Ecology, behavior, and biological characteristics of juvenile lake sturgeon, Acipenser fulvescens, within an impounded reach of the Winnipeg River, Manitoba, Canada

By

Cameron C. Barth

A Thesis

Submitted to the Faculty of Graduate Studies

In partial fulfillment of the requirements

For the degree of

Doctor of Philosophy

Department of Biological Sciences

University of Manitoba

Winnipeg, Manitoba, Canada, 2011

Abstract

The lake sturgeon, *Acipenser fulvescens*, was once abundant throughout Canada and the United States, however, high commercial harvests and habitat alterations have dramatically reduced most populations. The species was extirpated from many rivers that it once inhabited, and has been designated as threatened or endangered throughout its range. Currently, few healthy lake sturgeon populations remain and the species is receiving considerable attention with respect to its protection and recovery. Although considerable effort is underway to conserve the species, several factors, including over-harvest and habitat alteration, pollution and a general lack of understanding about lake sturgeon ecology and behavior continue to hamper recovery efforts. This thesis examined the ecology and behavior of juvenile lake sturgeon within a 41 km long impounded section of the Winnipeg River, a large river in the Canadian Shield, over a three-year period (2006 – 2008). Habitat preferences, species associations, diet, and movement were described on a seasonal basis. Biological characteristics were also described for juvenile lake sturgeon within the study area. Studies presented in this thesis are among the first conducted for juveniles of this species in the Hudson Bay drainage basin, and from large riverine environments in general. Results are important, not only for improving our understanding of lake sturgeon at the juvenile life history stage, but for facilitating further research. In particular, future research studies identified in the final chapter have the potential to enhance our understanding of factors influencing mortality during the early life history stages of the lake sturgeon, and therefore, greatly enhance recovery efforts.

Acknowledgments

I am especially grateful to my supervisor, Dr. W. G. Anderson. Gary has provided me with invaluable direction, guidance, and support over the past five years.

I also would like to thank all those involved in my supervision throughout the PhD. In particular, my supervisory committee, Dr. D. Gillis and Dr. M. Paterson are thanked for their contributions to the research. Dr. M. Abrahams is also acknowledged for his advice and direction. Dr. T. Haxton is acknowledged for the numerous conversations and discussions that have sparked several ideas. The statistical advice provided by Dr. N. Arnason is also greatly appreciated.

Considerable time and effort were spent in the field collecting data. I greatly appreciate the help of the following field assistants, lab mates and/or colleagues: Cheryl Klassen, Dr. Peter Allen, Jon Peake, Ray Lafantasie, Laura Henderson, Holly Labadie, Claire Hrenchuk, Christine Lacho, Megan Alexander, Carl Bradley, Michelle Gray, and numerous Manitoba Science Academy summer students.

Manitoba Hydro and NSERC are gratefully acknowledged for their financial support of this research.

I would like to thank all of those who have contributed, and/or helped in some way towards improvement of this research project. The folks at Manitoba Hydro, particularly Shelley Matkowski and Marilynn Kullman, are thanked for providing additional funding to attend conferences. There are many at North/South Consultants, including Stuart Davies, Don Macdonell, Richard Remnant, Patrick Nelson, and many

more, who are thanked for their advice, direction and most importantly equipment in times of need. Jarod Larter and Michelle Lavergne are acknowledged for their contributions in mapping and formatting, respectively.

Finally, I would like to thank all my family and friends, particularly, Megan, Renfield and Ron. My mom and dad are also thanked for their influence and never ending support. Without these people, none of this would have been possible.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1: General Introduction

1.1 Introduction to Acipenseriformes

Acipenseriformes are an ancient group of fish that have existed in the Holarctic region for the last 200 million years (Findeis 1993; Bemis and Kynard 1997; Bemis et al. 1997; Choudhury and Dick 1998). They are comprised of two families, the sturgeons, Acipenseridae, and paddlefish, Polydontidae, with the sturgeon being divided into 2 genera, Acipenser and Scaphyrhinchus. In total, 25 species are described within these genera (Bemis and Kynard 1997).

Aciperserids are referred to as “living fossils” because they are an extant link between primitive fish (i.e., sharks and other elasmobranchs), and more derived bony fish (teleosts) (Krieger et al. 2000). They have received considerable study with respect to the development of many hypotheses regarding evolution and systematics. The sturgeons are perhaps best known for their large size and unique morphological features, which include a cartilaginous skeleton, five rows of bony plates or scutes, four chemosensory barbels, a heterocercal tail, spiral valve in the gastrointestinal tract and a protrusible mouth (Harkness and Dymond 1961; Scott and Crossman 1973, Krieger 2000). Sturgeon are also notorious for their unique life history characteristics, including late age at sexual maturity, periodic spawning, slow growth and high fecundity (Bemis and Kynard 1997).

Unfortunately, Acipenseriformes are also renowned for being classified as either rare, threatened or endangered. Populations worldwide have endured severe anthropogenic impacts owing to overfishing, pollution and detrimental habitat changes associated with large scale developments (Boreman 1997; Birstein et al. 1997; Krieger

2000; Haxton and Findlay 2009). These impacts have resulted in severe population declines, and as a result the sturgeons are amongst the most threatened groups of fishes in the world (Birstein 1993; Bemis and Findeis 1994; Lenhardt et al. 2006). Of the 25 species of sturgeons, 24 are listed as threatened to critically endangered with Siberian sturgeon, *Acipenser baeri*, being the exception (Birstein 1993).

Eight species of sturgeon can be found in North America, with the lake sturgeon, *Acipenser fulvescens*, being the only species endemic to the Great Lakes and Hudson Bay drainage basins (Houston 1987; Auer 1996). Lake sturgeon occupy a large range throughout the United States and Canada and are found as far south as Arkansas in the Mississippi River; as far north as the Churchill River in northern Manitoba; extending west in the Saskatchewan River into the province of Alberta; and as far east as the St. Lawrence River estuary in Quebec (Scott and Crossman 1973; Power and McKinley 1997) (Figure 1.1). Similar to other species of sturgeon, few abundant populations of lake sturgeon remain, and the species is considered threatened in Canada and the United States (Ferguson and Duckworth 1997). More recently, the lake sturgeon is being considered for designation as a protected species in Western Canada under the Species at Risk Act.

