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Lake sturgeon population characteristics in Rainy Lake, Minnesota and Ontario

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Summary

Rainy Lake contains a native population of lake sturgeon *Acipenser fulvescens* that has been largely unstudied. The aims of this study were to document the population characteristics of lake sturgeon in Rainy Lake and to relate environmental factors to year-class strength for this population. Gill-netting efforts throughout the study resulted in the capture of 322 lake sturgeon, including 50 recaptures. Lake sturgeon in Rainy Lake was relatively plump and fast growing compared with a 32-population summary. Population samples were dominated by lake sturgeon between 110 and 150 cm total length. Age–structure analysis of the samples indicated few younger (< 10 years) lake sturgeon, but the smallest gill net mesh size used for sampling was 102 mm (bar measure) and would not retain small sturgeon. Few lake sturgeon older than age 50 years were captured, and maximum age of sampled fish was 59 years. Few correlations existed between lake sturgeon year-class indices and both annual and monthly climate variables, except that mean June air temperature was positively correlated with year-class strength. Analysis of Rainy Lake water elevation and resulting lake sturgeon year-class strength indices across years yielded consistent but weak negative correlations between late April and early June, when spawning of lake sturgeon occurs. The baseline data collected in this study should allow Rainy Lake biologists to establish more specific research questions in the future.

Introduction

Although the lake sturgeon *Acipenser fulvescens* is a Minnesota state-listed species of special concern (Minnesota Department of Natural Resources (MN DNR), 1996), few population characteristics have been determined for this fish in Rainy Lake, Minnesota and Ontario. The limited information is especially of concern because females of this species typically may not mature until they are age 20 (Auer, 1996) and may spawn only once every 7–9 years (Roussow, 1957).

Dams constructed on the outlets of Rainy and Namakan lakes in the early 1900s prevent the upstream movement of lake sturgeon and have isolated the populations in the resulting Rainy and Namakan reservoirs from each other and from known populations in the Rainy River and Lake of the Woods (Mosindy and Rusak, 1991). Although commercial fishing occurred in Rainy Lake through 1990, natural resource agencies in Minnesota and the province of Ontario have now established harvest regulations to protect the lake sturgeon.

Environmental variables can affect recruitment in many freshwater fishes. 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 hydrologic variables. Year-class strength was determined during the first months of life, with climatic and hydrologic conditions in June being important.

Regulated lake levels have been part of the hydrology of Rainy Lake since the early 1900s with the operation of a hydroelectric dam at the outlet of Rainy Lake and two regulatory dams on Namakan Reservoir immediately 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 came to the forefront with the establishment of Voyageurs National Park in 1975 (Cole, 1979, 1982). Initial research by the US National Park Service attempted to establish alternatives to the existing water management plan (Kallemeyn, 1983). Research was directed toward the primary sport fishes of Rainy Lake, including walleye *Sander vitreus* and northern pike *Esox lucius* (Kallemeyn, 1987a,b), with no work directed at lake sturgeon.

The aims of this study were to document the lake sturgeon population characteristics and assess recruitment patterns in Rainy Lake. Specifically, we determined lake sturgeon population size structure, weight–length relation, condition, age structure, mortality, and growth. Age structure was then related to climatology and reservoir water levels to assess potential relations with year-class strength.

Study site

Rainy Lake is located on the northern Minnesota–Ontario border and 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. The North Arm and Redgut Bay are both located entirely in Canada. All lake sturgeon captured in this study were from the South Arm. The South Arm runs for 56 km along the border of the USA and Canada, with approximately 45% of the surface area in the USA. Of this area, 91% of the South Arm lies within Voyageurs National Park. 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.

