moved into the main basin of Lake of the Woods during the winter months. If a similar dichotomy exists in the Rainy Lake/Seine River population, there may be greater movement of lake sturgeon between these two areas during the time period in which I did not attempt to locate fish (i.e., fall and winter). McKinley et al. (1998) found that upstream movement of lake sturgeon to spawning grounds began in January on the Mattagami River system in

Ontario and continued through May. Thus, lake sturgeon may move from Rainy Lake into the Seine River during this time period.

Movement patterns varied for individual lake sturgeon in Rainy Lake. Some fish did not exhibit discernable movement patterns. This lack of pattern was exhibited by fish 21 (Figure 4-13), which was located throughout the east end of the South Arm from Stokes Bay to the Brule Narrows and also in Seine Bay and at the mouth of Seine Bay. The pattern varied somewhat between years with the 2003 locations beginning in the east and moving west with the last location east of the Brule Narrows. The first locations in 2004 were in the Seine Bay/Seine River area with the remainder of locations further east. One factor contributing to the differential patterns between years may be the spawning interval exhibited by lake sturgeon.

Other lake sturgeon were found in distinct locations, such as fish 15 (Figure 4-14) that was tagged at the Squirrel Falls Dam during 2003 and was next located in the Brule Narrows area. Subsequent locations were in the area of the Brule Narrows until August 26, 2003. The next locations were in the Squirrel Falls Dam area beginning on September 28, 2003. The fish was then located in the Squirrel Falls Dam area on May 18, 2004 and was not located in the Brule Narrows area until June 30, 2004.

Telemetry data from Rainy Lake suggest that some lake sturgeon remained in the same area for extended periods. Home ranges for lake sturgeon in Rainy Lake varied, with a maximum home range size of 14,844 ha, a minimum size (excluding fish 106, possible mortality) of 84 ha, and a mean home range size of 4,625 ha (Table 2). Lyons and Kempinger (1992) reported that most lake sturgeon in the Lake Winnebago system had consistent movement patterns, while others demonstrated variable movement patterns. They also found that lake sturgeon in Lake Winnebago did not remain in any particular location for long periods of time.

Egg sampling

Egg samplers were placed below the Squirrel Falls Dam, in the Canadian Channel, and below the falls in the Pipestone River. Fish eggs were collected at all three sites. Walleye *Sander vitreus*, white sucker *Catostomus commersonii*, mooneye *Hiodon tergisus*, and lake sturgeon eggs were collected. The majority of eggs collected were from white sucker with low numbers of walleye and mooneye eggs collected. Lake sturgeon spawning was confirmed at the Squirrel Falls Dam between June 14 and June 17 of 2004. All sampled lake sturgeon eggs came from the same sampling block that was saturated with eggs. A subsample was removed from that sampling block and subsequently brought back to the laboratory, hatched, and the fry identified as lake sturgeon. Lake sturgeon eggs appeared to be light brown to yellow in color and approximately 2-3 mm in diameter.

Table 4-1. Fish description, transmitter code, and capture location at time of tagging for lake sturgeon implanted with Lotek CART transmitters in Rainy Lake, 2002-2004.

Code #	Tagging date	Total length (mm)	Fork length (mm)	Girth (mm)	Weight (kg)	Sex[a]	Age	Tagging location
1	10/2/02	NA	1100	444	11.5	FI	22	Canadian Channel
2	5/21/03	1506	1433	635	30	F	55	Brule Narrows
3	10/9/02	NA	1210	556	19	FM	26	Stokes Bay
4	10/9/02	NA	1275	615	22.5	FM	27	Canadian Channel
5	10/9/02	NA	994	372	8	MM	15	Stokes Bay
6	10/9/02	NA	1050	425	9.5	Unk	19	Stokes Bay
7	10/9/02	NA	951	395	7.5	MM	17	Squirrel Falls
8	10/8/02	NA	1212	485	16	Unk	28	Squirrel Falls
9	10/8/02	NA	1313	582	20.5	FM	32	Canadian Channel
10	10/8/02	NA	1386	614	23.5	FM	28	Canadian Channel
11	10/8/02	NA	1447	639	30	FM	31	Stokes Bay
12	10/8/02	NA	1388	585	22.5	FM	26	Kettle Falls
13	10/8/02	NA	1200	445	13.5	Unk	18	Squirrel Falls
14	10/8/02	NA	1125	407	11.5	Unk	19	Squirrel Falls
15	5/28/03	1372	1260	495	14.5	Unk	21	Kettle Falls
16	5/20/03	1400	1270	503	16.5	Unk	NA	Brule Narrows
17	5/28/03	1404	1300	520	16.75	MM	21	Kettle Falls
18	5/28/03	1410	1285	475	15	MM	35	Kettle Falls
19	6/18/03	1270	1140	410	9.5	M	32	Kettle Falls
20	5/28/03	1200	1060	415	9	MM	20	Kettle Falls
21	6/18/03	1425	1280	570	20	FM	30	Squirrel Falls
22	5/28/03	1505	1365	545	1935	FM	27	Kettle Falls
23	6/18/03	1120	1000	460	11	Unk	21	Kettle Falls
24	5/21/03	1460	1315	578	20.75	FM	22	Brule Narrows
25	5/20/03	1379	1260	525	18	Unk	26	Brule Narrows
27	5/23/03	1640	1505	585	19.25	FM	47	Seine River
30	5/29/03	1444	1291	595	17.5	F	29	Squirrel Falls
39	5/23/03	1555	1429	580	22	FM	47	Stokes Bay
43	5/29/03	1335	1205	520	16.5	FI	22	Stokes Bay
51	5/29/03	1180	1063	405	8.5	Unk	19	Seine River
56	5/23/03	1575	1443	589	16	Unk	44	Seine River
63	5/23/03	1135	1025	435	8	Unk	18	Seine River
69	5/28/03	1280	1140	410	10	F	23	Rat River Bay Mouth
75	10/8/03	1449	1325	568	21	F	NA	Seine River
82	10/7/03	1400	1275	486	12.5	Unk	31	Brule Narrows
87	10/8/03	1095	997	431	8	Unk	18	Seine River
93	10/8/03	1265	1134	442	10.5	M	16	Seine River
99	10/8/03	1217	1094	450	9.5	Unk	16	Brule Narrows
106	10/8/03	1288	1186	461	12	M	18	Seine River
111	10/8/03	1272	1138	467	11.5	M	25	Seine River
119	10/8/03	1160	1045	480	10.5	Unk	19	Seine River

NA=not available
a F=female, maturity unknown; FM=female, mature; FI= female, immature;
M=male, maturity unknown; MM=male, mature; Unk=sex unknown

Table 4-2. Home ranges and mean movement rates (SD) separated by year for lake sturgeon in Rainy Lake.

Fish number	Total locations	Home range (ha)	Mean movement rate 2003 (km/d)	Mean movement rate 2004 (km/d)
1	25	2,164	0.320 (0.22)	0.265 (0.31)
2	12	7,758	0.170 (0.14)	0.564 (0.26)
3	17	2,985	0.267 (0.20)	0.372 (0.33)
4	7	14,844	0.619 (0.50)	.
5	13	3,779	0.285 (0.33)	0.510 (0.36)
6	15	5,416	0.448 (0.70)	0.663 (0.72)
7	23	3,558	0.289 (0.28)	1.065 (0.74)
8	20	7,277	0.076 (0.05)	0.554 (1.11)
9	11	8,600	0.156 (0.20)	.
10	29	11,894	0.808 (0.67)	0.977 (1.29)
11	17	10,501	0.309 (0.23)	0.382 (0.23)
12	12	578	0.233 (0.25)	0.261 (0.43)
13	31	4,404	0.420 (0.54)	0.120 (0.23)
14	12	3,806	1.121 (1.00)	0.195 (0.21)
15	34	7,141	0.352 (0.42)	0.714 (0.92)
16	19	2,434	0.324(0.25)	.
17	29	10,245	0.565 (0.53)	0.552 (0.41)
18	28	3,517	0.279 (0.28)	0.513 (0.46)
19	14	6,434	0.396 (0.39)	1.091 (1.74)
20	34	1,859	0.299 (0.51)	0.870 (1.30)
21	15	10,017	0.316 (0.11)	0.817 (0.61)
22	26	8,492	0.459 (0.36)	0.511 (0.38)
23	19	4,095	0.684 (0.80)	0.187 (0.20)
24	19	9,411	0.587 (0.94)	0.236 (0.31)
25	7	7,677	.	1.713 (1.56)
27	10	1,921	0.324 (0.19)	0.200 (0.20)
30	10	1,196	.	0.527(0.66)
51	18	1,049	0.131 (0.06)	0.262 (0.38)
56	6	1,499	.	0.651 (0.81)
69	10	2,448	0.267 (0.36)	0.960 (1.26)
75	14	159	.	1.160 (2.77)
82	6	641	.	0.213 (0.26)
87	5	433	.	0.397 (0.15)
93	8	2,355	.	0.995 (0.97)
106	14	71	.	0.099 (0.04)
111	3	84	.	1.114 (0.35)
119	6	380	.	0.583 (0.90)

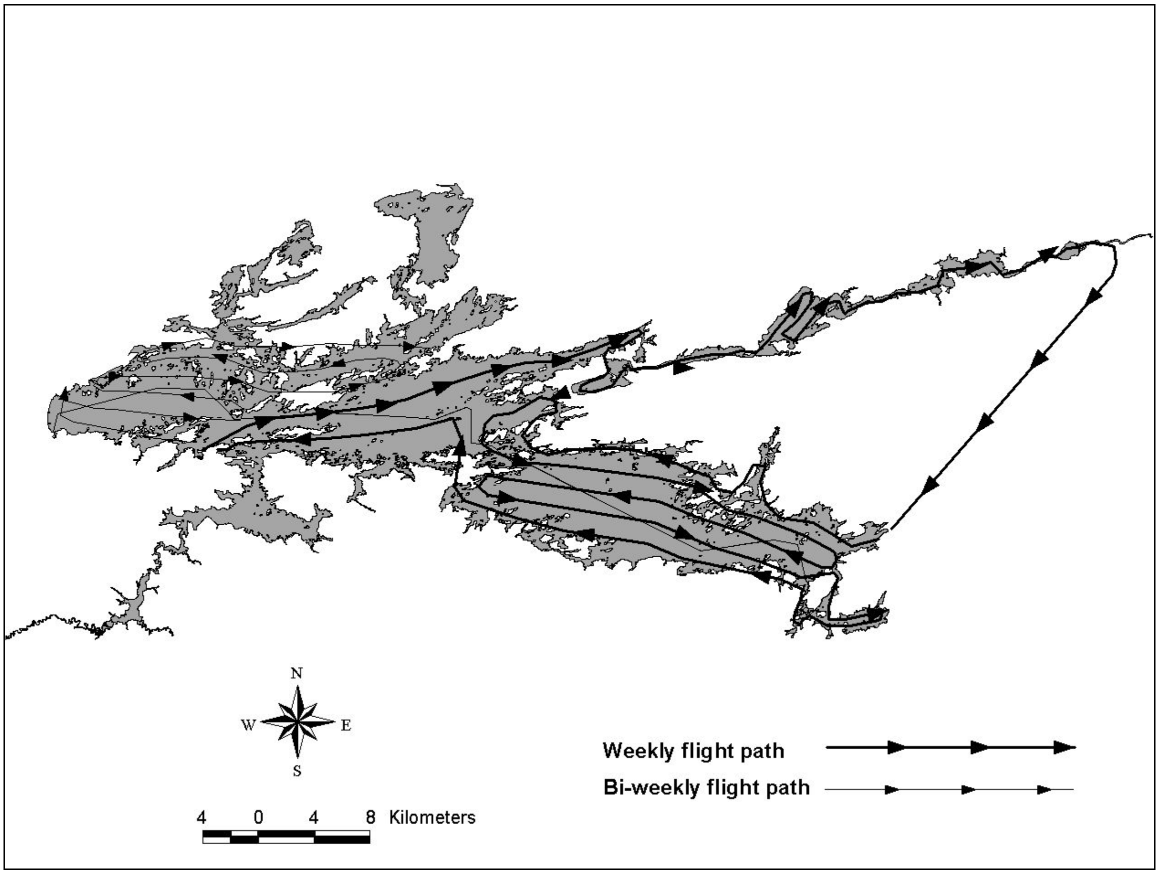


Figure 4-1. Flight path during weekly telemetry sampling on Rainy Lake, 2003-2004.