Considering the state of worldwide sturgeon stocks and continued threats to remnant wild stocks, conservation efforts are urgently needed. However, development and implementation of recovery and conservation strategies have proven difficult due to the current state of most populations, which are too low to recover unaided, continued poaching and fishing pressure on existing stocks, and finally, gaps in our understanding of ecological processes that influence mortality and growth at each life history stage. Studies on remaining wild stocks are essential to guide conservation efforts.

1.2 Life history traits, data gaps and research direction

Fundamental to understanding the relationship between an animal and its environment, and the factors that influence its fitness, is the study of individual life history traits and life history strategy. It is theorized that natural selection has shaped individual life history traits in order to maximize fitness and reproductive output (Roff 1992). Stearns (1992) lists size at birth, growth rate, age and size at sexual maturity, number of offspring, size of offspring, reproductive investment, mortality rate and length of life as the principal life history traits. Ecological processes that affect these traits change with size and age (De Roos et al. 2003), and these ontogenetic changes are key determinants of habitat use and diet at each life history stage (Werner and Gillam 1984; Gagliano et al. 2007).

Life history traits of the lake sturgeon are consistent with the periodic life history strategy described by Winemiller and Rose (1992), or the K-selected strategy as described by Pinaka (1970). Species that have evolved this type of life history strategy are characterized by traits such as longevity, large size, high fecundity, and late age at sexual maturity (Pinaka 1970; Winemiller and Rose 1992). Evolution of K-selected traits are thought to have occurred in environments where either density independent factors such as temperature, or density dependent factors such as competition between con-specifics, influence recruitment into a population (Murphy 1968; Pinaka 1970). Musick (1999) suggests that animals possessing these traits are especially vulnerable to population declines associated with anthropogenic stressors such as overfishing, and are generally slow to rebound in areas where populations are depressed. This complicates conservation and recovery of K-selected species because in most cases the physical and biological components of habitat in which they evolved has been altered, and a general lack of understanding exists as to the ecological factors that limit population growth (Bruch 2008). Furthermore, an understanding of the young life history stages in K-selected species may be critical for species rehabilitation since it is likely that the majority of mortality within the population occurs during these life-stages (Murphy 1968; Gross et al. 2002).

For many fish species inhabiting large river systems, a lack of information regarding their life history traits, and the ecological processes that influence population growth have hampered efforts to manage and restore populations (Reynolds et al. 2005). This is especially true for many sturgeon species since little is known about their basic ecology, especially during the younger life history stages. This gap in understanding has been attributed to the environment in which these lifestages are thought to live (deep, fast flowing, main channel environments of large rivers), which makes capture and thus study, difficult (Secor et al. 2002). Consequently, very few studies have focused on seasonal habitat use, seasonal movement and diet of juvenile lake sturgeon, especially in large riverine environments (Auer 1996). Several areas of research have been identified as critically important to further understand juvenile lake sturgeon ecology and to potentially benefit species rehabilitation, including: 1) development of protocols enabling collection of wild juveniles in large rivers (Secor et al. 2002); 2) determination of habitat use, diet and seasonal movements of juvenile lake sturgeon (Auer 1996); and 3) determination of growth and mortality rates of wild juveniles (Secor et al. 2002). This thesis attempts to address the aforementioned research areas, and lay the groundwork for understanding habitat selection in juvenile lake sturgeon in large riverine environments.

This thesis describes the ecology and behavior of juvenile lake sturgeon, focusing on the abiotic (chapter 2) and biotic factors (chapter 3) that combine, or may have combined, to influence habitat selection in large riverine environments. Diet of juvenile lake sturgeon is described by season and habitat type in Chapter 4. I have employed a number of techniques such as mark and recapture and acoustic telemetry to describe seasonal movement patterns and factors influencing home range size in Chapter 5. Biological statistics, such as condition and growth, are described for juvenile lake sturgeon in the Winnipeg River study area in Chapter 6. Finally, Chapter 7 identifies several key research questions that should be considered for future research.

1.3 References

Auer, N. A., 1996: Importance of habitat and migration to sturgeons, with emphasis on lake sturgeon. Can. J. Fish. Aquat. Sci. **53**, 152-160.

Bemis, W. E.; Findeis, E. K., 1994: The sturgeons plight. Nature **370**, 602.

Bemis, W. E.; Findeis, E. K.; Grande. L., 1997: An overview of Acipenseriformes. Environ. Biol. Fish. **48**, 25-71.

Bemis, W. E.; Kynard, B., 1997: Sturgeon rivers: an introduction to Acipenseriform biogeography and life history. Environ. Biol. Fish. **48**, 167-183.

Birstein, V. J., 1993: Sturgeons and paddlefishes: threatened fishes in need of conservation. Conserv. Biol. **7**, 773-787.

Birstein, V. J.; Bemis, W. E.; Waldman, J. R., 1997: The threatened status of Acipenseriform species: a summary. Environ. Biol. Fish. **48**, 427-435.

Boreman, J., 1997: Sensitivity of North American sturgeons and paddlefish to fishing mortality. Environ. Biol. Fish. **46**, 399-405.

Bruch, R., 2008: Modeling the population dynamics and sustainability of lake sturgeon in the Lake Winnebago system, Wisconsin. PhD thesis dissertation, University of Wisconsin, Milwaukee, WI, USA.

Choudhury, A.; Dick, T. A., 1998: The historical biogeography of sturgeons (Osteichthyes:Acipenseridae): a synthesis of phylogenetics, palaeontology and palaeogeography. J. Biogeogr. **25**, 623-640.

De Roos, A. M.; Persson, L.; McCauley, E., 2003: The influence of size-dependent life-history traits on the structure and dynamics of populations and communities. Ecol. Lett. **6**, 473-487.

Ferguson, M. M.; Duckworth, G. A., 1997: The status and distribution of lake sturgeon, *Acipenser fulvescens*, in the Canadian provinces of Manitoba, Ontario and Quebec: a genetic perspective. Environ. Biol. Fish. **48**, 299-309.

Findeis, E. K., 1993: Skeletal anatomy of the North American shovelnose sturgeon, *Scaphirhyncus platorynchus* (Rafinesque 1820) with comparisons to other Acipenseriformes. Ph D thesis, University of Massachusetts, Amherst, MA, USA.