Commercial harvest of lake sturgeon was allowed on the U.S. side of Rainy Lake through 1940 and on the Canadian side through 1990 (Fig. 1). The commercial harvest of lake sturgeon in Rainy Lake peaked in 1959 at 2762 kg, with all fish taken from Canadian waters. Harvest declined to 1007 kg by 1964, and never again exceeded that level. Harvest was nearly

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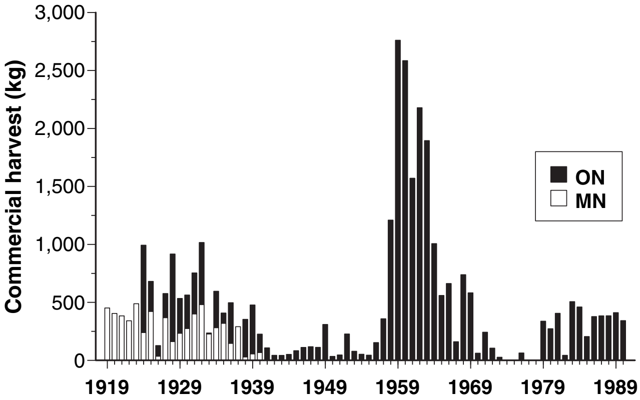

Fig. 1. Commercial harvest of lake sturgeon from Rainy Lake, Minnesota (MN) and Ontario (ON), from 1919 to 1990. Commercial fishing discontinued in MN waters in 1940, and in ON waters in 1990

zero from 1974 to 1978, but then averaged 345 kg annually from 1979 to 1990.

Methods

Lake sturgeon were collected using nylon 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 recorded by the various biologists involved in fish collection. Net lengths varied between 30 and 273 m, with all nets having a height of 1.83 m. Fish were collected during May and October of 2002; May, June, August, and October of 2003; and May, June, and August of 2004 at 27 sampling locations on the South Arm (Fig. 2). All fish captured were measured for total (TL) and fork (FL) lengths (mm) and weight (kg). An anterior, proximal portion of the pectoral fin was taken from each fish for age determination.

Lake sturgeon size structure was qualitatively assessed by inspection of length–frequency histograms. The TL (mm) and weight (kg) relationship was assessed for this population using logarithmic transformation (base 10) of both variables to linearize the relation. Fortin et al. (1996) provided a method that we used to compare condition (i.e. plumpness) of lake sturgeon; they calculated mean weights of 1000-mm (TL; sexes pooled) lake sturgeon from 32 lakes or river sectors across the distribution of the species in the USA and Canada.

Pectoral fin rays were allowed to dry for approximately 1 month 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 with an Olympus Model SZH1D 0.7-7.0 microscope.

Age structure analysis was conducted on pooled data for the 3 years so that the sample size would be sufficient, and thus was performed 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 the first fully recruited to the sampling gear because all younger cohorts were less abundant; the 1965 year-class was the last year-class for which a minimum of five lake sturgeons were sampled. To complete the catch curve, ages had to be assigned to each year-class, so we 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 was first summarized as mean length at time of capture by age group, even though individual fish within a cohort may have been captured any time between May and October. We compared lake sturgeon growth in Rainy Lake with growth rates for 32 lake sturgeon populations from the USA and Canada using the mean of mean TL at ages 23–27 years (sexes pooled) as previously undertaken by Fortin et al. (1996). The von Bertalanffy growth functions were also fit to the Rainy Lake sturgeon data set using the Fishery Analyses and Simulation Tools (FAST) software (Slipke and Maceina, 2000).

The residual method was used to index year-class strength (Maceina and Stimpert, 1998). A catch curve was first developed by plotting the natural logarithm (base e) of the

