

BIOLOGY AND ECOLOGY OF LAKE STURGEON *Acipenser
fulvescens* IN THE GRASSE RIVER, NEW YORK

A Dissertation
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
Wildlife and Fisheries Biology

by
Drew G. Trested
May 2010

Accepted by:
Dr. J. Jeffery Isely, Committee Chair
Dr. William W. Bowerman
Dr. William C. Bridges
Dr. Arnold G. Eversole
Dr. Reuben Goforth
Dr. James P. Kirk

ABSTRACT

The objectives of this dissertation were to (1) evaluate the age, growth, mortality, and abundance of lake sturgeon *Acipenser fulvescens* in the Grasse River, New York; (2) characterize seasonal movement patterns and mesohabitat use for adult and juvenile lake sturgeon in the Grasse River, New York; and (3) quantify the immediate and delayed post-procedure mortality for shovelnose sturgeon after insertion of an endoscope through an incision. I determined age for 196 of 211 lake sturgeon by examination of sectioned pectoral fin rays. Ages ranged from 0–32 years and the annual mortality rate for fish between ages 7 and 14 was 16.8%. The weight (W, g) to total length (TL, mm) relationship was $W = 1.281 \times 10^{-6} TL^{3.202}$. The von Bertalanffy growth equation was $TL = 1,913(1 - e^{-0.0294(t+9.5691)})$. An open population estimator using the POPAN sub-module in the Program MARK produced an abundance estimate of 793 lake sturgeon (95% CI = 337–1,249). Minimum daily distances moved were greater for adult lake sturgeon during the spring season than those observed for juvenile lake sturgeon. I was unable to detect significant differences in displacement or absolute distance moved by adult and juvenile lake sturgeon within any of the four seasons. Differences in mean home range size between adult and juvenile lake sturgeon were detected during the spring season. Lake sturgeon in the Grasse River behaved as would be expected for the species. Adult and juvenile fish within the three river reaches made use of core areas on either a seasonal or annual basis. Lake sturgeon demonstrated a greater use of pool mesohabitat and lower use of run mesohabitat under both low and mid flow conditions. During the majority of

the year, adult and juvenile lake sturgeon demonstrated a greater use of silt substrate. Sex of adult fish was determined using an abdominally invasive endoscopic technique. The immediate and post-procedure survival of sturgeon subjected to that surgical technique was assessed using shovelnose sturgeon. The initial and latent survival rates of test fish was 100%. Short procedure duration and high post-procedure survival make the technique ideal for collecting biological data from sturgeon during field studies such as the Grasse River.

DEDICATION

I would like to thank my entire family whose encouragement and support throughout this process helped to carry me through. In particular I would like to thank my wife, Becca. Without her love, belief in me and never ending patience, this experience would not have been possible.

ACKNOWLEDGEMENTS

This process would not have been possible without the support and assistance of a great number of people. I am deeply indebted to my advisor and good friend, Dr. Jeff Isely, whose encouragement and guidance helped to make this process a success. In addition, I appreciate the assistance and professional guidance provided by my committee: Dr. William Bowerman, Dr. William Bridges, Dr. Arnold Eversole, Dr. Phil Kirk, and Dr. Reuben Goforth. I would also like to recognize fellow student Beth Wrege, who was a great source of knowledge and a helpful driving force to keep me moving along. Field work on the Grasse River would not have been possible without the help of numerous Normandeau Associates biologists including Chris Avalos, Chris Baker, Joel Detty, Corey Francis, Brian Hanson, Mike Jeanneau, Don Mason, Sean Maxwell, Helen Shoap, Ethan Sobo, Rick Simmons, and Sean Stimmell. These individuals all provided valuable labor and field expertise related to the sampling for lake sturgeon as well as countless hours of radio-tracking. Chris Gurshin, Shelly Sherman, and Peter Stevens of Normandeau Associates and Ben Galuardi at the University of New Hampshire provided helpful input regarding analysis and interpretation of field data. Funding for the Grasse River lake sturgeon studies was provided by The Town of Massena Electric Development (MED). Matthew Chan, Paul Shiers, and Shirley Williamson with PB Power and Andy McMahan with MED were supportive and provided critical reviews for the lake sturgeon studies presented here. Michael Allen, Jon Amberg, Jessica Leet, Ben Miller, Caleb Rennaker, Robert Rode, Jeffery Weber, and Michael Wellman of the Department of

Forestry and Natural Resources at Purdue University and the Purdue University
Aquaculture Research Laboratory provided valuable field and laboratory assistance for
the shovelnose sturgeon survival assessment.

TABLE OF CONTENTS

	Page
ABSTRACT.....	ii
DEDICATION.....	iv
ACKNOWLEDGEMENTS.....	v
LIST OF TABLES.....	ix
LIST OF FIGURES.....	x
CHAPTER	
1. PREFACE.....	1
<u>Organization of this Dissertation</u>	3
<u>References</u>	4
2. AGE, GROWTH, MORTALITY, AND ABUNDANCE OF LAKE STURGEON IN THE GRASSE RIVER, NEW YORK.....	6
<u>Introduction</u>	6
<u>Methods</u>	7
<u>Results</u>	15
<u>Discussion</u>	24
<u>References</u>	33
3. SEASONAL MOVEMENT AND MESOHABITAT USE OF LAKE STURGEON IN THE GRASSE RIVER, NEW YORK.....	36
<u>Introduction</u>	36
<u>Methods</u>	38
<u>Results</u>	48
<u>Discussion</u>	66

Table of Contents (Continued)

	Page
<u>References</u>	81
4. SURVIVAL OF SHOVELNOSE STURGEON FOLLOWING ABDOMINALLY- INVASIVE ENDOSCOPIC EVALUATION.....	86
<u>Introduction</u>	86
<u>Methods</u>	88
<u>Results</u>	91
<u>Discussion</u>	93
<u>References</u>	96

LIST OF TABLES

Table	Page
1. Release-recapture matrix for lake sturgeon in the Grasse River for the months April–November, 2007.	13
2. Quasi-Akaike Information Criterion (QAICc) values for the top two Cormack-Jolly-Seber models for the population of lake sturgeon within the Grasse River.	23
3. Parameter estimates and 95% confidence intervals derived from model-averaged estimates of survival (S) and capture (p) probabilities for the top two Cormack-Jolly-Seber models.....	25
4. Definitions of mesohabitat types mapped for an 15-km stretch of the Grasse River for use in determining lake sturgeon habitat preferences.	44
5. Description of radio-tagged lake sturgeon whose seasonal movements and habitat use in the Grasse River, New York, were monitored.	49

LIST OF FIGURES

Figure	Page
1. The Grasse River near Massena, New York, showing river reach sampled during 2007 and 2008.	9
2. Length frequency of Grasse River lake sturgeon captured between 1 April 2007 and 9 October 2008.	16
3. Length-weight relationship of Grasse River lake sturgeon captured between 1 April 2007 and 9 October 2008.	17
4. Age frequency of Grasse River lake sturgeon captured between 1 April 2007 and 9 October 2008.	18
5. Mean total length at age (\pm 95% confidence intervals) of Grasse River lake sturgeon captured between 1 April 2007 and 9 October 2008. Line depicts the von Bertalanffy growth curve.	19
6. Length frequency distributions for catch from small mesh experimental gill nets (dark shading) and large mesh experimental gill nets (light shading) for lake sturgeon from the period June to November 2007.	21
7. Catch curve for Grasse River lake sturgeon. Open diamonds denote age classes prior to full recruitment to sampling gear and not included in estimate of Z and closed diamonds denote age classes included in estimate of Z.	22
8. Map of the study area, consisting of the Grasse River below the Madrid Dam where movement and habitat use of lake sturgeon were monitored.	39
9. River kilometer positions of individual adult radio-tagged lake sturgeon in the Grasse River below the Madrid Dam from November 2007 through September 2009. The solid lines connecting points indicate the movements of individual fish. The solid bar represents the relative location of the breached low-head weir.	51
10. River kilometer positions of individual juvenile radio-tagged lake sturgeon in the Grasse River below the Madrid Dam from July 2007 through September 2009. The solid lines connecting points indicate the movements of individual fish. The solid bar represents the relative location of the breached low-head weir.	52
11. Within and between season comparisons of the mean (\pm SE) minimum daily movement (km/d) of radio-tagged adult male (open shading), adult female (solid shading) and juvenile (hatched shading) lake sturgeon in the Grasse River below Madrid Dam from July 2007 through September 2009. Different letters indicate significant differences within and between groups and seasons.	57

List of Figures (Continued)

	Page
12. Within season comparisons of the mean (\pm SE) displacement (km) of radio-tagged adult male (white shading), adult female (gray shading) and juvenile (black shading) lake sturgeon in the Grasse River below Madrid Dam from July 2007 through September 2009. Different letters indicate significant differences between groups within a season.....	59
13. Within season comparisons of the absolute distance moved (km) of radio-tagged adult male (white shading), adult female (gray shading) and juvenile (black shading) lake sturgeon in the Grasse River below Madrid Dam from July 2007 through September 2009. Different letters indicated significant differences between groups within a season.....	60
14. Within and between season comparisons of the mean home range size (km) of radio-tagged adult male (open shading), adult female (solid shading) and juvenile (hatched shading) lake sturgeon in the Grasse River below Madrid Dam from July 2007 through September 2009. Different letters indicate significant differences within and between groups and seasons.....	62
15. Frequency distributions of mesohabitat availability (all seasons combined) and radio-tagged lake sturgeon usage during low flow conditions within the mesohabitat mapped portion of the Grasse River from July 2007 through September 2009. Open bars indicates the observed habitat usage of lake sturgeon and dark bars the mapped substrate proportion.....	65
16. Frequency distributions of mesohabitat availability (all seasons combined) and radio-tagged lake sturgeon usage during mid flow conditions within the mesohabitat mapped portion of the Grasse River from July 2007 through September 2009. Open bars indicates the observed habitat usage of lake sturgeon and dark bars the mapped substrate proportion.....	67
17. Frequency distributions (all seasons combined) of substrate availability (dark shading) and substrate use by radio-tagged lake sturgeon (open shading) within the mesohabitat mapped portion of the Grasse River from July 2007 through September 2009.....	68
18. Frequency distributions of substrate use by radio-tagged lake sturgeon within the mesohabitat mapped portion of the Grasse River during the spring season (open shading) and all other seasons combined (dark shading).....	69
19. Endoscopy system used for gender and gonad developmental stage evaluation: A. individual components including borescope, light source, video camera, display monitor, trocar, and air supply. B. Insertion of trocar into anesthetized shovelnose sturgeon.	90
20. Endoscopic views of shovelnose sturgeon ovarian tissue: A. Mature stage female. B. Post-spawn female.....	92

CHAPTER ONE

PREFACE

The Grasse River flows 185 km northeast from its source in the foothills of the Adirondack Mountains to its confluence with the St. Lawrence River in Massena, New York (Parsons Brinkerhoff 2006). A small low-head weir was constructed at river kilometer 12.9 in the village of Massena, New York, during 1792. The original dam structure was renovated in 1913 and remained in place until it was breached by debris and high flows during the spring of 1997. The Massena low-head weir created a reservoir which formed the basis for the town waterfront area. A second low-head dam is presently located at river kilometer 51.2 in the town of Madrid, New York. The Madrid Dam is not used for the generation of hydroelectric power nor is it equipped with a fish passage facility.

Fisheries surveys within the portion of the Grasse River between the Madrid Dam and its confluence with the St. Lawrence River have documented the presence of 58 species of freshwater fish (Normandeau 2009). Among those fish species, a single member of the sturgeon family Acipenseridae (lake sturgeon; *Acipenser fulvescens*) was present in the Grasse River. Nearly all sturgeon species are considered to be threatened or endangered (Birstein 1993; Birstein et al. 1997). Although the factors influencing the decline of sturgeon populations may vary by location, declines in abundance can be attributed to a variety of anthropogenic factors including overfishing, water quality of large rivers utilized for spawning, and blockage of historic migration routes by dam

facilities (Birstein et al. 1997). Lake sturgeon are the only native member of the family Acipenseridae found in New York State and are listed as threatened there (Carlson 1995). Spawning locations within New York State are limited (Carlson 1995), and prior to this study were known to include the portion of the Grasse River below the Madrid Dam (LaPan et al. 1998). Previous work with lake sturgeon in the State has focused not only on the acquisition of basic life history and habitat preferences (Johnson et al. 1998; Werner and Hayes 2004; Hughes et al. 2005) but also on habitat rehabilitation (Johnson et al. 2006) as well as the potential for reintroduction to areas where the species had been extirpated (Jackson et al. 2002).

In order for fisheries scientists to effectively manage and restore sturgeon populations, an understanding of basic population dynamics is required. Length and weight information is routinely collected during field surveys and can be used in the calculation of condition factors (Fortin 1993; Lallaman et al. 2008). Determination of sturgeon population age structure has been conducted using either traditional pectoral fin ray analysis (Rossiter et al. 1995) or newer techniques utilizing bomb radiocarbon analysis of otoliths (Bruch et al. 2009). Knowledge of population age structure allows for fisheries managers to construct both growth and mortality models for the target population. Due to the observed differences in growth between male and female sturgeon (Fortin et al. 1996) information on the gender and developmental stage of individuals within the target population is critical for developing appropriate management plans. In addition, the knowledge of population sex ratios, spawning frequency and other

parameters associated with gender will play an important role in the effective recovery and management of depressed sturgeon populations.

Organization of this Dissertation

This dissertation reports the findings from studies evaluating the ecology and biology of lake sturgeon *Acipenser fulvescens* in the Grasse River near Massena, New York. In addition, the assessment of initial and post-procedure survival for shovelnose sturgeon *Scaphirhynchus platorynchus* subjected to a modified endoscopic technique for assessing gender and reproductive stage is also presented in this dissertation. That technique as well as the associated results should transfer to not only lake sturgeon in the Grasse River but also sturgeon species elsewhere. This dissertation consists of four chapters, including this Preface (Chapter 1). The body of this dissertation is comprised of three independent manuscripts formatted for publication in a scientific journal.

Therefore, some of redundancy of material was necessary. The three manuscripts and their targeted journal are: (I) Age, growth, mortality, and abundance of lake sturgeon in the Grasse River, New York, prepared for the *Journal of Applied Ichthyology* (II) Seasonal movement and mesohabitat use of lake sturgeon in the Grasse River, New York, prepared for *Transactions of the American Fisheries Society*, and (III) Survival of shovelnose sturgeon following minimally invasive endoscopic evaluation, accepted by *North American Journal of Fisheries Management*.

References

- Birstein, V. J. 1993. Sturgeons and paddlefishes: threatened fishes in need of conservation. *Conservation Biology* 7: 773-787.
- Birstein, V. J., W. E. Bemis, and J. R. Waldman. 1997. The threatened status of Acipenseriform species: a summary. *Environmental Biology of Fishes* 48: 427-435.
- Bruch, R. M., S. E. Campana, S. L. Davis-Foust, M. J. Hansen, and J. Janssen. 2009. Lake sturgeon age validation using bomb radio carbon and known age fish. *Transactions of American Fisheries Society* 138: 361-372.
- Carlson, D. M. 1995. Lake sturgeon waters and fisheries in New York State. *Journal of Great Lakes Research* 21: 35-41.
- Fortin, R., J. R. Mongeau, G. Desjardins, and 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.
- Hughes, T. C., C. E. Lowie, and J. M. Haynes. 2005. Age, growth, relative abundance and scuba capture of a new or recovering spawning population of lake sturgeon in the lower Niagara River, New York. *North American Journal of Fisheries Management* 25: 1263-1272.
- Jackson, J. R., A. J. VanDeValk, T. E. Brooking, O. A. vanKeeken, and L. G. Rudstam. 2002. Growth and feeding dynamics of lake sturgeon, *Acipenser fulvescens*, in Oneida Lake, New York: results from the first five years of a restoration program. *Journal of Applied Ichthyology* 18: 439-443.
- Johnson, J. H., D. S. Dropkin, S. R. LaPan, J. E. McKenna, and R. M. Klindt. 1998. Age and growth of lake sturgeon in the upper St. Lawrence River. *Journal of Great Lakes Research* 24: 474-478.
- Johnson, J. H., S. R. LaPan, R. M. Klindt, and A. Schiavone. 2006. Lake sturgeon spawning on artificial habitat in the St. Lawrence River. *Journal of Applied Ichthyology* 22: 465-470.

- LaPan, S. R., A. Schiavone, R. M. Klindt, and R. T. Colesante. 1998. New York State Department of Environmental Conservation 1997 Annual Report to the Great Lakes Fishery Commission's Lake Ontario Committee. Watertown, NY.
- Lallaman, J. J., R. A. Damstra, and T. L. Galarowicz. 2008. Population assessment and movement patterns of lake sturgeon (*Acipenser fulvescens*) in the Manistee River, Michigan USA. *Journal of Applied Ichthyology* 24: 1-6.
- Normandeau Associates, Inc. 2009. A general fish community study of the Grasse River near Massena, NY. Submitted to Town of Massena Electric Department. Bedford, NH.
- Parsons Brinckerhoff. 2006. Preliminary Application Document: Massena Grasse River Multipurpose Hydroelectric Project. FERC # 12607.
- Rossiter A., D. L. G. Noakes, and F. W. H. Beamish. 1995. Validation of Age Estimation for the Lake Sturgeon. *Transactions of the American Fisheries Society* 124: 777-781.
- Werner, R. G., and J. Hayes. 2004. Contributing factors in habitat selection by lake sturgeon (*Acipenser fulvescens*). State University of New York, College of Environmental Science and Forestry, Syracuse.

CHAPTER TWO
AGE, GROWTH, MORTALITY, AND ABUNDANCE OF LAKE STURGEON
IN THE GRASSE RIVER, NEW YORK

Introduction

The lake sturgeon *Acipenser fulvescens* is native to larger river and lake systems throughout the northeastern and central United States, including the Laurentian Great Lakes and Hudson Bay drainage (Scott and Crossman 1973; Peterson et al. 2006). This species is present within the St. Lawrence River (Scott and Crossman 1973; Smith 1985; Carlson 1995) and commercial landings there constituted one of the most important sturgeon fisheries in North America (Dumont et al. 1987; 2004).

Construction of Beauharnois (1942) and Moses-Saunders (1960) Generating Stations altered the hydrology of the St. Lawrence River (Morin and Leclerc 1988) and created an impounded section of river known as Lake St. Francis. The population of lake sturgeon isolated in Lake St. Francis has been negatively impacted by dam construction along with overfishing (Dumont et al. 2004) and was considered depleted during the 1960s, 1970s, and 1980s (Cuerrier and Roussow 1951; Jolliff and Eckert 1971; Dumont et al. 1987). Recent assessment in the Quebec portion of the lake suggests it remains depressed (Dumont et al. 2004). Commercial and recreational fisheries management within Lake St. Francis is shared by Quebec, Ontario, New York, and the Mohawk Government of the Akwesasne. Commercial fisheries for lake sturgeon in Lake St. Francis were closed in New York State during 1976, in Ontario during 1984 and in

Quebec during 1987. An unquantified commercial harvest of lake sturgeon from Lake St. Francis remains on the Akwesasne Reservation.

The Grasse River is one of three major tributaries entering the upper end of Lake St. Francis near the Moses-Saunders Generating Station in Massena, New York. Limited spawning habitat was located below a low-head weir located at river kilometer 12.9 (Jolliff and Eckert 1971), as measured from the confluence of the Grasse River with Lake St. Francis. Under certain flow conditions, lake sturgeon could perhaps move past that obstruction and into the upper reaches of the Grasse River (Carlson 1995). However, the low-head weir was breached during a flood in 1997.

Little is currently known about Grasse River lake sturgeon age structure, growth, condition, mortality, and abundance. The Grasse River population of lake sturgeon is one of a few populations in New York State where spawning has been documented, and the population appears to include both resident and migratory individuals (Carlson 1995). Therefore, a greater knowledge of Grasse River lake sturgeon would be valuable towards enhanced management within the Grasse River and potentially the management of lake sturgeon in Lake St. Francis. In this study, I assess the current status of lake sturgeon in the Grasse River system. Specifically, I determine age, growth, mortality, and abundance and compare these values with lake sturgeon populations elsewhere.

Methods

Study Area

The Grasse River flows northeast for 185 km from its source in the foothills of the Adirondack Mountains to its confluence with the St. Lawrence River where it flows into Lake St. Francis (Figure 1). Lake St. Francis runs for approximately 80-km between the Moses-Saunders Generating Station in Massena, New York, and the Beauharnois Generating Station in Valleyfield, Quebec. The Grasse River drains approximately 1,702 km², has an average annual stream flow of 31.1 m³/s and a median flow of approximately 19.8 m³/s (Parsons Brinckerhoff 2006). The lower Grasse River (river km 0–11.5, as measured from the confluence with Lake St. Francis) was dredged during the early 1900s and is relatively deep (4.5–7.5 m) compared to the remainder of the system, which typically ranges in depth from 1.5–3.0 m. The remains of an old low-head weir breached during 1997 are located at river km 12.9 and are not a barrier to migration, except during seasonally low flows. A second low-head dam (Madrid Dam) is located at river km 51.2 and does not have fish passage facilities. All lake sturgeon examined during this study were captured below Madrid Dam and downstream to approximately river km 6.0 of the Grasse River. Sampling was restricted to areas with suitable water depth for boat access. Fixed sample sites were located between river km 6.0–11.3, 12.9–18.5, and at river km 25.7 and 51.0.

