

**Detection of Natural Barriers to Lake Sturgeon Movement within the Namakan River,  
Ontario**

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2 the Namakan River, Ontario.

3

4 **Abstract**

5 Many lake sturgeon (*Acipenser fulvescens* Rafinesque, 1817) populations are below historic  
6 population sizes and migration barriers have likely contributed to some of these population  
7 declines. Dams and natural barriers can potentially isolate populations along a single river and  
8 can have a strong effect on the ability of lake sturgeon to move upstream. Along the Namakan  
9 River in Ontario, a series of natural rapids could impede lake sturgeon movement and fragment  
10 the sturgeon into several small populations. Lake sturgeon movement patterns were assessed  
11 using genetics and acoustic telemetry. Samples were collected from five locations along the  
12 river, each one separated by a rapid or falls, and were analyzed at 12 microsatellite loci. No  
13 significant genetic differences were observed between the five segments, indicating that the lake  
14 sturgeon groups are not isolated. There were no significant differences in genetic diversity  
15 between the five segments. Therefore, migration is likely occurring both upstream and  
16 downstream. The acoustic telemetry study also confirmed bidirectional movement of adult fish.  
17 The natural rapids and falls along the Namakan River do not appear to be a significant barrier to  
18 lake sturgeon movement and the lake sturgeon within this river represent a single population.

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20

21

22 **Introduction**

23           The lake sturgeon (*Acipenser fulvescens* Rafinesque, 1817) has a wide range throughout  
24 North America, including the Great Lakes and St Lawrence River, Lake Winnipeg, Hudson Bay,  
25 and the Mississippi River systems. Many populations throughout their range are reduced in size  
26 relative to historic population numbers due mainly to overfishing and habitat modifications  
27 (Peterson et al. 2007). Although fishing has been restricted in many jurisdictions, habitat  
28 changes, such as the construction and operation of dams, continue to have an effect on some lake  
29 sturgeon populations. On the Ottawa River, greater abundance and faster growth of lake  
30 sturgeon were observed on reaches that were not impounded (Haxton and Findlay 2008). On the  
31 Mattagami River, hydroelectric operations appeared to have an effect on reproductive  
32 development (McKinley et al. 1998). Flow regimes on the Sturgeon River had an impact on  
33 sturgeon spawning activity (Auer 1996a). In the Red River of the North basin, lake sturgeon  
34 have been extirpated due to dams blocking access to historic spawning grounds (Aadland et al.  
35 2005).

36           Studies on lake sturgeon movements can provide additional information on the potential  
37 impacts of natural and artificial barriers. Current studies offer conflicting information, with  
38 some reporting large migration distances and others reporting minimal movement. In the Great  
39 Lakes, a range of adult migration distances from 32-225 km have been reported (reviewed in  
40 Auer 1996b). Movements of juveniles appear to be shorter (Holtgren and Auer 2004; Smith and  
41 King 2005). In the upper Mississippi River, lake sturgeon movements ranged from 3-198 km,  
42 with fish moving both upstream and downstream past dams (Knights et al. 2002). In the Ottawa  
43 River, movements of four radio-tracked lake sturgeon were limited (Haxton 2003). The sturgeon  
44 remained in their respective basins and the maximum distance traveled was 10 km.

45           The Namakan River in Ontario contains several rapids and falls that may act as potential  
46 barriers to complete migration along the river. The river connects Lac La Croix to Namakan  
47 Lake and ultimately flows into the Rainy River/Lake of the Woods within the Lake Winnipeg  
48 drainage system (Figure 1). At least nine natural rapids and four falls exist along the river and  
49 the objective of this study was to determine if any of these rapids significantly limit movement of  
50 lake sturgeon along different stretches of the river. Lake sturgeon are known to occur  
51 throughout the Namakan River from Lac La Croix downstream to Namakan Reservoir. An  
52 understanding of current lake sturgeon movement along the river and an identification of natural  
53 barriers can help evaluate the potential effects of construction of the proposed generation sites.

54           We tested the hypothesis that areas of rapid elevation change (rapids and falls) along the  
55 Namakan River would present significant barriers to adult lake sturgeon movement throughout  
56 the system. We predicted that the rapids may not impede downstream movement in the system,  
57 but upstream movement would be limited. This prediction was tested using genetic analysis and  
58 acoustic telemetry. Insignificant genetic differentiation between groups on either side of the  
59 rapids would result from downstream movement. However, higher levels of genetic diversity  
60 would be expected at downstream locations due to the higher level of immigration (Jager et al.  
61 2001). Upstream locations would be expected to have a lower number of alleles and lower  
62 heterozygosity. Significant differences in upstream and downstream movements of adult  
63 sturgeon tracked with acoustic telemetry would also confirm the prediction.