Gagliano, M.; McCormick, M. I.; Meekan, M. G., 2007: Survival against the odds: ontogenetic changes in selective pressure mediate growth-mortality trade-offs in a marine fish. Proc. R. Soc. B **274**, 1575-1582.

Gross, M. R.; Repka, J.; Robertson, C. T.; Secor, D. H., 2002: Sturgeon Conservation: Insights from elasticity analysis. Am. Fish. Soc. Symp. **20**, 184-200.

Harkness, W. J. K.; Dymond, J. R., 1961: The lake sturgeon. Ontario. Department of Lands and Forests, Toronto, Ontario, Canada.

Haxton, T. J.; Findlay, C. S., 2009: Variation in large-bodied fish-community structure and abundance in relation to water-management regime in a large regulated river. J. Fish. Biol. **74**, 2216-2238.

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

Krieger, J.; Fuerst, P. A.; Cavender, T. M., 2000: Phylogenetic relationships of North American sturgeons (Order Acipenseriformes) based on mitochondrial DNA sequences. Mol. Phylogenet. Evol. **16**, 64-72.

Lenhardt, M.; Jaric, I.; Kalauzi, A.; Cvijanovic, G., 2006: Assessment of extinction risk and reasons for decline in sturgeon. Biodivers. Conserv. **15**, 1967-1976.

Murphy, G. I., 1968: Pattern in life history and the environment. Am. Nat. **102**, 391-403.

Musick, J. A., 1999: Ecology and conservation of long-lived marine mammals. Am. Fish. Soc. Symp. **23**, 1-10.

Pianka, E. R., 1970: On r- and K- selection. Am. Nat. **104**, 592-597.

Power, M.; McKinley, R. S., 1997: Latitudinal variation in lake sturgeon size as related to thermal opportunity for growth. Trans. Am. Fish. Soc. **126**, 549-558.

Reynolds, J. D.; Webb, T. J.; Hawkins, L. A., 2005: Life history and ecological correlates of extinction risk in European freshwater fishes. Can. J. Fish. Aquat. Sci. **62**, 854-862.

Roff, D. A., 1992. Life history evolution. Champman and Hall, London, UK.

Scott, W. B.; Crossman, E. J., 1973: Freshwater Fishes of Canada. Fish. Res. Board Can. **184,** 966 pp.

Secor, D. H.; Anders, P. J.; Van Winkle, W.; Dixon, D. A., 2002: Can we study sturgeons to extinction? What we do and don't know about the conservation of North American Sturgeons. Am. Fish. Soc. Symp. **28**, 3-10.

Stearns, S. C., 1992: The evolution of life histories. Oxford University Press, Oxford.

Winemiller, K. O.; Rose, K. A., 1992: Patterns of life-history diversification in North American fishes: implications for population regulation. Can. J. Fish. Aquat. Sci. **49**, 2196-2218.

Figure 1.1. Current distribution of lake sturgeon, *Acipenser fulvescens*, throughout North America. Source: Ron Bruch, unpublished.

Chapter 2: Habitat utilization of juvenile lake sturgeon, Acipenser fulvescens, in a large Canadian river

2.0 Chapter Abstract

An increased understanding of the juvenile life history stage of the lake sturgeon, *Acipenser fulvescens*, has been recognized as a key requirement for improving conservation efforts for this once abundant species. The objectives of the current study were to develop an effective methodology for capturing juvenile lake sturgeon in a large riverine environment; to describe the physical characteristics (depth, water velocity and substrate) associated with locations that juvenile lake sturgeon were captured; and to describe the composition of the fish community in areas that juveniles occupied on a seasonal basis. The Winnipeg River, a large river in the Hudson Bay drainage, was sampled using gillnets (of different mesh sizes 25 – 108 mm) from June 12 to November 6, 2006. A total of 2,154 juvenile (< 530 mm FL) lake sturgeon were captured, which represented over 74% of the 2006 catch. Moderate (51 – 108 mm) and small (25 mm) mesh gill nets were found to be efficient for sampling juvenile lake sturgeon, with the former capturing a wider range of sizes and the latter capturing fewer fish but resulting in lower mortality. Regardless of season, juvenile lake sturgeon were captured at high densities in habitats characterized by water depths > 13.7 m, detectable water velocities > 0.20 m.s-1, and over both fine (< 2 mm) and coarse substrate types. These habitat types were dominated by juvenile lake sturgeon as CPUE values of other fish species were comparatively low.

2.1 Introduction

The lake sturgeon, *Acipenser fulvescens*, is one of eight species of sturgeon found in North America, and is the only species endemic to the Great Lakes and Hudson Bay drainage basins (Auer 1996). Known for their longevity and large size, individual lake sturgeon can live for over 100 years and reach lengths in excess of 1.5 m (Scott and Crossman 1973). This species, once considered abundant throughout its distribution in North America, is now considered threatened in Canada and the United States, and listed as vulnerable in the Canadian province of Manitoba under the Manitoba endangered species act (Williams et al. 1989; Ferguson and Duckworth 1997).

One of the largest gaps regarding our current understanding of lake sturgeon life-history is the juvenile phase (Auer 1996). This is especially true in large rivers, where few abundant populations exist, recruitment to the juvenile life stage is thought to be low; and logistic issues associated with the capture of juvenile fish have hindered detailed study (Houston 1987; Auer 1996; Secor et al. 2002; Thomas and Haas 2002). As a consequence, our understanding of juvenile lake sturgeon ecology including, habitat use, diet, and movements, has been derived from studies conducted in tributaries of the Great Lakes (Thuemler 1988; Kempinger 1996; Holtgren and Auer 2004; Benson et al. 2005; Lord 2007) or smaller rivers in the Moose River drainage basin in Northern Ontario, Canada (Beamish et al. 1996; Chiasson et al. 1997; Noakes et al. 1999); in addition to laboratory based investigations using hatchery-reared fish (Peake 1999).