Data Collection

Lake sturgeon were collected monthly from April 2007 through November 2007 and during October 2008 using monofilament gill nets. The three different sinking monofilament gill nets fished were a 38.1 m (length) x 2.4 m (depth) x five 7.6 m wide

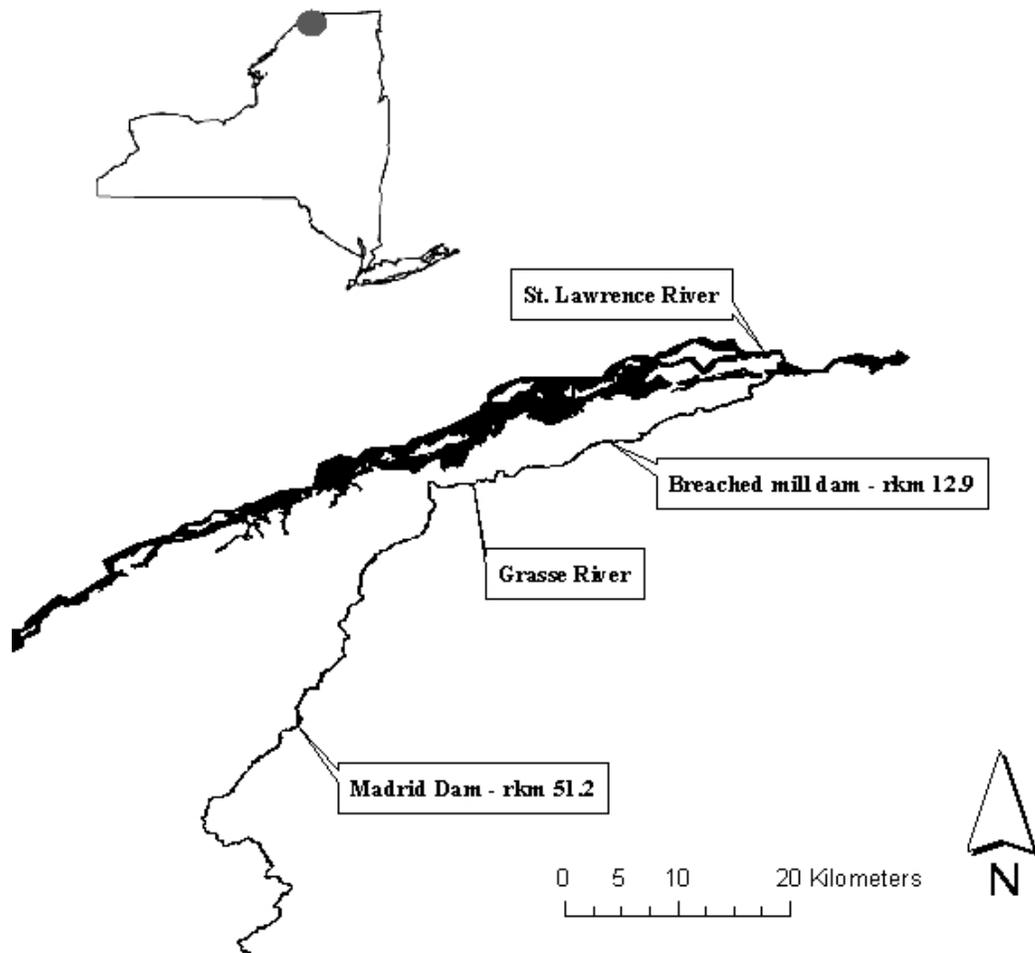


Figure 1. The Grasse River near Massena, New York, showing the river reach sampled during 2007 and 2008.

panels with stretch mesh ranging from 3.8–12.8 cm (small-mesh experimental gill net), 45.7 m x 1.8 m x three 15.2 m wide panels of 12.8–17.8 cm stretch mesh (large-mesh experimental gill net), and 45.7 m x 1.8 m with 20.4 cm stretch mesh (single mesh gill net). Gill nets were anchored at the shoreline, set perpendicular to the current, and fished during daylight hours.

Following capture, lake sturgeon were placed in a holding tank on the boat. Total length (TL, nearest mm) and weight (W, nearest 0.01 kg) were recorded. Due to the lack of external distinguishing characteristics, sex was not determined for individuals captured during this study. A passive integrated transponder (PIT) tag (134.2 kHz, 12.45-mm Super Tag II; Biomark Inc., Boise, Idaho) was injected into the dorsal musculature of each individual.

A section of pectoral spine was removed from the margin using cutting pliers as described by Rossiter et al. (1995). Pectoral spines were sectioned using a low-speed diamond blade saw (Isomet Saw; Buehler Inc., Lake Bluff, Illinois). Thin (0.5 mm) transverse sections were mounted to glass slides using thermal cement, polished using 600-grit lapidary film and examined under transmitted light using a dissecting microscope at 25× magnification. Age was assigned to each individual as the number of complete opaque bands visible (Rossiter et al. 1995). Spring-collected samples exhibited opaque margins, which were interpreted as annuli. Sections were examined by a single reader on two separate occasions. An estimated age was assigned to a single pectoral spine section from each individual sturgeon. When estimated ages differed, pectoral spine sections were examined a third time by the original reader to assign a final age

estimate and reason for disagreement. If agreement with one of the two previous readings did not occur, the section was not included in analysis.

Data Analysis

Catch per unit effort (CPUE) was calculated as the total number of lake sturgeon captured per 8-hour net set. Samples resulting in zero catch were included in the calculation of mean CPUE values for all gear types. A weight-length relationship ($W = aL^b$) was derived as described by Ricker (1975). A von Bertalanffy growth equation using all available data points was calculated using $TL = L_{\infty}[1 - e^{-k(t-t_0)}]$, where L_{∞} is the asymptotic length, t is age (years), t_0 is the hypothetical age at length 0, and k is the Brody growth coefficient (von Bertalanffy, 1938). This procedure was carried out in Statistical Analysis System using NLIN procedures (SAS, SAS Institute, Cary, North Carolina, USA) using an iterative non-linear least squares procedure.

The total instantaneous mortality rate (Z) was estimated from the slope of the catch curve (\log_e frequency versus age; Ricker 1975). Early age classes were excluded if they were not abundant in the age frequency due to gear bias and I removed older age classes if they contained fewer than five fish (Ricker 1975). This analysis assumed that (1) recruitment is constant from year to year, (2) fishing and natural mortality are constant, and (3) vulnerability to the fishing gear (gear selectivity) is constant above a given age (Ricker 1975). Annual mortality was calculated as: $A = 1 - e^{-Z}$, where A is the annual mortality estimate, e is natural log base constant and Z is total instantaneous mortality rate. The annual survival estimate (S) was then calculated as $S = 1 - A$.

Between-month rates of survival (S) and capture probability (p) were estimated through a series of Cormack-Jolly-Seber (CJS) models constructed using Program MARK (White 2007). The survival parameter S provides an estimate of combined survival given losses due to mortality and emigration from the sampling area for a given time period. The capture-recapture parameter (p) provides an estimate of the likelihood of capturing a particular marked individual during a given sampling event. The release-recapture matrix used in this analysis is presented in Table 1 and represents effort from the months of April through November, 2007. Sampling dates were pooled within month to provide a total of eight time intervals. Although this resulted in a minimal loss of within-month recaptures, the decreased number of parameters provided to Program MARK allowed for improved model precision (Cooch and White 2007). Models were selected from a suite of candidate models and included:

Model A: Fully-time Dependent Model $\{S(t)p(t)\}$

Model B: Constant Survival and Time Dependent Capture Model $\{S(.)p(t)\}$

Model C: Time-Dependent Survival Constant Capture Model $\{S(t)p(.)\}$

Model D: Fully-time Invariant Model $\{S(.)p(.)\}$

Where S is the probability of survival, p is the probability of capture, (t) indicates that the parameter varies with time between sampling periods and $(.)$ indicates that the parameter is constant across sampling periods.

Goodness of fit testing using the variance inflation factor (\hat{c}) for the general model was performed to estimate the dispersion in the data and was conducted using the Median- \hat{c} test provided in Program MARK. The global model was determined to have

Table 1. Release-recapture matrix for lake sturgeon in the Grasse River for the months April - November, 2007.

Release Occasion	Number of Releases	Recapture Occasion							Total
		May	Jun	Jul	Aug	Sep	Oct	Nov	
Apr	36	2	0	1	0	0	0	1	4
May	8		1	0	0	0	4	4	9
Jun	19			0	0	0	0	0	0
Jul	23				0	0	2	3	5
Aug	1					0	0	0	0
Sep	6						0	0	0
Oct	8							8	8

sufficient goodness of fit if the variance-inflation factor, \hat{c} , was < 3.0 (Lebreton et al. 1992). A $\hat{c} = 1.0$ would be considered a perfect fit of the model to the data. For situations where $\hat{c} = 1.0$, candidate models are ranked using the second-order bias adjusted Akaike Information Criterion (AIC_c ; Burnham and Anderson 2002). Where \hat{c} differs from 1, models are ranked using quasi- AIC_c ($QAIC_c$) instead of AIC_c to account for dispersion of the data (Burnham and Anderson 2002). The models were tested starting with the fully-time dependent model (Model A). If Model A, the fully-time dependent model, did not provide adequate goodness of fit, reduced parameter models were tested until an adequate global model was found. Model averaging was then employed to generate survival (S) and capture-recapture (p) and 95% confidence intervals for the lake sturgeon population in the Grasse River.

The population abundance (N) of lake sturgeon within the Grasse River was estimated using the POPAN function (Jolly-Seber model) within the Program MARK (White 2007). The POPAN sub-module of the Program MARK assumes the existence of a super population (N) and the parameter b which is the probability that an individual from the super population will enter the sampled population between two sampling events (Schwartz and Arnason 1996). My estimate of N represents the value obtained using the model averaging function within Program MARK. Similar to the selection of CJS models used for generation of S and p parameters, POPAN models which did not allow the probability of capture to vary with time were not included in the calculation of the mean estimate presented here.

Results

A total of 211 individual lake sturgeon were captured between 1 April 2007 and 9 October 2008. Catch per unit effort for the small-mesh experimental gill nets was 0.4 lake sturgeon per 8-hr daytime set (range: 0–7.7; SD = 1.0), for the large-mesh experimental gill nets it was 0.8 (range: 0–1.8; SD = 14.8), and for the single-mesh gill net it was 0.4 (range: 0–0.7; SD = 2.5). A single young-of-year fish ($TL = 175$ mm; $W = 22$ g) captured by electrofishing was included in age, growth, and mortality analyses. Total length averaged 796 mm (range: 175–1,368 mm; SD = 163.8 mm; Figure 2) and weight averaged 2,757 g (range: 22–13,680 g; SD = 2,002 g). The W – TL relationship was $W = 1.281 \times 10^{-6} \times TL^{3.202}$ ($r^2 = 0.96$; $N = 201$; Figure 3).

A total of 196 spines were read for age. Initial agreement in ages between two independent readings was 75.0%. Of the 49 occasions where initial age estimates disagreed, 76% differed by 1 year and 24% differed by 2 years or more. Disagreement in initial age estimates was caused by uncertainty in location of the first annulus and compression of annuli near the margin in samples from older fish. Final age estimates ranged from 0–32 years (mean = 8.7 years; Figure 4). Total lengths ranged from 175 mm at age 0 to 1,368 mm at age 32 (Figure 5). The von Bertalanffy growth equation for length was $TL = 1,913(1 - e^{-0.0294(t-9.5691)})$. Confidence intervals (95%) were 842–2,983 for L_{∞} , -0.00018–0.0590 for k , and -14.5356–4.6026 for t_0 .

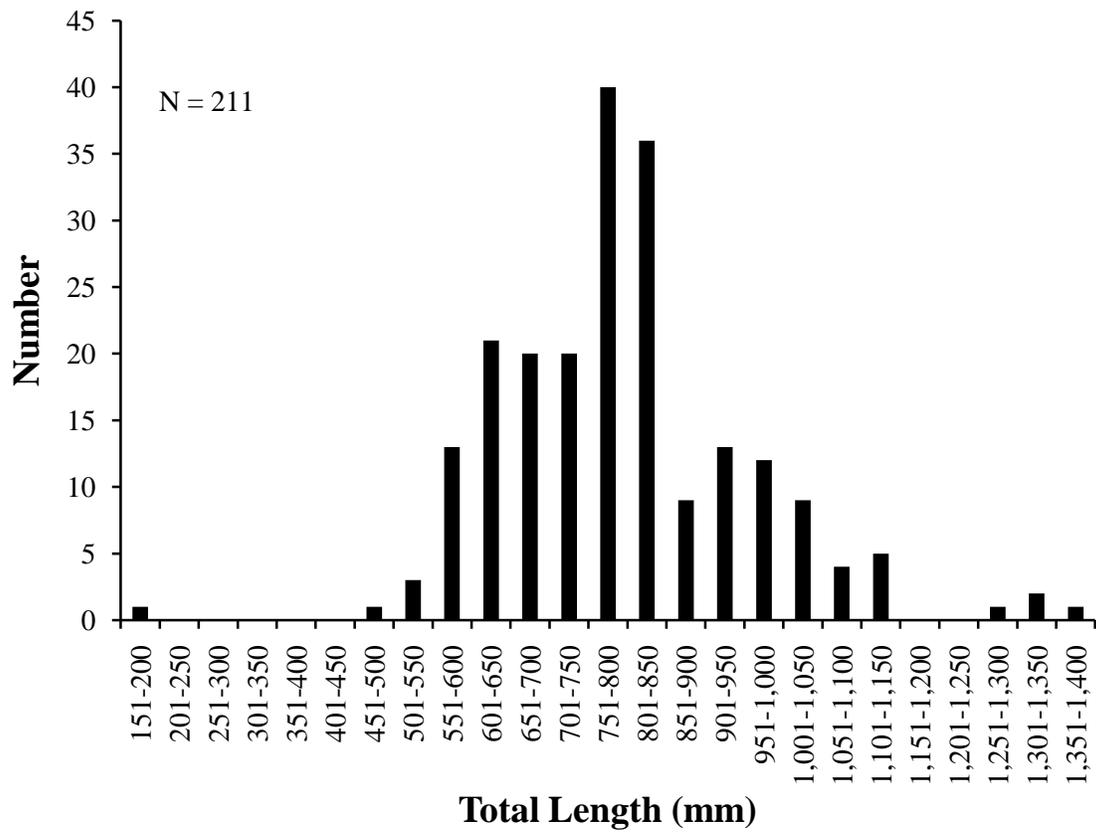


Figure 2. Length frequency of Grasse River lake sturgeon captured between 1 April 2007 and 9 October 2008.

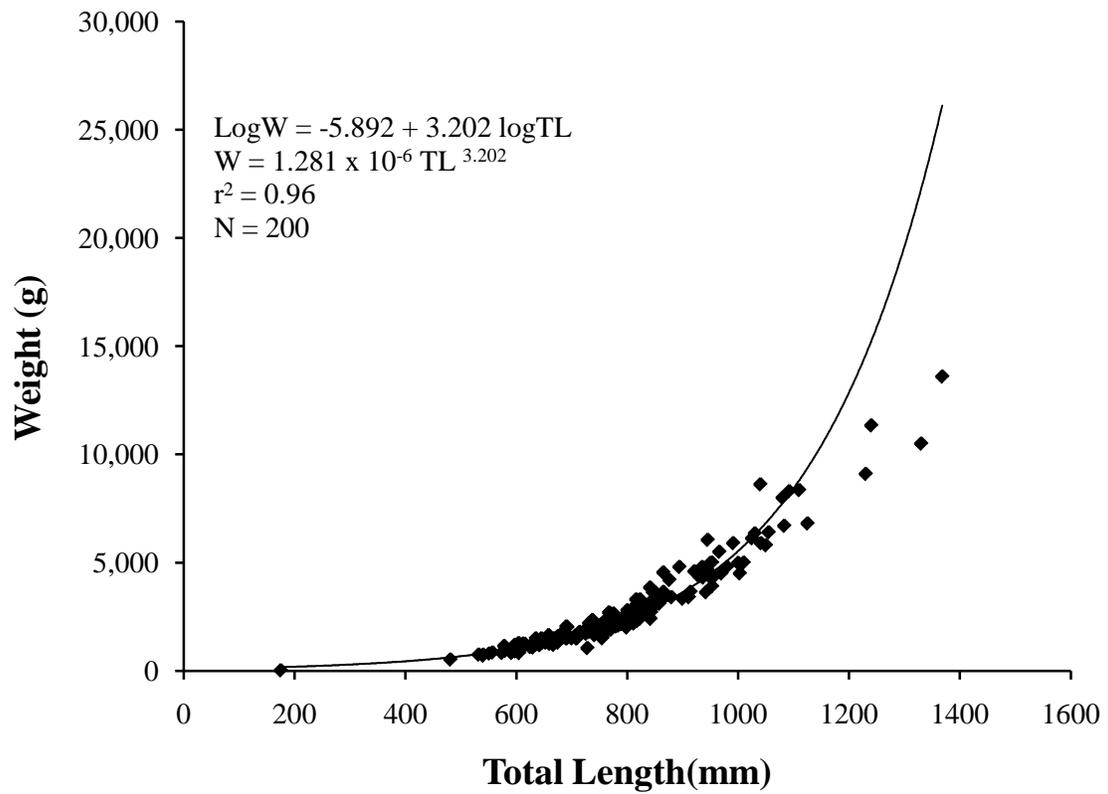


Figure 3. Length-weight relationship of Grasse River lake sturgeon captured between 1 April 2007 and 9 October 2008.

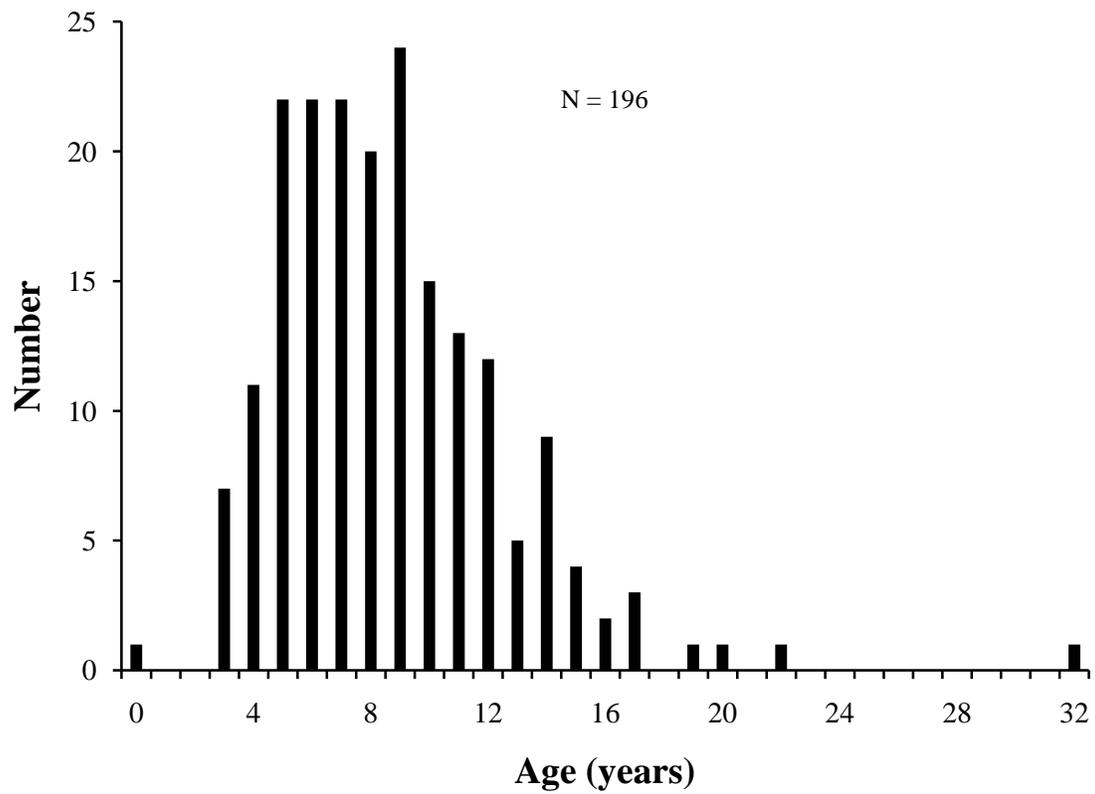


Figure 4. Age frequency of Grasse River lake sturgeon captured between 1 April 2007 and 9 October 2008.

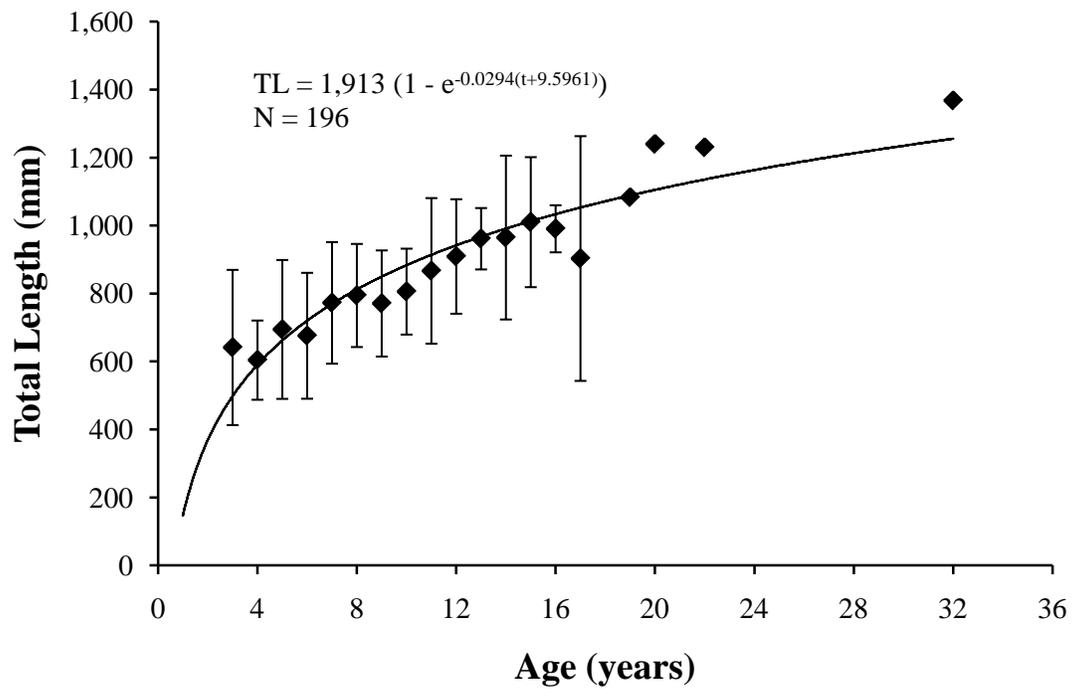


Figure 5. Mean total length at age (\pm 95% confidence intervals) of Grasse River lake sturgeon captured between 1 April 2007 and 9 October 2008. Line depicts the von Bertalanffy growth curve.

The estimate of Z for ages 7–14 was 0.184 ($r^2 = 0.74$; 95% C.I. = 0.076–0.291), which equates to an annual survival rate (S) of 83.2% or an annual mortality rate (A) of 16.8%. Confidence intervals (95%) for A were 7.3%–25.2%. The assumption of constant recruitment was addressed through examination of the age-frequency distribution (Figure 4). Figure 6 presents the length frequency distributions used in the catch curve analysis. The mean TL for individuals captured in the small mesh experimental gill nets was 759 mm while mean TL for individuals captured in the large mesh experimental gill nets was 784 mm. The length frequency distributions of catch from both net types indicated that sturgeon over a wide range of lengths were vulnerable to the sampling gears (Figure 6). When the mean TL for sturgeon captured by the two experimental gill net gear types are compared to the mean TL at age (Figure 5) it appears that sturgeon became fully vulnerable to the gill nets at an age of 7 years (Figure 7). The added use of the large mesh gill nets should have allowed for the capture of older and larger year classes if they had been present in the system.