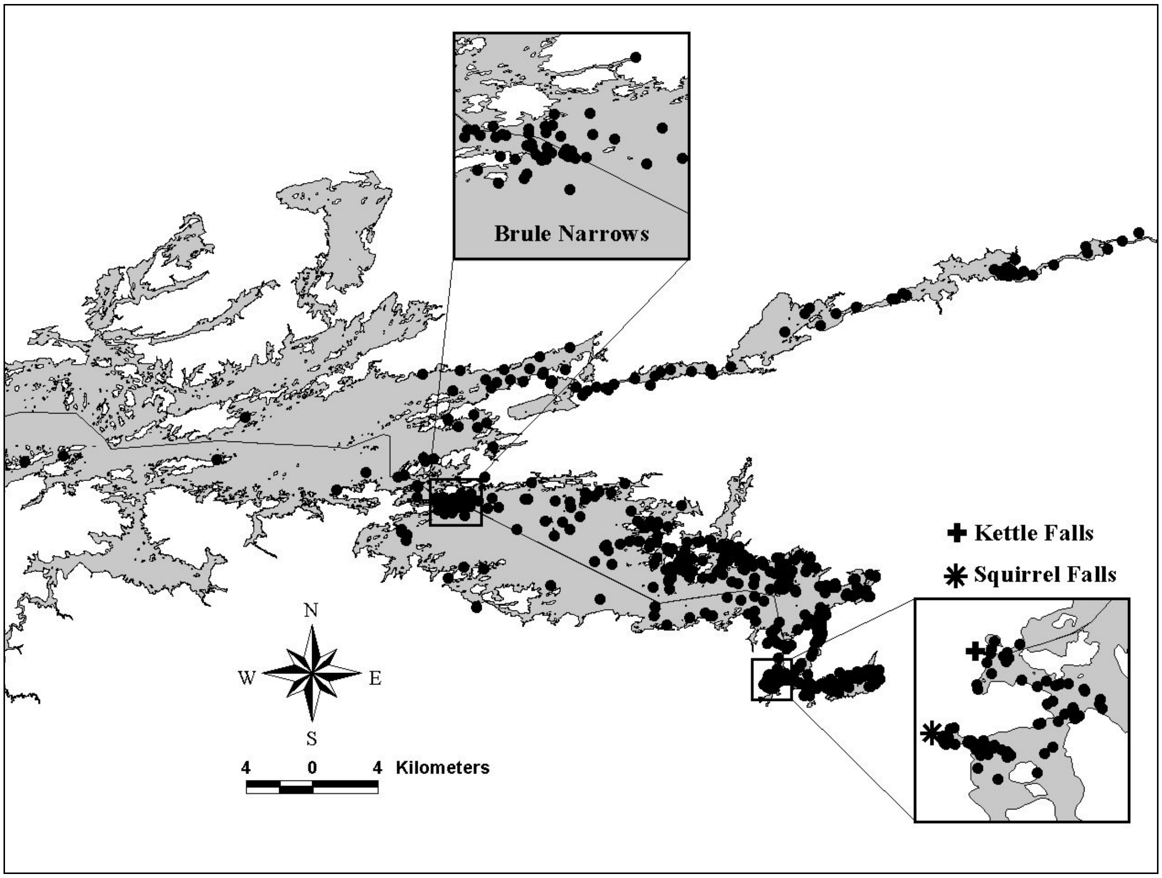


Figure 4-2. Lake sturgeon locations on Rainy Lake during 2003 and 2004.

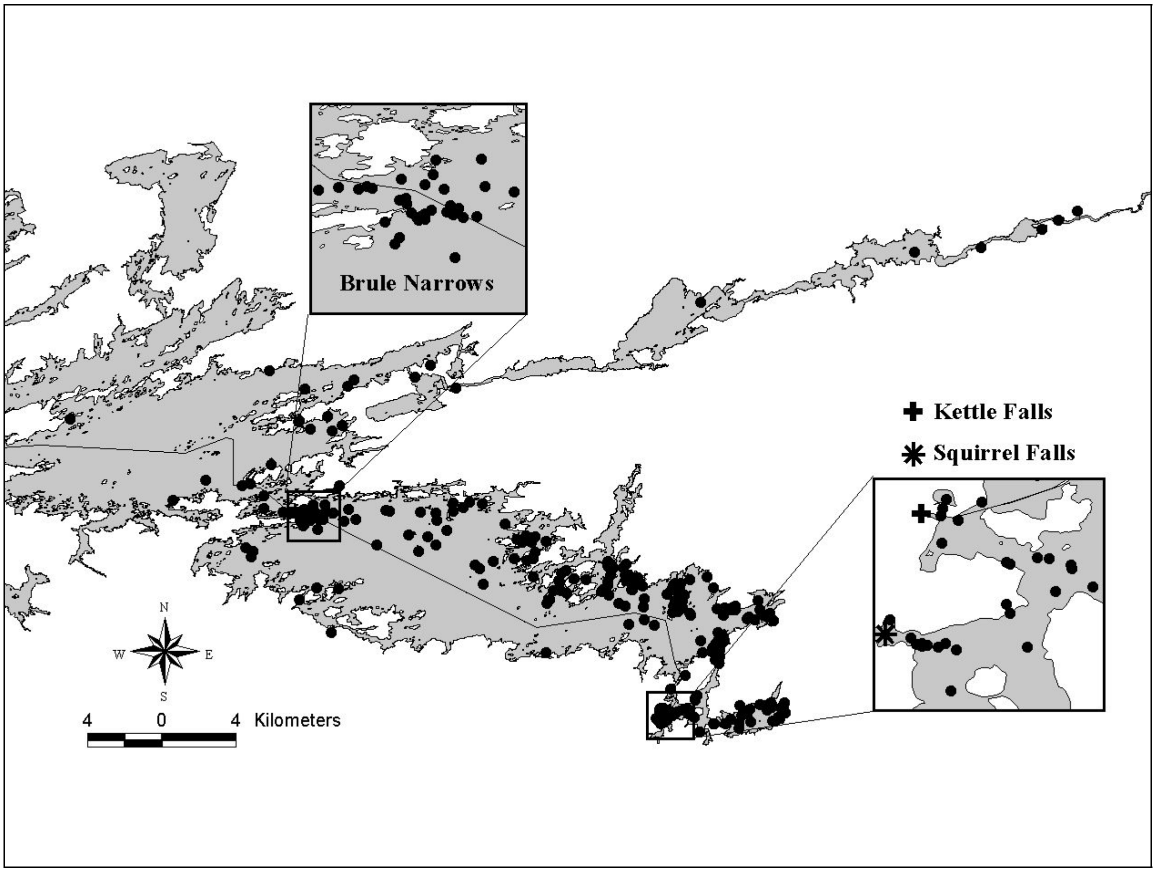


Figure 4-3. Lake sturgeon locations on Rainy Lake during 2003.

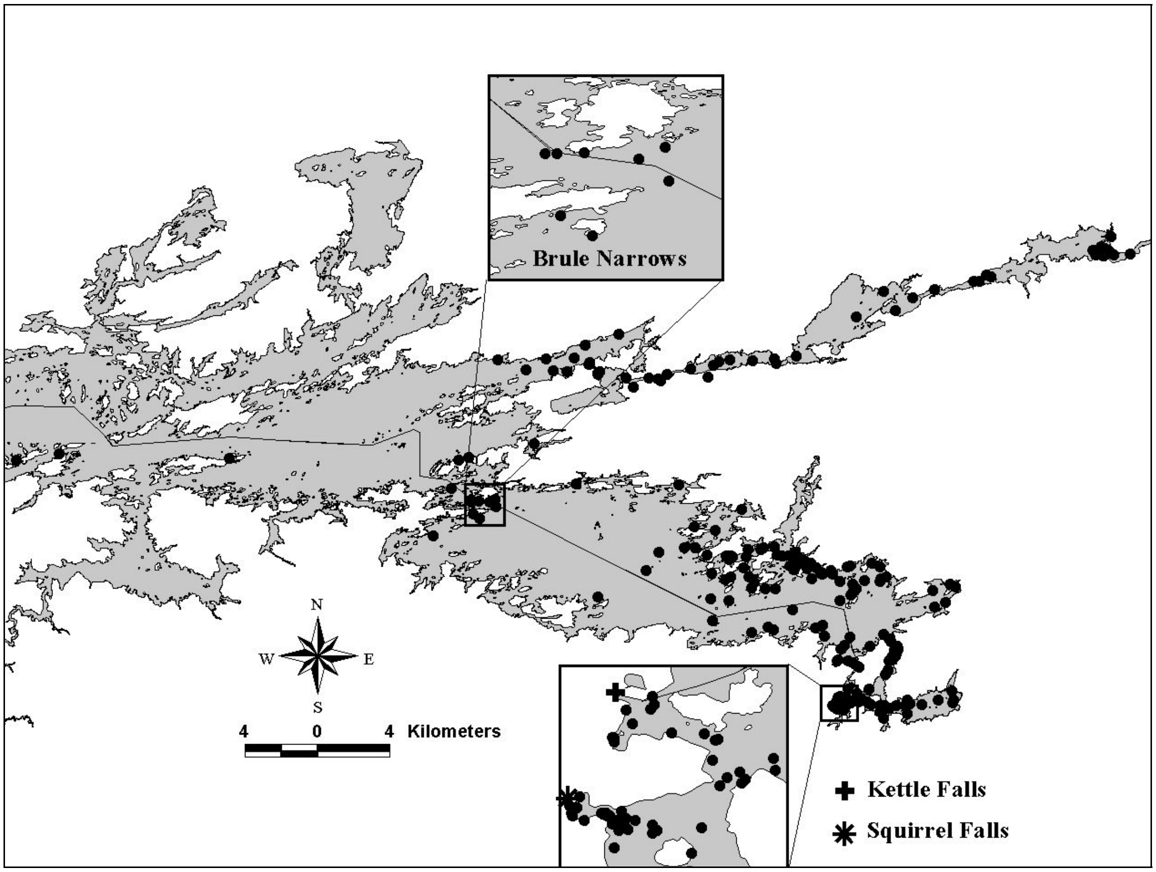


Figure 4-4. Lake sturgeon locations on Rainy Lake during 2004.

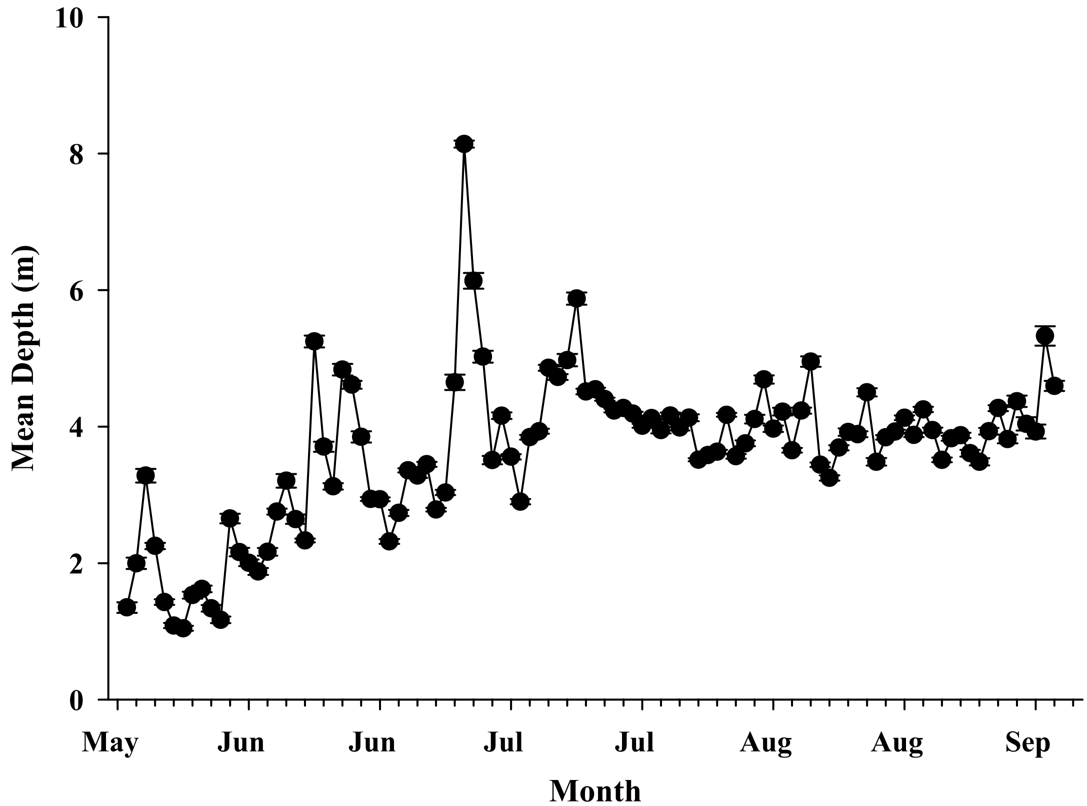


Figure 4-5. Mean daily depth (±SE) recorded by archival tag implanted in fish 30, Rainy Lake 2003.