64

## 65 **Methods**

### 66 *Study Site*

67           The Namakan River is located immediately downstream of Lac La Croix and upstream of  
68 Namakan Reservoir (Figure 1), approximately 80 km southeast of Fort Frances, Ontario. This  
69 mesotrophic river is found in the southern range of the boreal forest in North America, and is  
70 typical of Canadian Shield lakes and rivers with soft water and little submerged aquatic  
71 vegetation. The Namakan River drains close to 8,860 km<sup>2</sup> in Ontario with an elevation drop of  
72 19.2 m over a distance of 30.5 km from Lac La Croix to Namakan Reservoir (OPEG 2007).

73           A number of potential barriers to fish migration exist along the river from the outlet of  
74 Lac La Croix downstream to the Namakan Reservoir. The following elevation changes are  
75 reported for the various rapids/falls under average flow conditions: 3.2 m at Snake Falls (29 rkm  
76 upstream), 4.0 m at Myrtle Falls and Ivy Falls (25 rkm upstream), 1.0 m at Twisted Rapids (20  
77 rkm upstream), 0.7 m at Quetico Rapids (14.7 rkm upstream), 6.8 m at High Falls (11.7 rkm  
78 upstream), 7.0 m at the Back Channel (over 2 km and 8-9 rapids; 10.2 rkm upstream), 3.0 m at  
79 Hay Rapids (7.4 rkm upstream), and 1.6 m at Lady Rapids (4 rkm upstream) (Figure 1) (OPEG  
80 2007).

81           Water levels and flows in the Namakan River are not regulated. A Meteorological  
82 Service of Canada (Environment Canada) water level gauge at the outlet of Lac La Croix  
83 provides relevant information on inflows to the Namakan River since 1921 (LWCB, 2008). A  
84 maximum flow of 771 m<sup>3</sup>/sec was recorded in June, 1950 while a minimum flow of 15 m<sup>3</sup>/sec  
85 was recorded in January, 1977 and February, 1924. Annual flow metrics derived from a recent  
86 20-year period (1980-1999) provided a mean and median flow of 118 m<sup>3</sup>/sec and 87 m<sup>3</sup>/sec  
87 respectively. Time exceeded (percentile) flows are estimated at 182 m<sup>3</sup>/sec (20%) and 51 m<sup>3</sup>/sec  
88 (80%).

### 89 ***Sample Collection***

90 Fin clips from the tip of the pectoral fin were collected during spring 2007 from lake  
91 sturgeon at five suspected spawning sites along the Namakan River: A) below Lady Rapids  
92 ( $n=31$ ), B) below Hay Rapids ( $n=30$ ), C) below the Back Channel (Little Eva Lake) ( $n=31$ ), D)  
93 below Quetico Rapids (Bill Lake) ( $n=14$ ), and E) below Ivy Falls ( $n=23$ ) (Figure 1). Groups  
94 consisted of a mixture of mature and immature/developing fish so not all the samples came from  
95 actively spawning adults. However, sampling was conducted during the active spawning season  
96 and water temperatures were within the range conducive for spawning.

### 97 *Genetic Analysis*

98 Tissue samples were preserved in 95% ethanol. DNA was extracted using either the  
99 Promega Wizard SV 96 Genomic DNA Purification System or the Gentra Puregene Tissue Kit,  
100 according to manufacturers' protocols. Extracts were then quantified either using a microplate  
101 reader or a fluorometer. Twelve microsatellite loci were then amplified (AfuGs 9, 56, 63, 74,  
102 112, 160, 195, 204; Afu 68, 68b; Spl 120; Aox 27; described in Welsh and May 2006). PCR  
103 reagents included: 1X PCR buffer, 1.5 mM MgCl<sub>2</sub>, 0.2 mM dNTPs, 0.2 μM fluorescently-  
104 labeled forward primer, 0.2 μM unlabeled reverse primer, 0.25 U GoTaq polymerase (Promega),  
105 and 20 ng of DNA. A BioRad iCycler was used and thermal cycling conditions for all loci  
106 (except AfuG 56 and Spl 120) were as follows: 95°C for two minutes; 40 cycles of 95°C for 30  
107 seconds, 52°C for 30 seconds, and 72°C for 45 seconds; 72°C for seven minutes, ending with a  
108 4°C hold. Thermal cycling conditions for AfuG 56 and Spl 120 were: 94°C for one minute; 20  
109 cycles of 92°C for 30 seconds and 70°C for 40 seconds with a 0.5°C decrease in the second step  
110 each cycle; 20 cycles of 92°C for 30 seconds and 60°C for 40 seconds with a one-second increase  
111 in the second step each cycle; ending with a 4°C hold. PCR products were then pooled into three  
112 groups and visualized on a Beckman Coulter CEQ 8000 Genetic Analysis System.