Goodness of fit testing indicated adequate goodness of fit of the global model to the mark-recapture data. The Median \hat{c} (median $\hat{c} = 2.293$) test indicated adequate fit ($\hat{c} < 3.0$) of the fully time dependent Model A. Therefore, Model A was used as the global model for all subsequent analyses. The CJS model identified Model B, with constant survival and varying capture rate as the model with the “best” fit to the mark-recapture data (Table 2). Models C and D were dropped due to biological concerns over maintaining the capture probability (p) as a constant. Model B had a QAICc weight of 0.9873. The second-ranked model (Model A) was identical to the first model but

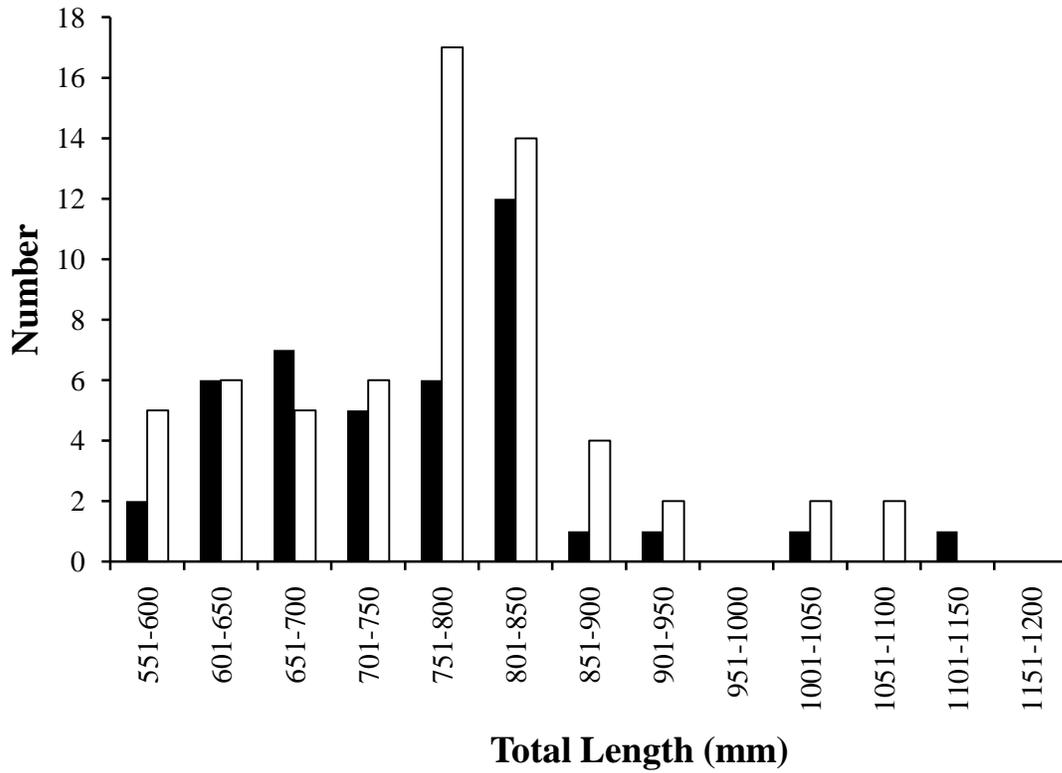


Figure 6. Length frequency distributions for catch from small mesh experimental gill nets (dark shading) and large mesh experimental gill nets (light shading) for lake sturgeon from the period June to November 2007.

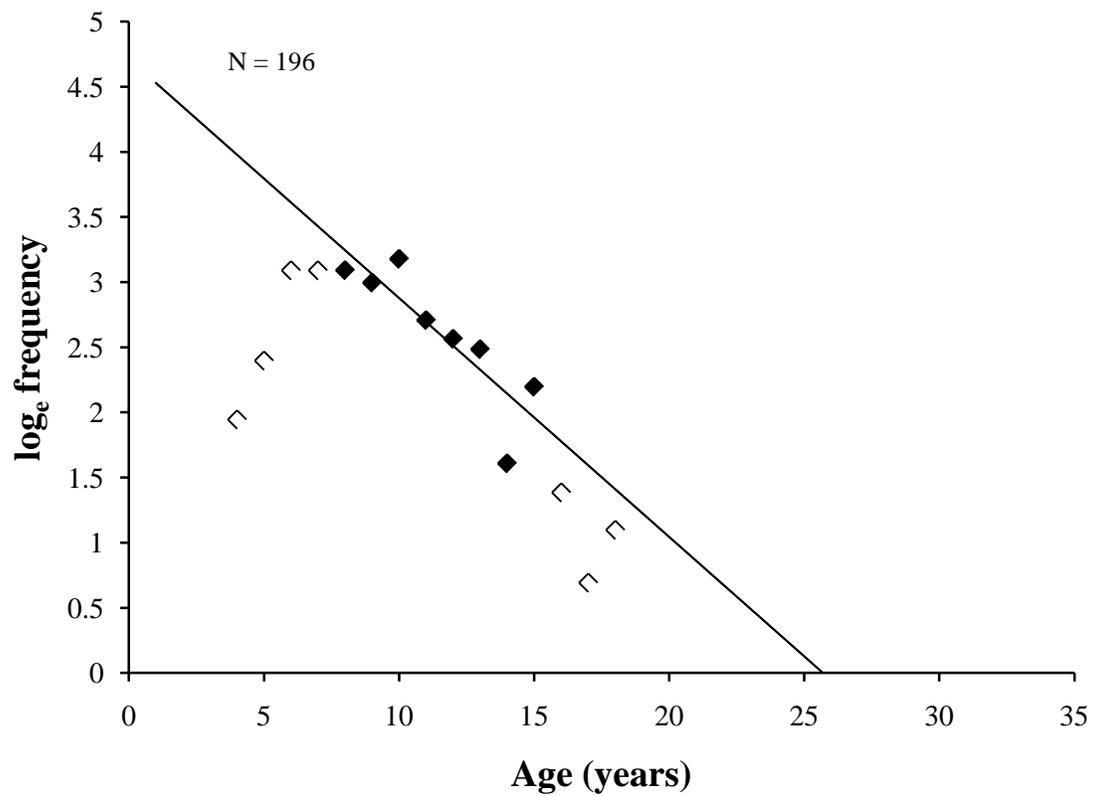


Figure 7. Catch curve for Grasse River lake sturgeon. Open diamonds denote age classes prior to full recruitment to sampling gear and not included in estimate of Z and closed diamonds denote age classes included in estimate of Z .

Table 2. Quasi-Akaike Information Criterion (QAICc) values for the top two Cormack-Jolly-Seber models for the population of lake sturgeon within the Grasse River.

Model	QAIC _c	ΔQAIC _c	QAIC _c Weight	Number of Parameters
B	94.00	0.00	0.9873	8
A	102.71	8.70	0.0127	13

allowed both survival and capture parameters to vary with time. Model A had a QAICc weight of 0.0127. Estimates of S between sampling months were similar, ranging between 86.2% and 87.1% (Table 3). Lake sturgeon abundance as estimated by the POPAN model was 793 individuals (95% CI; 337–1,249).

Discussion

This study has provided new information for lake sturgeon in the Grasse River. Lake sturgeon are prevalent within the Grasse River from the area of its confluence with Lake St. Francis upstream to the first obstruction to fish passage (Madrid Dam) at river km 51.2. Abundance of lake sturgeon in the Grasse River upstream from Madrid Dam is currently undetermined. Although mesh sizes are unknown, previous work reported CPUE values of 1.5 fish per gill net night in the nearby Lake St. Francis (St. Lawrence River) and from 0.2–0.5 fish per gill net night in the Grasse River (Carlson et al. 2001). Although differences in the diel timing of sampling between these two studies do exist, my values are similar to those reported previously for the Grasse River suggesting that lake sturgeon abundance has remained relatively stable over the last eight years. Lallaman et al. (2008) reported gill net CPUE values for the Manistee River in Michigan as ranging from 0.10–0.59 fish per net night. The Manistee River system supports a small but stable population of lake sturgeon with a range of year classes (Lallaman et al. 2008). Although a direct comparison between Grasse River and Manistee River abundance values may potentially be confounded by differences in mesh sizes and diel

Table 3. Parameter estimates and 95% confidence intervals derived from model-averaged estimates of survival (S) and capture (p) probabilities for the top two Cormack-Jolly-Seber models.

Parameter	Time Period	Estimate	Confidence Interval
Survival (S)	Apr-May	0.862	0.404-0.983
	May-Jun	0.871	0.476-0.981
	Jun-Jul	0.871	0.476-0.981
	Jul-Aug	0.871	0.476-0.981
	Aug-Sep	0.871	0.476-0.981
	Sep-Oct	0.866	0.437-0.982
	Oct-Nov	0.864	0.000-1.000
Probability of capture or recapture (p)	Apr	0.066	0.006-0.430
	May	0.029	0.001-0.319
	Jun	0.022	0.001-0.033
	Jul	0	
	Aug	0	
	Sep	0.117	0.023-0.430
	Oct	0.186	0.000-1.000

timing of sampling, the similarity between CPUE values suggest that lake sturgeon in the Grasse River are of a comparable density to a population with known continual recruitment.

Total length and weight values of lake sturgeon captured from the Grasse River are comparable to nearby populations from the St. Lawrence River (Fortin et al. 1993; Johnson et al. 1998). Commercial gill net catch from Lake St. Louis of the St. Lawrence River reported mean TL by year class ranging from 493 mm at age 5 to 1,493 mm at age 33 and mean W ranged from 3,300–16,500 g (Fortin et al. 1993). Gill net catch reported from two studies conducted in the tailwater of Moses-Saunders Generating Station on the St. Lawrence River, ranged from approximately 743–1,486 mm TL during 1969–1970 sampling (Jolliff and Eckert 1971) and from approximately 660–1,560 mm TL during 1993–1994 sampling (Johnson et al. 1998). Differences in mesh sizes used in this study may have contributed to the abundance of smaller length fish I observed in the Grasse River. The wide range of sizes observed in gill net catch, supported by the presence of a 175 mm TL individual and sturgeon eggs (Normandeau Associates, *unpublished data*) suggests some recruitment is occurring.

Variations in growth in length and body weight of lake sturgeon have been studied for populations throughout the range (e.g., Fortin et al. 1996; Power and McKinley 1997) and the comparison of weights at a given reference length is necessary as the length-weight relationship for lake sturgeon is generally not isometric (Fortin et al. 1993). Fortin et al. (1996) described an inverse relationship between latitude and growth rate for lake sturgeon within their range. Based on the length-weight relationships for St.

Lawrence River populations, a calculated weight for an individual of 1,000 mm TL was estimated at 6,461 g for Lake St. Louis, 6,763 g for the Upper St. Lawrence River, and 5,872 g for Lake St. Francis. For the Grasse River population, the calculated weight for an individual at 1,000 mm TL was 5,174 g. My study value is lower than those previously reported for lake sturgeon from nearby systems. Differences in weight may be related to gear bias or selection for gravid females in other systems and not actual growth differences. The collection of length-weight data from the Grasse River was conducted using non-commercial gear. Alternatively, observed differences in weight could also be attributed to differences in feeding behaviors, quality of available habitat characteristics or competition. Power and McKinley (1997) suggested that quantity and quality of food sources may be important in explaining differences in the variation of growth rates among lake sturgeon populations.

My age estimates from pectoral spines of lake sturgeon are within the ranges of those observed for nearby St. Lawrence River populations. Ages estimated from commercial catch of lake sturgeon from Lake St. Louis of the St. Lawrence River ranged from 5–97 years (Fortin et al. 1993). Values reported for catch from the tailwater of the Robert Moses Generating Station on the St. Lawrence during sampling conducted during 1969 and 1970 ranged from 7–38 years (Jolliff and Eckert 1971) and sampling conducted from 1993–1994 ranged from approximately 4–51 years (Johnson et al. 1998). Nearly 80% of the total catch (N = 139) reported from the 1969–1970 sampling was between the ages of 9 and 13 years (Jolliff and Eckert 1971). Recent work conducted by Bruch et al. (2009) assessed the accuracy of lake sturgeon pectoral spines for age determination and

stated that pectoral spine sections underestimated the true age of fish older than 14 years with error increasing with age. Bruch et al. (2009) stated that ages estimated from otoliths were valid up to 52 years of age. In addition, Bruch et al. (2009) provided a power function to provide a means of correcting existing age estimates obtained from lake sturgeon pectoral spines. Due to the threatened status of lake sturgeon in New York State and the lack of population specific knowledge for the Grasse River, the use of otoliths for age determination was not feasible. While a strong relationship exists for the true age-estimated age function developed by Bruch et al. (2009) for Lake Winnebago sturgeon, uncertainty over the transferability of that relationship out of system prevented me from incorporating that into this study. Previous age determination studies for nearby St. Lawrence River populations of lake sturgeon (Fortin et al. 1993; Johnson et al. 1998) were conducted using the same aging methodologies as this study and their results, although potentially underestimating true ages, were comparable, in my judgment. In addition to potential biases in age determination related to individuals older than age 14, the lack of abundance of lake sturgeon older than 32 years in the Grasse River can potentially be attributed to sampling bias associated with smaller mesh gill nets than those used in commercial sampling. It is also possible that the Grasse River is used primarily by juvenile sturgeon.

Studies have fitted a von Bertalanffy growth equation to length and age (Johnson et al. 1998; Smith and Baker 2005) and several literature reviews are available (Fortin et al. 1996; Power and McKinley 1997). Based on available length data from commercial fisheries from nearby portions of the St. Lawrence River (Fortin et al. 1993), I feel my

estimate of L_{∞} is biologically reasonable. My growth coefficient (k) estimate of 0.029 is similar to that reported for lake sturgeon captured in the tailwater of the nearby Robert Moses Dam (0.042; Johnson et al. 1998). Onset of sexual maturity and first occurrence of sexual dimorphism in growth rates for lake sturgeon populations in Quebec range from 23–27 years (Fortin et al. 1996). Mean length of this age range within St. Lawrence River populations were reported as 1,241 mm for Lake St. Louis, 1,262 mm for the Upper St. Lawrence River, and 1,138 mm for Lake St. Francis (Fortin et al. 1996). For the Grasse River population, the mean length of individuals within this age range was calculated as 1,220 mm (range = 1,179–1,260 mm). The calculated value using my von Bertalanffy parameters for mean TL for fish ages 23–27 was similar to previously reported parameters for similar latitudes within the St. Lawrence River watershed.

Prior to assessment of mortality, I examined possible violations of the assumptions as cited by Ricker (1975). I felt that the assumption of constant recruitment could be supported through examination of the age frequency distribution obtained from my sampling. Although age 1 and 2 fish were not sampled by my gear within the Grasse River, the presence of a young of year fish as well as documentation of spawning through the collection of two eggs during 2008 and 2009, each at different spawning sites, suggested that some recruitment was occurring (Normandeau Associates, *unpublished data*). In addition, support for relaxation of the assumption of constant recruitment was reported by Maceina (1997) who calculated similar estimates of mortality for a fish population which exhibited varied year class strength between sampling time periods. Since greater access to spawning habitat above the breached low-head weir in the lower

Grasse River took place during 1997, recruitment in this system may have increased with greater access to more spawning habitat. In a population experiencing increasing recruitment, a catch-curve constructed from a single random sample will overestimate annual mortality (Miranda and Bettoli 2007) and therefore, my estimate is conservative (i.e. higher). The assumption of constant mortality is supported due to the closure of commercial fisheries by New York State and the Provinces of Quebec and Ontario in the waters of Lake St. Francis, which eliminated most fishing mortality as of 1987. Although commercial harvest on the nearby Akwesasne Reservation occurs, catch records for this fishery are not available. As a result, I could not assume that the calculated total instantaneous mortality rate for the Grasse River is currently attributed to only natural mortality (M). Based on the assessment of the length-frequency distributions, I did not believe that gear selectivity was important after age seven. Catch curve estimates of total instantaneous mortality (Z) obtained for lake sturgeon from the Grasse River ($Z = 0.184$, ages 7–14) were less than those reported by Fortin et al. (1996) for Lake St. Louis of the St. Lawrence River for the 1981–1985 time period. Similarly, total annual mortality ($A = 16.8\%$) estimates for the Grasse River were lower than estimates for the Lake St. Louis population calculated during 1981 ($A = 20.0$), 1982 ($A = 23.0$) and 1983 ($A = 23.0$) for sturgeon ages 16–31 (Fortin et al. 1993). Previously reported values from the St. Lawrence River were estimated during a period of both natural and significant fishing mortality. Incidental catch and release by recreational anglers and an unquantified commercial harvest on the nearby Akwesasne Reservation do occur. However, the lower mortality, when compared to a commercially harvested population, coupled with the

collection of small individuals and eggs, indicates some level of recruitment to this population and provides a positive indicator.

I justified the removal of CJS models C and D by the open nature of the Grasse River to the St. Lawrence River, the short time frame of capture with respect to the spawning periodicity of lake sturgeon and variability in riverine conditions between sampling events. I felt that the likelihood of recapture should not be estimated as a constant value through time. Maintaining the survival probability as a constant seemed plausible given the short duration of the sampling period and the life span of the species. Estimates of survival (S) obtained from Program MARK represent the combined losses of individuals due to both mortality and emigration from the sampling area. Given that lake sturgeon are long lived, reaching ages in excess of 55–80 years (Scott and Crossman 1973), and the short duration of the data set used in my analysis, I believe that my monthly survival estimates from Program MARK likely represent the level of temporary or permanent emigration from the study site into the St. Lawrence River rather than mortality. Estimates for S were consistent throughout the duration of this study suggesting that emigration to Lake St. Francis occurs at a rate of approximately 13% throughout the months of April to November.

This study was intended to provide needed information related to the age, growth, abundance, and mortality of lake sturgeon in the Grasse River. Age distribution of Grasse River lake sturgeon was similar to those previously reported from nearby St. Lawrence River populations. Length at age as predicted by my von Bertalanffy growth model was similar to previously predicted values for St. Lawrence River populations of

lake sturgeon. I have provided the first estimates of abundance and mortality in the Grasse River. These estimates will contribute to the enhancement of future management of lake sturgeon in the Grasse River, and in general.

References

- Bruch, R. M., S. E. Campana, S. L. Davis-Foust, M. J. Hansen, and J. Janssen. 2009. Lake sturgeon age validation using bomb radio carbon and known age fish. *Transactions of American Fisheries Society* 138: 361-372.
- Burnham, K. P. and D. R. Anderson. 2002. *Model selection and multimodel inference: a practical information-theoretic approach*, 2nd edition. Springer-Verlag, New York, 488 pp.
- Carlson, D. M. 1995. Lake sturgeon waters and fisheries in New York State. *Journal of Great Lakes Research* 21: 35-41.
- Carlson, D. M., R. Colesante, J. S. Hayes, and S. L. Schlueter. 2001. Lake sturgeon populations and recovery programs. Poster session presented at the Fourth International Sturgeon Symposium, Oshkosh, WI.
- Cooch, E. and G. White. 2007. *Program MARK: a gentle introduction* 8th edition. Colorado State University, Fort Collins.
- Currier, J. P., G. Roussow. 1951. Age and growth of lake sturgeon from Lake St. Francis, St. Lawrence River. *Canadian Fish Culturist* 10: 17-29.
- Dumont, P., R. Fortin, G. Desjardins, and M. Bernard. 1987. Biology and exploitation of lake sturgeon (*Acipenser fulvescens*) on the Quebec waters of the Saint-Laurent River. Pages 57-76 in Olver, C. H., editor. *Proceedings of a workshop on lake sturgeon (Acipenser fulvescens)*, Feb 27-28 1986, Timmins, Ontario. Technical Report Series No. 23.
- Dumont, P., J. Leclerc, S. Desloges, P. Bilodeau, Y. Mailhot, R. Dumas, M. La Haye, R. Verdon, and R. Fortin. 2004. The biology, status and management of lake sturgeon (*Acipenser fulvescens*) in the Quebec part of the St. Lawrence: a summary. Appendix Pages 1-7 in Threader, R. W., T. Haxton, A. Mathurs, and C. Pullen, editors. *Proceedings of a workshop on lake sturgeon (Acipenser fulvescens) in Lake St. Francis and surrounding waters*, Sept 22-23 2004, Cornwall, Ontario.
- Fortin, R., J. R. Mongeau, G. Desjardins, and 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.
- Johnson, J. H., D. S. Dropkin, S. R. LaPan, J. E. McKenna, and R. M. Klindt. 1998. Age and growth of lake sturgeon in the upper St. Lawrence River. *Journal of Great Lakes Research* 24: 474-478.
- Jolliff, T. W. and T. H. Eckert. 1971. Evaluation of present and potential sturgeon fisheries of the St. Lawrence River and adjacent waters. New York. Department of Environmental Conservation, Cape Vincent Fisheries Station, New York, 86 pp.
- Lallaman, J. J., R. A. Damstra, and T. L. Galarowicz. 2008. Population assessment and movement patterns of lake sturgeon (*Acipenser fulvescens*) in the Manistee River, Michigan USA. *Journal of Applied Ichthyology* 24: 1-6.
- Lebreton, J. D., K. P. Burnham, J. Clobert, and D. R. Anderson. 1992. Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. *Ecological Monographs* 62: 67-118.
- Maceina, M. J. 1997. Simple application of using residuals from catch-curve regression to assess year class strength in fish. *Fisheries Research* 32: 115-121.
- Miranda, L. E. and P. W. Bettoli. 2007. Mortality. Pages 229-278 in C.S. Guy and M.L. Brown, editors. *Analysis and interpretation of freshwater fisheries data*. American Fisheries Society, Bethesda Maryland.
- Morin, J. and M. Leclerc. 1988. From pristine to present state: hydrology evolution of Lake Saint-Francois, St. Lawrence River. *Canadian Journal of Civil Engineering* 25: 864-879.
- Parsons Brinckerhoff. 2006. Preliminary Application Document: Massena Grasse River Multipurpose Hydroelectric Project. FERC # 12607.
- Peterson, D. L., P. Vecsei, and C. A. Jennings. 2006. Ecology and biology of the lake sturgeon: a synthesis of current knowledge of a threatened North American *Acipenseridae*. *Review of Fish Biology and Fisheries* 17: 59-76.
- Power, M., and R. S. McKinley. 1997. Latitudinal variation in lake sturgeon size as related to the thermal opportunity for growth. *Transactions of the American Fisheries Society* 126: 549-558.
- Ricker, W. E. 1975. Computations and interpretations of biological statistics of fish

- populations. Fisheries Research Board of Canada Bulletin 191. 382 pp.
- Rossiter A., D. L. G. Noakes, and F. W. H. Beamish. 1995. Validation of Age Estimation for the Lake Sturgeon. Transactions of the American Fisheries Society 124: 777-781.
- Schwartz, C. J. and A. N. Arnason. 1996. A general methodology for the analysis of capture-recapture experiments in open populations. Biometrics 52: 860-873.
- Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Bulletin 184, Fisheries Research Board of Canada. Ottawa, 966 pp.
- Smith, C. L. 1985. The Inland Fishes of New York State. The New York State Department of Environmental Conservation, Albany, NY, 522 pp.
- Smith, K. M., and E. A. Baker. 2005 Characteristics of spawning lake sturgeon in the Upper Black River, Michigan. North American Journal of Fisheries Management 25: 301-307.
- von Bertalanffy, L. 1938. A quantitative theory of organic growth. Human Biology 10: 181-213.
- White, G. C. 2007. Program MARK, Version 5.1. Colorado State University, Fort Collins.

CHAPTER THREE
SEASONAL MOVEMENT AND MESOHABITAT USE OF LAKE
STURGEON IN THE GRASSE RIVER, NEW YORK

Introduction

The lake sturgeon is native to larger river and lake systems throughout the northeastern and central United States, including the Laurentian Great Lakes and Hudson Bay drainage (Scott and Crossman 1973; Peterson et al. 2006). Although lake sturgeon once supported large commercial fisheries, few self-sustaining populations remain (Wilson and McKinley 2004). The species is present within the St. Lawrence watershed (Smith 1985; Carlson 1995) and is listed by the State of New York as threatened (Carlson 1995).

Assessments of the seasonal movement patterns for lake sturgeon have been conducted for both contiguous lake and river systems (Lyons and Kempinger 1992; Rusak and Mosindy 1997; Lallaman et al. 2008) and riverine populations (Fortin et al. 1993; Borkholder et al. 2002; Knights et al. 2002). Populations residing in contiguous lake and river systems generally use river habitat for spawning during the spring season and use lake habitat for feeding and overwintering during the remainder of the year (Auer 1999; Lallaman et al. 2008). However, another study has documented populations of lake sturgeon as remaining resident within riverine habitats following spring spawning (Rusak and Mosindy 1997). It has been suggested that the Grasse River includes both

resident and migratory stocks of lake sturgeon (Carlson 1995). Resident behavior in lake sturgeon has been linked to accessibility of pool habitat (Borkholder et al. 2002).