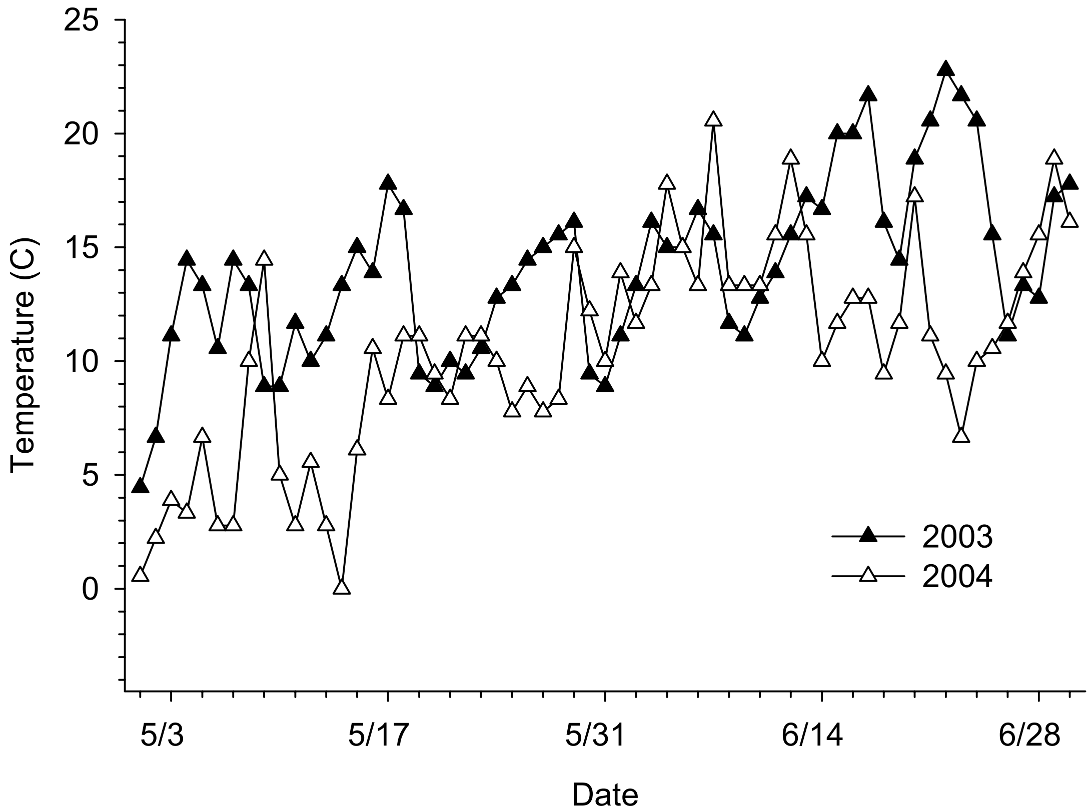


Figure 4-6. Mean daily air temperature at Squirrel Falls Dam for 2003 and 2004 (http://climate.umn.edu/doc/prelim_lcd_inl.htm).

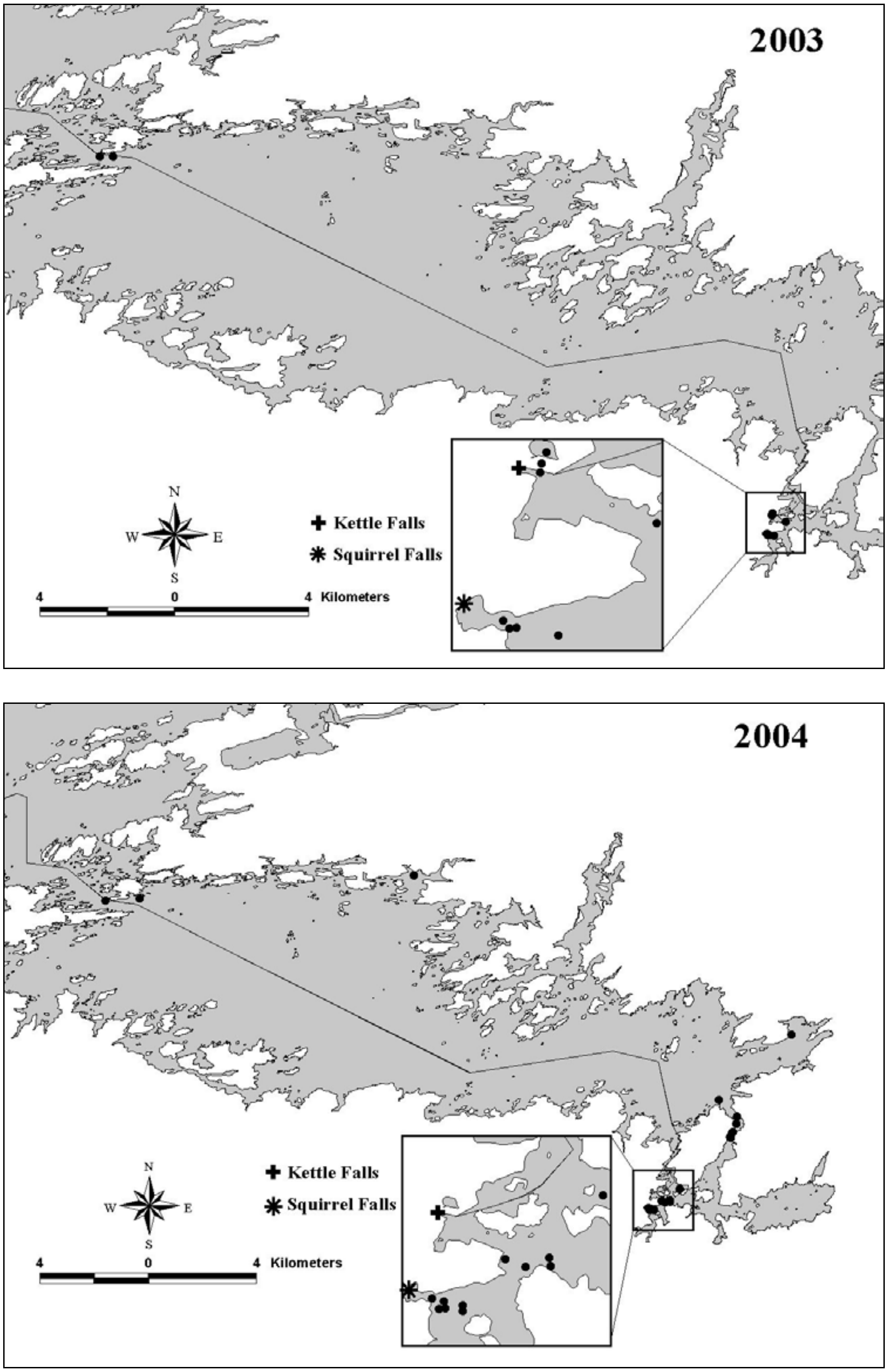


Figure 4-7. Distribution of lake sturgeon locations in Rainy Lake during May, 2003 and 2004.

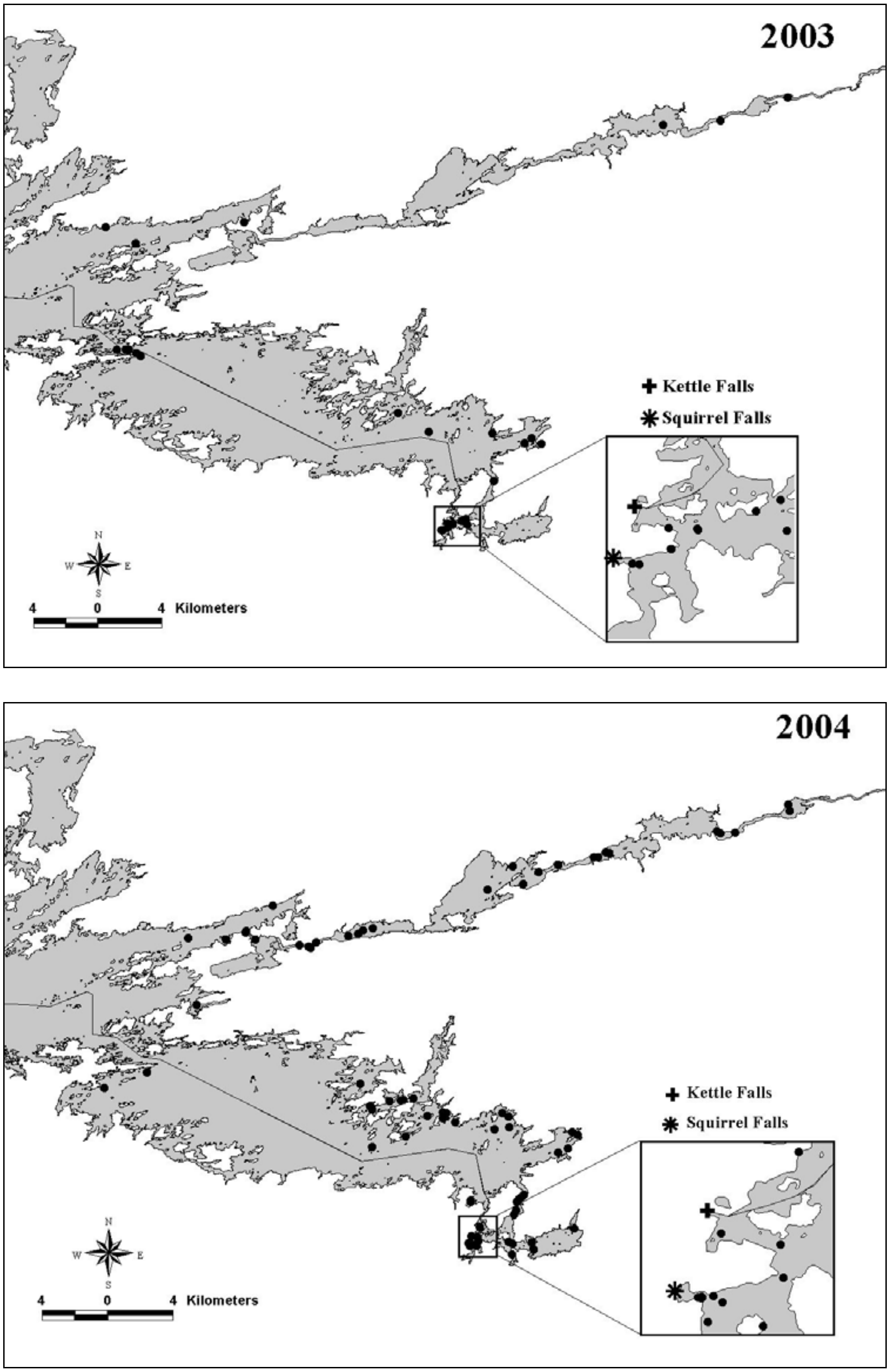
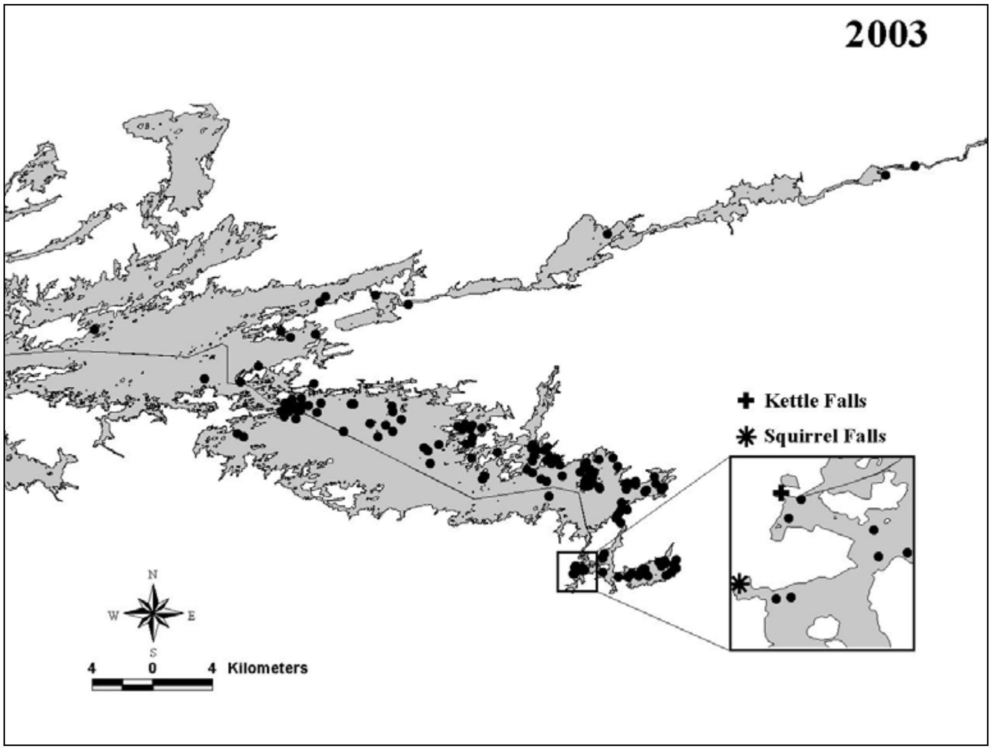


Figure 4-8. Distribution of lake sturgeon locations in Rainy Lake during June, 2003 and 2004.