113 Each sampled group was tested for conformance to Hardy-Weinberg equilibrium (HWE)  
114 and for linkage disequilibrium (LD) between locus pairs using the software GDA (Lewis and  
115 Zaykin 2001). The five sampled groups were also pooled together to determine if the river as a  
116 whole was in Hardy-Weinberg equilibrium. Genetic differentiation between groups along the  
117 Namakan River was measured using the Weir and Cockerham (1984) estimator of  $F_{ST}$  (estimated  
118 using the software Arlequin (Schneider et al. 2000)) and pairwise contingency tests of allele  
119 frequency heterogeneity (Raymond and Rousset 1995), estimated using the software TFPGA  
120 (Miller 1997).  $F_{ST}$  values can range from zero to one, with zero signifying no genetic  
121 differentiation and one indicating complete differentiation at all loci. The significance of the  
122 pairwise  $F_{ST}$  comparisons was based on 3,024 permutations. For the pairwise contingency tests,  
123 10 batches of 2000 permutations each were run, with 1,000 dememorization steps. Significance  
124 of the HWE, LD, pairwise  $F_{ST}$ , and contingency tests was assessed after a sequential Bonferroni  
125 correction (Rice 1989). Genetic distance was also calculated and a Mantel test (Mantel 1967)  
126 was performed to determine if there was a correlation between genetic distance and geographic  
127 distance and the number of potential barriers. Significance of the Mantel test was based on 999  
128 permutations and the analysis was performed using the software GENALEX (Peakall and  
129 Smouse 2006).

130 Genetic diversity of each group along the Namakan River was also measured using  
131 heterozygosity and allelic richness (number of alleles corrected for differences in sample size; El  
132 Mousadik and Petit 1996). TFPGA was used to calculate heterozygosity and the software  
133 FSTAT (Goudet 2001) was used to measure allelic richness. Significant differences in genetic  
134 diversity were tested using t-tests. A regression was done to determine if there was a correlation

135 between genetic diversity (i.e., heterozygosity and allelic richness) and distance upstream and  
136 number of potential barriers.

### 137 *Acoustic Telemetry*

138 Lake sturgeon were first captured using large mesh (203–305 mm stretched mesh)  
139 multifilament gill nets in May 2007. All fish were sampled for total and fork length (mm), girth  
140 (mm), and round weight (g); tagged with an individually numbered Carlin disk dangler tag; and  
141 live released. A 3-4 cm section of the large, marginal ray of the left pectoral fin was removed for  
142 age determination. Thirty individual fish were selected for surgical implantation of acoustic  
143 transmitters (V16-4L; Vemco - Amirix Systems Inc., Halifax, Nova Scotia) at four different  
144 sample locations: below Hay Rapids ( $n=10$ ), below the Eva Island back channel in Little Eva  
145 Lake ( $n=10$ ), below Quetico Rapids in Bill Lake ( $n=5$ ), and below Ivy Falls in Three Mile Lake  
146 ( $n=5$ ). The transmitters operated at 69 kHz, were 68 x 16 mm in size, and weighed 10 g in water,  
147 therefore did not exceed 2% of the total body weight for any given fish. Each transmitter emitted  
148 a unique code on a random interval of 60 to 120 seconds with a programmed operating life of  
149 2,190 days.

150 Surgical procedures followed guidelines by Hart and Summerfelt (1975), and were  
151 similar to Adams et al. (2006). A 3-5 cm incision was made with a surgical scalpel on the  
152 ventral surface approximately 1 cm off the midline and 3-4 cm anterior to the pelvic girdle. The  
153 transmitter was inserted into the abdominal cavity with minimal pressure exerted on the internal  
154 organs. Following implantation, the peritoneum and associated muscle tissue were closed with a  
155 continuous modified Cushings suture technique (3-0 Ethicon PDS II, ½” CT-2 needle) followed  
156 by five simple interrupted sutures (2-0 Ethicon Prolene, ½” SH needle) to close the skin. Post-

157 operative fish were immediately released at the surgical site which was in close proximity to the  
158 capture site.

159         An array of 13 submersible acoustic receivers (VR2W; Vemco) with Bluetooth wireless  
160 download capability was used to collect data on lake sturgeon locations and movements. The  
161 receivers were 308 x 73 mm in size and weighed 1,450 g in air, with an 8 MB flash memory (1  
162 million detections). Each receiver contained a 3.6 v lithium battery with an expected operating  
163 life of 12-15 months. At selected sample locations, each stationary receiver was suspended  
164 vertically approximately 1 m off bottom with a nylon rope, 15 kg cement anchor, and round net  
165 buoy in water depths of 3- 6 m to avoid winter freeze-up. Anchors were also attached to an  
166 exposed shore anchor or treed shrub with 20-30 m of lead core rope in order to provide easy  
167 deployment and retrieval.