A wide variety of environmental factors can influence habitat use including water quality, hydraulics, substrate, cover, food availability, and intra- and inter-species interactions. Fish meso-scale habitats (mesohabitats) typically correspond in size with hydromorphologic units such as pool, riffle, and run, and are defined by hydraulic patterns along with attributes that provide shelter and create favorable conditions (Parasiewicz 2008). The use of mesohabitat classification systems has been used in the assessment of fish populations on both the community (Bisson et al. 1988; Dider and Kestemont 1996; Kehmeier et al. 2007) and individual species levels (Baran et al. 1997; Muhlfield et al. 2001; Santoul et al. 2005). Spatial and temporal distribution of lake sturgeon within mesohabitats present in riverine systems may vary based on a range of environmental variables. Rusak and Mosindy (1997) stated that the selection of habitat by lake sturgeon could be linked to foraging behavior. Previous work conducted in the Mattagami and Groundhog rivers of Ontario, indicated that juvenile lake sturgeon will remain in habitats with moderate prey abundance (Chiasson et al. 1997). However, a separate study in the St. Lawrence River system found that although juvenile lake sturgeon did aggregate in localized areas, the presence of fish in those areas could not be fully explained by their feeding habits (Nilo et al. 2006). Knights et al. (2002) observed variation in the selection of habitat types related to river discharge. Variation in the use of habitats in relation to flow may ensure that individuals do not get trapped in areas that have seasonally unfavorable conditions during low flow periods or areas with increased

energy costs and lower food resources during high flow periods (Knights et al. 2002). Age-0 lake sturgeon typically occupy shallow, less than 2 m, low flow riverine habitats (Kempinger 1996; Benson et al. 2005) while juvenile fish (< 530 mm fork length) prefer riverine water depths greater than 13.7 m (Barth et al. 2009). Werner and Hayes (2004) found that habitat selection by juvenile and adult lake sturgeon within the St. Lawrence River was partitioned based on substrate. Juvenile lake sturgeon were more abundant over silt and sand substrate than were adult fish (Werner and Hayes 2004).

Seasonal movement patterns and habitat use of lake sturgeon in the Grasse River is poorly understood. The objectives of this study were to (1) characterize the seasonal movement patterns of lake sturgeon within the Grasse River, (2) assess seasonal movement patterns of adult and juvenile lake sturgeon through a recently breached low-head weir, (3) evaluate the degree to which lake sturgeon are resident or non-resident within the Grasse River, and (4) determine the mesohabitat and substrate use by juvenile and adult lake sturgeon within the middle Grasse River.

Methods

Study area

The Grasse River flows 185 km northeast from its source in the foothills of the Adirondack Mountains to its confluence with the St. Lawrence River in Massena, New York (Figure 8). The confluence of these two rivers is located downstream of the Moses-Saunders Generating Station in Massena, New York, within a portion of the St. Lawrence River known as Lake St. Francis. Lake St. Francis runs for approximately 80 km

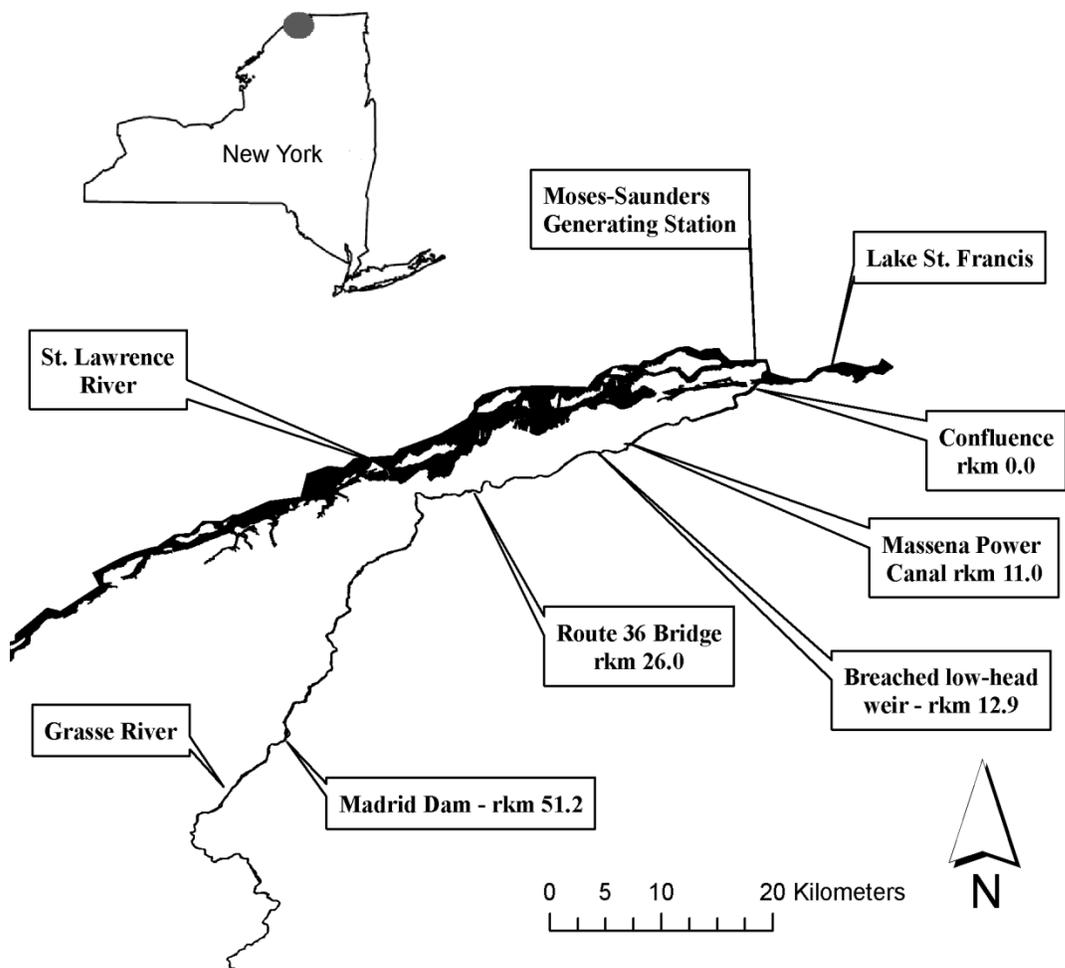


Figure 8. Map of the study area, consisting of the Grasse River below the Madrid Dam where movement and habitat use of lake sturgeon were monitored.

between the Moses-Saunders Generating Station and the Beauharnois Generating Station in Valleyfield, Quebec. The Grasse River drains approximately 1,702 km², has an average annual stream flow of 31.1 cubic meters per second (m³/s), and a median flow of approximately 19.8 m³/s (Parsons Brinckerhoff 2006). The lower Grasse River (river km 0–11.5, as measured from the confluence with Lake St. Francis) was dredged during the early 1900s and is relatively deep (4.5–7.5 m) compared to the remainder of the system, which typically ranges in depth from 1.5–3.0 m. The remains of a low-head weir that breached during the winter of 1997 are located at river km 12.9, but no longer present a barrier to migration except during seasonal low flow periods. A second low-head dam (Madrid Dam) is located at river km 51.2 and does not have fish passage facilities. All lake sturgeon examined during this study were captured below Madrid Dam and downstream to approximately river km 6.0 of the Grasse River. Sampling was restricted to areas with suitable water depth (> 1 m) for small boat access. The study area for this project was defined as the Grasse River between river km 0.0 and 51.0, and was divided into three reaches for analysis. These reaches were the upper river (river km 51.1–26.0), the middle river (river km 26.0–12.9) and the lower river (river km 12.9–0.0). The three primary capture areas were located between river km 6.0–11.3, 12.9–18.5, and at river km 49.6.

Data collection

Juvenile lake sturgeon (defined here as individuals < 980 mm total length [TL]) and adult lake sturgeon (defined here as individuals ≥ 980 mm TL) were captured in the Grasse River for radio-tagging during July 2007, November 2007, and October 2008.

Two different sinking gill net types (experimental and fixed mesh) were used. Experimental nets measured 38.1 m (length) x 2.4 m (depth) x five 7.6 m wide panels with stretch mesh ranging from 12.8–17.8 cm. Fixed mesh nets measured 45.7 m (length) × 1.8 m (depth) and were composed of 20.4 cm stretch mesh. Gill nets were anchored at the shoreline, set perpendicular to the current, and fished during daylight hours. Total length (nearest mm) and weight (nearest 0.01 kg) of each fish captured was recorded.

Radio transmitters were inserted into the abdominal cavity based on techniques described by Hart and Summerfelt (1975). A 3-cm incision was made just off the ventral mid-line. Placement of the incision was approximately 4–6 cm anterior to the insertion of the pelvic fins. Care was taken to lift the skin upward during incising to ensure no damage to internal organs. For transmitters with trailing antennae, a 1-mm diameter stainless steel cannula was inserted into the incision and excised out of the body wall laterally. The antenna wire of the transmitter was threaded through the cannula and the cannula was pulled through the body wall, leaving the antenna protruding laterally from the fish. For transmitters with coiled antennae, the entire unit was inserted into the abdominal cavity. The incision was closed with four or five interrupted sutures (Prolene polypropylene; 3-0 cutting FS-1 needle; Ethicon Inc., Somerville, New Jersey, USA). Radio transmitters (SR-16-25; 18-mm diameter; 50-mm long; Lotek Inc., Newmarket, Ontario, Canada) transmitted pulse-coded signals at 148.400 and 148.340 MHz, weighed approximately 22 g, and had a life expectancy of 730 d. Sex of individuals (≥ 980 mm TL) captured during 2007 was determined by visual assessment of the gonads through the

transmitter incision. Sex for individuals captured during 2008 was determined in the field with the use abdominal insufflation and an endoscope following methods described by Trested et al. (2010). Observed images were classified as male or female following descriptions presented by Bruch et al. (2001). Sexual condition was recorded as either ripe (late stage development) or non-ripe (early stage development). Fish were allowed to recover and were released within 30 minutes of surgery in the vicinity of their capture site. Individuals were classified as juveniles based on literature reported age values for the onset of sexual maturity of the species of 12–18 years (Peterson et al. 2006) and the mean estimated length for individuals of those ages (980 mm TL) derived from the von Bertalanffy growth curve specific to this population (Trested and Isely, *unpublished data*). However, when ripe gametes were present, the individual was classified as adult regardless of size (n = 1).

I attempted to locate all radio-tagged lake sturgeon twice monthly during open water periods (April through November), and monthly during ice-covered periods (December through March). In addition, daily tracking was conducted during a 12-d period from 21 April to 2 May, 2008, and a 21-d period from 15 April to 6 May, 2009. Manual tracking was conducted by boat, truck, and foot depending on conditions, and all tracking was conducted during daylight hours. The receiving antenna used for manual searches was either a four-element Yagi antenna or a whip antenna. A receiver (SRX-400; Lotek Inc., Newmarket, Ontario, Canada) was used to detect transmitter signals. Fish location (latitude/longitude) was recorded with a GPS (Garmin 76; Garmin International Inc., Olathe, Kansas, USA). In addition to manual tracking effort, three

stationary telemetry monitoring stations were established for year-round detection of radio-tagged individuals. These were located at river km 3.1 (near the confluence with the St. Lawrence River), river km 11.5 (at the base of the first riffle/rapid complex encountered by individuals moving upstream), and at river km 12.9 (just downstream of the breached low-head weir). Each monitoring station consisted of a data-logging receiver and a four-element or a nine-element Yagi antenna. Monitoring stations were installed during July 2007 at river km 3.1 and 12.9 and during January 2008 at river km 11.5. All stationary telemetry monitoring stations were removed during the last week of June 2009.

Mesohabitats were visually identified and mapped for a 15-km stretch of river from the confluence with the Massena Power Canal (river km 11.0) at the downstream end to the Route 36 Bridge (river km 26.0) in Louisville, New York, on the upstream end (Figure 8). As described by Armantrout (1998), channel units were defined as relatively homogenous areas of a riverine system differing in depth, velocity and substrate characteristics from adjoining areas. Within this study, these mesohabitat or channel units were classified as riffle, rapid, glide, run, pool, and backwater, based on modified definitions from Bisson et al. (1996) and Dollof et al. (1993) (Table 4). An additional classification type, ruffle, was included for channel units exhibiting the characteristics of both riffle and run (i.e., a run-like habitat but with surface turbulence, swift current, and greater depth relative to riffle habitat). Mesohabitat boundaries were identified by means of visual changes in depth, velocity, and substrate. Following visual determination, boundaries were delineated by collection of point data using a GPS (GeoXH; Trimble

Table 4. Definitions of mesohabitat types mapped for an 15-km stretch of the Grasse River for use in determining lake sturgeon habitat preferences.

Mesohabitat Type	Mesohabitat Description
riffle	Shallow stream reaches with moderate current velocity, some surface turbulence and higher gradient. Convex streambed.
rapid	Higher gradient reaches with faster current velocity, coarser substrate, and more surface turbulence. Usually convex streambed.
glide	Moderately shallow stream channels with laminar flow, lacking pronounced turbulence. Streambed shape is flat.
run	Monotone shallow stream channels with laminar flow, lacking pronounced turbulence. Streambed shape is flat.
pool	Low velocity, deep water impounded by a channel bed control, blockage or partial channel obstruction. Usually convex streambed.
backwater	Slack areas along channel margins and areas behind obstructions with an eddy.
ruffle	An area exhibiting traits of both riffles and run; i.e. a run-like habitat but with surface turbulence and swift currents.

Navigation Ltd., Sunnyvale, California, USA). Due to decreases in the diversity of mesohabitat types with increases in river flow, habitat mapping for this stretch of the Grasse River was conducted during low (3.0 m³/s) and mid flow (17.4 m³/s) conditions. Dominant substrate type within each unique channel unit was classified based on physical diameters presented in Bovee (1986) with some aggregation of categories for simplification.

Data analysis

The Statistical Analysis System (SAS 9.1; SAS Institute, Cary, North Carolina, USA) was used for data analysis and a probability value of ≤ 0.05 was used to reject the null hypothesis in all statistical tests. To facilitate the analysis of movement data, I divided the year into four seasons. These seasons were defined based on recorded water temperature data for the Grasse River (Normandeau 2008). Winter was defined as the cold-water period indicated by ice-over conditions and included the months of December to March. Increasing water temperatures coupled with the expected increase in biological activity defined the spring period of April through June, a peak in annual water temperatures defined summer as July to September and declining water temperatures defined the fall season as October and November. Analysis of location data was facilitated using ArcView 9.3 (ESRI, Inc.; Redlands, California, USA). Distances between consecutive locations (absolute value of distance moved between telemetry locations, disregarding upstream or downstream directionality of the movement) were measured as run of the river and the minimum daily movement rates were calculated by dividing the distance between sequential locations by the number of days between those

locations. When available, location observations obtained during manual tracking efforts were supplemented with data from the stationary telemetry monitoring stations in an effort to fine tune minimum daily movement rates. Absolute distance moved for each individual (km) was calculated as the sum of all run of the river distances moved between consecutive manual relocations. Displacement was calculated as the net distance moved when accounting for upstream and downstream directionality relative to the preceding manually determined location. Mean seasonal home range sizes for individual sturgeon were calculated as the section of river enclosed by the most upriver and downriver positions detected by manual telemetry for an individual on a seasonal basis. Similar to the definition provided by Kernohan et al. (2001), I defined the home range of an individual lake sturgeon as the extent of river with a defined probability of occurrence (100%) during a specified time period (season). Similar to analyses conducted by Rusak and Mosindy (1997), data collected from fish exhibiting spawning behavior during the spring were not included for analyses of seasonal movement data.

The hypotheses that minimum daily movement rate, mean absolute distance moved, displacement, and mean home range size differed among stage (juvenile and adult) and sex (fixed effects) were tested with a mixed-model analysis of variance (GLIMMIX Procedure, SAS) while controlling for individuals, season, and year (random effects). The hypotheses that these values differed seasonally (fixed effect) were tested with a mixed-model analysis of variance while controlling for individuals, sex, stage, and year (random effects). I used Fishers Protected Least Significant Difference Procedure to perform pair-wise comparisons of each sex and stage between seasons.

Mesohabitat and substrate use was determined by overlaying location on the channel unit and substrate coverages produced for the 15-km stretch of river between Route 36 in Louisville and the confluence with the Massena Power Canal. Each lake sturgeon telemetry location as recorded by manual telemetry was assigned the attributes of the low flow mesohabitat, mid flow mesohabitat and substrate type shapefiles based on their intersection using ArcView 9.3. Observations were then partitioned based on river flow. River flow values were obtained from the USGS gauging station (# 04265432; available at <http://waterdata.usgs.gov/ga/nwis/ny?04265432>) on the Grasse River at Chase Mills, New York. Sturgeon observations over the range of flows from 2.8–12.7 m³/s were examined for habitat use patterns under low flow mesohabitat availability and observations over the range of flows from 12.8–28.3 m³/s were examined for habitat use patterns under the mid flow mesohabitat availability. Dominant substrate was considered unlikely to change regardless of flow condition and as a result all sturgeon observations were used to assess substrate use patterns.

The frequency distributions of mesohabitat types were pooled to five major categories (pool, rapid, run, ruffle, other) and the distributions of mapped habitat were compared with the frequency distribution of observed locations. The hypothesis that no differences in the frequency distributions between mapped habitat and habitat used by lake sturgeon would differ by sex and stage was tested using the Pearson exact Chi-square test which corrected for repeated measures. Given that there were no significant effects due to sex or stage, distributions were combined and the hypothesis that distributions between mapped habitat and habitat used by lake sturgeon would differ was

tested using the Pearson exact Chi-square test. The hypothesis that observed differences did not differ through time (season and year as fixed effects) was tested with a mixed-model analysis of variance controlling for individuals, sex, and stage (random effects). Substrate usage was analyzed in a similar manner to mesohabitat. The distribution of substrate types were pooled to five major categories (silt, sand, cobble, boulder, bedrock).

Results

Captures

Lake sturgeon ($n = 211$) were captured between 1 April 2007 and 9 October 2008 from the Grasse River. Of the total catch, 22 were captured within the upper river, 161 were captured within the middle river and 28 were captured within the lower river. Of those, 23 lake sturgeon (12 juveniles and 11 adults) were outfitted with radio transmitters: 4 within the upper river, 16 within the middle river, and 3 within the lower river (Table 5). Mean total length for radio-tagged juvenile lake sturgeon was 779 mm (range = 561–970 mm) and for adult lake sturgeon was 1,109 mm (range = 953–1,368 mm) and differed significantly ($t = 5.72$, $df = 21$, $P = < 0.0001$). Mean weight for radio-tagged juvenile lake sturgeon was 1,930 g (range = 850–5,000 g) and for adult lake sturgeon was 7,540 g (range = 4,250–13,600 g) and differed significantly ($t = 6.25$, $df = 21$, $P < 0.0001$). Six adult fish (3 females, 3 males) contained developed gametes during fall season radio tagging, suggesting they would spawn during the following spring. The early developmental stage of gametes or post-spawn condition at the time of tagging in the 5 remaining radio-tagged adult fish (4 females, 1 male) suggested they were not likely

Table 5. Description of radio-tagged lake sturgeon whose seasonal movements and habitat use in the Grasse River, New York, were monitored.

Transmitter Frequency	ID	Maturity	Sex	Condition	TL (mm)	Weight (g)	Tagging Date	Tagging Location
148.400	28	adult	F	ripe	953	4,250	11/14/2007	middle river
148.400	27	adult	M	ripe	1,092	8,300	11/14/2007	middle river
148.400	29	adult	F	ripe	991	5,900	11/17/2007	upper river
148.400	21	adult	F	non-ripe	1,100	8,350	9/30/2008	lower river
148.400	30	adult	F	non-ripe	1,083	6,700	10/1/2008	middle river
148.400	24	adult	M	non-ripe	1,330	10,500	10/1/2008	middle river
148.400	22	adult	M	ripe	980	4,800	10/2/2008	middle river
148.340	52	adult	F	ripe	1,010	5,000	10/2/2008	middle river
148.400	25	adult	F	spent	1,368	13,600	10/2/2008	middle river
148.400	23	adult	M	ripe	1,055	6,400	10/7/2008	middle river
148.340	51	adult	F	spent	1,230	9,100	10/9/2008	middle river
148.400	15	juvenile	-	-	594	1,050	7/19/2007	upper river
148.400	14	juvenile	-	-	639	1,300	7/19/2007	upper river
148.400	20	juvenile	-	-	775	2,100	7/19/2007	upper river
148.400	16	juvenile	-	-	835	1,200	7/20/2007	middle river
148.400	19	juvenile	-	-	835	1,200	7/20/2007	middle river
148.400	18	juvenile	-	-	845	1,230	7/20/2007	middle river
148.400	17	juvenile	-	-	900	1,230	7/20/2007	middle river
148.400	13	juvenile	-	-	561	850	11/12/2007	lower river
148.400	12	juvenile	-	-	692	1,500	11/13/2007	middle river
148.400	11	juvenile	-	-	752	2,000	11/13/2007	middle river
148.400	26	juvenile	-	-	953	5,000	11/15/2007	lower river
148.340	54	juvenile	-	-	970	4,500	10/9/2008	middle river

to spawn during the following spring. Sex of radio-tagged juvenile fish was not determined.

I relocated 23 radio-tagged lake sturgeon a total of 1,104 times from 19 July 2007 to 28 September 2009. Radio-tagged juvenile lake sturgeon were tracked an average of 690 d (range 206–802 d) and individual fish were relocated 27–73 times (mean = 61; SE = 4.8). Radio-tagged adult fish were tracked an average of 422 d (range 174–684 d) and individual fish were relocated 9–65 times (mean = 36; SE = 4.8).