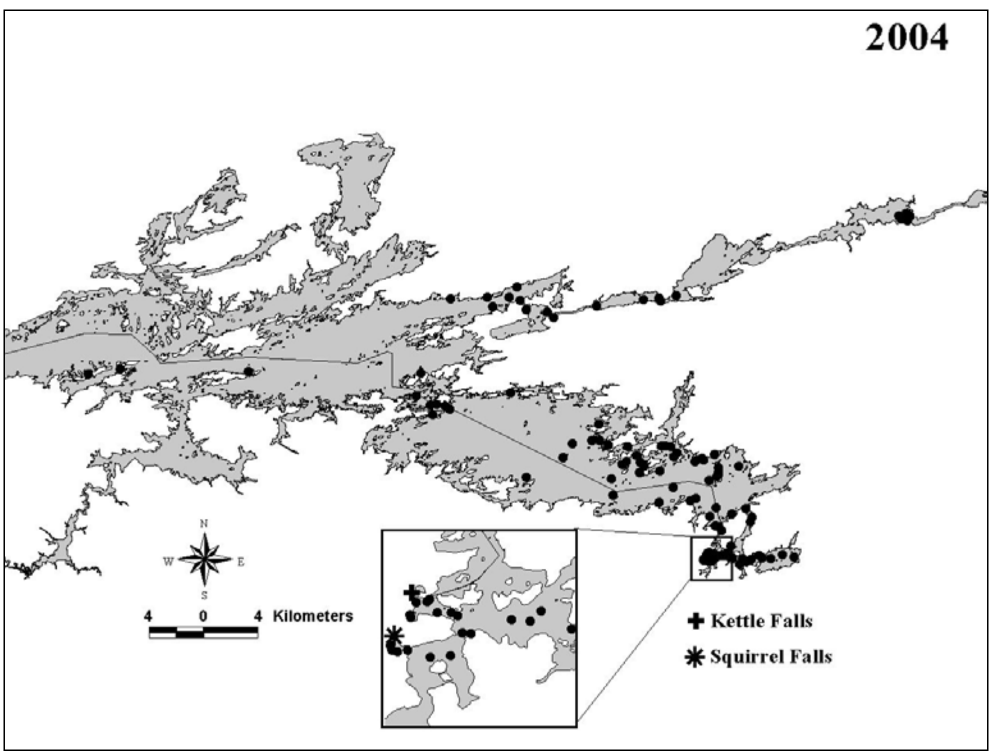


Figure 4-9. Distribution of lake sturgeon in Rainy Lake during July and August, 2003 and 2004.

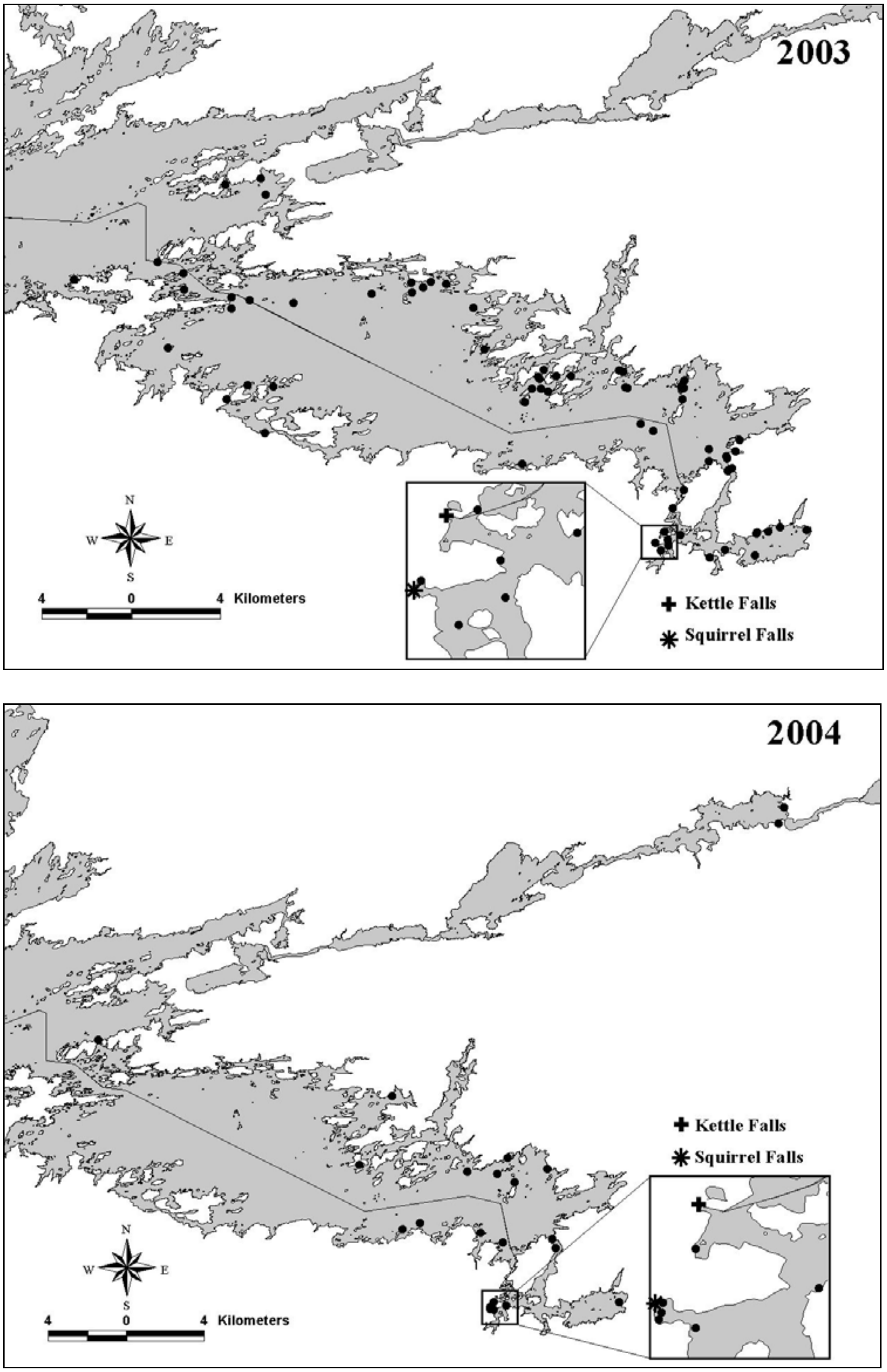


Figure 4-10. Distribution of lake sturgeon locations in Rainy Lake during September and October, 2003 and September, 2004.

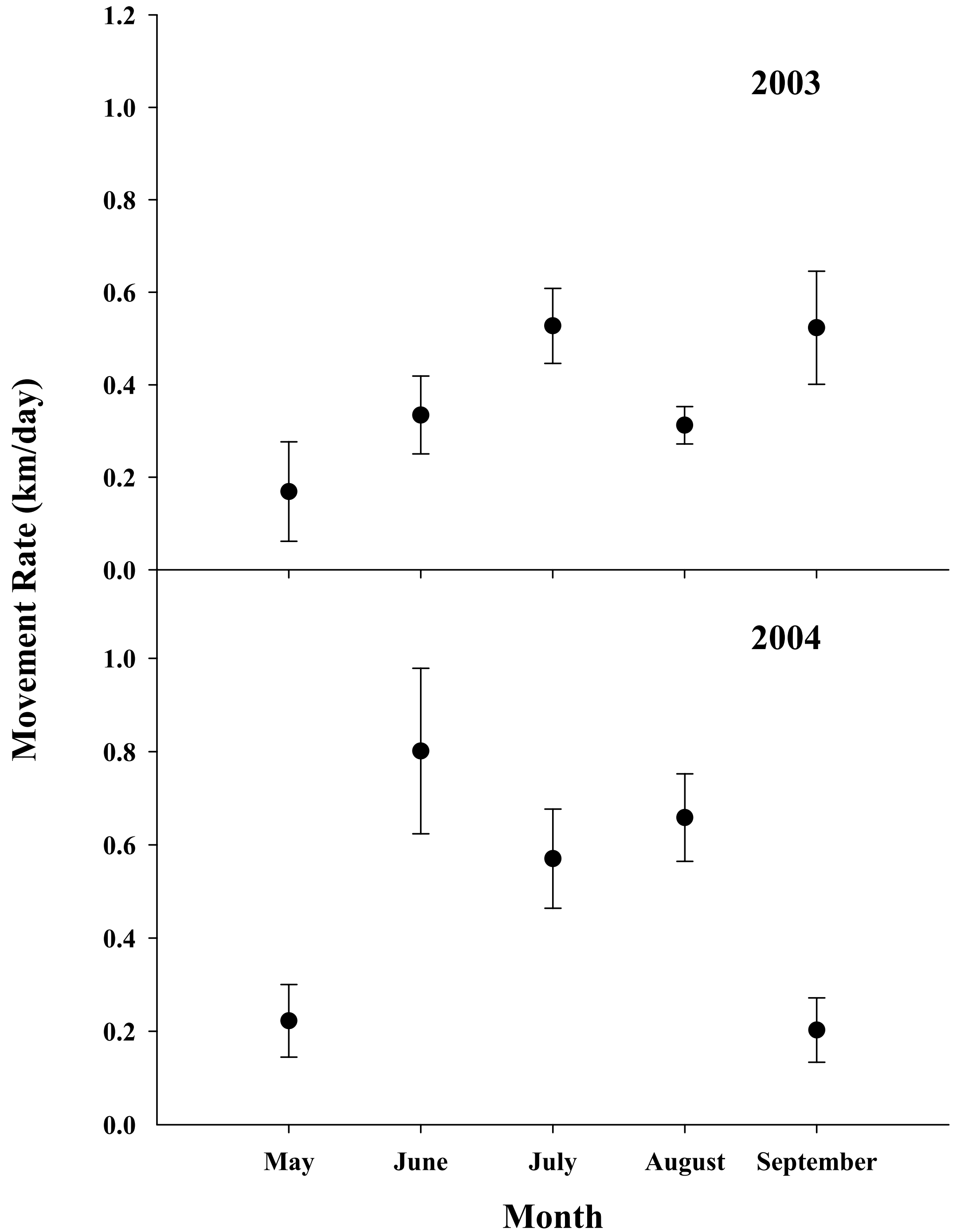


Figure 4-11. Mean monthly movement rate (± SE) of lake sturgeon in Rainy Lake during 2003 and 2004.

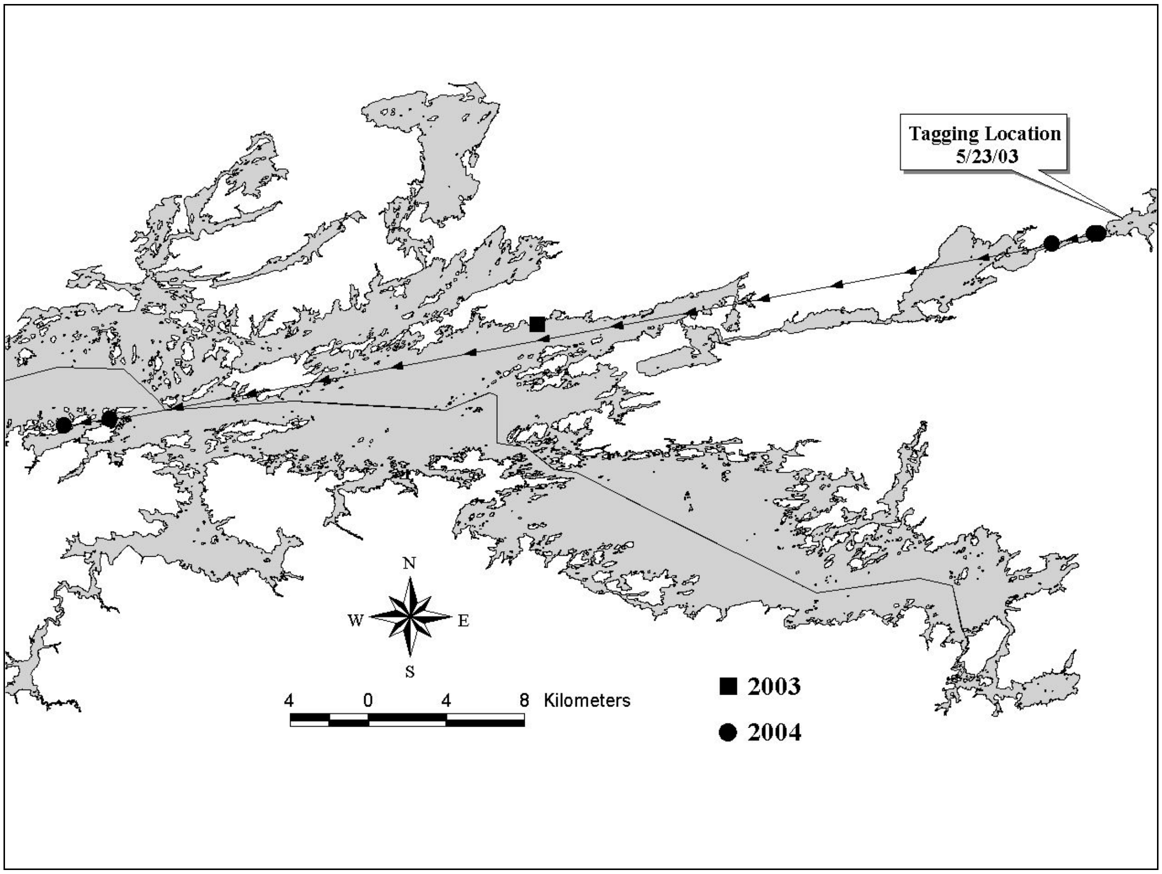


Figure 4-12. Distribution of locations for lake sturgeon #56 on Rainy Lake, during 2003 and 2004.