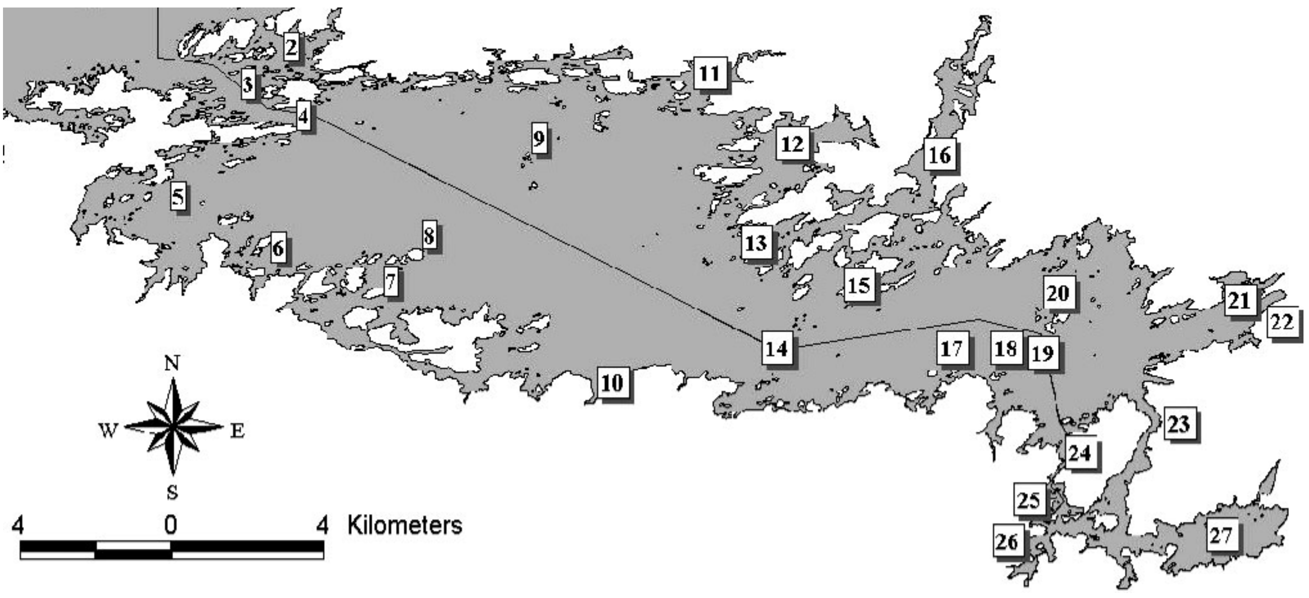

Fig. 2. Locations of lake sturgeon sampling sites on the South Arm of Rainy Lake, 2002–2004. The east–west line progressing through the lake indicates the international border between the USA and Canada. 1, Seine River; 2, Canoe Channel; 3, Brule Narrows; 4, Soldier Point; 5, Saginaw Bay; 6, Finlader Bay; 7, Norway Island; 8, Shelland Island; 9, Anchor Island; 10, Browns Bay; 11, Moose Bay; 12, Cormorant Bay; 13, Green Island; 14, Minitaki Island; 15, Blackpoint Island; 16, Rat River Bay; 17, Sand Bay Island; 18, Rabbit Island; 19, US marker 39; 20, Breezy Island; 21, Stokes Bay; 22, Pipestone River; 23, Canadian Channel; 24, American Channel; 25, Kettle Falls; 26, Squirrel Falls; 27, Hale Bay

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 were indicated by positive residuals. The residuals were then related to climatologic and hydrologic data from Rainy Lake. Climate data were obtained from the National Oceanic and Atmospheric Administration International Falls Station. Hydrologic data were obtained from the Lake of the Woods Control Board. Because this was an exploratory analysis, we used the correlation procedure (PROC CORR) in SAS (SAS© Institute, Inc., 1999) 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 some of the climatologic and hydrologic variables were non-normally distributed. Therefore, we used the non-parametric Spearman rank correlation for the analyses. 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

Population characteristics

Captured during this study were 322 lake sturgeon, 50 of which were recaptures. The majority (217; 67.4%) was collected below the Squirrel Falls Dam (Fig. 2). Over the 3-year period, 283 lake sturgeon were collected and TL measurements taken (Fig. 3); these fish ranged from 83 to 166 cm, with most from 110 to 150 cm. Based on 275 lake sturgeon for which both TL and FL measurements were obtained, the two measures were highly correlated [TL = 48.26 + 1.06(FL); r = 0.988; P = 0.0001].

Total length (mm) and weight (kg) measurements for 271 lake sturgeon exhibited the expected curvilinear relation between weight and length. Logarithmic transformation linearized the relationship: $\log_{10}$ (weight) = −8.323 + 3.033($\log_{10}$TL), where weight is in kg and TL is in mm (r = 0.94; P = 0.0001). Based on this relationship, a 1000-mm lake sturgeon from Rainy Lake would typically weigh 5970 g (5.97 kg).