Seasonal Movements

Manual telemetry data indicated that the annual movements of juvenile and adult lake sturgeon radio-tagged within the upper Grasse River were limited to a 9.9-km stretch of river extending from the Madrid Dam tailwater downstream to the upper portions of the Chase Mills rapid complex (Figures 9 and 10). Although seasonal movement patterns for juvenile lake sturgeon within the upper Grasse River varied by individual, all fish displayed strong site fidelity to particular reaches of river on either a seasonal or annual scale. The majority of seasonal locations for one individual juvenile (Figure 10; denoted by solid diamond) were restricted to the 2.0 km of river immediately below the Madrid Dam during the summer seasons of 2007, 2008 and 2009, a narrow 1-km reach between river km 45.5–46.5 during the fall and winter months of 2007 and 2008 and a 4-km reach between river km 41.0–41.5 during the spring months of 2008 and 2009. The single adult female lake sturgeon in the upper Grasse River also exhibited seasonal site fidelity (Figure 9; denoted by solid diamond). The majority of fall and winter (2007 and 2008)

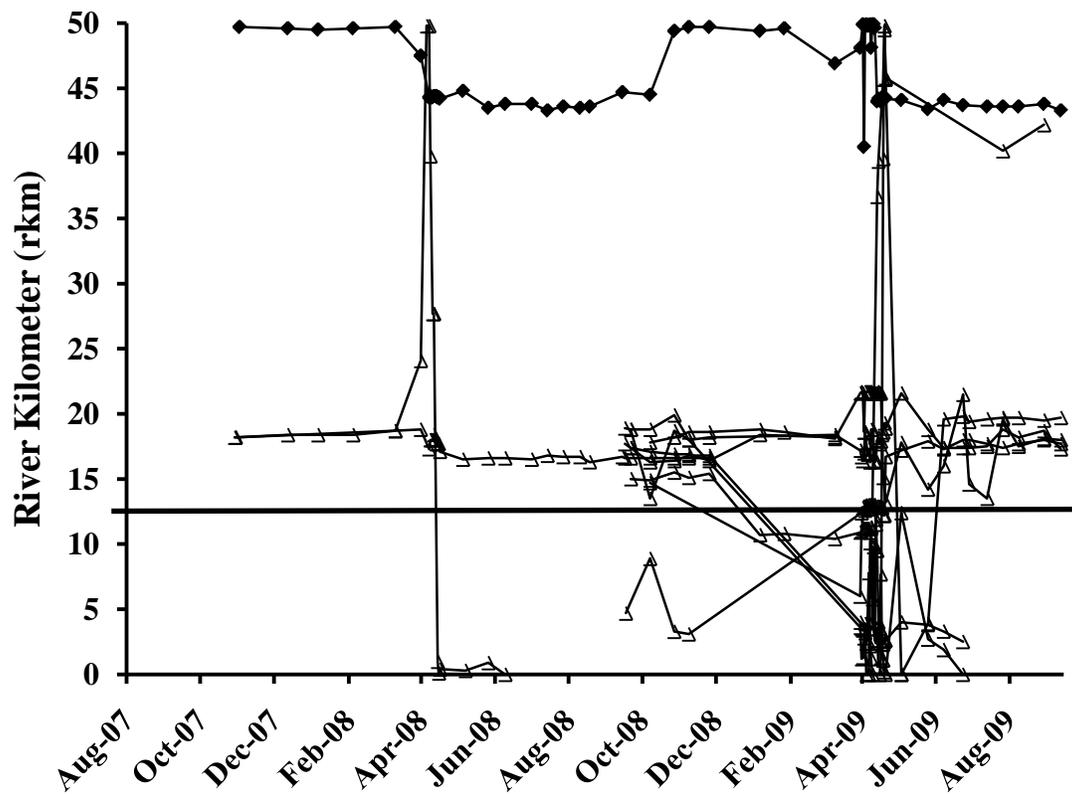


Figure 9. River kilometer positions of individual adult radio-tagged lake sturgeon in the Grasse River below the Madrid Dam from November 2007 through September 2009. The solid lines connecting points indicate the movements of individual fish. The solid bar represents the relative location of the breached low-head weir.

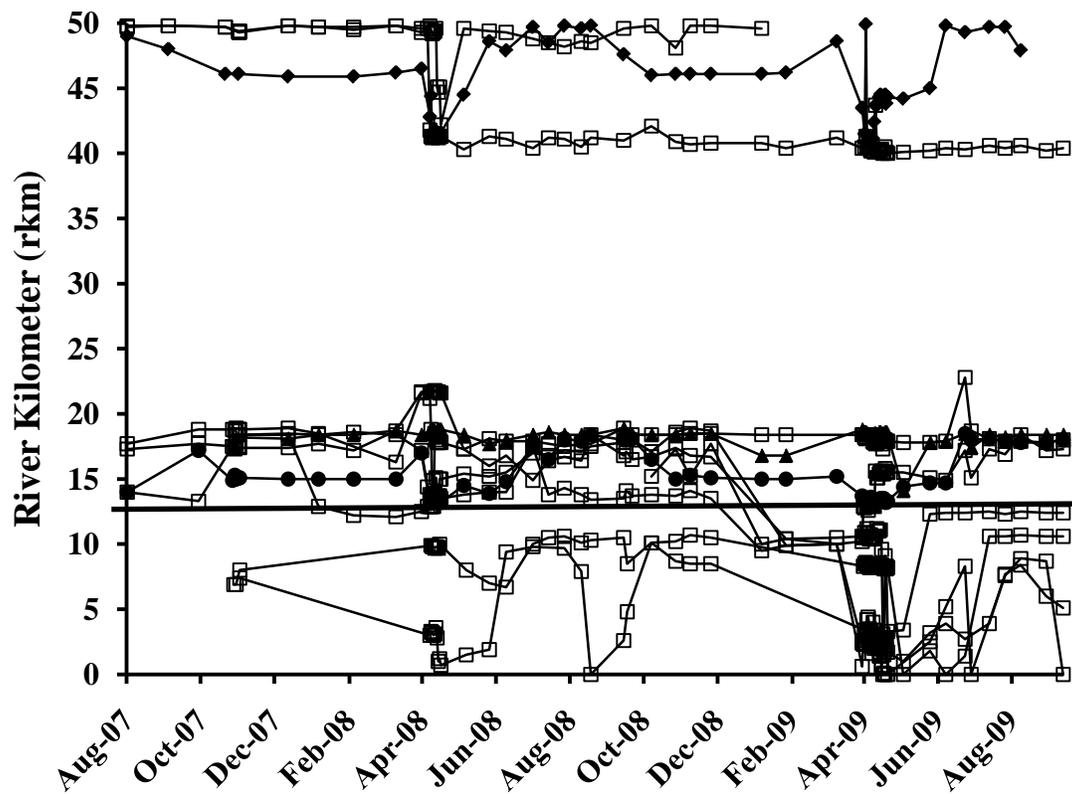


Figure 10. River kilometer positions of individual juvenile radio-tagged lake sturgeon in the Grasse River below the Madrid Dam from July 2007 through September 2009. The solid lines connecting points indicate the movements of individual fish. The solid bar represents the relative location of the breached low-head weir.

seasonal locations were restricted to a 0.5-km stretch of river located just downstream of the Madrid Dam. With the exception of a 10-d period spent in the tailrace of Madrid Dam during the spring of 2009, spring and summer locations for this individual were confined to a 1.1-km reach between river km 43.3–44.2 during both 2008 and 2009.

Movement patterns of the juvenile ($n = 7$) and adult ($n = 9$) lake sturgeon radio-tagged in the middle reach of the Grasse River consisted of individuals that either remained wholly resident within the middle river or individuals that moved downstream through the breached low-head weir and into the lower Grasse River (Figure 9 and 10). A total of 38% ($n = 6$) of lake sturgeon radio-tagged in the middle river remained resident in that stretch for the duration of the study. Resident middle river juvenile fish ($n = 2$) displayed a high degree of site fidelity to particular reaches of river on either an annual or a seasonal basis. One individual juvenile displayed a high degree of site fidelity on an annual basis through the maintenance of a core usage area (95% of all observations) within a stretch of river between river km 17.4–18.9 (Figure 10; denoted by solid triangle). The majority of seasonal locations for another juvenile were between river km 14.9–15.3 (78% of seasonal observations) during the fall and winter seasons of 2007 and 2008 and between river km 12.9–13.9 (85% of seasonal observations) during the spring seasons of 2008 and 2009 (Figure 10; denoted by solid circle). Between-year site fidelity for this juvenile individual was less apparent during the summer season; locations during 2007 were concentrated between river km 14.0–15.0, during 2008 were concentrated between river km 16.5–18.4, and during 2009 were concentrated between river km 17.8–18.5. In contrast, resident middle river adult fish ($n = 4$; 3 females, 1 male) did not

display such a high degree of seasonal site fidelity to short reaches of river. The majority of observations (95%) of adult lake sturgeon resident to the middle Grasse River were recorded between river km 16.0–22.0.

Five transient juvenile lake sturgeon, originally radio-tagged in the middle river, moved downstream through the breached low-head weir and into the lower river. Downstream movements for all of these individuals took place during the winter season of either 2007-2008 ($n = 1$) or 2008-2009 ($n = 4$). Mean daily discharge during the date of downstream passage could only be determined for one individual due to icing conditions at the Chase Mills gauge. Mean daily discharge on the date of downstream passage for the individual fish during the winter of 2007-2008 was $74.8 \text{ m}^3/\text{s}$. Of these five juvenile lake sturgeon, two individuals returned upstream through the breached low-head weir and reestablished residence within the middle river the following spring. Mean daily discharge on the dates of upstream passage through the breached weir for juvenile lake sturgeon was 29.7 and $44.2 \text{ m}^3/\text{s}$. During periods of residency in the middle river section, movement patterns for each of the five juvenile lake sturgeon were comparable to individuals which remained resident for the duration of the study. All individuals exhibited high site fidelity to particular reaches of river on either a year-round or seasonal basis. The majority of locations (82%) for the five transient juvenile fish while within the middle river were located from three core areas located between river km 17.0–19.0, 14.7–15.5, and 13.0–14.0.

A total of five adult lake sturgeon, originally radio-tagged in the middle river, were considered transient due to observed upstream or downstream movements (3 males,

2 females). Four adult lake sturgeon radio-tagged during the fall season of 2008 emigrated from the middle river, through the breached low-head weir and into the lower Grasse River during winter of 2008-2009. Mean daily discharge for the date of downstream passage could not be determined for those individuals due to icing conditions at the Chase Mills gauge. During periods of residency in the middle river section, 60% of the locations for these fish were detected within the same three core areas of use noted for juvenile fish in the middle river. Two of those adult lake sturgeon (1 male, 1 female) returned to the middle Grasse River the following spring and mean daily discharge on the date of upstream passage through the breached low-head weir was 27.4 and 28.0 m³/s. A single male adult lake sturgeon tagged during the fall of 2007 was consistently located between river km 18.2 to 18.7 during the fall and winter seasons prior to departing the middle Grasse River for an upstream spawning area in the Madrid Dam tailwater. Following its upstream migration, this individual moved quickly downstream through the middle river and descended through the breached low-head weir and into the lower Grasse River. Mean daily discharge on the date of downstream passage through the breached low-head weir for that adult lake sturgeon was 30.3 m³/s.

One adult and two juvenile lake sturgeon radio-tagged in the lower Grasse River demonstrated a high degree of site fidelity to two particular stretches of river, a 2 km reach between river km 2.0–4.0 and a second reach between river km 8.0–10.7 (Figure 10 and 3). Of the total observations for sturgeon originally tagged in the lower Grasse River, 72% of the lower river observations were recorded within those two stretches of river. The non-gravid adult female lake sturgeon, originally radio-tagged in the lower

Grasse River, moved upstream through the breached low-head weir during May 2009 and established residence in the upper river, approximately 10.0 km downstream of the Madrid Dam. Mean daily discharge on the date of upstream passage through the breached low-head weir for this adult lake sturgeon was 37.7 m³/s.

Manual telemetry data suggested that radio-tagged lake sturgeon do not remain exclusively within the Grasse River, presumably moving into Lake St. Francis. Sixteen percent (n = 2) of the juvenile sturgeon were undetected for some period of time in the Grasse River throughout the duration of the study whereas 45% (n = 5) of the adult sturgeon were undetected for a period of time. Duration of non-detection periods ranged from 60–148 d for juvenile fish and from 3–326 d for adult fish. Departures from the Grasse River were typically observed during the spring season for juvenile fish and during the spring and summer seasons for adult fish.

Seasonal Movement Rates and Home Range Sizes

Mean minimum daily movement rates were examined using only assumed non-spawning related movements. Over all seasons and years combined, mean minimum daily movement rates for adult male and adult female lake sturgeon were greater than for juvenile lake sturgeon ($F_{2,21} = 9.18$, $P = 0.0014$). Minimum daily movement rates for adult male lake sturgeon in spring were greater than those observed for adult female and juvenile lake sturgeon during the spring as well as adult male, adult female, and juvenile lake sturgeon during the summer, fall, and winter seasons (Figure 11; $F_{6,1,050} = 2.27$, $P = 0.0346$). Adult female lake sturgeon minimum daily movement rates during the spring

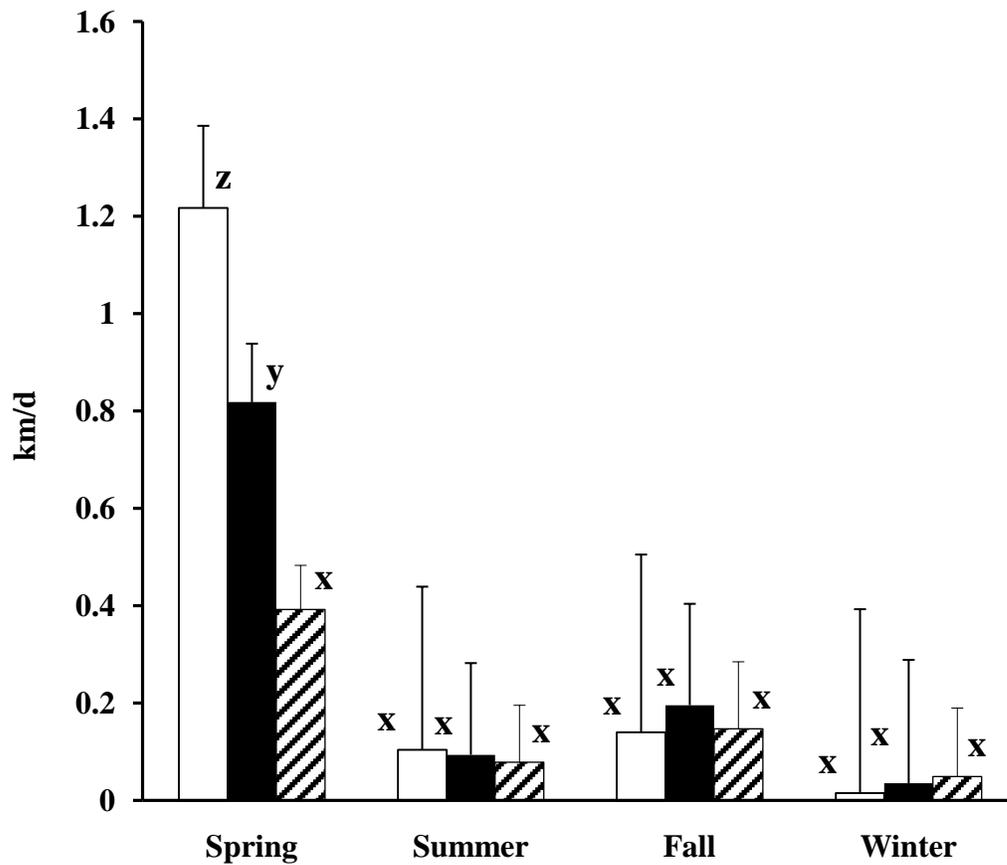


Figure 11. Within and between season comparisons of the mean (\pm SE) minimum daily movement (km/d) of radio-tagged adult male (open shading), adult female (solid shading) and juvenile (hatched shading) lake sturgeon in the Grasse River below Madrid Dam from July 2007 through September 2009. Different letters indicate significant differences within and between groups and seasons.

season were significantly greater than those observed for adult female lake sturgeon during the summer, fall, and winter seasons and juvenile lake sturgeon throughout all seasons. I was unable to detect significant differences in the minimum daily movement rates for adult male and adult female lake sturgeon and between adult male and juvenile lake sturgeon during the summer, fall, and winter seasons.

When all seasons and years were combined, I was unable to detect a significant difference in mean displacement among radio-tagged adult male, adult female, and juvenile lake sturgeon ($F_{2,21} = 0.60, P = 0.5586$). Due to the uneven distribution of sampling events among seasons (i.e., more effort was expended during the spring season than during winter) and the additive nature of this metric, potential observed differences in mean displacement could only be compared within a season. I was unable to detect a significant difference in mean displacement for adult male, adult female, and juvenile lake sturgeon during the spring, summer, fall, and winter seasons (Figure 12; $F_{6,114} = 1.19, P = 0.3178$).

When all seasons and years were combined, I was unable to detect a significant difference in mean absolute distance moved among radio-tagged adult male, adult female, and juvenile lake sturgeon ($F_{2,21} = 2.39, P = 0.1157$). Similar to the displacement metric, potential observed differences in mean absolute distance moved could only be compared within a season. Mean absolute distance moved by male adult lake sturgeon was greater than mean absolute distance moved for female adult lake sturgeon and juvenile lake sturgeon during the spring season (Figure 13; $F_{6,114} = 5.47, P = 0.0001$). Mean absolute distance moved by female adult lake sturgeon was greater than

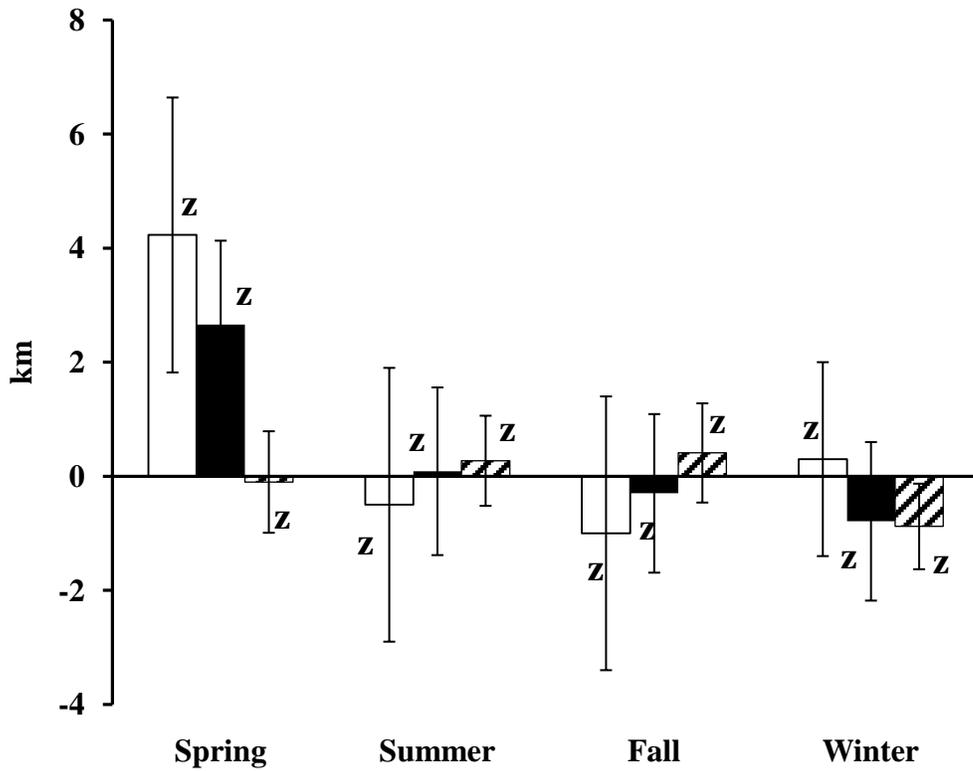


Figure 12. Within season comparisons of the mean (\pm SE) displacement (km) of radio-tagged adult male (white shading), adult female (gray shading) and juvenile (black shading) lake sturgeon in the Grasse River below Madrid Dam from July 2007 through September 2009. Different letters indicated significant differences between groups within a season.

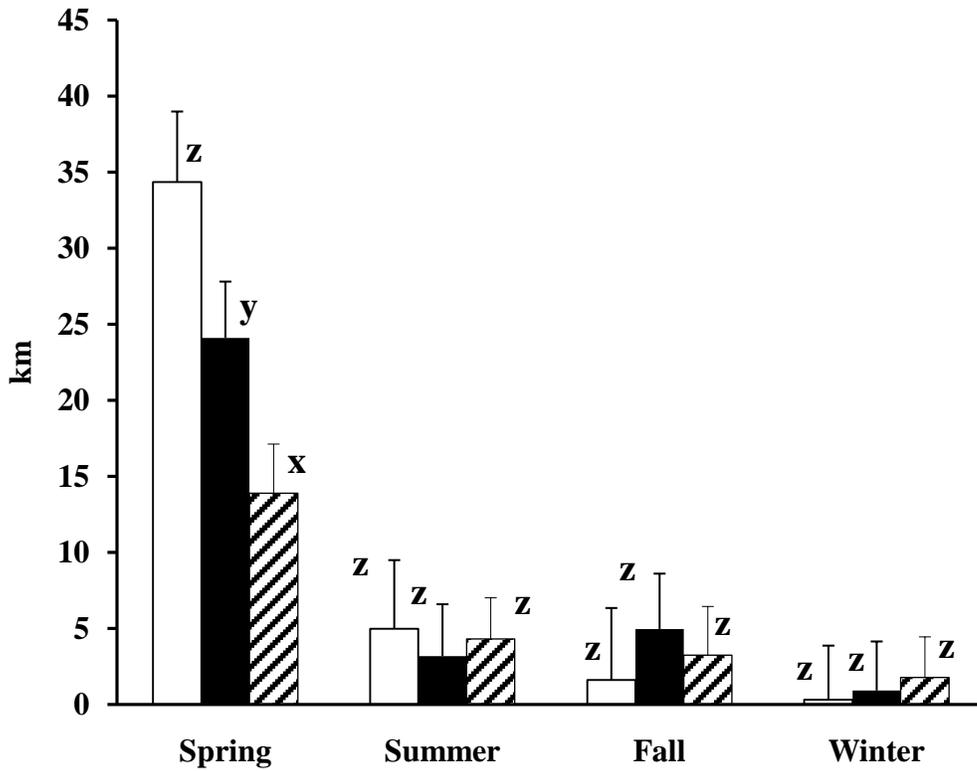


Figure 13. Within season comparisons of the absolute distance moved (km) of radio-tagged adult male (white shading), adult female (gray shading) and juvenile (black shading) lake sturgeon in the Grasse River below Madrid Dam from July 2007 through September 2009. Different letters indicated significant differences between groups within a season.

mean absolute distance moved for juvenile lake sturgeon during the spring season. I was unable to detect a significant difference in mean absolute distance moved for adult male, adult female, and juvenile lake sturgeon during the summer, fall, and winter seasons.

When all seasons and years were combined, I was unable to detect a significant difference in mean seasonal home range size among radio-tagged adult male, adult female, and juvenile lake sturgeon ($F_{2, 21} = 1.49, P = 0.2490$). Mean seasonal home range size for adult female lake sturgeon were greater than those observed for juvenile lake sturgeon during the spring (Figure 14; $F_{6, 82} = 2.92, P = 0.0126$). I was unable to detect a significant difference in the mean home range size of adult male lake sturgeon and juvenile lake sturgeon during the spring. Additionally, I was unable to detect a significant difference in mean seasonal home range size for adult male, adult female, and juvenile lake sturgeon during the summer, fall, and winter seasons.

Spawning Movements

During 2008 and 2009, adult sturgeon that remained within the Grasse River during the previous winter began upstream migrations during mid to late April when water temperatures were approximately 10–12 °C. A single radio-tagged male fish moved from the middle river upstream to the tailwater at the Madrid Dam over a six day period (4.3 km/d) during April 2008. Following a three day stay in the tailwater, this individual moved downstream to the lower river over a seven day period (7.0 km/d). This individual departed the Grasse River during early July 2008. Mean daily discharge on the date of downstream passage through the breached low-head weir for this adult lake sturgeon was 30.3 m³/s.