Scientific research focused on improving knowledge of juvenile lake sturgeon ecology is urgently needed to accurately assess impacts of potential development and improve conservation and restoration efforts (Secor et al. 2002). Research is particularly required on juvenile fish measuring < 600 mm as it is thought that the survival of lake sturgeon in this size class may have a significant influence over population growth rate (Gross et al. 2002). Therefore, the objectives of this thesis chapter were: (1) to determine an effective gill net mesh size for capturing juvenile lake sturgeon in a large riverine environment that maximized capture efficiency and minimized mortality; (2) to describe the physical habitat characteristics (depth, water velocity and substrate) associated with areas where juvenile lake sturgeon were captured; and, (3) to describe the composition of the fish community by habitat type and identify species that associate with juvenile lake sturgeon on a seasonal basis.

2.2 Materials and methods

2.2.1 Study area

The Winnipeg River drains an area of approximately 150,000 km^2 encompassing northern Minnesota in the United States, and southwestern Ontario and eastern Manitoba in Canada. The river is approximately 260 km long from its outlet at Lake of the Woods, Ontario to Lake Winnipeg, with a vertical descent of 105 m (St. George 2006). Winnipeg River flows are regulated by the Lake of the Woods Control Board mainly at the Norman Dam, the most upstream hydroelectric generating station built at the river outlet on Lake of the Woods, Ontario. Monthly discharges in the Winnipeg River generally range between 500 m^3/s and 1,500 m^3/s, with historical monthly peaks reaching approximately 3,000 m^3/s (St. George, 2006). Development of the Winnipeg River for hydroelectricity in Manitoba began in 1906. Presently, six generating stations (GS) operate on the river, which from upstream to downstream include: Pointe Du Bois GS (built in 1911), Slave Falls GS (1931), Seven Sisters Falls GS (1931), MacArthur Falls GS (1954), Great Falls GS (1923) and Pine Falls GS (1951) with the Pinawa dam site being shut down in 1951 (Manitoba Hydro 1990).

Field studies, were conducted during open water periods between May 2006 and October 2008, in an impounded reach of the Winnipeg River bordered by the Slave Falls GS (50º13’39N, 95º37’51W) at the upstream end, and Seven Sisters Falls GS (50º07’09N, 96º01’03W) at the downstream end (Figure 2.1). This section of the Winnipeg River (hereforth referred to as the study area) can be described as an inter-connected series of riverine and lacustrine environments that contain both lotic and lentic habitat features. The study area is located in the Canadian Shield, with the surrounding landscape being comprised of boreal forest. The shorelines are moderate to steeply sloped, and large bedrock outcroppings and ridges are common. Many islands, reefs and back bays are found along the length of the river. Although narrow channels with water velocities > 1.0 m.s-1 can be found at the outlet of many lakes in the study area, the main sets of rapids (characterized by turbulent flows and water velocities > 1.5 m.s-1) occur at Scotts Rapids, Sturgeon Falls and Otter Falls (Figure 2.1). Cottage development exists on the south side of the river from Eleanor Lake to Nutimik Lake, and the town of Pinawa is located on the north shore of the river between Margaret Lake and Natalie Lake. Both the Slave Falls GS and Seven Sisters Falls GS are considered run-of-the-river hydroelectric facilities because water is passed at the same rate that it enters the system (i.e., inflows equal outflows). Provision for upstream fish passage has not been provided at either GS.

The study area was subdivided into eight river sections (RS) (Figure 2.1) with boundaries being delineated by rapids, constrictions of the river, or inlets and/or outlets of “lakes” (lakes = areas where the Winnipeg River widens). For example, the most upstream river section, river section (RS) RS-1, was bounded by the Slave Falls GS at the upstream end and Scotts Rapids at the downstream end. This RS measured 6.0 km in total, including river kilometers (rkm) 0.0 – 6.0, and since the Slave Falls GS is the most upstream location in the Study Area, it was designated as rkm 0. The river sections of this study area, from upstream to downstream included: RS-1: as described above; RS-2: Numao Lake (4.0 km long, rkm 6.0 – 10.0), RS-3: Nutimik Lake (4.0 km long, rkm 10.0 -14.0), RS-4: Dorothy Lake (9.0 km long rkm 14.0 – 23.0), RS-5: Margaret Lake (5.0 km long; rkm 23.0 – 28.0), RS-6: Eleanor Lake (4.5 km long, rkm 23.0A – 27.5A), RS-7: Sylvia Lake (2.0 km long; rkm 27.5A – 29.5A) and RS-8: Natalie Lake (11 km long, rkm 28.0 – 39.0).

Although both lotic and lentic habitats can be found in each RS, lotic habitat is generally located in the upstream reaches of the study area (RS-1, RS-2 and RS-3), and lentic areas are generally found in the lower reaches (RS-4, RS-5, RS-6, RS-7, and RS-8). The substrate in the main channel of each river section is influenced by corresponding flow conditions. Generally, substrates with particle sizes > 0.063 mm (the lower limit of the sand classification) are associated with lotic habitats found in RS-1, RS-2 and RS3, whereas substrates with particle sizes < 0.063 mm (depositional) are found in the lower reaches of the study area (RS-4 – RS-8). Water depths < 5 m are generally found along shorelines or in back bays, with depths reaching 10 m – 25 m in the main channel. The maximum water depth in the study area is approximately 45 m.

The study area has been classified as mesotrophic (CCME 1999) having moderate nutrient levels. Generally, the waters in this study area are well oxygenated with low turbidity. The moderately basic alkalinity is due entirely to contributions from the anion bicarbonate and calcium is the dominant cation (CCME 1999). Water quality information from the Winnipeg River are available by request from Manitoba Water Stewardship.

Field studies were conducted in the upper 14 km of the study area (i.e., RS-1, RS-2 and RS-3) (Figure 2.1). These river sections offer a diversity of physical habitat conditions, including a variety of substrate types (silt, sand, gravel/cobble and bedrock), variable water depths (ranging from 0 - 45 m), and variable water velocities (0 to > 1.5 $m.s^{-1}$).

2.2.2 Fish capture and sampling

Gill nets of varying mesh sizes were set in different combinations of depth, water velocity and substrate to determine if a particular combination served as suitable/preferred habitat for juvenile lake sturgeon. Gill nets were used because other gear types such as hoop nets or trap nets, would not be suitable for sampling juvenile sturgeon in the deep, flowing environments of the Winnipeg River. Gillnetting was conducted from June 12 to November 8, 2006, and included three six week sampling periods: spring (June 12 – July 27), summer (August 1 – September 13), and fall (September 28 – November 8). All procedures in this and subsequent chapters were conducted under the guidelines established by the Canadian Council for Animal Care and animal use protocol F07-006 approved by the University of Manitoba, Fort Garry Campus, Animal Care Committee.