168         The vendor-provided interface software (Vemco User Environment, VUE) was used for  
169 initialization, configuration, data upload, and storage from each receiver. The VUE software  
170 package also allowed data from multiple receivers and transmitters to be combined into a single  
171 integrated database. Each submersible receiver detects and decodes the ultrasonic pulses from  
172 transmitters within approximately 500 m, logging the date, time, and individual transmitter code  
173 for each detection to internal storage.

174         Telemetry data obtained from fish implanted with transmitters were used to examine  
175 movement of fish through rapids/falls, and range of travel within the Namakan River.  
176 Movement of individual lake sturgeon was determined by recording the first daily detection at  
177 each station for every fish detected, and their range within the river was determined using  
178 detections from the two extreme receiver stations traveled. A  $\chi^2$  test was performed to determine

179 if there were significant differences in upstream and downstream movement across potential  
180 barriers.

181

## 182 **Results**

### 183 *Genetic Analysis*

184 All loci in all five sampled groups were in Hardy-Weinberg equilibrium and locus pairs  
185 showed no evidence of linkage disequilibrium. When the five sampled groups were pooled  
186 together as a single population, all loci remained in Hardy-Weinberg equilibrium. There were no  
187 significant genetic differences between the five spawning locations along the Namakan River  
188 (Table 1). Pairwise  $F_{ST}$  values indicated low levels of genetic variation, ranging from 0.00-0.03.  
189 All  $F_{ST}$  values and pairwise contingency values were not significant. Genetic distance was not  
190 correlated with either geographic distance ( $R^2 = 0.002$ ;  $p = 0.075$ ) or the number of potential  
191 barriers ( $R^2 = 0.002$ ;  $p = 0.065$ ) (Figure 2).

192 Average observed heterozygosity across all 12 loci ranged from 0.31 to 0.35. Average  
193 allelic richness ranged from 2.30 to 2.54. Heterozygosity and allelic richness values were similar  
194 among the five different groups (Figure 3). There were no significant differences in levels of  
195 genetic diversity between any of the five groups. Genetic diversity was not correlated to the  
196 distance upstream (heterozygosity:  $R^2 = 0.000$ ;  $p = 0.99$ ; allelic richness:  $R^2 = 0.008$ ;  $p = 0.88$ )  
197 or to the number of potential barriers (heterozygosity:  $R^2 = 0.015$ ;  $p = 0.85$ ; allelic richness:  $R^2 =$   
198  $0.059$ ;  $p = 0.69$ ).

### 199 *Acoustic Telemetry*

200 Lake sturgeon implanted with transmitters had a mean total length of 1,211 mm (863-  
201 1,662 mm), mean girth of 426 mm (329-659 mm), mean round weight of 11,453 g (4,250-30,800

202 g) and mean age of 27.9 year (16-47 years). Based on the round weight of individual fish,  
203 implanted transmitters ranged from 0.03 to 0.23% of body weight. Sex could only be determined  
204 on 15 of the implanted fish (7 females and 8 males). All of the implanted sturgeon were adults at  
205 various stages of sexual development.

206       Eleven submersible receivers were deployed in the Namakan River on May 15 to 25,  
207 2007. Two additional receivers were deployed on April 30 and May 22, 2008 below and above  
208 Snake Falls, in order to investigate potential movements of telemetered fish through Myrtle, Ivy  
209 and Snake Falls in the upper most reaches of the Namakan River (Figure 1). A total of  
210 1,109,290 detections were recorded throughout the Namakan River over the 2007-2008 sampling  
211 period (to October 21, 2008). The maximum number of detections from a single fish was  
212 196,709, while the minimum was 249. In addition, one individual fish was detected at 11 of the  
213 13 stations, over a distance of 28.8 km. Three individuals were detected at one station only, and  
214 the mean number of receivers at which an individual fish was detected was 4.2 (SD = 2.8). Each  
215 receiver detected a mean of 15.0 fish (SD = 9.7) with a range of 0-33.

216       Movements of individual fish through shallow rapids and falls along the river were also  
217 evaluated based on detections from both upstream and downstream receivers (Table 2).  
218 Movements through the proposed hydro development sites at Hay Rapids, Hay Falls, Back  
219 Channel, and Ivy/Myrtle Falls were documented, as well as all other undeveloped sites along the  
220 Namakan River and Quetico River. The only exceptions were that no movements were recorded  
221 through Snake Falls or upstream at High Falls. The maximum number of movements ( $n = 64$ )  
222 was observed at Twisted Rapids at the outlet of Three Mile Lake, and were equally distributed  
223 between upstream and downstream over the sampling period. The most significant observations  
224 were 7 recorded downstream movements of 5 individual fish over High Falls, an elevation drop

225 of 6.8 m. In addition, both upstream and downstream movements of sturgeon through 8-9  
226 shallow rapids in the Back Channel first occurred in October, 2007, with a significantly greater  
227 number of upstream movements ( $p < 0.05$ ) (Table 2). Of the 19 recorded fish movements, the  
228 majority (74%) were moving upstream from Little Eva Lake to Bill Lake.