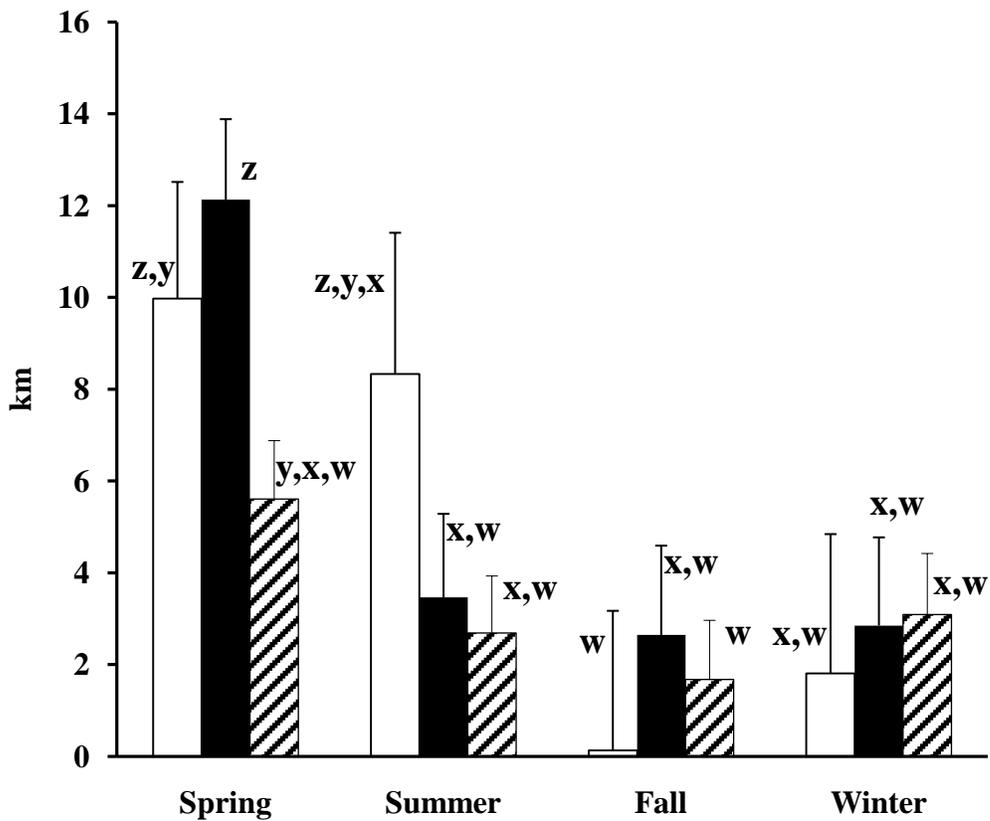


Figure 14. Within and between season comparisons of the mean home range size (km) of radio-tagged adult male (open shading), adult female (solid shading) and juvenile (hatched shading) lake sturgeon in the Grasse River below Madrid Dam from July 2007 through September 2009. Different letters indicate significant differences within and between groups and seasons.

Three adult lake sturgeon (two male, one female) moved from the lower Grasse River to the area below the breached low-head weir during April 2009. These individuals moved 2–9 km upstream from the lower river over a period of 24 h. These individuals each remained in the area below the breached weir over an 8–10 day period when water temperatures were 10–15 °C. Following this apparent spawning migration, one male fish moved upstream through the breached low-head weir and into the middle river. Mean daily discharge on the date of upstream passage through the breached low-head weir for that adult lake sturgeon was 28.0 m³/s. The other two adult lake sturgeon (one female, one male) moved downstream to the lower river and both presumably departed the Grasse River during July 2009 when they were no longer detected. The single radio-tagged male observed during 2008, returned to the Grasse River in early May 2009 when it was relocated and moved rapidly upstream to the tailwater of the Madrid Dam (16.1 km/d). Following a multiple-day stay in the tailwater area, this individual moved downstream and again became undetectable and presumably departed the Grasse River by mid-May 2009. Mean daily discharge on the date of upstream passage through the breached low-head weir for this adult lake sturgeon was 61.4 m³/s and on the date of downstream passage was 64.8 m³/s.

Mesohabitat Availability and Use

A total of 1.02 km² of mesohabitat was mapped during low flow conditions and was comprised of pool (62.5%), run (29.2%), rapid (0.1%), and other (8.2%) mesohabitat types. A total of 1.04 km² of mesohabitat was mapped during mid flow conditions and was comprised of run (51.7%), pool (27.7%), ruffle (12.1%), rapid (8.0%) and other

mesohabitat types (0.5%). I made 578 observations of radio-tagged lake sturgeon within the mapped reach of the Grasse River. When sorted by flow conditions at the time of detection, 90 lake sturgeon records were available during the low flow condition and 158 lake sturgeon records were available during the mid flow condition.

Silt accounted for 33.0% of the substrate type over the mapped reach of the Grasse River. Bedrock (27.6%), sand (15.6%), boulder (11.9%) and cobble (11.3%) substrates were also present. A total of 578 observations of radio-tagged lake sturgeon were available for assessment of substrate usage within the mapped reach.

Usage of mesohabitat type during mid flow conditions (12.8–28.3 m³/s) in the Grasse River did not differ significantly among adult male, adult female, and juvenile lake sturgeon over all seasons and years combined ($\chi^2 = 5.58$, $df = 8$, $p = 0.6507$). The frequency distribution observed for the combined adult and juvenile lake sturgeon habitat usage differed significantly from the mapped distribution of mesohabitat types under mid flow conditions (Figure 15; $\chi^2 = 63.05$, $df = 4$, $p < 0.0001$). Lake sturgeon demonstrated greater use of pool mesohabitat while exhibiting a lower use of run mesohabitat during mid-flow conditions. I was unable to detect a significant difference in the distribution of habitat usage among the four seasons ($F_{5, 131} = 0.46$, $P = 0.8062$).

Usage of mesohabitat type during low flow conditions (2.8–12.7 m³/s) in the Grasse River did not differ significantly among adult male, adult female, and juvenile lake sturgeon over all seasons and years combined ($\chi^2 = 2.53$, $df = 2$, $p = 0.3407$). Similar to observed preferences during mid-flow conditions, the frequency distribution observed for the combined adult and juvenile lake sturgeon habitat usage differed

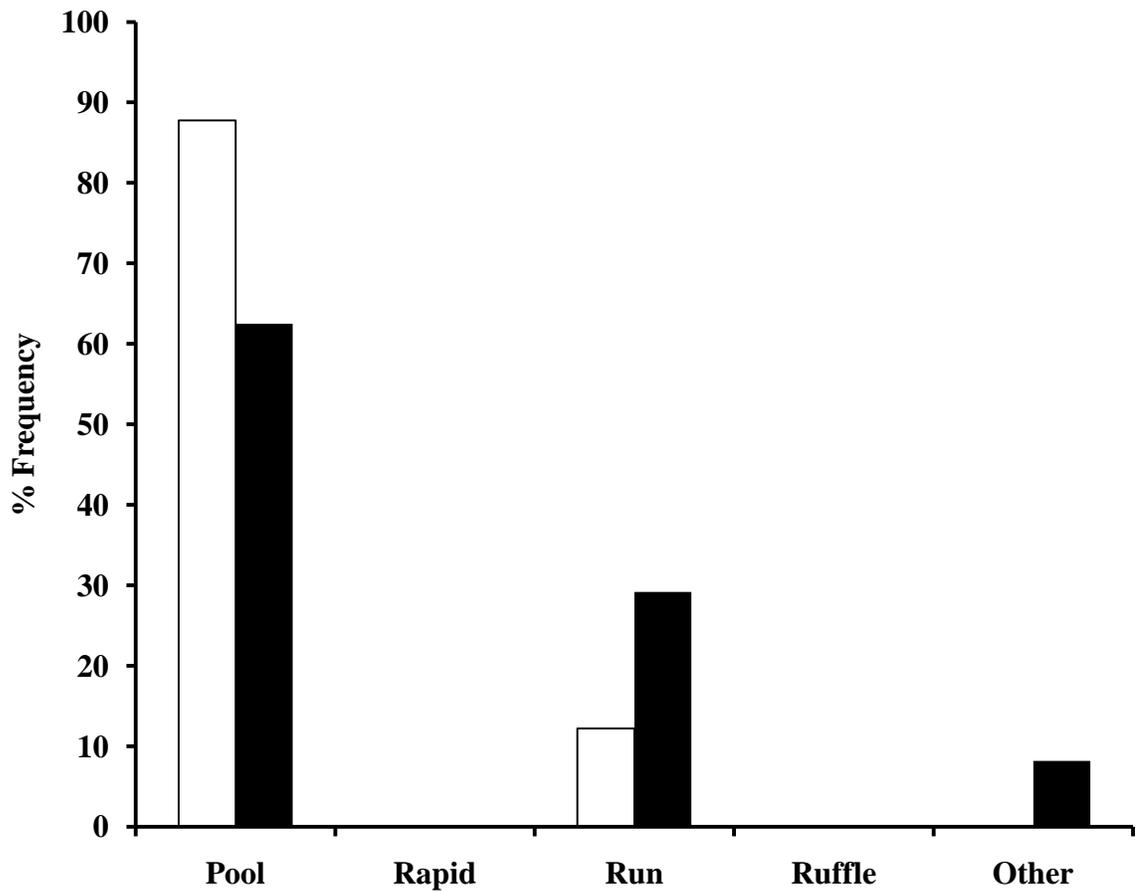


Figure 15. Frequency distributions of mesohabitat availability (all seasons combined) and radio-tagged lake sturgeon usage during low flow conditions within the mesohabitat mapped portion of the Grasse River from July 2007 through September 2009. Open bars indicates the observed habitat usage of lake sturgeon and dark bars the mapped substrate proportion.

significantly from the mapped distribution of mesohabitat types available under low-flow conditions (Figure 16; $\chi^2 = 23.87$, $df = 1$, $p < 0.0001$). Lake sturgeon demonstrated greater use of pool mesohabitat while exhibiting lower use of run mesohabitat relative to availability during low-flow conditions. I was unable to detect a significant difference in the distribution of habitat usage among the four seasons ($F_{3, 552} = 1.44$, $P = 0.2299$).

I was unable to detect a difference in substrate usage for adult male, adult female, and juvenile lake sturgeon within the Grasse River ($F_{1, 16} = 1.54$, $P = 0.2326$). The frequency distribution observed for the combined adult and juvenile lake sturgeon substrate usage differed significantly from the mapped substrate distribution (Figure 17; $\chi^2 = 461.44$, $df = 4$, $p < 0.0001$). Lake sturgeon demonstrated a greater use of silt substrate while exhibiting lower use of bedrock substrate within the Grasse River. When examined on a seasonal basis, there were no detectable differences between the frequency distributions for the summer, fall, and winter seasons ($\chi^2 = 8.22$, $df = 6$, $p = 0.2219$). The spring season frequency distribution differed significantly from the combined summer, fall, and winter frequency distribution (Figure 18; $\chi^2 = 49.89$, $df = 4$, $p < 0.0001$). Usage of silt substrate decreased and usage of boulder and bedrock substrate increased during the spring season.

Discussion

Seasonal Movements

Overall movement patterns for riverine populations of lake sturgeon have been described as both wide-ranging (McKinley et al. 1998; Knights et al. 2002) and localized (Threader

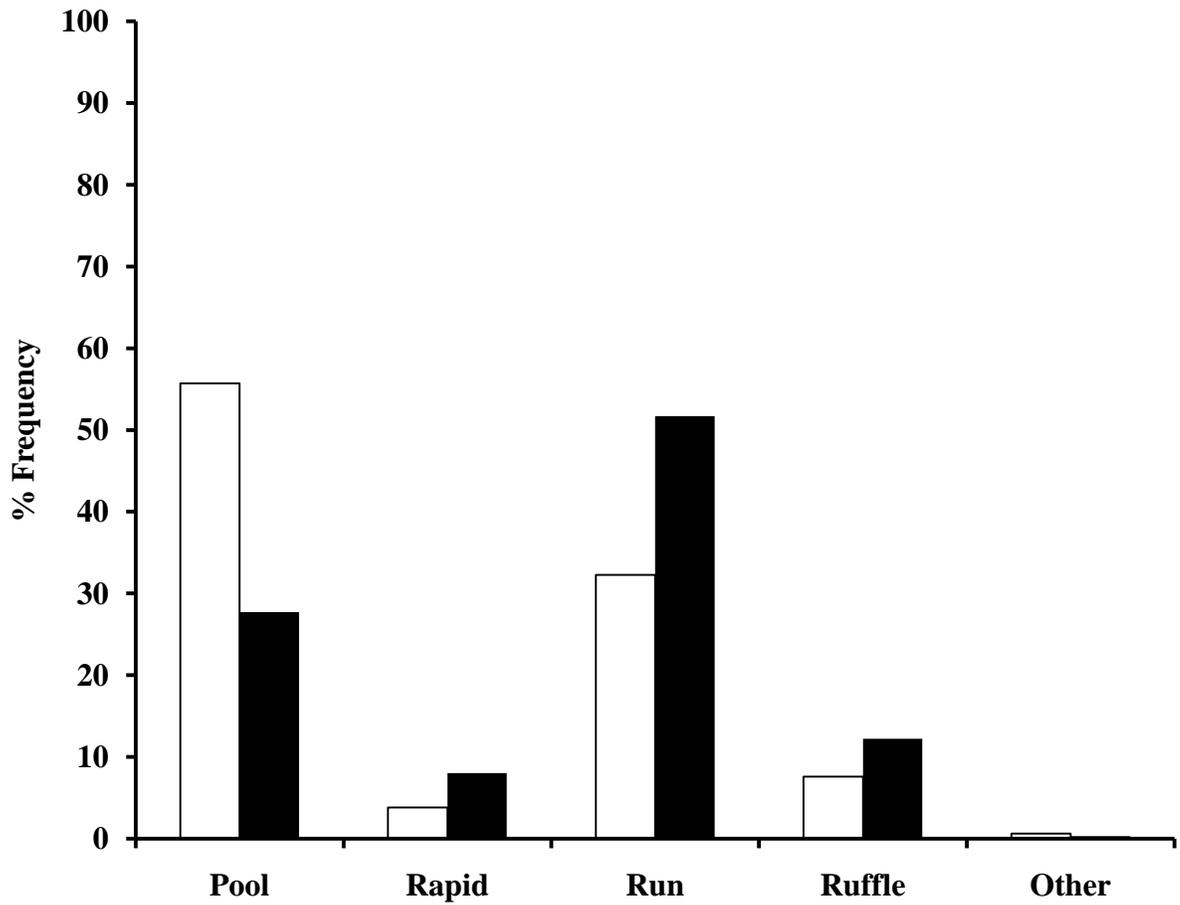


Figure 16. Frequency distributions of mesohabitat availability (all seasons combined) and radio-tagged lake sturgeon usage during mid flow conditions within the mesohabitat mapped portion of the Grasse River from July 2007 through September 2009. Open bars indicates the observed habitat usage of lake sturgeon and dark bars the mapped substrate proportion.

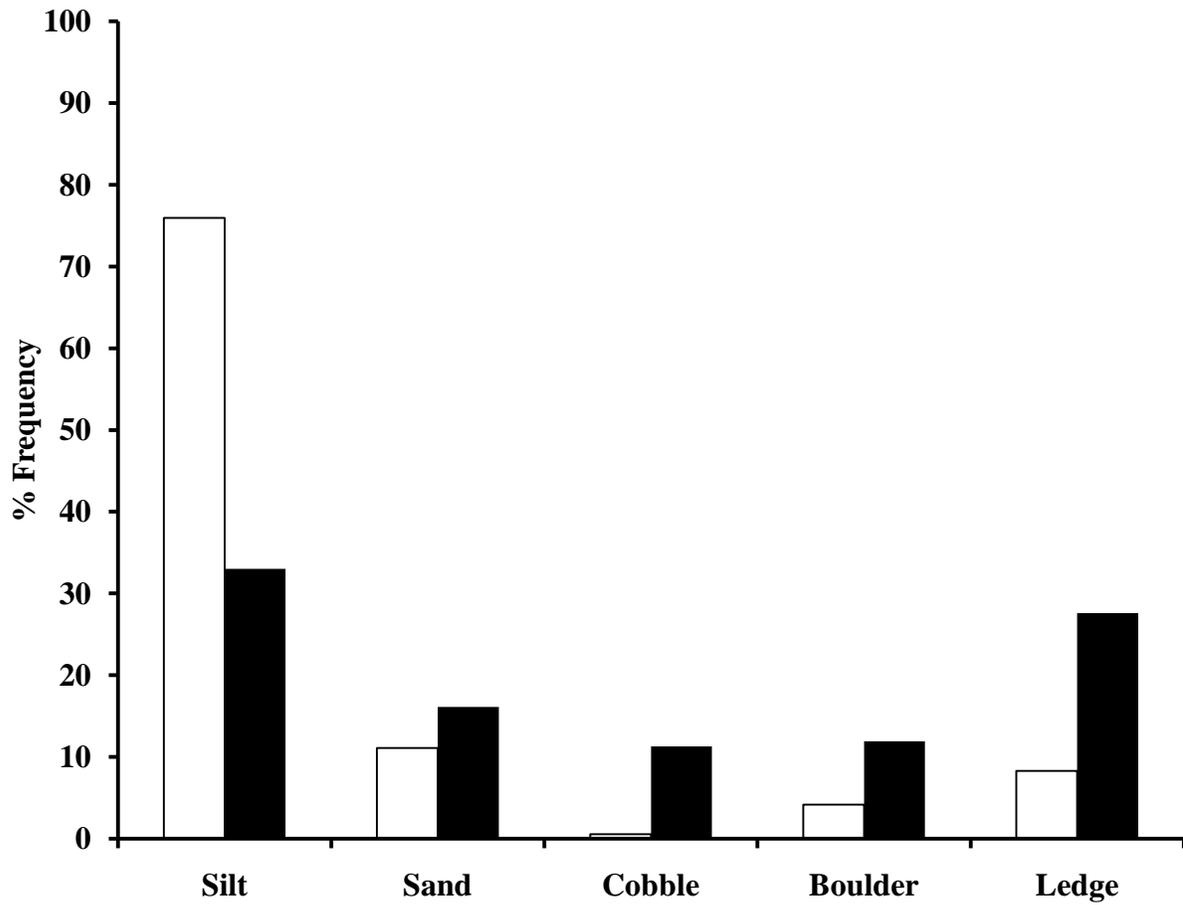


Figure 17. Frequency distributions (all seasons combined) of substrate availability (dark shading) and substrate use by radio-tagged lake sturgeon (open shading) within the mesohabitat mapped portion of the Grasse River from July 2007 through September 2009.

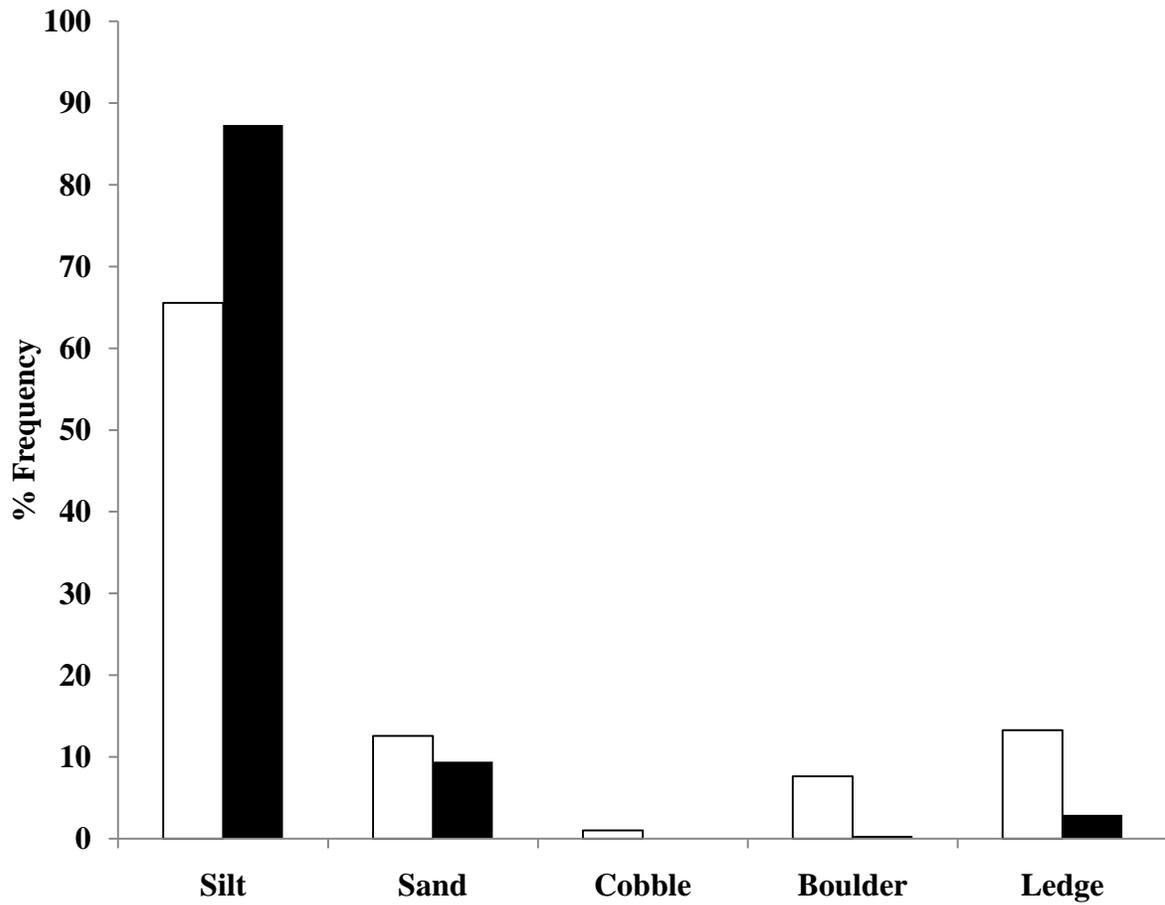


Figure 18. Frequency distributions of substrate use by radio-tagged lake sturgeon within the mesohabitat mapped portion of the Grasse River during the spring season (open shading) and all other seasons combined (dark shading).

and Brousseau 1986; Borkholder et al. 2002; Haxton 2003). Prior to this assessment, the seasonal movement patterns of lake sturgeon within the Grasse River were poorly understood. Movement patterns observed for individuals radio-tagged in the upper Grasse River during this study were limited to the 9.9-km stretch of river below the Madrid Dam. Previously reported movement patterns for acoustically-tagged lake sturgeon in the upper Grasse River were similar (J. Hayes, *unpublished data*). Hayes (*unpublished data*) was limited to the movements of four adult male fish acoustically-tagged during the spring below the Madrid Dam within the upper Grasse River. Of those lake sturgeon, two remained resident to the area between the Madrid Dam and the first set of downstream rapids. Following downstream movement through rapids to deep pool habitat located within the upper portion of the Grasse River, the remaining two fish exhibited localized movements through the fall season (J. Hayes, *unpublished data*).