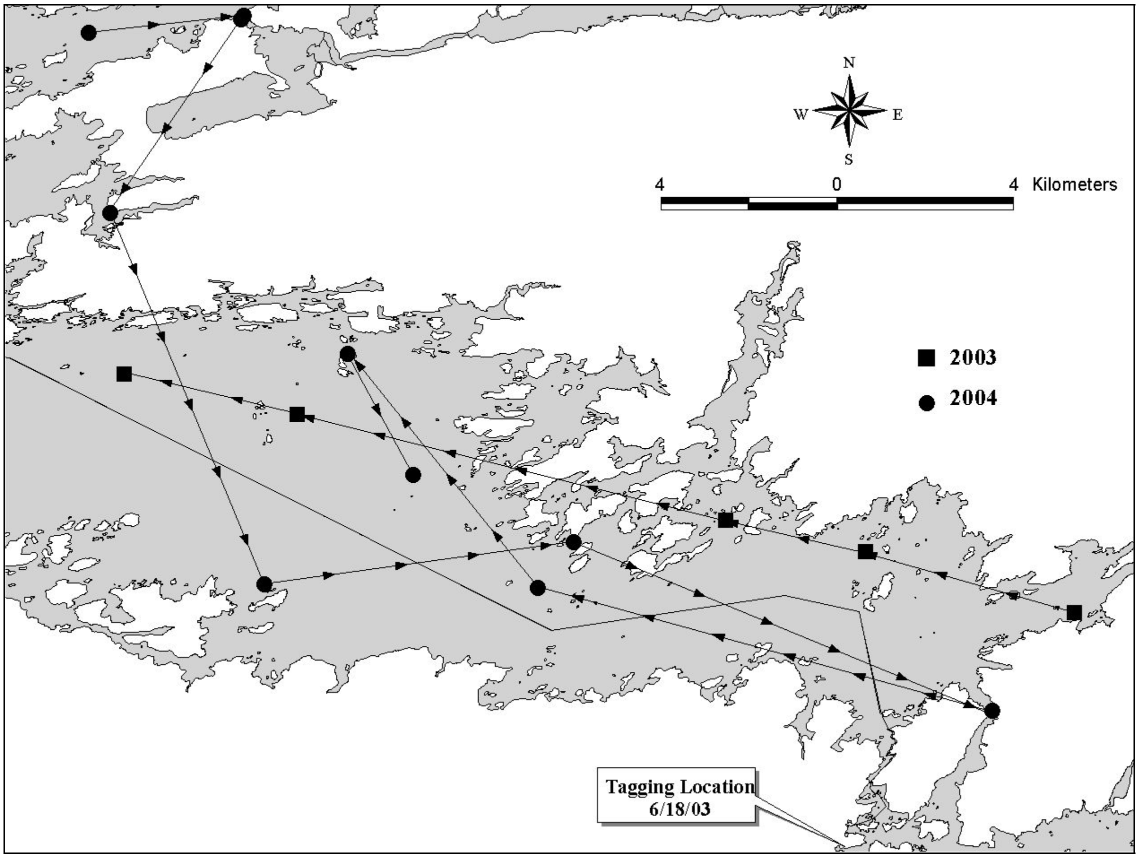


Figure 4-13. Distribution of locations for lake sturgeon #21 on Rainy Lake, during 2003 and 2004.

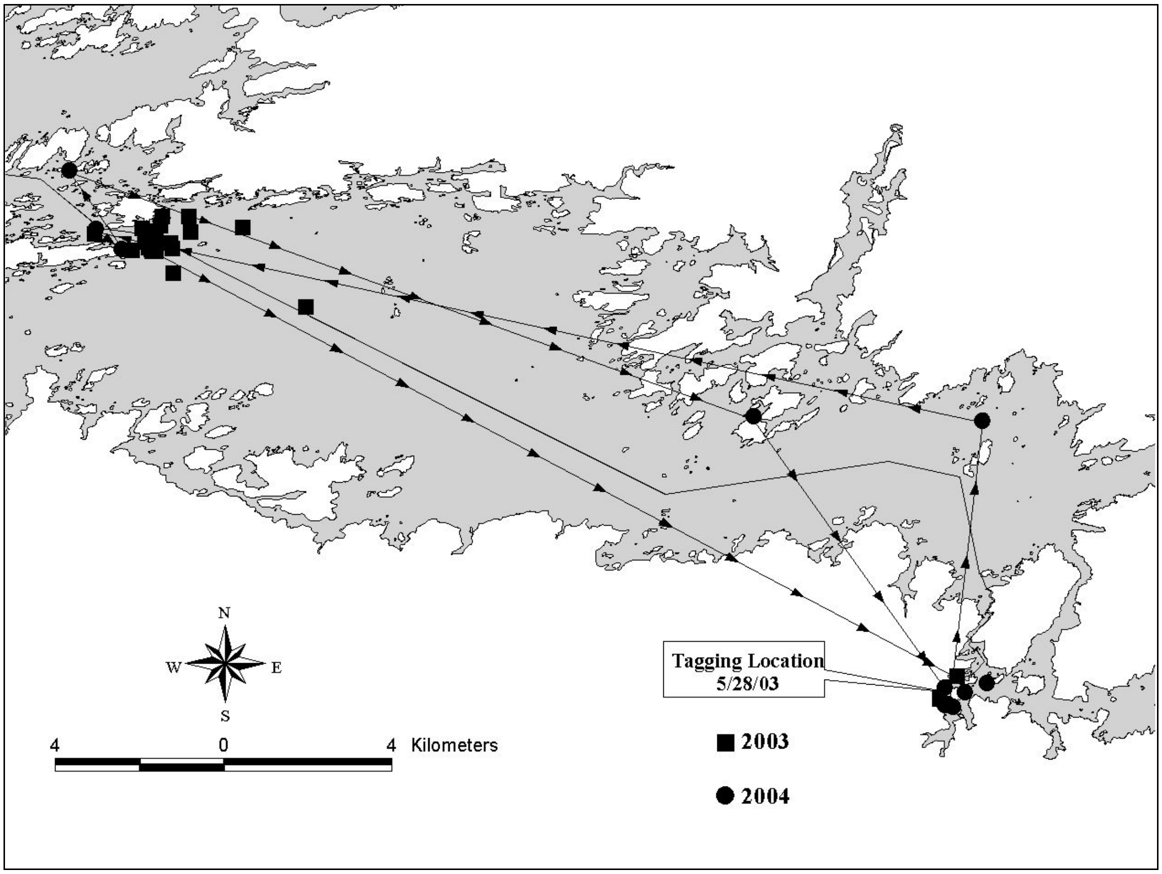


Figure 4-14. Distribution of locations for lake sturgeon #15 on Rainy Lake, 2003 and 2004.

Chapter 5. Relation of lake sturgeon year-class strength in Rainy Lake to Climate, Namakan Lake discharge, and Rainy Lake levels

Introduction

Environmental variables can affect recruitment in many freshwater fishes (e.g., Beck et al. 1997; Maceina and Stimpert 1998). Variables such as water levels, water retention, evaporation, and air temperature often can be related to recruitment patterns. However, little is known about how such variables affect lake sturgeon recruitment throughout their range. Nilo et al. (1997) related year-class strength of lake sturgeon in the St. Lawrence River to climate and hydrological variables. Year-class strength of lake sturgeon in this system was determined during the first months of life with climatic and hydrological conditions in June being important.

Regulated lake levels have been part of the hydrology of Rainy Lake since the early 1900's with the operation of a hydroelectric dam at the outlet of Rainy Lake and two regulatory dams on the reservoir upstream. The operation of these structures is dependent on the needs of a variety of consumers in the region. Concerns over how regulated lake levels affect fish populations and other aquatic biota in Rainy Lake have come to the forefront since the establishment of Voyageurs National Park (Cole 1979, 1982). Initial research by the U.S. National Park Service attempted to establish alternatives to the existing water management plan (Kallemeyn 1983). Such research has been directed toward the primary sport fishes of Rainy Lake, including walleye and northern pike *Esox lucius* (Kallemeyn 1987a; 1987b), with no work directed at lake sturgeon. Therefore, the objective of this chapter is to relate climate, Namakan Lake discharge, and Rainy Lake levels to year-class strength of lake sturgeon in Rainy Lake.

Methods

Lake sturgeon were captured with gill nets from 2002 to 2004 as part of an attempt to establish precision of standardized gill net samples (Chapter 3) and to attain fish for implantation of telemetry and archival tags (Chapter 4). Ages were determined by counting growth rings of pectoral fin rays (Wilson 1987). All fish sampled had a proximal, anterior portion of their pectoral fin ray removed. Fin rays were dried for a minimum of 3 weeks prior to sectioning. A total of 259 lake sturgeon were aged. For further details on capture methods and aging of lake sturgeon refer to Chapter 3.

The residual method was used to index year-class strength (Maceina and Stimpert 1998). A catch curve was developed by plotting the natural logarithm (base e) of the number of lake sturgeon in each age group as a function of age. The residuals for each data pair then provided the index to year-class strength. Weaker year classes were indicated by negative residuals and stronger year classes by positive residuals. The residuals were then related to climatological and hydrological data from Rainy Lake. Climatic data, Namakan Lake discharge data, and Rainy Lake water elevation data were obtained from the U.S. Geological Survey office at Voyageurs National Park, International Falls, Minnesota (Larry Kallemeyn, U.S. Geological Survey, personal communication).

Because this was an exploratory analysis, I used the correlation procedure (PROC CORR) in SAS (SAS© Institute, Inc. 2000) to relate the year-class index to climate, inflow, and lake elevation data. The residual data (i.e., indexes to year-class strength) were normally distributed, but one of five annual climate variables (total annual precipitation, maximum temperature, minimum temperature, average annual temperature, and total snowfall) at International Falls was non-normally distributed at $\alpha = 0.10$; neither of two monthly (May-June, June-August) precipitation variables were non-normally distributed; two out of 12 monthly means for air temperature at International Falls were non-normally distributed at $\alpha = 0.05$; four of 12 daily level measurements at Rainy Lake were non-normally distributed at $\alpha = 0.10$ (three were significant at $\alpha = 0.05$); and four of the 12 discharge measurements (by 10-d periods) from Namakan Lake were non-normally distributed at $\alpha = 0.05$. Therefore, I used the nonparametric Spearman rank correlation for my analyses rather than the parametric Pearson correlation. A high number of correlations were completed per data type, thus increasing the risk for spurious correlations. In some situations, Bonferroni corrections for multiple comparisons were determined to help assess the reliability of any particular relationship (Rao 1998).

Results and Discussion

Determination of year-class index

The catch curve for the Rainy Lake lake sturgeon population (Figure 5-1) did indicate variation in recruitment patterns among years. Positive residuals (i.e., stronger year classes) occurred for ages 25-34, while residuals were negative for ages 35 and older. Noakes et al. (1999) found substantial variations in recruitment over the last 50 years for lake sturgeon in the Groundhog and Mattagami rivers in Ontario, Canada. Priegel and Wirth (1975) reported variable recruitment in the lake sturgeon population in Lake Winnebago, Wisconsin.

Annual climate correlations

The lake sturgeon year-class index was not correlated with any of the annual climate variables measured at International Falls (Table 5-1). Correlation coefficients were ≤0.15 for all five variables (total precipitation; maximum, minimum, and mean air temperature; and total snowfall). I cannot be certain whether there simply are no correlations between lake sturgeon year-class strength and these climate variables, or whether the annual summation and means result in insufficient resolution to identify differences among years.

Monthly climate correlations

Because simply looking at annual precipitation patterns may not provide sufficient resolution, I also assessed potential relations between year-class strength (i.e., residuals) and both May-June total precipitation and June-August total precipitation at International Falls. I found no correlation between the year-class index and precipitation during the spawning season (May-June; $r_s = 0.15$, $P = 0.50$; Figure 5-2), even though fish species can be affected (either positively or negatively) by high water levels during the spawning season (e.g., Staggs and Otis 1996). I also found no correlation between year-class index and precipitation during June through August (r_s = -0.11, P = 0.62; Figure 5-3). High water during this time period could potentially affect productivity in the system, which might then affect lake sturgeon growth during the first growing season, thus influencing recruitment to the adult population. However, I could find no evidence to support such a supposition.

When the lake sturgeon year-class index was correlated with monthly means for air temperature at International Falls, most correlations were nonsignificant (Table 5-1). However, the year-class index was significantly and positively correlated with June temperature data (r_s = 0.59; P = 0.004; Figure 5-4). Even with a Bonferroni correction for multiple comparisons, this relationship may exist, as α = 0.05/12 comparisons yields 0.004. In addition, the relationship seems to be biologically feasible, as June temperatures could certainly be related to food supplies produced for emerging, age-0 lake sturgeon. In years with colder June temperatures, food supplies might be less abundant or later to develop, thus potentially affecting growth and survival of the young lake sturgeon. Nilo et al. (1997) related year-class strength of St. Lawrence River lake sturgeon to climatic and hydrological variables. They found positive, significant correlations between year-class strength and daily rate of increase in St. Lawrence River water temperatures in May and June.