229

## 230 **Discussion**

231 Lake sturgeon in this telemetry study represented a broad segment of the adult  
232 population, with total lengths ranging from 605 to 1,746 mm and ages ranging from 16 to 47  
233 years. Lake sturgeon can be highly mobile and exhibit complex behaviour patterns, especially in  
234 large systems where movements are not restricted. This study confirmed a smaller range of  
235 movements from 0 to 29 km, which represents the entire distance of the Namakan River to below  
236 Snake Falls. The total distance travelled by these fish will likely increase as additional  
237 movements are documented downstream in the Namakan Reservoir. Several fish ( $n = 6$ ) in this  
238 study showed very limited movement with detections at only one receiver location. The extent  
239 of movement within a season was also highly variable among fish; some fish readily moved  
240 among habitats while movements of others were more constrained. Monthly movements within  
241 the Namakan River indicate that individual sturgeon travelled over a range of 0 to 48.9  
242 km/month from May to October. No movement of fish was observed between receiver locations  
243 from November to April over the two study years. In the Namakan River, lake sturgeon appear  
244 to move upstream in the late summer and fall to possibly forage and over-winter in lake  
245 environments, as well as in early spring to reach potential upstream spawning areas.

246 Both the genetic and acoustic telemetry data suggest that the putative spawning groups  
247 along the Namakan River represent a single population. If the rapids or High Falls along the

248 river have presented a long-term barrier to migration, genetic differences would have likely  
249 accumulated between the groups. Instead, no significant genetic differences were observed  
250 between the groups. However, the level of genetic differentiation was close to significant  
251 between Quetico Rapids and Hay Rapids (without a sequential Bonferroni correction) and may  
252 be due to lack of power resulting from the small sample size at Quetico Rapids. This lends  
253 support for the apparent lack of upstream movement directly at High Falls identified in the  
254 telemetry portion of the study. When the five sampled groups were pooled together, the sturgeon  
255 in the river as a whole were in Hardy-Weinberg equilibrium. If deviations from HWE were  
256 observed, it may have provided evidence for the presence of multiple populations (Wahlund  
257 effect; Wahlund 1928). The lack of HWE deviations indicates that the Namakan River lake  
258 sturgeon represent a single population. Individuals also do not become more genetically distant  
259 at more geographically distance stretches of the river, indicating that sturgeon movements are  
260 currently unimpeded along the Namakan River.

261         Additionally, there were no significant differences in genetic diversity between the five  
262 groups and genetic diversity did not decrease with increasing upstream distance, indicating that  
263 migration is likely occurring in both directions along the river. Asymmetrical movement would  
264 likely result in differences in genetic diversity along the river. If lake sturgeon were primarily  
265 moving downstream, upstream populations would be expected to have lower genetic diversity  
266 due to lack of migration into those populations (Jager et al. 2001).

267         Telemetry findings confirm movements through all natural constrictions in the system  
268 with the exception of Snake Falls and upstream movement at High Falls, which have an  
269 elevation drop of 3.8 and 6.8 m respectively under average flow conditions. Although the Back  
270 Channel around Eva Island and High Falls has an elevation change of approximately 7.0 m, the

271 numerous shallow rapids help dissipate this change over a distance of approximately 2 km. Lake  
272 sturgeon appear to use this natural by-pass channel to migrate both upstream and downstream  
273 around High Falls. Upstream movement was greater than downstream movement in the Back  
274 Channel and this route likely compensates for the lack of upstream movement at High Falls. The  
275 return in spring 2008 of 8 fish that departed the river during summer/fall 2007, and the upstream  
276 movement of another 13 fish from the reservoir in 2008 indicates a high degree of preference to  
277 the Namakan River.

278         Effects of river fragmentation can vary depending on the type of barrier and the life  
279 histories of the species. In the Menominee River, Michigan, the lake sturgeon population was  
280 found to be fragmented into sections by hydroelectric dams (Thuemler 1997). Knights et al.  
281 (2002) also found that dams appeared to be intermittent barriers to upstream passage. However,  
282 the genetic effects of fragmentation from dams may not be as apparent as the effects of natural  
283 barriers due to differences in time since fragmentation (Deiner et al. 2007). The genetic effects  
284 of dams may also be temporarily masked in long-lived species with long generation times like  
285 the lake sturgeon. The putative natural barriers on the Namakan River have likely been in place  
286 for a sufficient amount of time to permit genetic divergence if the rapids were true migration  
287 barriers. Species characteristics can also provide insight into vulnerability to fragmentation.  
288 Haponski et al. (2007) suggested that non-migratory fish may not become significantly isolated  
289 in the presence of a low-head dam. In contrast, habitat specialists and species inhabiting the  
290 edges of their range may be particularly vulnerable to fragmentation (Reid et al. 2008).