Movements of lake sturgeon within the middle and lower reaches of the Grasse River as well as potential interchange with the lake sturgeon in the Lake St. Francis portion of the St. Lawrence River have not previously been described. Inferences based on genetic testing suggest that migration of lake sturgeon between the Grasse River and Lake St. Francis does occur (Welsh and May, *unpublished data*). My findings suggest that lake sturgeon in the middle and lower portions of the Grasse River are similar to riverine populations elsewhere and consist of both resident (Borkholder et al. 2002) and transient individuals (Rusak and Mosindy 1997). The upstream spring migration behavior by a non-gravid adult lake sturgeon observed during this study is similar to behavior observed by Lallaman et al. (2008) where > 40% of tagged adult sturgeon found

near upriver spawning sites were not ripe or gravid prior to their migration. Radio-tagged adult and juvenile lake sturgeon in this study were able to move upstream through the breached low-head weir under river discharge conditions ranging from 27.4 to 61.4 m³/s and 29.7 to 44.2 m³/s, respectively, suggesting that these fish can move between the lower and middle portions of the Grasse River under discharge conditions greater than the median annual flow of approximately 19.8 m³/s. Upstream passage was limited to the higher discharge months of April through June. This may be associated with the relatively lower river discharge during the remainder of the year but is more likely related to the lower movement rates observed for Grasse River lake sturgeon outside of the spring season.

Within riverine systems, the use of “core areas” (Knights et al. 2002) or “activity centers” (Borkholder et al. 2002) have been identified and defined as areas of habitat receiving extensive use and frequent revisits by individual lake sturgeon. Within the Kettle River, Minnesota, four of these centers of activity, ranging from 0.3–1.3 km in length accounted for approximately 80% of the total observations during a 23-month study (Borkholder et al. 2002). Core areas for two geographically separated groups of lake sturgeon within the Mississippi River contained approximately 50% of the observed locations during an 18-month study (Knights et al. 2002). Grasse River lake sturgeon demonstrated a similar use of core areas. This study identified three core areas of lake sturgeon use within the middle river, ranging from 0.8–2.0 km in length and two core areas of use within the lower river ranging from 2.0–2.7 km in length. The majority of fish in this study exhibited core area site fidelity on either a seasonal or annual basis and

use of core areas by an individual occurred over a single time period, multiple time periods, or for the duration of the study. This diverse pattern of use has been noted for other riverine populations of lake sturgeon (Knights et al. 2002).

Within contiguous lake and river systems, previous movement studies have observed tagged lake sturgeon in riverine habitat to move into adjacent lake waters on a seasonal basis (Lyons and Kempinger 1992; Rusak and Mosindy 1997; Lallaman et al. 2008). My data suggests that juvenile and adult lake sturgeon tagged during this study moved from the Grasse River into the Lake St. Francis segment of the St. Lawrence River, with the majority of probable migrations occurring during the spring and early summer period.

Seasonal Movement Rates and Home Range Sizes

Adult lake sturgeon in this study displayed significantly greater minimum daily movement rates during the spring than observed during the remainder of the year. Similar to my findings, previous studies have documented greater movement rates for radio-tagged lake sturgeon during the spring season (Knights et al. 2002; Rusak and Mosindy 1997). The sedentary behavior observed in adult lake sturgeon within the Grasse River during the summer and winter seasons is similar to seasonal behavior documented elsewhere for the species during the summer (Rusak and Mosindy 1997; McKinley et al. 1998) and winter (Rusak and Mosindy 1997; Borkholder et al. 2002). McKinley et al. (1998) theorized that reduced movement by lake sturgeon during the summer period is a coping mechanism for thermal stress during the warmest period of the year. Unlike the significant differences in minimum daily movement rates and absolute

distances moved during the spring season between adult male and female lake sturgeon observed in this study, Rusak and Mosindy (1997) did not observe a significant difference in movement rates between sexes. It is possible that the differential movement rates between male and female adult lake sturgeon observed during the spring season could be attributed to behavioral differences associated with varying stages of reproductive development. Similar to the seasonal minimum daily movement rates for juvenile lake sturgeon in this study, Haxton (2003) did not detect a significant seasonal difference in the average movement rate for lake sturgeon with a total length of ≤ 98 cm in the Ottawa River.

Mean minimum distances moved (0.1–0.2 km/d) for juvenile lake sturgeon in the Grasse River during the summer and fall seasons were lower than values reported for juvenile lake sturgeon during the same seasons in the Sturgeon River/Portage Lake system (0.3–1.64 km/d; Holtgrem and Auer 2004) and in Black Lake (1.43 km/d; Smith and King 2005). Adult male lake sturgeon in the Rainy River/Lake of the Woods system were reported to move an average of 0.78 km/d during the spring, 0.79 km/d during the summer, 0.46 km/d during the fall and 0.12 km/d during the winter. Adult female lake sturgeon in the Rainy River/Lake of the Woods system were reported to move an average of 0.94 km/d during the spring, 0.71 km/d during the summer, 0.52 km/d during the fall and 0.10 km/d during the winter. Observed daily movement rates for male and female lake sturgeon in the Grasse River were similar during the spring season (1.22 and 0.82 km/d) but lower during the remainder of the year (≤ 0.2 km/d). Reduced system connectivity associated with shallow water depths during seasonal periods of low flow

conditions in the Grasse River may have factored into the lower minimum daily movement rates outside of the spring season. The strong core area fidelity observed in Grasse River lake sturgeon could also have contributed to the lower rates of daily movement observed in this study.

Riverine home range sizes have been previously reported for a number of lake sturgeon populations (Borkholder et al. 2002; Caswell et al. 2004; Smith and King 2005). Although not defined on a seasonal basis, lake sturgeon in the Kettle River were reported to use an annual home range area of 11.4–26.7 km (Borkholder et al. 2002) while adult lake sturgeon in the Detroit River maintained an annual home range area of approximately 10 km (Caswell et al. 2004). Seasonal home range estimates for adult lake sturgeon in the Grasse River ranged from 0.1–12.1 km. Similar to mean minimum distances moved, it is likely that limitations in system connectivity due to fluctuations in water depths and the strong core area site fidelity observed in Grasse River lake sturgeon contributed to the smaller observed home range areas, particularly during the summer season. Reported home range areas during the summer and fall seasons for lake sturgeon > 90 cm TL were significantly greater than those reported for lake sturgeon < 90 cm TL in Black Lake (Smith and King 2005). Within the Grasse River, there were no detected differences in mean home range size observed during the summer or fall seasons between lake sturgeon > 98 cm TL or \leq 98 cm TL.

Spawning Movements

Lake sturgeon spawning has been reported to occur during the spring, usually between mid-April and early June (Peterson et al. 2006). Spawning activity has been

reported as occurring over a temperature range of 11.1–14.8 °C in the Big Manistee River (Chiotti et al. 2008) and as peaking between the temperatures of 11.5 and 16 °C in the Fox and Wolf rivers (Bruch and Binkowski 2002). During 2008 and 2009, apparent spawning movements and presence of radio-tagged lake sturgeon in spawning areas occurred within the previously reported temperature ranges. Grasse River lake sturgeon remained in spawning areas over a period of three to ten days. The observed spawning period duration from this study is similar to the reported duration of observed spawning behavior over a 16-year period in the Wolf River (Bruch and Binkowski 2002).

Following spawning, lake sturgeon have been noted to exhibit rapid downstream movement in the Wolf River (Lyons and Kempinger 1992; Bruch and Binkowski 2002) and the Sturgeon River (Auer 1996). Lake sturgeon in the Grasse River behaved in a similar manner, moving rapidly downstream into the lower portion of the Grasse River and presumably exiting the system into Lake St. Francis. A single female individual moved upstream and settled into one of the core areas frequented by lake sturgeon in the middle river. The presence of two post-spawned adult lake sturgeon captured within a middle river core area during fall gill-netting in 2008 suggests that the individual behavior observed during the spring 2009 was not an isolated occurrence. Down-river migrating lake sturgeon in the Grasse River were observed to move as quickly as 7.0 km/d. Thuemler (1998) noted that juvenile lake sturgeon (30–48 cm individuals) could move downstream at rates of 0.6–14.5 km/h. Post-spawn outmigration rates for the related shortnose sturgeon *A. brevirostrum* have been reported as ranging between 1–32 km/d (Hall et al. 1991).

Bemis and Kynard (1997) provided a summary of spawning migration patterns and provided definitions for one-step and two-step spawning migrations. One-step spawning migrations were defined as those where fish moved directly to an upstream spawning site, spawned and then returned back downstream. A short two-step spawning migration was defined as one where fish moved upstream during the fall season, overwintered near the spawning site, then moved the final short distance to the spawning area during the spring. Examples of both patterns have been documented for lake sturgeon. Lyons and Kempinger (1992) observed a short two-step spawning migration for lake sturgeon in the Lake Winnebago system while Rusak and Mosindy (1997) observed lake sturgeon in the Rainy River/Lake of the Woods system that utilized a one-step migration pattern. Hayes (*unpublished data*) noted a short two-step migration pattern for lake sturgeon below Robert Moses Dam at the upper end of Lake St. Francis. Upstream fall movements of tagged lake sturgeon to a known pre-spawn spring staging area were observed (Hayes, *unpublished data*). Based upon my observations, I cannot be certain whether Grasse River lake sturgeon are using a one-step or a two-step migratory pattern, or both. All lake sturgeon exhibiting apparent spawning behavior during this study were radio-tagged within the Grasse River during the previous fall season. Whether or not these individuals had been resident in the Grasse River during the entire year or had recently moved into the Grasse River from Lake St. Francis is unknown. Evidence of a short two-step migration pattern may be supported by the post-spawn behavior of radio-tagged lake sturgeon which moved rapidly downstream from spawning areas and presumably departed the Grasse River. However, the single radio-tagged

individual which demonstrated apparent spawning behavior in consecutive spring seasons would be defined as a one-step migration using the definitions provided by Bemis and Kynard (1997). That individual appeared to move into the Grasse River from Lake St. Francis during the spring season, rapidly ascended to the spawning area and then returned back downstream.

Mesohabitat Availability and Use

Observations of lake sturgeon during mid and low flow conditions in this study suggested increased use of pool and decreased use of run mesohabitat. Hayes (*unpublished data*) noted that tagged lake sturgeon in the Grasse River were regularly detected in deep water pools. Similar to observations from the Grasse River, Borkholder et al. (2002) also noted frequent relocations of tagged lake sturgeon from pool habitat in a riverine system. Few comparable studies have quantitatively examined usage of mesohabitat types by sturgeon, in particular lake sturgeon. Knights et al. (2002) assessed the use of aquatic habitat types by lake sturgeon in the Mississippi River and determined that usage of habitat types was not random. It was theorized that habitats utilized by lake sturgeon frequently correlated with transition zones from high to slower current velocities due to local changes in river morphometry. The reduced velocities within those transition zones led to the deposition of fine sediments and were suggested to represent important feeding habitats. Pool habitats mapped during field efforts for this study were characterized by reduced velocities when compared to adjacent run mesohabitat. Substrate within pool mesohabitat in the mapped portion of the Grasse River was dominated by fine sediments and it seems likely that lake sturgeon in this study are

demonstrating similar utilization of velocity transitional areas as has been previously observed. The majority of radio-telemetry contacts for juvenile white sturgeon *A. transmontanus* in the Kootenai River were recorded in glide mesohabitat (Young and Scarnecchia 2005), although Kynard et al. (2000) noted that shortnose sturgeon made greater use of river bends than run habitats.

The present study found no statistical differences in substrate usage between juvenile and adult lake sturgeon. In contrast, Werner and Hayes (2004) observed partitioning of habitat use in relation to fish size in the St. Lawrence River. Observations of juvenile lake sturgeon were closely correlated with silt-sand substrates, while adult lake sturgeon had expanded habitat usage and were detected over a wider range of substrate types. Stomach contents analysis suggested that juvenile fish were predominantly eating soft bodied invertebrates that were common in silt-sand substrates, while adult fish had expanded their diet to include bivalves, common over rocky substrate types (Werner and Hayes 2004). Similar to the findings of Werner and Hayes (2004), Smith and King (2005) suggested that juvenile fish may utilize different habitat types to avoid competition with adult fish. Utilization of silt substrate by juvenile fish in this study was similar to that observed by Werner and Hayes (2004). In contrast, juvenile lake sturgeon have been reported as utilizing sand-clay in the Moose River (Chiasson et al. 1997), organic substrates in Black Lake (Smith and King 2005), and sand substrate in laboratory experiments (Peake 1999). Prey availability has been correlated with juvenile lake sturgeon abundance over soft sediment types (Chiasson et al. 1997). However, Nilo et al. (2006) found that although juvenile lake sturgeon did aggregate in localized areas,

the presence of fish in those areas could not be fully explained by their feeding habits. Barth et al. (2009) did not observe a statistical difference in the abundance of juvenile lake sturgeon over small and large particle sizes and suggested that water depth and detectable water velocities may be important to the spatial distribution of juvenile lake sturgeon.

The observed usage of silt substrate noted for adult lake sturgeon in this study is in contrast to observations from Werner and Hayes (2004) which recorded increased use of boulder and large cobble substrates by adult fish. Adult lake sturgeon in Black Lake were frequently detected over muck substrate (Hay-Chmielewski 1987), sand substrate in the Kettle River (Morse et al. 1997) and silt-sand substrates in the Mississippi River (Knights et al. 2002).

In summary, lake sturgeon movements and usage of core areas within the Grasse River were consistent with observations for the species elsewhere in its range. Observed core areas were relatively small, ranging in length from 1–2 km. Although minimum daily distance movement rates differed, I was unable to detect any differences in the absolute distances, displacement or mean home range sizes between adult and juvenile lake sturgeon. Mesohabitat and substrate usage for both adult and juvenile lake sturgeon in the Grasse River was characterized by frequent use of pool habitats and silt substrate. My data suggests lake sturgeon in the Grasse River do move between waters of the Grasse River and the adjacent Lake St. Francis. My study observations provide additional information on the behavior of lake sturgeon in a riverine system. Coupled

with previous findings regarding the movement patterns and distributions of habitat and substrate use, this study has continued to enhance the understanding of this species.

References

- Armantrout, N. B., compiler. 1998. Glossary of aquatic habitat inventory terminology. American Fisheries Society, Bethesda, Maryland.
- Auer, N. 1996. Importance of habitat and migration to sturgeons, with emphasis on lake sturgeon. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 481-489.
- Auer, N. 1999. Population characteristics and movements of lake sturgeon in the Sturgeon River and Lake Superior. *Journal of Great Lakes Research* 25: 282-293.
- Baran, P., M. Delacoste, and J. M. Lascaux. 1997. Variability of mesohabitat used by brown trout populations in the French Central Pyrenees. *Transactions of the American Fisheries Society* 126: 747-757.
- Barth, C. C., S. J. Peake, P. J. Allen, and W. G. Anderson. 2009. Habitat utilization of juvenile lake sturgeon *Acipenser fulvescens* in a large Canadian River. *Journal of Applied Ichthyology* 25: 18-26.
- Bemis, W. E., and B. Kynard. 1997. Sturgeon rivers: an introduction to acipenseriform biogeography and life history. *Environmental Biology of Fishes* 48: 167-183.
- Benson, A. C., T. M. Sutton, R. F. Elliott, and T. G. Meronek. 2005. Seasonal movement patterns and habitat preferences of age-0 lake sturgeon in the lower Peshtigo River, Wisconsin. *Transactions of the American Fisheries Society* 134: 1400-1409.
- Bisson, P. A. D. R. Montgomery, and J. M. Buffington. 1996. Valley segments, stream reaches, and channel units. Pages 23-50 in Hauer, F.R. and G.A. Lamberti, Editors. *Methods in Stream Ecology*. Elsevier Publishing, Amsterdam, Netherlands.
- Bisson, P. A., K. Sullivan, and J. L. Nielsen. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. *Transactions of the American Fisheries Society* 117: 262-273.
- 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 radiotelemetry and tagging. *North American Journal of Fisheries Management* 22: 888-894.
- Bovee, K. D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. *Instream Flow Information Paper*

21. U.S. Fish and Wildlife Service Biological Report 86(7). 235 pp.
- Bruch, R. M., T. A. Dick, and A. Choudhury. 2001. A field guide for the identification of stages of gonad development in lake sturgeon *Acipenser fulvescens* Rafinesque: with notes on lake sturgeon reproductive biology and management implications. Sturgeon for Tomorrow, Fond Du Lac, Wisconsin.
- Bruch, R. M., and F. P. Binkowski. 2002. Spawning behavior of lake sturgeon *Acipenser fulvescens*. *Journal of Applied Ichthyology*. 18: 570-579.
- Carlson, D. M. 1995. Lake sturgeon waters and fisheries in New York State. *Journal of Great Lakes Research* 21: 35-41.
- Caswell, N. M., D. L. Peterson, B. A. Manny, and G. W. Kennedy. 2004. Spawning by lake sturgeon *Acipenser fulvescens* in the Detroit River. *Journal of Applied Ichthyology* 20: 1-6.
- Chiasson, W. B., D. L. G. Noakes, and F. W. H. Beamish. 1997. Habitat, benthic prey, and distribution of juvenile lake sturgeon *Acipenser fulvescens* in northern Ontario rivers. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 2866-2871.
- Chiotti, J. A., J. M. Holtgrem, N. A. Auer, and S. A. Ogren. 2008. Lake sturgeon spawning habitat in the Big Manistee River, Michigan. *North American Journal of Fisheries Management* 28: 1009-1019.
- Didier, J., and P. Kestemont. 1996. Relationships between mesohabitats, ichthyologic communities, and IBI metrics adapted to a European river basin (The Meuse, Belgium). *Hydrobiologia*. 341: 133-144.
- Dollof, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. General Technical Report SE-83. Asheville, NC: Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 25 pp.
- Fortin, R., J. R. Mongeau, G. Desjardins, and 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.
- Hall, W. J., T. I. J. Smith, and S. D. Lamprecht. 1991. Movements and habitats of shortnose sturgeon *Acipenser brevirostrum* in the Savannah River. *Copeia* 1991: 695-702.

- 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.
- Haxton, T. 2003. Movements of lake sturgeon *Acipenser fulvescens* in a natural reach of the Ottawa River. Canadian Field Naturalist 117: 541-545.
- Holtgrem, J. M., and N. A. Auer. 2004. Movement and habitat of juvenile lake sturgeon (*Acipenser fulvescens*) in the Sturgeon River-Portage Lake system. Michigan Journal of Freshwater Ecology 19: 419-429.
- Hay-Chmielewski, E. M. 1987. Habitat preferences and movement patterns of the lake sturgeon *Acipenser fulvescens* in Black Lake, Michigan. Michigan Department of Natural Resources, Fisheries Research Report 1949. Ann Arbor.
- Kehmeier, J. W., R. A. Valdez, C. N. Medley, and O. B. Myers. 2007. Relationship of fish mesohabitat to flow in a sand-bed southwestern river. North American Journal of Fisheries Management 27: 750-764.
- Kempinger, J. J. 1996. Habitat, growth, and food of young lake sturgeon in the Lake Winnebago system, Wisconsin. North American Journal of Fisheries Management 16: 102-114.
- Kernohan, B. J., R. A. Gitzen, and J. J. Millspaugh. 2001. Analysis of animal space use and movements. Pages 125-126 in J. J. Millspaugh and J. M. Marzluff, editors. Radio tracking and animal populations. Academic Press, San Diego, California.
- 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.
- Kynard, B., M. Horgan, and M. Kieffer. 2000. Habitats used by shortnose sturgeon in two Massachusetts Rivers, with notes on estuarine Atlantic sturgeon: a hierarchical approach. Transactions of the American Fisheries Society 129: 487-503.
- Lallaman, J. J., R. A. Damstra, and T. L. Galarowicz. 2008. Population assessment and movement patterns of lake sturgeon *Acipenser fulvescens* in the Manistee River, Michigan USA. Journal of Applied Ichthyology 24: 1-6.
- Lyons, J., and J. J. Kempinger. 1992. Movements of adult lake sturgeon in the Lake Winnebago system. Wisconsin Department of Natural Resources Research Report 156: 17 pgs.

- McKinley, S., G. VanDerKraak, 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.
- Morse, S. D., H. T. Weaver, A. T. Linder, and R. A. Hugill. 1997. Habitat suitability curves for lake sturgeon based on radiotelemetry observations in the Kettle River, Minnesota. Minnesota Department of Natural Resources, FR29-R(P)-16, Hinckley.
- Muhlfield, C. C., D. H. Bennett, and B. Marotz. 2001. Summer habitat use by Columbia River redband trout in the Kootenai River drainage, Montana. *North American Journal of Fisheries Management* 21: 233-235.
- Nilo, P., S. Tremblay, A. Bolon, J. Dodson, P. Dumont, and R. Fortin. 2006. Feeding ecology of juvenile lake sturgeon in the St. Lawrence River system. *Transactions of the American Fisheries Society* 135: 1044-1055.
- Normandeau (Normandeau Associates Inc.). 2008. Summary report of water quality monitoring in the Grasse River, Massena, NY, during the 2007 and 2008 field seasons. Report to the Town of Massena Electric Department, Project 20507.020, Bedford, NH.
- Parasiewicz, P. 2008. Application of MesoHABSIM and target fish community approaches to restoration of the Quinebaug River, Connecticut and Massachusetts, USA. *River Research and Applications* 24: 459-471.
- Parsons Brinckerhoff. 2006. Preliminary Application Document: Massena Grasse River Multipurpose Hydroelectric Project. FERC #12607.
- Peake, S. 1999. Substrate preferences of juvenile hatchery-reared lake sturgeon *Acipenser fulvescens*. *Environmental Biology of Fishes* 56: 367-374.
- Peterson, D. L., P. Vecsei, and C. A. Jennings. 2006. Ecology and biology of the lake sturgeon: a synthesis of current knowledge of a threatened North American *Acipenseridae*. *Review of Fish Biology and Fisheries* 17: 59-76.
- Rusak, J. A., and T. Mosindy. 1997. Seasonal movements of lake sturgeon in Lake of the Woods and Rainy River, Ontario. *Canadian Journal of Zoology* 74: 383-395.
- Santoul, F., N. Mengin, R. Cereghino, J. Figuerola, and S. Mastroiello. 2005. Environmental factors influencing the regional distribution and local density of a small benthic fish; the stone loach *Barbatula barbatula*. *Hydrobiologia* 544: 347-355.

- Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Bulletin 184, Fisheries Research Board of Canada. Ottawa, 966 pp.
- Smith, C. L. 1985. The Inland Fishes of New York State. The New York State Department of Environmental Conservation, Albany, NY. 522 pp.
- Smith, K. M., and D. King. 2005. Movement and habitat use of yearling and juvenile lake sturgeon in Black Lake, Michigan. Transactions of the American Fisheries Society 134: 1159-1172.
- Threader, R. W., and C. S. Broussaeu. 1986. Biology and management of the lake sturgeon in the Moose River, Ontario. North American Journal of Fisheries Management 6: 383-390.
- Thuemler, T. F. 1988. Movements of young lake sturgeons stocked in the Menominee River, Wisconsin. Pages 104-109 in, Hoyt, R. D. 11th Annual Larval Fish Conference. American Fisheries Society, Symposium 5, Bethesda, Maryland.
- Trested, D. G., R. Goforth, J. P. Kirk, and J. J. Isely. 2010. Survival of shovelnose sturgeon following abdominally invasive endoscopic evaluation. North American Journal of Fisheries Management 30: 121-125.
- Werner, R. G., and J. Hayes. 2004. Contributing factors in habitat selection by lake sturgeon (*Acipenser fulvescens*). State University of New York, College of Environmental Science and Forestry, Syracuse.
- Wilson, J. A., and R. S. McKinley. 2004. Distribution, habitat and movements. Pages 40-69 in LeBreton, G. T. O., F. W. H. Beamish, and R. S. McKinley, editors. Sturgeon and paddlefish of North America. Kluwer Academic Publishers.
- Young, W. T., and D. L. Scarnecchia. 2005. Habitat use of juvenile white sturgeon in the Kootenai River, Idaho and British Columbia. Hydrobiologia 537: 265-271.