Namakan Lake discharge correlations

I found little correlation between the Namakan Lake discharge patterns and the index to lake sturgeon year-class strength (Table 5-3). A potentially significant correlation was evident with mean discharge from August 11 through 20 (r_s = -0.50; P = 0.02; Figure 5-5). However, I am reluctant to place too much confidence in this relationship. First, as mentioned above, the P value for this relationship would be nonsignificant after a Bonferroni adjustment. Second, I am not certain of a biological explanation for influence caused by August discharge data, especially as all correlations with other time periods were nonsignificant. Thus, I recommend that further research be completed on the influence of Namakan Lake discharges to lake sturgeon recruitment prior to such relations being assumed present. There is also a need for research on lake sturgeon nursery areas and their relationships with discharge areas on Rainy Lake such as Squirrel Falls and Kettle Falls since small lake sturgeon may be susceptible to displacement during periods of higher discharge.

Rainy Lake elevation correlations

A potentially plausible pattern appeared when I related the lake sturgeon year-class strength index to Rainy Lake elevations across years (Table 5-4). Correlation coefficients exceeded 0.4 between days 110 and 160, which would refer to the time period between late April and early June that encompasses the spawning and hatching period for lake sturgeon in Rainy Lake. The correlation coefficient was highest for day 150 (Figure 5-6). While these correlations are relatively weak and Bonferroni corrections would render them nonsignificant, I suggest that the same negative relationships appeared for several of the comparisons within the spring season may indicate some validity to these correlations. At the least, I believe that further investigation along these lines is warranted. Kallemeyn (1987a, 1987b) found that the existing water level management plans had adverse affects on walleye and northern pike in Voyageurs National Park aquatic ecosystems.

Cautions about the utility of this data set

My analysis assumes that lake sturgeon can be accurately aged from the pectoral fin rays. Although Mackay et al. (1990) reported that pectoral fin rays are the preferred structure for aging lake sturgeon, Scott and Crossman (1973) warned that interpretation of ages from pectoral fin rays was not "easy or uniform." As the distance at which fin rays are removed from the body wall articulation point increases, the number of annuli decreases, thus increasing associated aging error (Threader 1981). Various biologists and technicians removed fin rays for this study, which could have imparted variation into the fin ray removal process.

In addition, the analysis technique used here assumes that deviation of each cohort from the catch-curve regression was the result of recruitment patterns, not differential mortality influencing cohorts in a differential manner. For example, it is possible that commercial fishing excessively cropped older age groups, while younger age groups have been less influenced (or not influenced) by commercial fishing. The commercial harvest of lake sturgeon in Rainy Lake peaked in approximately 1960 (< 2,500 kg), and remained substantial through 1970 (D. Mcleod, Ontario Ministry of Natural Resources, personal communication). Harvest was nearly zero from 1972 through 1979, but then was steady at a moderate level (400-500 kg) from 1979 through

1990. Commercial harvest by Canadian fishers ceased in 1990. Thus, the older year classes in my analysis may have been substantially affected by commercial fishing, while younger cohorts may have been too small to be commercially harvested in the 1980s, and thus appear more abundant in the population age structure than would be predicted based solely on recruitment patterns. A better analysis might utilize a long-term data set with an annual recruitment index (e.g., catch per unit effort of age-2 lake sturgeon in standardized gill-net samples).

Table 5-1. Spearman rank correlations (r_s) between lake sturgeon year-class index (residuals from the catch-curve analysis) and annual climate variables at International Falls, Minnesota, 1965-1986 (N = 22).

Climate variable	r_s	P
Total annual precipitation	0.08	0.71
Mean of monthly maximum temperature	0.15	0.50
Mean of monthly minimum temperature	0.08	0.73
Mean monthly temperature	0.13	0.56
Total annual snowfall	-0.13	0.57

Table 5-2. Spearman rank correlations (r_s) between lake sturgeon year-class index (residuals from the catch-curve analysis) and monthly mean annual air temperature at International Falls, Minnesota, 1965-1986 (N = 22).

Month	r_s	P
January	-0.24	0.29
February	0.13	0.56
March	-0.11	0.63
April	-0.20	0.37
May	0.10	0.66
June	0.59	0.004
July	0.13	0.57
August	0.19	0.40
September	-0.23	0.30
October	0.36	0.10
November	0.28	0.20
December	-0.24	0.27

Table 5-3. Spearman rank correlations (r_s) between lake sturgeon year-class index (residuals from the catch-curve analysis) and mean discharge (m^3/s) by 10-d period from Namakan Lake, 1965-1986 (N = 22).

Period	r_s	P
May 1-10	-0.08	0.74
May 11-20	-0.24	0.28
May 21-31	-0.22	0.33
June 1-10	-0.09	0.69
June 11-20	-0.15	0.50
June 21-30	-0.09	0.68
July 1-10	0.06	0.78
July 11-20	-0.12	0.59
July 21-31	-0.14	0.53
Aug 1-10	-0.36	0.11
Aug 11-20	-0.50	0.02
Aug 21-31	-0.28	0.21

Table 5-4. Spearman rank correlations (r_s) between lake sturgeon year-class index (residuals from the catch-curve analysis) and Rainy Lake water levels at various days of the year, 1965-1986 (N = 22).

Day of year	r_s	P
50	0.004	0.99
100	-0.2	0.38
110	-0.44	0.04
120	-0.5	0.02
130	-0.41	0.06
140	-0.46	0.03
150	-0.52	0.01
160	-0.41	0.06
170	-0.32	0.15
200	-0.44	0.04
250	-0.32	0.14
300	0.13	0.57

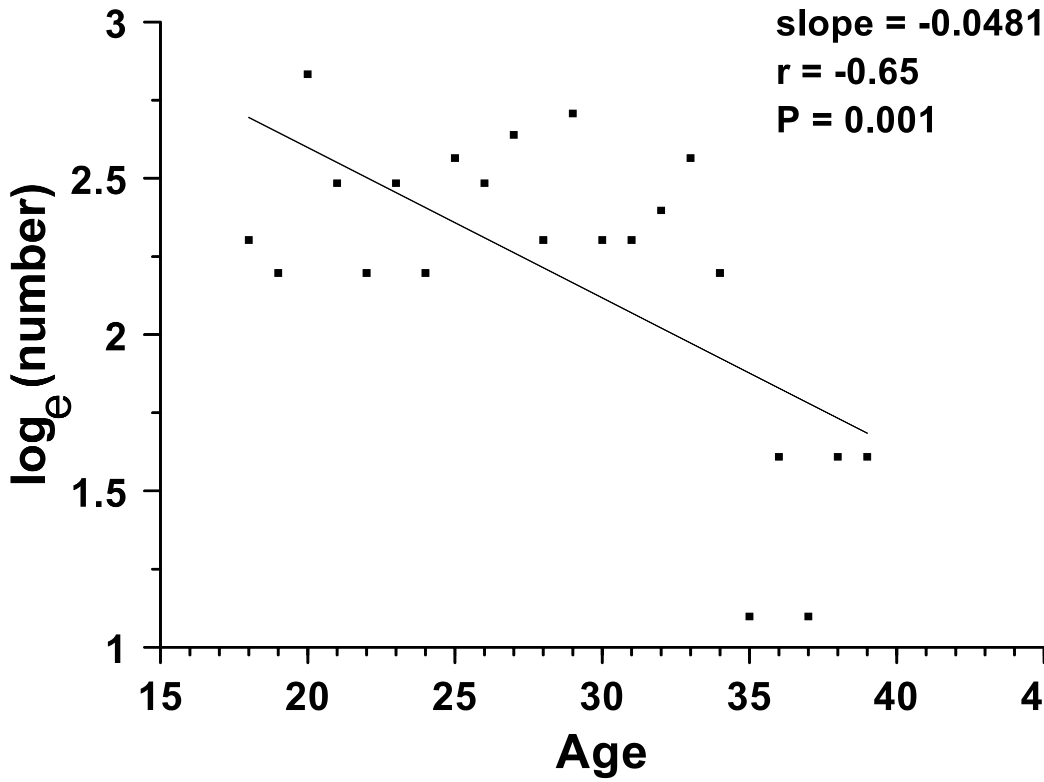


Figure 5-1. Catch curve for lake sturgeon from the 1965 (assigned age group 39) to 1986 (age group 18) year classes in Rainy Lake. See Chapter 3 for specifics on the catch-curve analysis. The residuals for each data pair were used as an index to year-class strength for lake sturgeon, with negative residuals indicating weaker year classes and positive residuals indicating strong year classes.

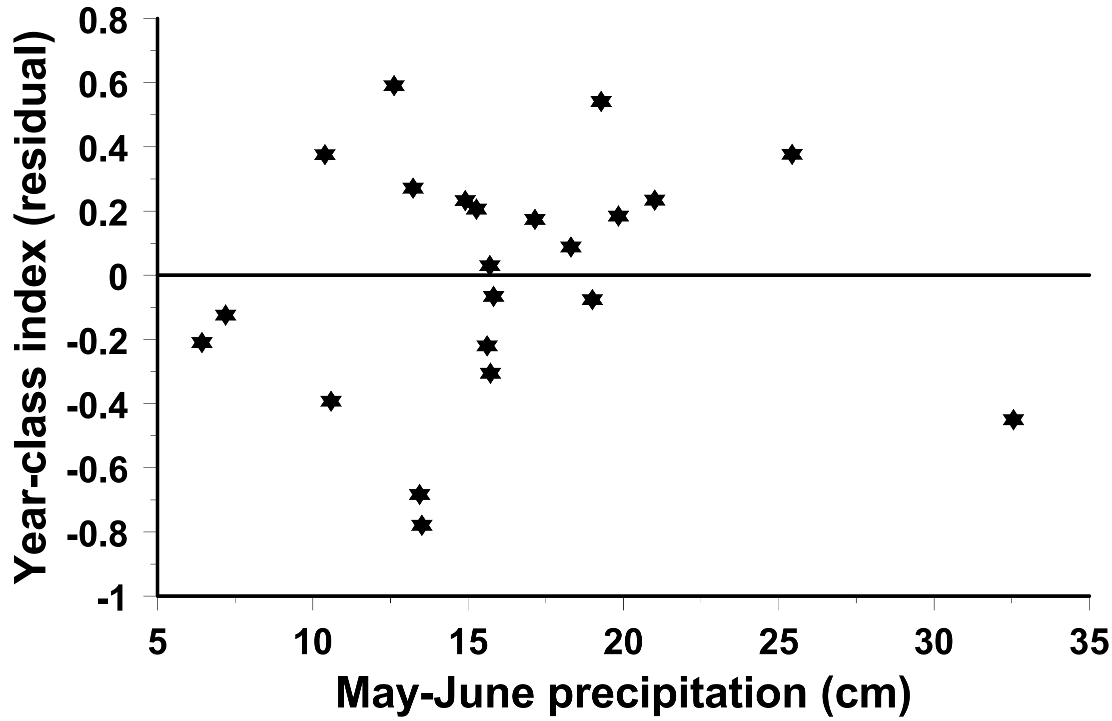


Figure 5-2. Relation between lake sturgeon year-class index (residual from catch-curve analysis) in Rainy Lake and total May-June precipitation at International Falls, Minnesota, 1965-1986 (N = 22).

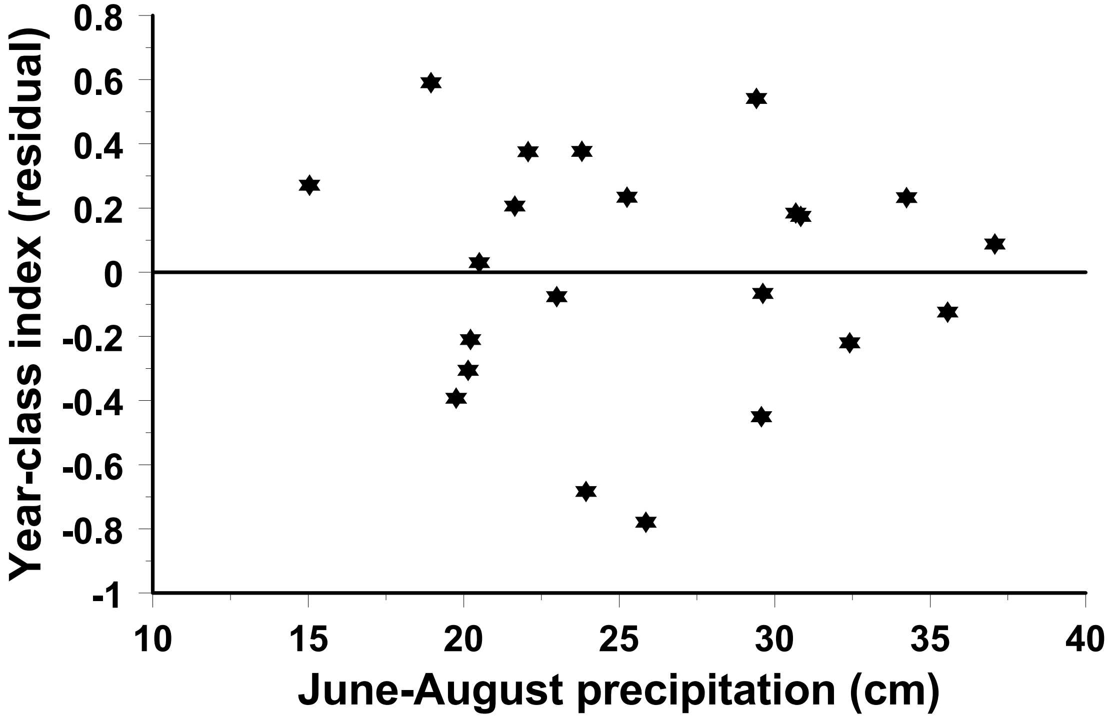


Figure 5-3. Relation between lake sturgeon year-class index (residual from catch-curve analysis) in Rainy Lake and total June-August precipitation at International Falls, Minnesota, 1965-1986 (N = 22).