291         The genetic diversity observed in the Namakan River is lower than the diversity observed  
292 in other Hudson Bay/James Bay populations and Great Lakes populations (DeHaan et al. 2006;  
293 Welsh et al. 2008). The diversity is also lower than that observed for most freshwater fishes

294 (average heterozygosity = 0.46; DeWoody and Avise 2000). Possible reasons for low genetic  
295 diversity include reduced population size, inbreeding, or genetic drift. However, because the  
296 Namakan River population is in HWE, it is unlikely those attributes are responsible for the low  
297 levels of genetic diversity. Alternatively, the low levels of genetic diversity may be an artifact of  
298 the glacial history of the Hudson Bay drainage. Low genetic diversity in Hudson Bay  
299 populations has been observed in previous genetic studies (McQuown et al. 2003; Welsh et al.  
300 2008). Evidence using mitochondrial DNA suggests that lake sturgeon in the Hudson Bay  
301 drainage may have originated from a different glacial refugia than the current Great Lakes  
302 populations (Ferguson et al. 1993). Fewer postglacial dispersal routes into the Hudson Bay  
303 (Mandrak and Crossman 1992) and longer periods of glaciation may have resulted in lower  
304 genetic diversity in current populations relative to populations in the Great Lakes.

305         The rapids along the Namakan River do not represent reproductive barriers to lake  
306 sturgeon and future management actions should preserve the integrity of this population. High  
307 Falls appears to be the only potential barrier to upstream fish passage. However, the Back  
308 Channel is providing a natural fish passage around High Falls, as the total elevation change is  
309 dissipated over 8-9 sets of shallow rapids. Fragmentation along rivers resulting from artificial  
310 barriers can lead to substantial genetic differentiation evolving within a few generations (e.g.,  
311 Hanfling and Weetman 2006; Heggenes and Roed 2006). Continual upstream and downstream  
312 migration can maintain the genetic diversity along all the segments of the river (Jager et al. 2001;  
313 Reid et al. 2008) and prevent further erosion of the remaining genetic diversity in lake sturgeon  
314 along the Namakan River.

315

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323

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**Table 1.** Genetic differentiation between lake sturgeon from five spawning locations along the Namakan River.

	<b>Lady Rapids</b>	<b>Hay Rapids</b>	<b>Back Channel</b>	<b>Quetico Rapids</b>	<b>Ivy Falls</b>
<b>Lady Rapids (n=31)</b>		24.07	24.05	24.60	20.53
<b>Hay Rapids (n=30)</b>	0.01 (0.19)		25.19	31.53	23.00
<b>Back Channel (n=31)</b>	0.00 (0.27)	0.01 (0.13)		21.96	31.25
<b>Quetico Rapids (n=14)</b>	0.00 (0.38)	0.03 (0.04)	0.00 (0.68)		29.38
<b>Ivy Falls (n=23)</b>	0.01 (0.21)	0.01 (0.25)	0.01 (0.08)	0.02 (0.10)	

Note: Chi-square values from pairwise contingency tests (above diagonal) and pairwise  $F_{ST}$  values (below diagonal).  $F_{ST}$  p-values are listed in parentheses. No comparisons were significant after a sequential Bonferroni correction.

**Table 2.** Upstream and downstream movements of telemetered lake sturgeon through undeveloped rapids/falls in the Namakan River, Ontario from May 15, 2007 to Oct. 21, 2008. Locations are listed from downstream to upstream, and proposed hydro development sites are in bold. Significant  $\chi^2$  values ( $p < 0.05$ ) are denoted with an asterisk.

Location	Elevation* (m)	Upstream	Downstream	Total	$\chi^2$
Lady Rapids	1.6	20	24	44	0.36
<b>Hay Rapids</b>	<b>3.0</b>	<b>21</b>	<b>17</b>	<b>38</b>	<b>0.42</b>
<b>Back Channel (Eva Island)</b>	<b>7.0</b>	<b>14</b>	<b>5</b>	<b>19</b>	<b>4.26*</b>
<b>High Falls</b>	<b>6.8</b>	<b>0</b>	<b>7</b>	<b>7</b>	<b>7.00*</b>
Quetico Rapids	0.7	20	20	40	0.00
Quetico River	-	1	1	2	0.00
Twisted Rapids	-	32	32	64	0.00
Bearpelt Creek	-	2	2	4	0.00
<b>Ivy/Myrtle Falls</b>	<b>4.0</b>	<b>6</b>	<b>6</b>	<b>12</b>	<b>0.00</b>
Snake Falls	3.2	0	0	0	--

\* change in elevation at an average flow of 120 m<sup>3</sup>/sec.