Depending on sampling period, gill net gangs consisted of two to five 22.9 m long, 1.8 m deep panels of 25 mm, 38 mm, 51 mm, 76 mm, 95 mm or 108 mm stretched twisted nylon mesh (Leckies net and twine, Winnipeg, Manitoba, Canada), anchored at each end with 22.5 kg concrete blocks. Each gill net panel was equipped with a 1-cm diameter braided float and lead line. Gill net gangs were set on the river bottom at a 45º angle (or less depending on water velocity) to water flow during the early or late afternoon and recovered the following morning with set durations generally lasting between 18 and 22 hours.

Gill net sampling locations and mesh sizes were altered throughout the study period in order to: a) locate juvenile lake sturgeon; b) reduce mortality of lake sturgeon and other fish species captured in the gill nets, especially during summer when water temperatures were high; and, c) determine size-based capture efficiency differences with increasing mesh size. During the spring sampling period, 20 sites were sampled with 114.5 m long gill net gangs comprised of five panels of different mesh sizes (25, 51, 76, 95 and 108 mm mesh) each 22.9 m long. During summer, 48 sites were sampled with gill net gangs comprised of 22.9 m long panels of 25 mm, 38 mm and 51 mm mesh. Only small mesh sizes were used during this sampling period in order to reduce mortality of lake sturgeon and other fish species. During the fall, 20 sites were sampled using 68.7 m long gill net gangs comprised of three different mesh sizes (25, 51 and 76 mm), each 22.9 m in length. The 38 mm, 95 mm and 108 mm were not used during fall sampling since following the summer sampling period, it was found that the 38 mm mesh did not capture significantly different sized lake sturgeon than the 25 mm and 51 mm mesh sizes; and the 95 mm and 108 mm mesh sizes (although effective at capturing juvenile lake sturgeon), resulted in high mortality of other fish species. All fish captured were enumerated by species, mesh size and measured for fork length (FL) to the nearest mm. Burbot were only measured for total length (TL) due to the lack of a forked tail. Each lake sturgeon captured was measured for FL and TL, while body mass (g) was collected from a sub sample of the catch.

2.2.3 Habitat characteristics

Water depth and location of both ends of each gill net gang were determined using a sonar/GPS combination unit (Lowrance 700 LCX-M, Lowrance, Tulsa, Oklahoma). Water velocity measurements were collected within 50 m of each sampling site using a Pulse Current Acoustic Doppler Profiler (ADP) (SonTek, San Diego, California, USA). Velocity profiles were created using River Surveyor software version 4.5 (SonTek, San Diego, California, USA). Substrate samples were collected within 50 m of each gill net site using a ponar (225 cm^3). Substrate classifications were identified based on particle size distribution, modified from Wentworth (1929). These were: clay/silt (particles < 0.063 mm); sand (particles > 0.063 mm and < 2mm); gravel/cobble (particles > 2 mm and < 100 mm). If the ponar was unable to collect a sample after three attempts, the substrate was assumed to consist of large cobble, boulders and/or bedrock (particles > 100 mm).

2.2.4 Data analysis

All lake sturgeon captured measuring < 610 mm TL were considered juvenile. This size was used as the cutoff as lake sturgeon measuring < 610 mm TL from this system have never been reported as sexually mature (D. Leroux, personal communication).

To facilitate catch comparisons among mesh size, CPUE values were calculated by enumerating the number of juvenile lake sturgeon captured in a 22.9 m long gill net panel per 24 hours of fishing (adjusted arithmetically for sets varying from 24 hours). To determine if significant differences existed between CPUE and mesh size, mean CPUE values were calculated from each mesh size, during each sampling period, and compared after log transformation (X+1 due to zero catches) using a one-way analysis of variance (ANOVA) (Sokal and Rohlf 1981). Tukey's multiple comparison procedure was used to compare CPUE's among different mesh sizes. Total length-frequency distributions were developed for lake sturgeon by 20 mm TL intervals for each of the six mesh sizes used during the study. A Kolmogorov-Smirnov (K-S) test was used to compare TL-frequency distributions among the mesh sizes.

2.2.5 Canonical correspondence analysis

To examine relationships between fish community structure and habitat variables, canonical correspondence analysis (CCoA) was conducted using log-transformed CPUE data and quantitative habitat data from 20 gill netting sites during spring and fall. Because several fish species were captured at low abundance, each species was classified into one of nine functional groups (i.e., fish species that exploit similar resources), based on known food and habitat preferences (Carlander 1969; Scott and Crossman 1973). Functional groups included:

1. Burbot (BURB)

2. Sub-adult and adult lake sturgeon measuring ≥ 610 mm TL (LKST Lg)
3. Juvenile lake sturgeon measuring between 300 mm TL and 609 mm TL (LKST med)
4. Juvenile lake sturgeon measuring ≤ 300 mm TL (LKST sm)
5. Benthic foragers (Benthic): (i.e., white sucker, *Catostomus commersoni*, shorthead redhorse, *Moxostoma macrolepidotum*, and lake whitefish, *Coregonus clupeformis*
6. Pelagic foragers (Pelagic) – mooneye, *Hiodon tergisus* and cisco, *Coregonus artedi*
7. Large piscivores (Lg Pisc): walleye, *Sander vitreus*, sauger, *Sander canadensis*, and northern pike, *Esox lucius,* measuring ≥ 250 mm FL
8. Small Omnivores (Sm Omn: smallmouth bass, *Micropterus dolomieu*, rock bass, *Ambloplites rupestris*, yellow perch, *Perca flavescens*, trout perch *Percopsis omiscomaycus*, and log perch *Percina caprodes*
9. Small piscivores (Sm Pisc) – walleye and sauger measuring < 250 mm FL

Habitat variables for each gill net site were assigned values based on the following criteria. Mean water depth for each gillnet site was determined by averaging the depth extremes along the length of the gill net gang. Water velocity was assigned a value of either 0.05, 0.2 or 0.5 (i.e., either low, medium or high, respectively) based on quantitative assessments of velocity either at or in the vicinity of each gill netting site. Finally, substrate was assigned values based on particle size either 0.06 (mm) (silt/clay), 2 (mm) (sand), 5 (mm) (gravel/cobble) or 15 (mm) (rock/boulder) (after Wentworth

1929). This analysis was conducted using SYNTAX 2000 (Podani 2001) (Exeter software, New York).