CHAPTER FOUR
SURVIVAL OF SHOVELNOSE STURGEON FOLLOWING
ABDOMINALLY- INVASIVE ENDOSCOPIC EVALUATION

Introduction

Nearly all sturgeon species within the family Acipenseridae are considered to be threatened or endangered (Birstein 1993; Birstein et al. 1997). Although the factors influencing the decline of sturgeon populations may vary by location, declines in abundance can be attributed to a variety of anthropogenic factors including overfishing, water quality of large rivers utilized for spawning, and blockage of historic migration routes by hydroelectric facilities (Birstein et al. 1997). Successful management of sturgeon species requires the ability to efficiently obtain accurate biological information regarding sex ratio, spawning frequency and other parameters associated with the gender and developmental stage of individuals within the population. Understanding population dynamics is essential for the effective recovery of rare or endangered species (Bajer and Wildhaber 2007). However, due to the protected status of most sturgeon species, traditional destructive methods of obtaining these data are prevented. The long term survival of individuals subjected to scientific examination is important for the conservation and restoration of wild populations.

The sex and gonad maturation stage of sturgeon species are routinely assessed using a variety of invasive and non-invasive techniques. Sonography, a non-invasive technique, produces high resolution ultrasonic images used to differentiate gonadal tissue

and assess reproductive state of sturgeon (Moghim et al. 2002; Colombo et al. 2004; Wildhaber et al. 2005) and other fish species (Bonar et al. 1989; Karlsen and Holm 1994; Martin-Robichaud and Rommens 2001). Invasive techniques such as direct inspection of the gonads through an incision in the body wall (Conte et al. 1988; Bruch et al. 2001) or the collection of a gonadal biopsy samples (Webb et al. 2002) are also effective in providing detailed reproductive information. The use of an endoscope to provide internal images has also been examined for a variety of fishes (Moccia et al. 1984; Ortenburger 1996; Swenson et al. 2007) including several species of sturgeon (Kynard and Kieffer 2002; Bryan et al. 2007; Hurvitz et al. 2007). In some cases, the endoscope is inserted through the urogenital canal (Kynard and Kieffer 2002; Wildhaber et al. 2005; Bryan et al. 2007). This method has been effective in determining gender and classifying individual maturation stage for shortnose sturgeon *Acipenser brevirostrum* (Kynard and Kieffer 2002); however, immature males and females could not be differentiated. Although the technique has been used successfully with shortnose sturgeon (Kynard and Kieffer 2002) and shovelnose sturgeon *Scaphirhynchus platyrhynchus* (Wildhaber et al. 2005), in species with an opaque urogenital duct, it becomes necessary to insert the endoscope into the coelom through a small incision in the abdominal wall (Wildhaber et al. 2005; Bryan et al. 2007; Hurvitz et al. 2007).

Though substantially more invasive (Wildhaber et al. 2005), immediate and latent mortality resulting from abdominal-insertion endoscopy has not been thoroughly investigated. To my knowledge, post-procedure mortality associated with this technique has only been examined in salmonids. For example, Swenson et al. (2007) observed

immediate post-procedure mortality of 3.3% for brook trout *Salvelinus fontinalis*. The objective of this study was to quantify the immediate and delayed post-procedure mortality for shovelnose sturgeon following insertion of an endoscope through an abdominal incision.

Methods

Adult shovelnose sturgeon (n = 48) were captured from the Wabash River near Lafayette, Indiana, between river km 502.0 and 510.3 during 17-18 June 2009, using a boat-mounted electrofisher (model SR-16H; Smith-Root Inc., Seattle, Washington, USA). Upon capture, shovelnose sturgeon were placed in an aerated live well and transported to the Purdue University Aquaculture Research Laboratory. Prior to examination, fish were anesthetized using 75 mg/L buffered tricaine methanesulphonate. Fork length (mm) and weight (0.1 kg) were recorded for all individuals. Each individual was uniquely marked using a T-bar tag (model FD-94; Floy Tag and Mfg. Inc., Seattle, Washington, USA) inserted into the musculature at the base of the left pectoral fin. Control fish (n = 10) were selected at random and immediately stocked into a 0.4-ha culture pond filled with aerated well water. Experimental fish (n = 38) were held in an aerated live well for an additional 1–3 hours prior to examination. Within 1–3 hours of the procedure, test subjects were stocked in the same culture pond containing control fish. At the time of capture, water temperature in the Wabash River was 22.3° C and dissolved oxygen concentration was 8.5 mg/L. Water temperature in the culture pond was 24.3° C at the time of release. Due to a change in the weather pattern and abnormally hot

weather, water temperatures in the culture pond increased to near 30.0° C during the first week of the 30-d evaluation period. Water temperatures declined over the remainder of the 30-d period with a value of 25.0° C at the time of survival evaluation.

Experimental fish were examined using a modification of an endoscopic technique described by Bryan et al. (2007). Briefly, a small (< 1 cm) incision was made 0.5–1.5 cm from the ventral midline 10–12 cm anterior to the insertion of the pelvic fins. Rather than inserting the endoscope directly into the body cavity, I inserted a threaded trocar (6 cm long × 7 mm diameter) through the incision and used a low-pressure air supply (model AH801 aquarium air supply pump; Aquatic Ecosystems, Tampa, Florida, USA) attached to the trocar to gently insufflate the body cavity (Figure 19). The endoscope was fed through the trocar and carefully manipulated within the body cavity until gender and developmental stage of the individual was obtained. The endoscope consisted of a 30° rigid borescope (4.0 mm diameter × 29 cm long; Model 62006 BA; Karl Storz Endoscopy-America Inc., Charlestown, Massachusetts, USA), a portable fiber-optic light source (Model 481C; Karl Storz Endoscopy – America Inc., Charlestown, Massachusetts, USA), a digital video camera (Model C3327SH; Clover Electronics; Cerritos, California, USA), and a color monitor (i-SAVE; Olympus, Oranburg, New York, USA). Reproductive developmental stages were classified using categories defined by Wildhaber et al. (2006) for shovelnose sturgeon. Each incision was closed with a single suture (3-0 Prolene, FS-1 cutting needle; Ethicon Inc., Somerville, New Jersey, USA). Fish were then allowed to recover in fresh, aerated water. Procedure

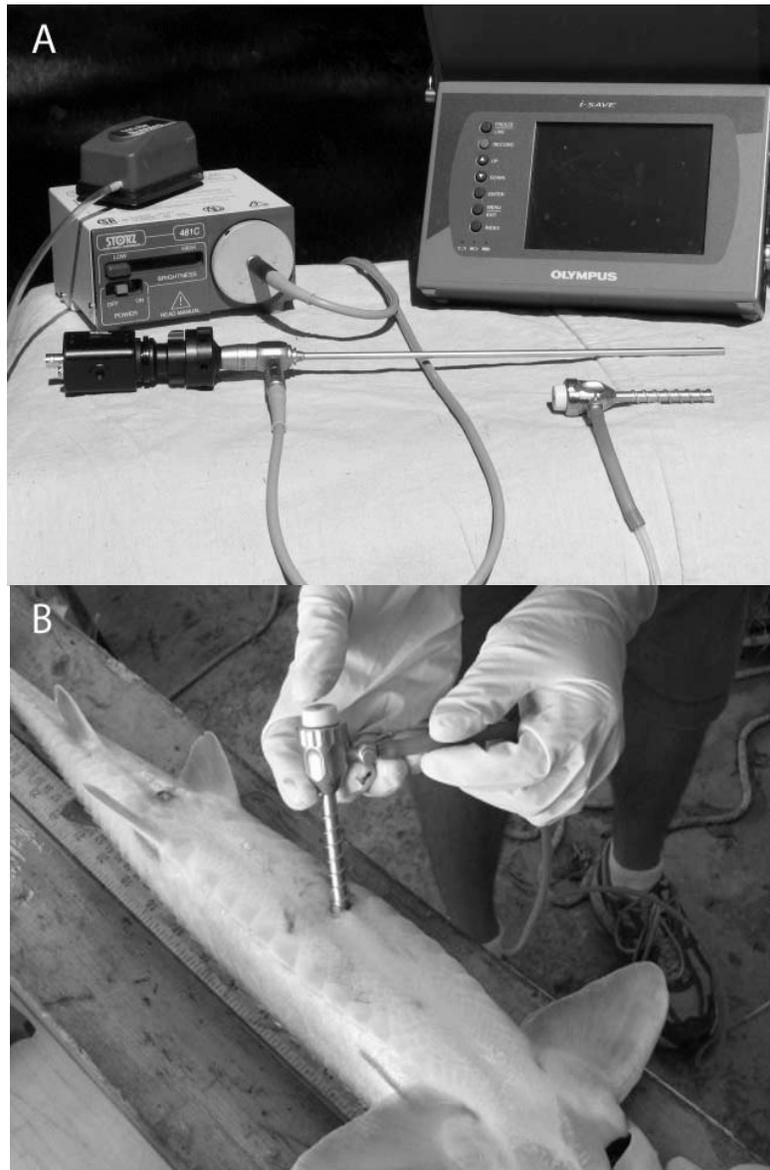


Figure 19. Endoscopy system used for gender and gonad developmental stage evaluation: A. individual components including borescope, light source, video camera, display monitor, trocar, and air supply. B. Insertion of trocar into anesthetized shovelnose sturgeon.

duration (seconds) from removal from anesthesia to initiation of recovery was recorded, and a digital image was archived.

Initial survival was assessed immediately after the procedure and 1 hour after recovery from anesthesia. The pond was checked on a daily basis for evidence of sturgeon mortality over a 30-d period. After 30 days, the pond was drained and surviving shovelnose sturgeon were recovered, assessed for latent survival and condition and returned to the wild. Individual identification number and incision condition were recorded.

Results

Fork length of control and experimental shovelnose sturgeon was 65.3 ± 5.5 cm ($n = 10$; range = 58.0–76.5cm; mean \pm SD) and 68.7 ± 4.2 cm ($n = 38$; range = 59.5–77.5 cm; mean \pm SD), respectively. Experimental fish were longer than control fish ($t = -2.16$; $P = 0.0294$). Weights of control and experimental shovelnose sturgeon were 1.0 ± 0.2 kg ($n = 10$; mean \pm SD) and 1.3 ± 0.3 kg ($n = 38$; mean \pm SD), respectively. Experimental fish weighed more than control fish ($t = -3.23$; $P = 0.0023$). Upon endoscopic examination, the experimental group was determined to be composed of 5 (13%) females (1 Stage III-IV, immature; 3 Stage V, mature; 1 Stage VI, post-spawning), and 33 (87%) males (22 Stage III – V, mature; 11 Stage VI, post-spawning). Although maturation stage of females could be assessed macroscopically (Figure 20), specific maturation state of males requires histological examination beyond the scope of the study. No spermiating male or ovulating female fish were collected.

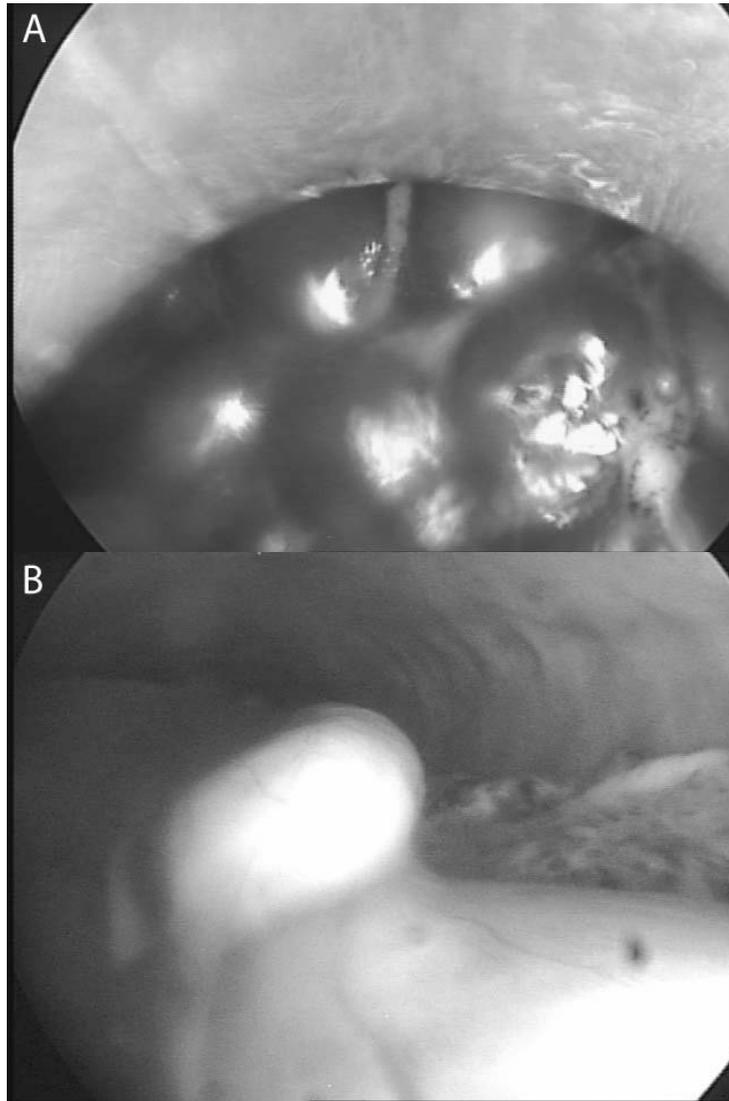


Figure 20. Endoscopic views of shovelnose sturgeon ovarian tissue: A. Mature stage female. B. Post-spawn female.

Procedure duration ranged 109–315 seconds (mean = 166 seconds). Initial survival of experimental and control shovelnose sturgeon was 100%. Latent survival of experimental and control shovelnose sturgeon was 100% and 90%, respectively. All incisions were closed upon visual examination after 30 days. Sutures were present in 19 (50%) individuals. Redness around the sutures was noted in 24 (63%) individuals, but was not considered serious.

Discussion

As sturgeon species do not display sexual dimorphism, methodologies for the effective determination of gender and gonad developmental stage have been investigated and incision endoscopy has been demonstrated as an effective method for determining both. Although rigid endoscopy has been recommended as a minimally invasive technique for assessing the reproductive organs of sturgeon (Divers et al. 2009) and results in minimal damage or stress to sturgeon (Hurvitz et al. 2007), the associated rate of mortality among individuals subjected to incision endoscopy has not been quantified. This study both quantifies and demonstrates that endoscopic techniques are indeed a minimally invasive and effective way to collect gender and sexual condition information from sturgeon.

Previous endoscopy for sturgeon has primarily been conducted by insertion of a rigid borescope through an incision in the posterior ventral portion of the body (Wildhaber et al. 2005; Bryan et al. 2007; Hurvitz et al. 2007). However, the borescope lens is prone to fouling, reducing visibility and effectiveness. Others reduced this

problem by encasing the lens within a glass sleeve. The addition of a trocar and air supply in this study enhanced the previous technique. Slight insufflation of the body cavity increased the volume within the body cavity, increasing focal distance and reducing incidental contact with reproductive structures and other organs. Survival of shovelnose sturgeon examined using this modified technique during this study was expected to be high based on published results of more invasive surgical procedures used on fish for other applications. Health and retention rates have been evaluated in a controlled setting for shortnose sturgeon implanted with coiled antennae radio transmitters and trailing antennae radio transmitters (Collins et al. 2002). Shortnose sturgeon implanted with coiled antennae transmitters exhibited 100% survival and complete healing of the incision at the completion of the 93-d test period. Shortnose sturgeon implanted with trailing antennae radio transmitters also exhibited 100% survival at the completion of the 93-d test period but the trailing antennae caused extensive damage to the body wall. Although survival rates of radio-tagged sturgeon species released into wild environments can be difficult to accurately assess without recapture information, collection of long term movement data from these individuals suggests that survival following invasive internal surgery is high. There are numerous examples of long-term telemetry studies conducted using internal radio transmitters (Kieffer and Kynard 1993; Bramblett and White 2001; Benson et al. 2007). Shovelnose sturgeon are a riverine species which prefer areas of moderate to swift currents over sand or gravel substrate in the open channel areas of large rivers (Etnier and Starnes 1993). Although no thermal habitat suitability curve is available for shovelnose sturgeon, it is likely that

the single control fish mortality I observed during that peak in water temperatures was associated with thermal stress. Additionally, forced adaptation to a 30-d period in a holding pond rather than previously occupied habitats in the Wabash River may have added additional stress.

I conclude that incision endoscopy coupled with insufflation of the body cavity through the use of trocar and an air supply provides a minimally invasive and effective way to determine gender and examine gonad developmental stage. The success observed with this technique on the shovelnose sturgeon will likely transfer to other endangered sturgeon species (e.g., pallid sturgeon). The compact size, relatively low cost, and limited power requirements of the endoscopy system used during this study suggest that it would be practical for use under both field and laboratory conditions. Short procedure duration and high post-procedure survival suggest this incision endoscopy technique may be suitable for evaluation of gender and gonad developmental stage of other endangered fish species as well.

References

- Bajer, P. G. and M. L. Wildhaber. 2007. Population viability analysis of Lower Missouri River shovelnose sturgeon with initial application to pallid sturgeon. *Journal of Applied Ichthyology* 23: 457-464.
- Benson, R. L., S. Turo, and B. W. McCovey. 2007. Migration and movement patterns of green sturgeon (*Acipenser medirostris*) in the Klamath and Trinity rivers, California, USA. *Environmental Biology of Fishes* 79: 269-279.
- Birstein, V. J. 1993. Sturgeons and paddlefishes: threatened fishes in need of conservation. *Conservation Biology* 7: 773-787.
- Birstein, V. J., W. E. Bemis, and J. R. Waldman. 1997. The threatened status of Acipenseriform species: a summary. *Environmental Biology of Fishes* 48: 427-435.
- Bonar, S. A., G. L. Thomas, G. B. Pauley, and R. W. Martin. 1989. Use of ultrasonic images for rapid nonlethal determination of sex and maturity in Pacific herring. *North American Journal of Fisheries Management* 9: 364-366.
- Bramblett, R. G., and R. G. White. 2001. Habitat use and movements of pallid and shovelnose sturgeon in the Yellowstone and Missouri Rivers in Montana and North Dakota. *Transactions of the American Fisheries Society* 130: 1006-1025.
- Bruch, R. M., T. A. Dick, and A. Choudhury. 2001. A field guide for the identification of stages of gonad development in lake sturgeon, (*Acipenser fulvescens*) Rafinesque: with notes on lake sturgeon reproductive biology and management implications. *Sturgeon for Tomorrow, Fond Du Lac, Wisconsin*. 40 pages.
- Bryan, J. L., M. L. Wildhaber, D. M. Papoulias, A. J. DeLonay, D. E. Tillitt, and M. L. Annis. 2007. Estimation of gonad volume, fecundity, and reproductive stage of shovelnose sturgeon using sonography and endoscopy with application to the endangered pallid sturgeon. *Journal of Applied Ichthyology* 23: 411-419.
- Collins, M. R., D. W. Cooke, T. I. J. Smith, W. C. Post, D. C. Russ, and D. C. Walling. 2002. Evaluation of four methods of transmitter attachment on shortnose sturgeon, *Acipenser brevirostrum*. *Journal of Applied Ichthyology* 18: 491-494.
- Colombo, R. E., P. S. Wills, and J. E. Garvey. 2004. Use of ultrasound imaging to determine sex of shovelnose sturgeon. *North American Journal of Fisheries Management* 24: 322-326.
- Conte, F. S., S. I. Doroshov, and P. B. Lutes. 1988. Hatchery manual for the white

- sturgeon *Acipenser transmontanus* Richardson with application to other North American Acipenseridae. University of California Division of Agriculture and Natural Resources, Oakland, CA. 104 pages.
- Divers, S. J., S. S. Boone, J. J. Hoover, K. A. Boysen, K. J. Killgore, C. E. Murphy, S. G. George, and A. C. Camus. 2009. Field endoscopy for identifying gender, reproductive stage, and gonadal anomalies in free-ranging sturgeon (*Scaphirhynchus*) from the Lower Mississippi River. *Journal of Applied Ichthyology* 25: 68-74.
- Etnier, D. A., and W. C. Starnes. 1993. *The Fishes of Tennessee*, the University of Tennessee Press, Knoxville. 689 pages.
- Hurvitz, A., K. Jackson, G. Degani, and B. Levavi-Sivan. 2007. Use of endoscopy for gender and ovarian stage determinations in Russian sturgeon (*Acipenser gueldenstaditii*) grown in aquaculture. *Aquaculture* 270: 158-166.
- Karlsen, O., and J.C. Holm. 1994. Ultrasonography, a non-invasive method for sex determination in cod (*Gadus morhua*). *Journal of Fish Biology* 44: 965-871.
- Kieffer, M. C., and B. Kynard. 1993. Annual movements of shortnose and Atlantic sturgeons in the Merrimack River, Massachusetts. *Transactions of the American Fisheries Society* 122: 1088-1103.
- Kynard, B., and M. Kieffer. 2002. Use of a borescope to determine the sex and egg maturity stage of sturgeons and the effect of borescope use on reproductive structures. *Journal of Applied Ichthyology* 18: 505-508.
- Martin-Robichaud, D. J., and M. Rommens. 2001. Assessment of sex and evaluation of ovarian maturation of fish using ultrasonography. *Aquaculture Research* 32: 113-120.
- Moccia, R. D., E. J. Wilkie, K. R. Munkittrick, and W. D. Thompson. 1984. The use of fine needle fibre endoscopy in fish for in vivo examination of visceral organs, with special reference to ovarian evaluation. *Aquaculture* 40: 255-259.
- Moghim, M., A. R. Vajhi, A. Veshkini, and M. Masoudifard. 2002. Determination of sex and maturity in *Acipenser stellatus* by using ultrasonography. *Journal of Applied Ichthyology* 18: 325-328.
- Ortenburger, A. I., M. E. Jansen, and S. K. Whyte. 1996. Nonsurgical videolaparoscopy for determination of reproductive status of the Arctic charr. *Canadian Veterinary Journal* 37: 96-100.

- Swenson, E. A., A. E. Rosenberger, and P. J. Howell. 2007. Validation of endoscopy for determination of maturity in small salmonids and sex of mature individuals. *Transactions of the American Fisheries Society* 136: 944-998.
- Webb, M. A. H., G. W. Feist, E. P. Foster, C. B. Schreck, and M. S. Fitzpatrick. 2002. Potential classification of sex and stage of gonadal maturity of wild white sturgeon using blood plasma indicators. *Transactions of the American Fisheries Society* 131: 132-142.
- Wildhaber, M. L., D. M. Papoulias, A. J. DeLonay, D. E. Tillitt, J. L. Bryan, M. L. Annis, and J. A. Allert. 2005. Gender identification of shovelnose sturgeon using ultrasonic and endoscopic imagery and the application of the method to the pallid sturgeon. *Journal of Fish Biology* 67: 114-132.
- Wildhaber, M. L., D. M. Papoulias, A. J. DeLonay, D. E. Tillitt, J. L. Bryan, and M. L. Annis. 2006. Development of methods to determine the reproductive status of pallid sturgeon in the Missouri River. Report to U.S. Fish and Wildlife Service, Bismark, North Dakota. 81 pp.