**Figure 1.** Location of genetic sampling sites and VR2W acoustic telemetry receivers in the Namakan River, Ontario.

**Figure 2.** Correlation between genetic distance and spatial measures. Correlations were not significant ( $p > 0.05$ ). A) Genetic distance and geographic distance (km) ( $R^2 = 0.002$ ). B) Genetic distance and number of potential barriers ( $R^2 = 0.002$ ).

**Figure 3.** Genetic diversity of the five putative spawning groups along the Namakan River. Standard deviations are also displayed. There were no significant differences in genetic diversity observed between the sampled groups. A) Observed heterozygosity averaged across all 12 loci. B) Allelic richness averaged across all 12 loci.

Figure 1.

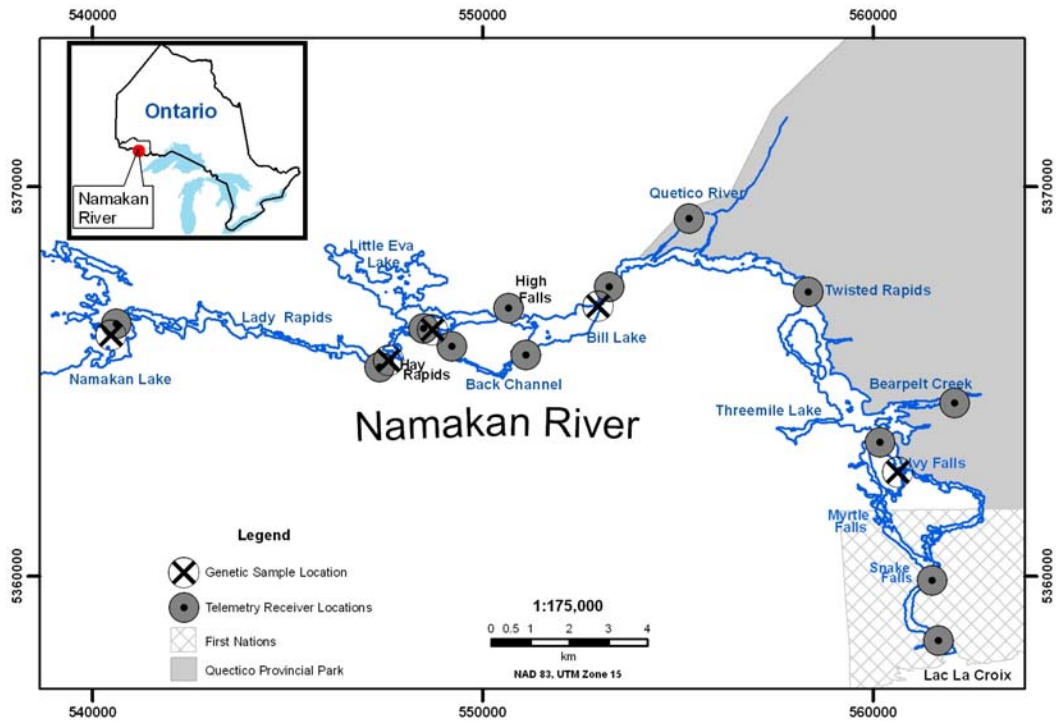
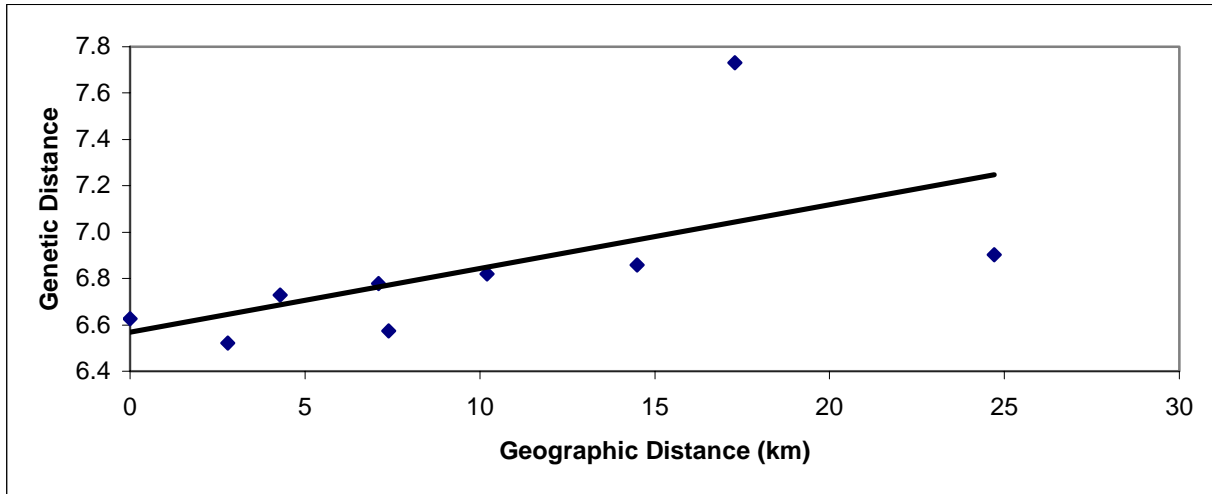
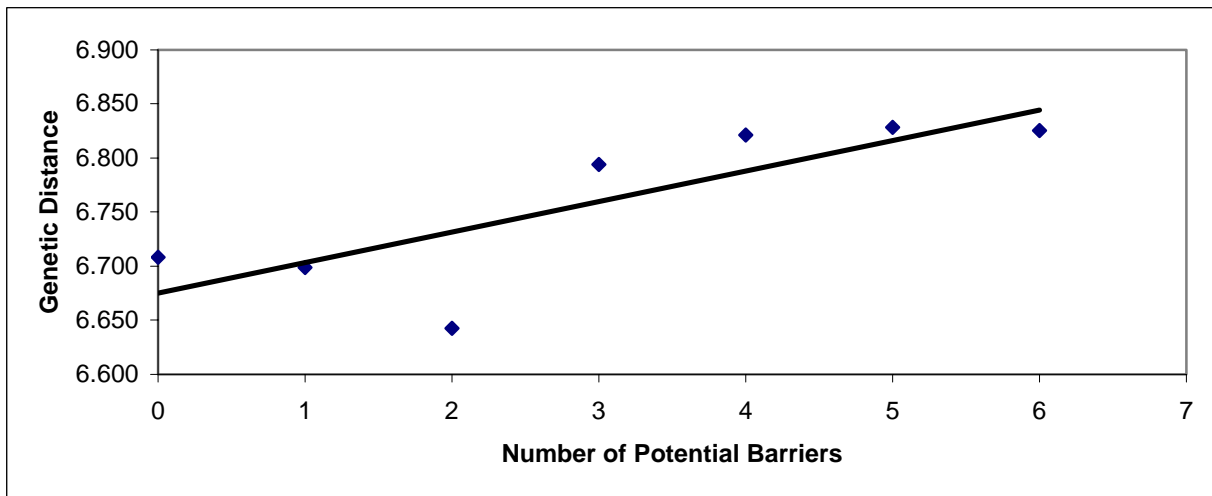