2.2.6 Habitat classification

The final analysis compared CPUE values of juvenile lake sturgeon among habitat types. Each gill netting site was assigned a habitat type based on depth, water velocity, and substrate. Depth was classified as either deep, areas predominantly found in the main channel of the river ≥ 13.7 m, or shallow, areas predominantly found in back bays or along shorelines < 13.7 m. Water velocity was classified as either low, (0.0 - 0.2 $m.s^{-1}$) (generally found in back bays, or along shorelines), medium, (0.2 – 0.4 $m.s^{-1}$) (typically found along channel margins or main channel areas distant from significant decreases in elevation) or high, (> 0.4 $m.s^{-1}$) (generally found in the main channel of the river). Substrate was classified based on particle size, as either small (particles < 2 mm such as clay or sand) or large (particles ≥ 2 mm such as gravel, cobble, boulder or bedrock). Gill nets were not set across habitat boundaries. For example, at deep sites the entire length of the gill net was located at depths > 13.7 m.

Juvenile lake sturgeon abundance (CPUE) was compared among habitat types during each season, using ANOVA and Tukey's multiple comparison procedure to determine if significant differences in CPUE existed amongst habitat types, after data were $\log_{10}$ transformed. Statistical analyses were conducted using XLSTAT (Version 2006.2) in Excel (Microsoft Corporation, Redmond, California). A significance level of $P < 0.05$ was used for all statistical analyses.

2.3 Results

Between June 12 and November 8, 2006, 2,154 juvenile lake sturgeon were captured in gill nets with 631, 1,044 and 479 caught during the spring, summer and fall sampling periods, respectively (Table 2.1). Of the 18 species of fish that were captured, juvenile lake sturgeon comprised over 74% of the total catch with walleye, *Sander vitreus*, sauger, *Sander canadensis*, lake sturgeon ≥ 610 mm TL, white sucker, *Catostomus commersoni*, and shorthead redhorse, *Moxostoma macrolepidotum*, comprising 6.3%, 5.2%, 3.9%, 3.4%, and 2.1%, of the total catch, respectively (Table 2.1). The remaining fish species were captured at a frequency of less than 1%. Length-frequency histograms were constructed by 20 mm total length intervals for lake sturgeon captured during each sampling period (Figure 2.2). Overall, the modal length interval was 410-429 mm TL, with sturgeon from the 370-509 mm length class intervals comprising 81.9% of the catch. The majority of sturgeon measuring between 210 and 290 mm TL were captured during summer and fall. Because different mesh sizes of gill nets were used during each sampling period, results are presented separately for each sampling period.

2.3.1 Mesh size efficiency

During the spring sampling period mean CPUE of juvenile lake sturgeon was significantly higher in the 76 mm, 95 mm and 108 mm mesh than in the 25 mm and 51 mm mesh (ANOVA, $P < 0.0001$, Tukey's HSD, $P < 0.02$) (Table 2.2). Significant differences in CPUE were not found (ANOVA, $P = 0.13$) among the three mesh sizes (25, 38 and 51 mm) used during the summer sampling period. During the fall sampling period, the mean CPUE was significantly higher in the 76 mm mesh than in the 25 mm mesh (ANOVA, $P < 0.05$, Tukey's HSD, $P < 0.05$). In total, 27 juvenile lake sturgeon suffered mortality during the three sampling periods combined, with 18, 7 and 2 occurring during the spring, summer and fall, respectively (Table 2.2). The highest percentage mortality by mesh size occurred in the 95 mm mesh (4.2 %) with the lowest occurring in the 25 mm mesh (0.3 %; Table 2.2). Significant differences were not found in length frequency distributions of lake sturgeon captured in the 25 mm, 38 mm and 51 mm mesh sizes (all seasons combined, K-S, $P > 0.05$; Figure 2.3). The size distribution of lake sturgeon captured in the 108 mm mesh was significantly different (longer) than all other mesh sizes tested (K-S, $P < 0.002$, all tests). Significant differences were also found in the size distribution of fish captured between the 76 mm mesh and all other mesh sizes (K-S, $P < 0.02$) with the exception of the 95 mm mesh (K-S, $P = 0.74$). Further, the size distribution of juvenile lake sturgeon capture in the 51 mm mesh was significantly different from all larger mesh sizes (K-S, $P < 0.01$).

2.3.2 Habitat classification and habitat preference of juvenile lake sturgeon

Canonical correspondence analysis was used to analyze biological and environment data from 20 gillnetting sites from both spring and fall (figures 2.4a and 2.4b). For the spring data, axis 1 (eigenvalue = 0.26; variance explained 94.3%) was positively correlated with depth (0.99) and velocity (0.65) and to a lesser extent substrate (0.12), whereas axis 2 (eigenvalue 0.01; variance explained 4.3%) was positively correlated with velocity (0.35) and depth (0.04) and negatively correlated with substrate (-0.10) (Figure 2.4a). The spring biplot shows that LKST med (juvenile lake sturgeon measuring 300 – 609 mm TL) were associated with deep, higher velocity habitat, whereas pelagic species, small piscivores and small omnivores were associated with shallow, lower velocity habitats. For the fall data, axis 1 (eigenvalue 0.20; variance explained 73.0%) was positively correlated with depth (1.0) and velocity (0.62) but to a lesser extent substrate (0.16), while axis 2 (eigen value 0.05; variance explained 18.2%) was positively correlated with substrate (0.75) and depth (0.07) but negatively correlated with velocity (-0.45). Similar to the results obtained with the spring data set, the fall biplot (Figure 2.4b) suggests that juvenile lake sturgeon measuring 300 – 609 mm TL were associated with deep, high velocity habitat, while pelagic, small piscivores and small omnivores were associated with shallow, low velocity habitats. The spring and fall data sets show very similar associations among functional groups and habitat variables.