Pectoral fin rays were removed from 259 lake sturgeon for aging purposes. Maximum age for the lake sturgeon population sample from Rainy Lake was 59. Fish were assigned to year classes ranging from 1945 to 1995 (Fig. 4), with most between 1970 and 1984. Catch-curve analysis indicated that instantaneous total mortality (Z) was 0.0481 (Fig. 5). Total annual mortality (A) for lake sturgeon from 1984 back to 1965 thus was calculated to be 4.7%, indicating annual survival (S) of 95.3% (Fig. 5).

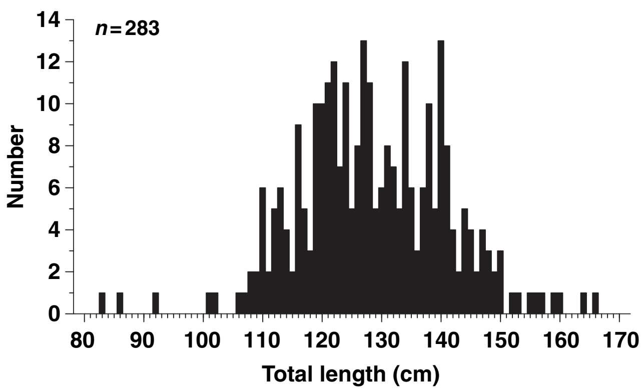

Fig. 3. Length frequency of lake sturgeon collected from the South Arm of Rainy Lake, 2002–2004; n = total number of fish, sexes combined

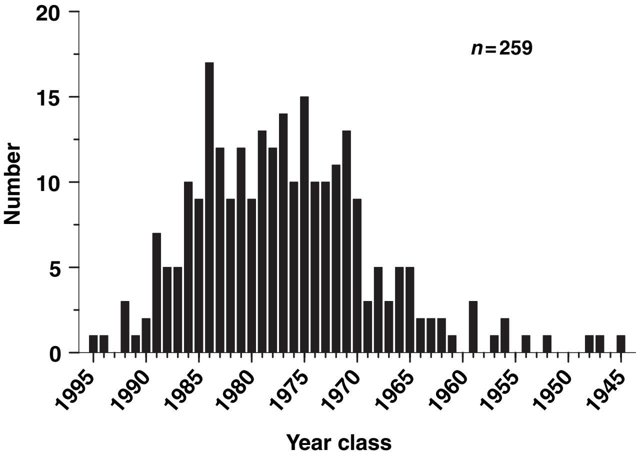

Fig. 4. Age structure for 259 lake sturgeon (sexes combined) collected from the South Arm of Rainy Lake, 2002–2004

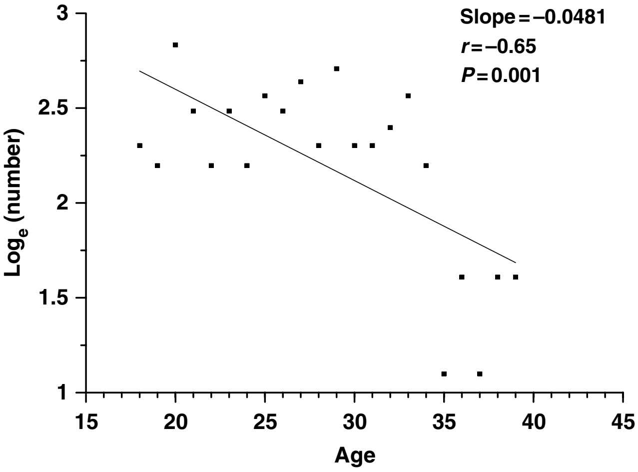

Fig. 5. Catch curve for lake sturgeon from the 1965 (assigned age group 39) to 1986 (age group 18) year classes in the South Arm of Rainy Lake. The residuals for each data pair were used as an index to year-class strength for lake sturgeon, with negative residuals indicating weaker year classes and positive residuals indicating strong year classes

Aged were 237 lake sturgeon to provide a growth summary for the Rainy Lake population (Table 1). The Rainy Lake population mean of mean lengths for ages 23–27 was 1289 mm (sexes pooled). Very 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, mean values for females exceeded the mean values for pooled sexes in all but one case, while mean values for males were similar to those for the pooled mean values (Table 1).