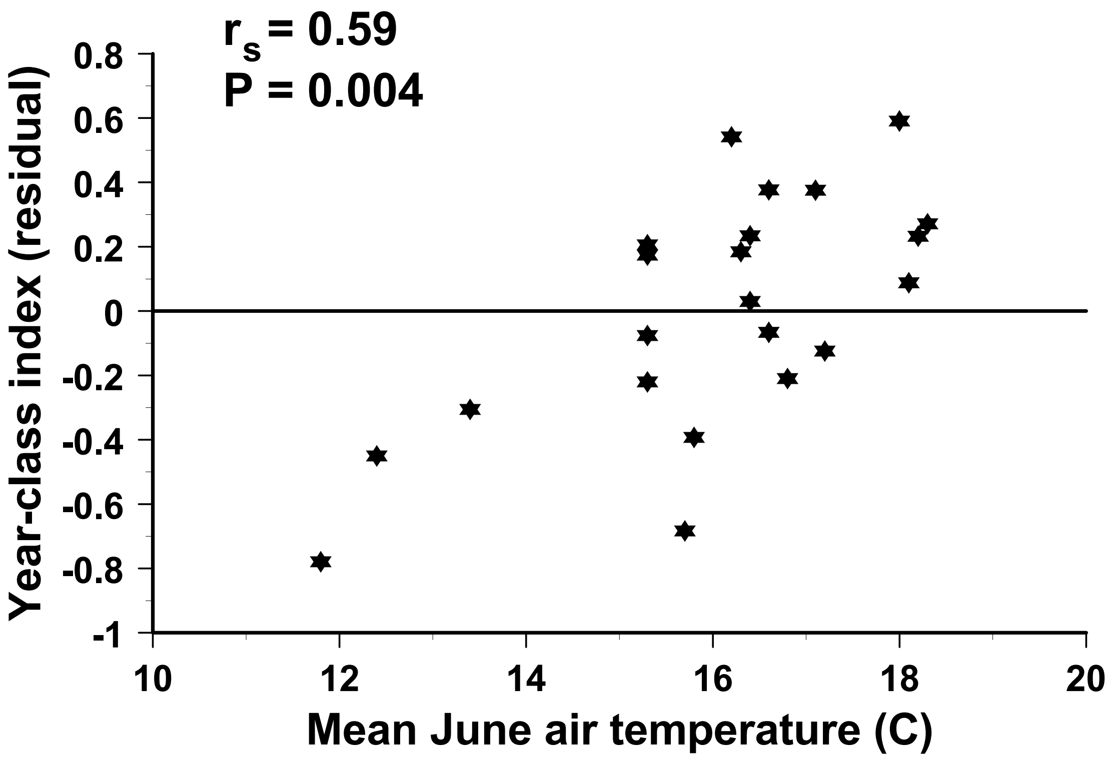


Figure 5-4. Relation between lake sturgeon year-class index (residual from catch-curve analysis) in Rainy Lake and mean June air temperature at International Falls, Minnesota, 1965-1986 (N = 22). Empirical data are plotted, while the analysis was completed with a Spearman rank correlation (r_s) because temperature data were not normally distributed.

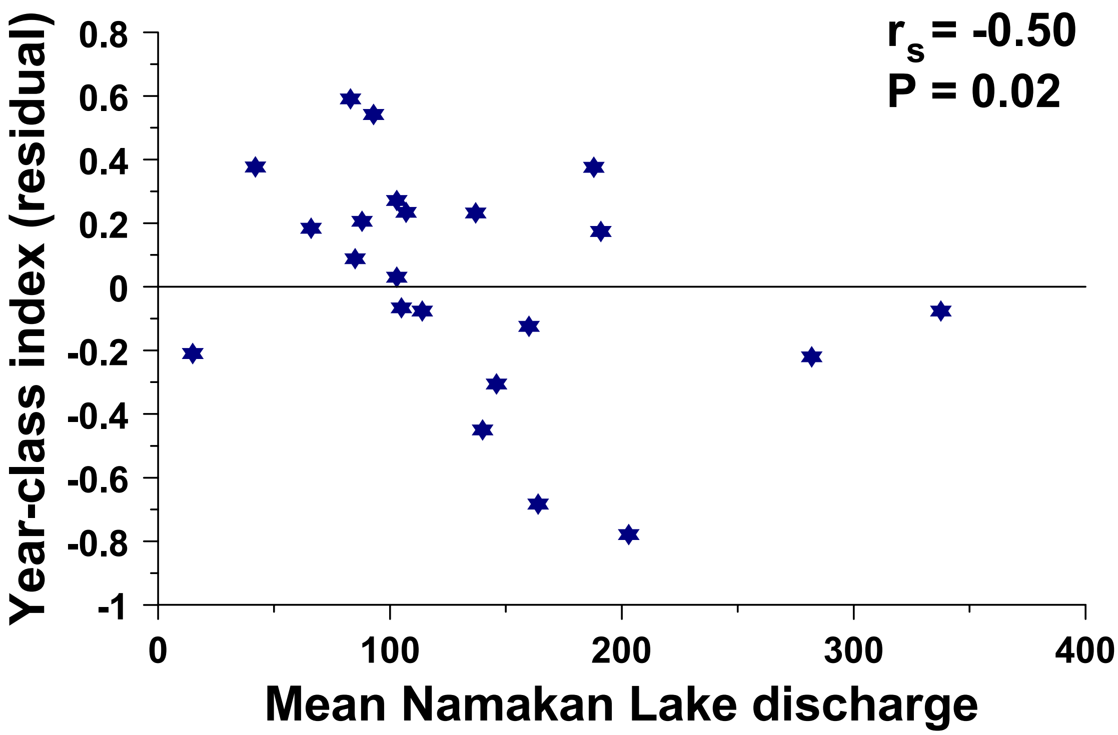


Figure 5-5. Relation between lake sturgeon year-class index (residual from catch-curve analysis) in Rainy Lake and mean discharge (m^3/s) from Namakan Lake during August 11-20, 1965-1985 (N = 21). Discharge data were not available for 1986. Empirical data are plotted, while the analysis was completed with a Spearman rank correlation (r_s).

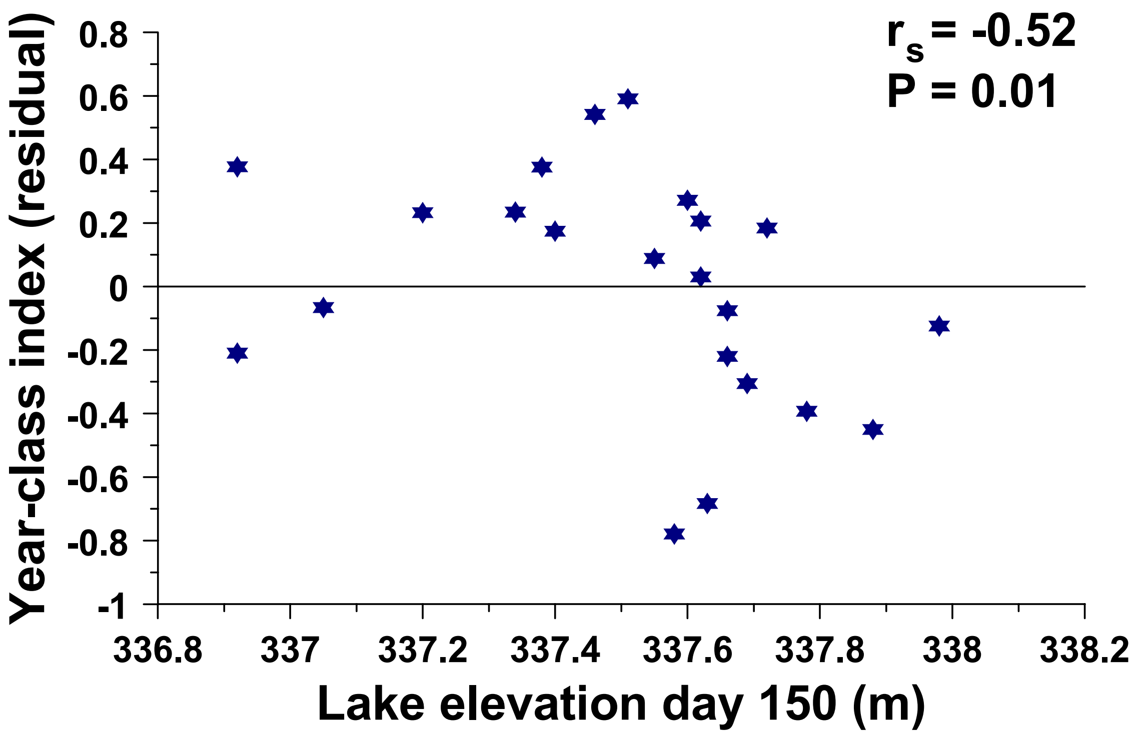


Figure 5-6. Relation between lake sturgeon year-class index (residual from catch-curve analysis) in Rainy Lake and Rainy Lake elevation on day 150 of the year. Empirical data are plotted, while the analysis was completed with a Spearman rank correlation (r_s).

Chapter 6. Conclusions and Research Needs

This research should provide biologists from multiple agencies much needed insight into population characteristics and general movement patterns of lake sturgeon inhabiting Rainy Lake. The baseline data collected should allow these biologists to establish more specific research questions in the future.

Gill-net sampling efforts throughout the study indicated a substantial population of lake sturgeon in Rainy Lake. Of the 322 lake sturgeon captured or recaptured during this study, 217 were in the area of and adjacent to the Squirrel Falls Dam indicating the importance of this location. Given such concentrations of lake sturgeon, a completely random sampling design to monitor the population overtime would likely be neither time nor cost effective. An alternative would be to establish a sampling design that would target areas of known lake sturgeon congregations. If sampling remained consistent from year to year, trends in lake sturgeon population could then be monitored.

Body condition and growth of lake sturgeon in Rainy Lake indicated that these fish were relatively plump and fast growing compared with 32 other populations summarized by Fortin et al. (1996). Size structure analysis revealed limited numbers of smaller (<105 cm total length) and larger (>150 cm total length) lake sturgeon. Age structure analysis indicated a similar trend, with few younger (<10 years) and older (>50 years) lake sturgeon, and a maximum age of 59 years. Future research should establish whether these smaller, younger fish are missing, not effectively sampled with the gill net mesh size complement used, or simply utilizing areas not sampled.

Telemetry data reinforced the high utilization of the Squirrel Falls area by lake sturgeon with 37% of my total locations occurring at that area. Squirrel Falls was the only site at which spawning was confirmed by collection of lake sturgeon eggs, although other aggregations in areas associated with Kettle Falls, the Pipestone River, and the Rat River could indicate spawning activity. Expanded use of egg sampling methods utilized during my study may prove useful to biologists to confirm spawning in some of these other areas. Movement of lake sturgeon between the Seine River and the South Arm of Rainy Lake indicates the likelihood of one integrated population on the east end of the South Arm. The lack of locations in the Seine River during the months of September and October might result from lake sturgeon moving into deeper water areas of the Seine River and out of the range of telemetry gear or simply moving back into the South Arm. Further research into this question would allow comparisons to the Lake of the Woods/Rainy River system and may provide insight into the winter range of lake sturgeon in Rainy Lake. Locations of lake sturgeon along the south shore of the South Arm indicate that lake sturgeon either were not using this area of deep water or the limitations of my telemetry gear inhibited my ability to locate these fish. If improvements in technology allow, future research is needed.

All lake sturgeon captured in this study were in the South Arm. Biologists believe that lake sturgeon do occur in the North Arm of Rainy Lake and in the riverine portion of the South Arm near International Falls, MN (L. Kallemeyn, U.S. Geological Survey, personal communication). Future research in these two locations would be crucial to truly understand the lake sturgeon population in Rainy Lake.

Few correlations existed between lake sturgeon year-class indices and both annual and monthly climate variables. The same was true for lake sturgeon year-class strength and Namakan Lake discharge. Correlation between Rainy Lake elevation and lake sturgeon year-class strength indices across years yielded consistent, but weak correlations during the time period between late April and early June when spawning of lake sturgeon occurs. Because lake levels have been shown to have adverse affects on other fish species in Voyageurs National Park aquatic ecosystems, I believe further research along these lines is warranted.

I recommend continued monitoring of this lake sturgeon population. One improved approach may be to establish an annual mark/recapture program that would provide a population estimate and insight into fluctuations in this population. The relative importance of lake sturgeon as a resource in Rainy Lake must first be considered because substantial time and cost would be associated with such a program.

The lake sturgeon has historically been a resource of both cultural and economic importance to the Rainy Lake area. The unique biological characteristics of this species combined with the size of the system in which they live require biologists to utilize diverse monitoring and management strategies. A proactive approach would allow lake sturgeon in this system to continue their role in the Voyageurs National Park aquatic ecosystem for many years to come.