2.3.3 CPUE comparisons

In order to provide a comparison of juvenile lake sturgeon abundance (CPUE) among habitat types in the Winnipeg River, the sampled areas were broadly categorized into four types based on depth, water velocity and substrate type. However, all potential combinations of depth, water velocity and substrate type did not exist (e.g., deep areas with low water velocities). Further, an equal amount of sampling effort did not occur within each habitat type. The four habitat types were:

HT-1: Deep, high velocity, large particle substrate. Characterized by water depths > 13.7 m, water velocities > 0.4 m.s-1 and large particle substrates i.e., > 2 mm. HT-1 was the dominant habitat type in the main channel of the river where water depths and water velocities were highest.

HT-2: Deep, medium velocity, small particle substrate. Characterized by water depths > 13.7 m, water velocities between 0.2 and 0.4 m.s-1, and small particle substrates i.e., < 2 mm. HT-2 was found adjacent to the main channel of the river, or in the main channel areas distant from significant drops in elevation.

HT-3: Shallow, low velocity, small particle substrate. Characterized by water depths < 13.7 m, water velocities between 0.0 and 0.2 m.s-1, and small particle substrates i.e., < 2 mm. HT-3 was found in either back bays or along shoreline margins.

HT-4: Shallow, high velocity, large particle substrate. Characterized by water depths < 13.7 m, water velocities > 0.4 m.s-1 and large particle substrates i.e., > 2 mm. HT-4 was found in shallow rapid areas, which were relatively unavailable in this study area. Due to its limited availability, this habitat type was not sampled during spring or fall and only two gillnets were set during the summer sampling period.

During spring, mean juvenile lake sturgeon CPUE was significantly lower in HT-3 (Gill net (GN) sites = 6; gill net gang (GNG) effort = 121.0 hours (h); mean CPUE: 1.8; range CPUE: 0.0 – 4.7) compared to HT-1 (GN sites = 10; GNG effort = 200.3 h; mean CPUE: 8.2: range CPUE: 2.9 – 13.1) and HT-2 (GN sites = 4; GNG effort = 80.7 h; mean CPUE: 13.9, range CPUE: 9.6 – 20.6) (ANOVA, P < 0.0001; Tukey's HSD, P < 0.05) (Figure 2.5). Similar results were observed during summer, where juvenile CPUE in HT-1 (GN sites = 17; GNG effort = 372.1 h; mean CPUE: 16.6; range CPUE: 3.7 – 55.4) and HT-2 (GN sites = 13; GNG effort = 295.9 h; mean: 13.3; range: 6.1 – 25.8) were significantly greater than in HT-3 (GN sites = 7; GNG effort = 155.9 h; mean CPUE: 1.6; range CPUE: 0.0 – 6.1) and HT-4 (GN sites = 2; GNG effort = 42.9 h; mean

CPUE: 3.1; range CPUE: 0.6 – 5.6) (ANOVA, $P < 0.0001$; Tukey's HSD, $P < 0.05$). During fall, juvenile sturgeon CPUE's were significantly greater in HT-1 (GN sites = 9; GNG effort = 209.7 h; mean CPUE: 7.3; range CPUE: 1.9 – 17.7) and HT-2 (GN sites = 6; GNG effort = 135.8 h; mean CPUE: 15.1; range CPUE: 4.6 – 28.7) than in HT-3 (GN sites = 5; GNG effort = 110.5 h; mean CPUE: 1.6; range CPUE: 0.0 – 5.9) (ANOVA, $P < 0.001$; Tukey's HSD, $P < 0.05$) (Figure 2.5).

2.3.4 Fish community composition by habitat type

Juvenile lake sturgeon dominated the catch in both HT-1 and HT-2 as mean CPUE values were 8 to 14 fold greater relative to the next most common fish species, depending on season (figures 2.6, 2.7 and 2.8). CPUE values of all other species were generally < 1.0 fish/22.9 m/24 hr. Although CPUE values were low relative to juvenile lake sturgeon, larger lake sturgeon (measuring > 610 mm TL), walleye, sauger and white sucker were the next most common species (or group) found in HT-1 and HT-2, depending on season. CPUE values were relatively similar between juvenile lake sturgeon and shorthead redhorse and walleye during spring, walleye and sauger during summer and fall in shallow water habitat (HT-3) (figures 2.6, 2.7 and 2.8).

2.4 Discussion

The first objective of this study was to determine gill net mesh sizes that maximize the likelihood of capture of juvenile lake sturgeon, while minimizing fish mortality. Mesh sizes ≤ 51 mm were effective at capturing a wide size range, often capturing juvenile lake sturgeon through entanglement of the scutes or snout (Figure 2.3). Mesh sizes ≥ 76 mm were almost ineffective at capturing juveniles < 300 mm FL. This suggests that a sampling protocol focused on capturing juveniles < 300 mm FL should utilize mesh sizes ≤ 51 mm. The smallest mesh size used in this study (25 mm) was not as effective at capturing juvenile sturgeon compared with other mesh sizes; however, its use did result in minimal fish mortality, particularly at higher water temperatures. As such, a 25 mm mesh size could be used when sampling areas where mortality of lake sturgeon and/or other fish species is a concern. It must be recognized however, that CPUE may be lower when using this or other comparable mesh size.

The second objective of this study was to describe physical habitat characteristics associated with locations where juvenile lake sturgeon were captured. In this study, it was assumed that gill nets fished with similar efficiency across all habitat types. Gill net efficiency is thought to decrease as the number of fish captured increases, and may be compromised in areas of strong currents (Hubert 1996; Askey et al. 2007). For these reasons, it would be expected that CPUE estimates may underestimate fish abundance in higher velocity habitats (i.e., HT-1) and in areas were large numbers of fish were captured (i.e., HT-1 and HT-2).

Regardless of season, our data clearly indicate that juvenile lake sturgeon preferred deep water areas (> 13.7 m), with water velocities > 0.2 $m.s^{-1}$, over a variety of substrate types (i.e., HT-1 or HT-2); to shallow areas, with lower water velocities, and small particle size substrates (figures 2.5, 2.6, 2.7 and 2.8). Further, juvenile lake sturgeon were absent from gill nets set at depths less than 7.75 m, and were rarely captured at depths less than 13.7 m. These data suggest that despite a high abundance of juvenile lake sturgeon in the study area, shallow areas were rarely utilized during day or night. Although there are few comparable studies others have also reported that juvenile lake sturgeon exhibit a preference for deep water. Lord (2007) reported that depth was a key factor influencing the distribution of juvenile lake sturgeon (582 – 793 mm TL) in the Lake St. Clair River. During this study, juvenile lake sturgeon tagged with acoustic transmitters were relocated most frequently at depths of 12 – 18 m, and were not relocated at depths of 6 m or less. Holtgren and Auer (2004) reported that of four juvenile and one sub-adult lake sturgeon tagged in the Portage River, Michigan, the two smallest juvenile lake sturgeon utilized significantly deeper water depths than the larger juveniles and sub-adult fish.