The von Bertalanffy model provided a reasonable model of lake sturgeon growth data (r = 0.90; P < 0.001). Ultimate length ($L\infty$; also termed asymptotic size) was 1403.8 mm, the Brody growth coefficient (K) was −0.11, and the hypothetic age at which the fish were 0 mm (t_0) was −0.56.

Assessment of recruitment

The catch curve for the Rainy Lake sturgeon population (Fig. 5) 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.

Table 1
Mean total length (TL; mm) at time of capture by age group for lake sturgeon collected from the South Arm of Rainy Lake, 2002–2004

	Sexes pooled			♂			♀		
Age	n	TL	SE	n	TL	SE	n	TL	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		
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		

Overall sample size (sexes pooled) often exceeds the total for male and female fish because all fish were not sexed.
n, sample size; SE, standard error of the mean; ♂, male; ♀, female.

The lake sturgeon year-class index was not correlated with any of the annual climate variables measured at International Falls. Correlation coefficients were ≤0.15 (P ≥ 0.50) for all five variables (total precipitation; maximum, minimum, and mean air temperature; and total snowfall). We also found no correlation between the year-class index and precipitation during the spawning season (May to June; $r_s = 0.15$, P = 0.50) and precipitation during June to August ($r_s = -0.11$, P = 0.62).

When the lake sturgeon year-class index was correlated with monthly mean values for air temperature at International Falls, most relations were non-significant. However, the year-class index was significantly and positively correlated with June temperature data ($r_s = 0.59$; P = 0.004; Fig. 6). Even after a Bonferroni correction for multiple comparisons, this relationship may be worthy of further investigation, as $\alpha = 0.05/12$ comparisons yield 0.004.

We found little evidence of correlations between the Namakan Lake discharge into Rainy Lake and our index to lake sturgeon year-class strength. A potentially significant correlation was only evident for mean discharge from August 11 through 20 ($r_s = -0.50$; P = 0.02). However, the P-value for this relationship would be non-significant after a Bonferroni adjustment.

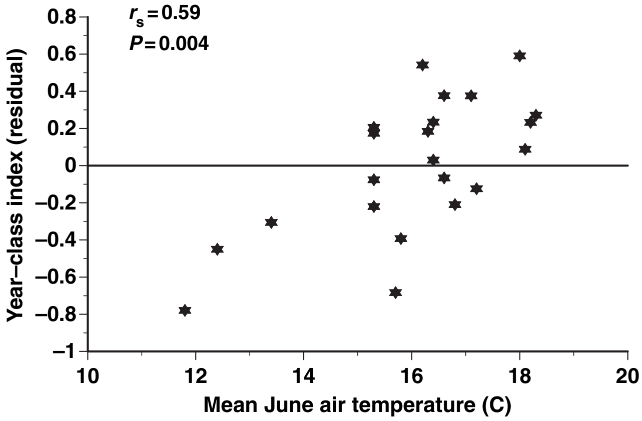

Fig. 6. Relation between lake sturgeon year-class index (residual from catch-curve analysis) in the South Arm of Rainy Lake and mean June air temperature at International Falls, Minnesota, 1965–1986 (n = 22). Empirical data are plotted, while the analysis was completed with a Spearman rank correlation (r_s) because temperature data were not normally distributed

The lake sturgeon year-class strength index may be related to Rainy Lake elevations across years (Table 2). Correlation coefficients exceeded 0.4 between days 110 and 160, the time period between late April and early June that encompasses the spawning and hatching period for lake sturgeon in Rainy Lake. While these correlations are relatively weak and Bonferroni corrections would render them non-significant, the same negative relations consistently appeared for consecutive time periods over those six increments of 10 days each.

Discussion

Because of the lack of previous research, comparison of population characteristics derived from this study with other lake sturgeon populations is crucial to properly ascertain the current state of lake sturgeon in Rainy Lake. Summaries of neighboring lake sturgeon population characteristics provided the foundation for our comparisons. Fortin et al. (1996) provided a summary of mean weights for 1000 mm (TL; sexes pooled) lake sturgeon from 32 lakes or rivers sectors across the distribution of the species in the USA and Canada; only 11 of those 32 mean values were higher than the Rainy Lake mean weight of 5.97 kg. The mean weight of 1000-mm lake sturgeon in the nearby (i.e. downstream from Rainy Lake) Lake of the Woods/Rainy River system was 6.1 kg, similar to our Rainy Lake predicted weight of 5.97 kg.