References

Auer, N.A. 1996. Importance of habitat and migration to sturgeons with emphasis on lake sturgeon. Canadian Journal of Fisheries and Aquatic Sciences 53(Supplement):152-160.

Auer, N.A. 1999. Population characteristics and movements of lake sturgeon in the Sturgeon River and Lake Superior. Journal of Great Lakes Research 25:282-293.

Beck, H.D., D.W. Willis, D.G. Unkenholz, and C.C. Stone. 1997. Relations between environmental variables and age-0 white bass abundance in four Missouri River Reservoirs. Journal of Freshwater Ecology 12:567-575.

Borkholder, B. D., S.D. Morse, H.T. Weaver, R.A. Hugill, A.T. Linder, L.M. Schwarzkopf, T.E. Perrault, M.J. Zacher, and J.A. Frank. 2002. Evidence of a year-round resident population of lake sturgeon in the Kettle River, Minnesota, based on radio telemetry and tagging. North American Journal of Fisheries Management 22:888-894.

Brousseau, C.S., and G.A. Goodchild. 1989. Fisheries and yields in the Moose River Basin, Ontario. Pages 145-148 *in* D.P. Dodge, editor. Proceedings of the international large river symposium. Edited by D.P. Dodge. Canadian Special Publication of Fisheries and Aquatic Sciences No. 106.

Brown, R.S., S.J. Cooke, W.G. Anderson, and R.S. McKinley. 1999. Evidence to challenge the “2% rule” for biotelemetry. North American Journal of Fisheries Management 19:867-871.

Bruch, R.M. 1999. Management of lake sturgeon on the Winnebago system – long term impacts of harvest and regulations on population structure. Journal of Applied Ichthyology 15:142-152.

Cohen, Y., and P. Radomsko. 1993. Water level regulations and fisheries in Rainy Lake and the Namakan Reservoir. Canadian Journal of Fisheries and Aquatic Sciences 50:1934-1945.

Cole, G.F. 1979. Mission-oriented research in Voyageurs National Park. Proceedings of the Second Conference on Scientific Research in National Parks 7:194-204.

Cole, G.F. 1982. Restoring natural conditions in a boreal forest park. Transactions of the North American Wildlife and Natural Resources Conference 47:411-420.

Environmental Systems Research Institute. 1999. ArcView GIS. Version 3.2. Environmental Systems Research Institute, Redlands, California.

Ericson, D.W., G.F. Lindholm, and J.O. Helgesen. 1976. Water resources of the Rainy Lake watershed, northeastern Minnesota. U. S. Geological Survey, Hydrologic Investigations Atlas HA-556, Washington, D.C.

Ferguson, M.M., and G.A. Duckworth. 1997. The status and distribution of lake sturgeon, *Acipenser fulvescens*, in the Canadian province of Manitoba, Ontario and Quebec: a genetic perspective. Environmental Biology of Fishes 48:299-309.

Fortin, R., J.-R. Mongeau, G. Desjardins, P. Dumont. 1993. Movements and biological statistics of lake sturgeon (*Acipenser fulvescens*) populations from the St. Lawrence and Ottawa River system, Quebec. Canadian Journal of Zoology 71:638-650.

Fortin, R., P. Dumont, and S. Guenette. 1996. Determinants of growth and body condition of lake sturgeon (*Acipenser fulvescens*). Canadian Journal of Fisheries and Aquatic Sciences 53:1150-1156.

Gallep, G.W., and J.J. Magnuson. 1972. Effects of negative buoyancy on the behavior of the bluegill, *Lepomis macrochirus* Rafinesque. Transactions of American Fisheries Society 101:507-512.

Gardiner, B.G. 1984. Sturgeons as living fossils. Pages 148-152 *in* N. Eldridge, and S.M. Stanley, editors. Living fossils, Springer Verlag, New York.

Harkness, W.J.K., and J.R. Dymond. 1961. The Lake sturgeon. Ontario Department of Lands and Forests, Toronto.

Hart, L.G., and R.C. Summerfelt. 1975. Surgical procedures for implanting ultrasonic transmitters into flathead catfish (*Pylodictis olivaris*). Transactions of the American Fisheries Society 104:56-59.

Holzkamm, T.E., V.P. Lytwyn, and L.G. Waisberg. 1988. Rainy River sturgeon: an Ojibway resource in the fur trade economy. The Canadian Geographer 32:194-205.

Houston, J.J. 1987. Status of lake sturgeon, *Acipenser fulvescens*, in Canada. Canadian Field-Naturalist 101:171-185.

International Rainy Lake Board of Control/International Lake of the Woods Control Board (IRLBC/ILWCB). 1984. Briefing paper submitted to the International Joint Committee.

Ishida, Y., A. Yano, M. Ban, and M. Ogura. 2001. Vertical movement of a chum salmon *Oncorhynchus keta* in the western north Pacific Ocean as determined by a depth-recording archival tag. Fisheries Science 67:1030-1035.

Kallemeyn, L.W. 1983. Action plan for aquatic research at Voyageurs National Park. Park Science 4:18.

Kallemeyn, L.W. 1987a. Correlations of regulated lake levels and climatic factors with abundance of young-of-the-year walleye and yellow perch in four lakes in Voyageurs National Park. North American Journal of Fisheries Management 7:513-521.

Kallemeyn, L.W. 1987b. Effects of regulated lake levels on northern pike spawning habitat and reproductive success in Namakan Reservoir, Voyageurs National Park. U.S. Department of the Interior, National Park Service, Research-Resources Management Report MWR-8, Omaha, Nebraska.

Kallemeyn, L.W., M.H. Reiser, D.W. Smith, and J.M. Thurber. 1988. Pages 133-146 *in* D.A. Wilcox, editor. Interdisciplinary approaches to freshwater wetlands research. Michigan State University Press, East Lansing.

Kallemeyn, L.W., Y. Cohen, and P. Rodomski. 1993. Rehabilitating the aquatic ecosystem of Rainy Lake and Namakan Reservoir by restoration of a more natural hydrologic regime. Pages 432-448 *in* L.W. Hesse, C.B.Stalnaker, N.G Benson, and J.R. Zuboy, editors. Restoration planning for the rivers of the Mississippi River ecosystem. U.S. Department of the Interior, National Biological Survey Biological Report 19, Washington, D.C.

Knights, B.C., J.M. Vallazza, S.J. Zigler, and M.R. Dewey. 2002. Habitat and movement of lake sturgeon in the upper Mississippi River System, USA. Transactions of the American Fisheries Society 131:507-522.

Lagler, K.F. 1956. Freshwater fishery biology, second edition. Wm. C. Brown Company Publishers, Dubuque, Iowa.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. 1980. Atlas of North American freshwater fishes. North Carolina State Museum of Natural History, Publication No. 1980-12, Raleigh.

Lyons, J., and J.J. Kempinger. 1992. Movements of adult lake sturgeon in the Lake Winnebago System. Wisconsin Department of Natural Resources, Research Report No. 156, Madison.

Maceina, M.J., and M.R. Stimpert. 1998. Relations between reservoir hydrology and crappie recruitment in Alabama. North American Journal of Fisheries Management 18:104-113.

Mackay, W.C., G.R. Ash, and H.J. Norris. 1990. Fish ageing methods for Alberta. R. L. and L. Environmental Services Ltd., in association with Alberta Fish and Wildlife Division and University of Alberta, Edmonton.

Magnin, E. 1966. Recherches sur les cycles de reproduction des sturgeons *Acipenser fulvescens Rafinesque*, Annales de la Station Centrale d'Hydrobiologie appliquee 9:8-242.

McCleave, J.D., and K.A. Stred. 1975. Effect of dummy telemetry transmitters on stamina of Atlantic salmon (*Salmo salar*) smolts. Journal of the Fisheries Research Board of Canada 32:559-563.

McKinley, S., G.V. Der Kraak, and G. Power. 1998. Seasonal migrations and reproductive patterns in the lake sturgeon, *Acipenser fulvescens*, in the vicinity of hydroelectric stations in northern Ontario. Environmental Biology of Fishes 51:245-256.

Mcleod, D.T. 1999. An assessment of lake sturgeon populations in the lower Seine River system, Ontario 1993-95. Ontario Ministry of Natural Resources, District Report Series No. 43, Fort Frances.

Minnesota Department of Natural Resources (MN DNR). 2003. Minnesota's list of endangered, threatened, and special concern species. Minnesota Rules, Chapter 6134. Available: www.dnr.state.mn.us/ets/fish/html (September, 2003).

Minnesota Department of Natural Resources/Ontario Ministry of Natural Resources (MN DNR/OMNR). 1998. Minnesota-Ontario boundary waters fisheries atlas for Lake of the Woods, Rainy River, Rainy Lake, Namakan Lake, and Sand Point Lake. Minnesota Department of Natural Resources, Section of Fisheries, St. Paul, and Ontario Ministry of Natural Resources, Toronto.

Moser, M.L., A.F. Olson, and T.P. Quinn. 1990. Effects of dummy ultrasonic transmitters on juvenile coho salmon. American Fisheries Society Symposium 7:353-356.

Mosindy, T. 1987. The lake sturgeon (*Acipenser fulvescens*) fishery of Lake of the Woods, 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, Toronto.

Mosindy, T., and J. Rusak. 1991. An assessment of lake sturgeon populations in Lake of the Woods and the Rainy River 1987-90. Ontario Ministry of Natural Resources, Lake of the Woods Fisheries Assessment Unit Report 1991:01, Toronto.

Nilo, P., P. Dumont, and R. Fortin. 1997. Climatic and hydrological determinants of year-class strength of St. Lawrence River lake sturgeon (*Acipenser fulvescens*). Canadian Journal of Fisheries and Aquatic Sciences 54:774-780.

Noakes, D.L.G., F.W.H. Beamish, and A. Rossiter. 1999. Conservation implications of behavior and growth of the lake sturgeon, *Acipenser fulvescens*, in northern Ontario. Environmental Biology of Fishes 55:135-144.

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, Toronto.

Payne, D.A. 1987. Biology and population dynamics of lake sturgeon (*Acipenser fulvescens*) from the Frederick 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, Toronto.

Pope, K.L., and D.W. Willis. 1996. Seasonal influences on freshwater fisheries sampling data. Reviews in Fisheries Science 4:57-73.

Priegel, G.R., and T.L. Wirth. 1975. Lake sturgeon harvest, growth, and recruitment in Lake Winnebago, Wisconsin. Wisconsin Department of Natural Resources, Technical Bulletin No. 83, Madison.

Rao, P.V. 1998. Statistical research methods in the life sciences. Duxbury Press, Pacific Grove, California.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada, Bulletin 191, Ottawa.

Rochard, E., G. Castelnaud, and M. Lepage. 1990. Sturgeons (Pisces: Acipenseridae): threats and prospects. Journal of Fish Biology 37:123-132.

Rusak, J.A., and T. Mosindy. 1997. Seasonal movements of lake sturgeon in Lake of the Woods and the Rainy River, Ontario. Canadian Journal of Zoology 74:383-395.

SAS© Institute, Inc. 2000. SAS language reference: dictionary, version 8. SAS Institute, Inc., Cary, North Carolina.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Bulletin 184, Ottawa.

Schaeffer, B. 1973. Interrelationships of chondrosteans. Pages 207-226 *in* P.H. Greenwood, R.S. Miles, and C. Patterson, editors. Interrelationships of fishes, London Academic Press.

Slipke, J.W., and M.J. Maceina. 2000. Fishery analyses and simulation tools (FAST). Auburn University, Auburn, Alabama.

Staggs, M.D., and K.J. Otis. 1996. Factors affecting first-year growth of fishes in Lake Winnebago, Wisconsin. North American Journal of Fisheries Management 16:608–618.

Stasko, A.B., and D.G. Pincock. 1977. Review of underwater biotelemetry, with emphasis on ultrasonic techniques. Journal of the Fisheries Research Board of Canada 34:1261-1285.

Thomas, M.V., and R.C. Haas. 2002. Abundance, age structure, and spatial distribution of lake sturgeon, *Acipenser fulvescens*, in the St. Clair System. Journal of Applied Ichthyology 18:495-501.

Threader, R.W. 1981. Age, growth and proposed management of the lake sturgeon (*Acipenser fulvescens*) in the Hudson Bay lowland. Ontario Ministry of Natural Resources, Moosonee District Report, Toronto.

Vladykov, V.D. 1955. A comparison of Atlantic sea sturgeon with a new subspecies from the Gulf of Mexico (*Acipenser oxyrhynchus de sotoi*). Journal of the Fisheries Research Board of Canada 12:754-761.

Williams, J.E., J.E. Johnson, D.A. Hendrickson, S. Contreras-Balderas, J.D. Williams, M. Navarro-Mendoza, D.E. McAllister, and J.E. Deacon. 1989. Fishes of North America endangered, threatened, or of special concern: 1989. Fisheries 14(6):2-20.

Wilson, N.C. 1987. Age determination of lake sturgeon (*Acipenser fulvescens*) by use of the marginal pectoral fin ray. Pages 77-83 *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, Toronto.

Winter, J. 1996. Advances in underwater biotelemetry. Pages 555-590 *in* B.R. Murphy, and D.W. Willis, editors. Fisheries techniques, second edition. American Fisheries Society, Bethesda, Maryland.