Figure 2.

A)

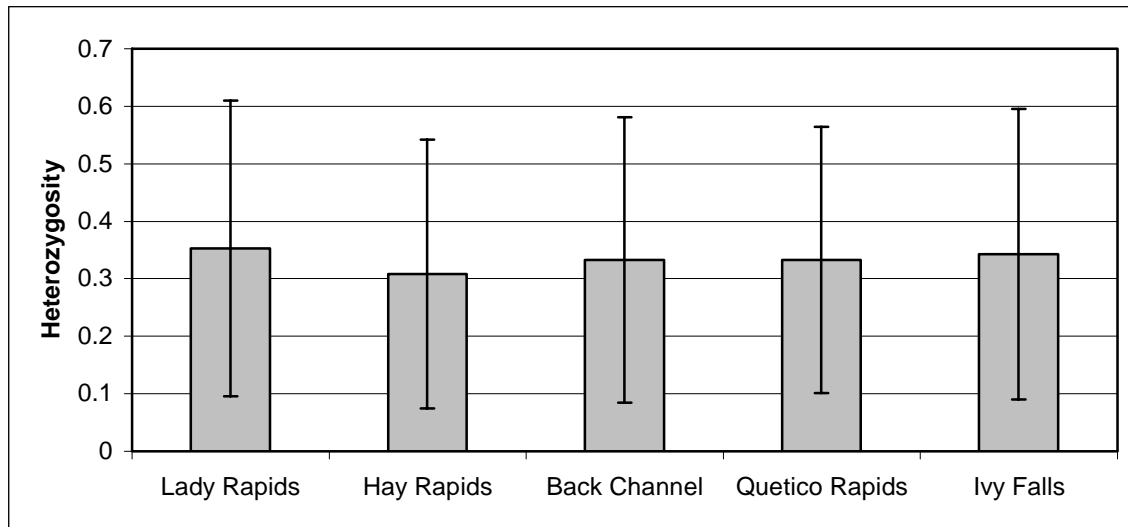


B)



**Figure 3.**

A)



B)