The Rainy Lake population mean of mean lengths for ages 23–27 was 1289 mm (sexes pooled), which exceeded 26 of the 32 populations summarized by Fortin et al. (1996) from the USA and Canada. While we primarily calculated von Bertalanffy growth parameters to allow future population modeling, Mosindy (1987) provided comparison data in the form of an $L\infty$ of 1421 mm, K of −0.085, and a t_0 of −0.0306 for lake sturgeon in the Lake of the Woods/Rainy River system. While we found a maximum age of 59 for the lake sturgeon in our Rainy Lake sample, Fortin et al. (1993) reported lake sturgeon maximum ages of 25 years (131 cm) from Lac des Deux Montagnes, 49 years (162 cm) from Lac Saint-Pierre, Quebec, and 97 years (187 cm) from Lac Saint Louis. Finally, our estimate of lake sturgeon total annual mortality in Rainy Lake was 4.7% over ages 18–39, quite similar to the 4.6% rate determined for lake sturgeon in the St Mary's River system, Michigan for ages 5–55 (Dr T. Sutton, Purdue University, pers. comm.).

The limited number of fish shorter than 110 cm in our samples is probably due to the 102-cm mesh being the smallest used for sampling; smaller lake sturgeon would swim through these nets. However, based on other studies (e.g. Fortin et al., 1993; Bruch, 1999), we expected to collect more lake sturgeon from 165 to 185 cm. 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. 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. 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 this harvest. Older year classes may have been substantially affected by the commercial fishing that did not end until after 1990 in Rainy Lake, while younger cohorts may have been too small to be commercially harvested 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).

We found erratic recruitment (i.e. year-class strength) for lake sturgeon in Rainy Lake. Similarly, 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, while Priegel and Wirth (1975) reported variable recruitment in the lake sturgeon population in Lake Winnebago, Wisconsin.

The lake sturgeon year-class index was not correlated with any of the annual climate variables measured at International Falls (Adams, 2004). However, the year-class index was significantly and positively correlated with June temperature data. This relationship is 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 develop later, thus potentially affecting growth and survival of the young lake sturgeon. Nilo et al. (1997) found positive correlations between year-class strength and daily rate of increase in St Lawrence River water temperatures in May and June.

The only potentially significant correlation between lake sturgeon year-class strength and discharge from upstream Namakan Reservoir into Rainy Lake involved mean discharge during mid-August. We are not certain of a biologic explanation for influence caused by August discharge data, especially as all correlations with the 11 other time periods were non-significant (Adams, 2004).

The lake sturgeon year-class strength index was negatively related to Rainy Lake elevations from day of year 100–160 across years. While these correlations are relatively weak ($r_s \leq 0.52$), we suggest that the consistent correlations by 10-day increments over that 60-day period indicate potential for biologic validity. Higher Rainy Lake water levels during this period were thus related to weaker lake sturgeon year-classes, which at first seem counterintuitive compared with most fish ecology investigations. However, habitat for spawning and early life history may be optimal at lower lake levels than higher lake levels. At the least, we believe that further investigation along these lines is warranted. Kallemeyn (1987a,b) found that the water level management program in place from 1970 to 1999 had adverse effects on walleye and

Table 2
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

northern pike in the Voyageurs National Park aquatic ecosystem and that knowledge of effects on lake sturgeon would be valuable.

Our analysis of age structure and year-class strength 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, age interpretation is not a simple exercise (Threader and Brousseau, 1986). 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. As previously mentioned, differential commercial harvest of younger and older cohorts may have violated that assumption.

The data collected in our study should provide biologists from multiple agencies with insight into population characteristics of lake sturgeon inhabiting Rainy Lake. All lake sturgeon captured during 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. Thus, future research in these two locations would be advisable to truly understand the lake sturgeon population in Rainy Lake.

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