Results of my study strongly suggest that sampling efforts for juvenile lake sturgeon in large rivers should focus on deep water habitats and failure to do so may lead to an underestimation of juvenile abundance. For example, data presented in Block (2001) from the same area as the present study only several years earlier, suggested that lake sturgeon less than 7 years of age were virtually absent from gill net catches. Block (2001) concluded that juvenile recruitment was limiting population growth in the area; however, given the abundance of juvenile lake sturgeon captured in my study, and their apparent preference for deep water habitat, it seems more likely that the juveniles were present, and that deep water habitats were not adequately surveyed.

The reason why juvenile lake sturgeon in the Winnipeg River prefer deep water habitats to shallow water habitats with similar velocities and/or substrate types remains unclear. In biological communities, resource availability and predation risk are two important determinants of habitat selection (Werner and Gilliam 1984). Secor et al. (2002) suggested that juvenile lake sturgeon may prefer deep water to find refuge from predators. However, evidence of a piscivorous fish species preying upon juvenile lake sturgeon has not been reported in the literature. Evidence from gut contents of predatory fish species from the Groundhog and Mattagami rivers in Northern Ontario (Noakes et al. 1999), and from the Winnipeg River (Barth, unpublished; see chapter 4), have failed to document any incidence of another fish species consuming a juvenile lake sturgeon. Further, invertebrate communities in shallow water environments tend to be higher in both diversity and quantity when compared to deeper water environments in the same water body (Chiasson et al. 1997; Holtgren and Auer 2004). Therefore, it is difficult to explain why juvenile lake sturgeon prefer deep water habitat. It is possible that juvenile lake sturgeon benefit from congregating in deep water through a number of factors such as increased foraging success; physiological benefits related to sociality (Allen et al. 2009); or increased survival due to group-size as observed with other gregarious animals (Alexander 1974; Pulliam and Caraco 1984; Hager and Helfman 1991).

Due to the relative availability of different habitat types in our study area, I could not fully determine how water velocity may affect the habitat preferences of juvenile lake sturgeon (i.e., habitats with low water velocity and deep water were not found). However, I found that juvenile lake sturgeon were abundant in areas with currents > 0.2 $m.s^{-1}$ in deep water areas, although a clear preference between medium and high water velocity was not found. Few studies have documented velocity preferences for juvenile lake sturgeon or other sturgeon species. Parsley et al. (1993) reported the presence of juvenile white sturgeon, *Acipenser transmontanus,* in water velocities ranging from 0.1 – 1.2 $m.s^{-1}$ and further, Parsley and Beckman (1994) suggested that 0.2 - 1.1 $m.s^{-1}$ were the most suitable water velocities for juveniles of this species. It is probable that the presence of a water velocity > 0.2 $m.s^{-1}$ is important for conveying drifting invertebrates. Kempinger

(1996) reported that young of the year lake sturgeon feed on drifting benthic organisms, and Nilo et al. (2006) did not find a relationship between diet and substrate preference of juvenile lake sturgeon in the St. Lawrence River, leading the authors to suggest a positive selection for drifting prey. Therefore, if drifting prey are important components of diet for juvenile lake sturgeon, then water velocity may have an important influence over habitat selection.

Juvenile lake sturgeon CPUE was statistically similar between small (HT-2) and large particle (HT-1) size substrate types in deep water. Other studies however, suggest that finer substrate types, such as sand and clay are preferred by juvenile lake sturgeon. For example, Hayes and Werner (2005) found that juvenile lake sturgeon in the St. Lawrence River were abundant in areas of low water velocity and silt/sand substrates. Sand substrate was preferred by juvenile lake sturgeon in a number of laboratory and field studies (Kempinger 1996; Chiasson et al. 1997; Peake 1999; Holtgren and Auer 2004; Benson et al. 2005; Smith and King 2005). Finer substrates are thought to provide optimal habitat for juvenile lake sturgeon as these substrates contain larger amounts of smaller-size benthic prey (Beamish et al. 1996; Kempinger 1996; Chiasson et al. 1997). Sand is also the preferred substrate for several other juvenile sturgeon species, including white sturgeon, (Parsley et al. 1993; Parsley and Beckman 1994), shortnose sturgeon, *Acipenser bevirostrum,* (Richmond and Kynard 1995) and Russian sturgeon, *Acipenser gueldenstaedii* (Levin 1988; Sbikin and Bibikov 1988). Further research involving fine-scale substrate mapping and telemetry tracking, along with intensive sampling efforts for prey availability and abundance, is required to better understand the relationship between diet and habitat preferences for juvenile lake sturgeon in large riverine environments.

The final objective of my study was to describe the composition of the fish community by habitat type and identify species that overlap spatially with juvenile lake sturgeon on a seasonal basis. Perhaps the most unique aspect of the Winnipeg River fish community was the abundance and density of the juvenile lake sturgeon relative to other fish species, especially in deep water habitats. CPUE values at several gill net sites were in excess of 25 juvenile lake sturgeon/22.9 m of net/24 hour period (maximum 55.5/22.9 m/24 hr) (Table 2.2), and to my knowledge, these represent the highest values reported for this species. The fact that lake sturgeon were so densely congregated in deep water habitats to the apparent, or near exclusion of other fish species (figures 2.6, 2.7 and 2.8) was an interesting finding that is discussed in the following chapter.

In summary, gill nets were found to be an effective method for capturing juvenile lake sturgeon in the habitats they occupied, with moderate mesh sizes adequately sampling a variety of fish sizes and having higher CPUE values than smaller mesh sizes. This study found that in a large river, juvenile lake sturgeon are likely to be found in deep water, with currents > 0.2 $m.s^{-1}$, over a variety of substrate types. In the Winnipeg River, juvenile lake sturgeon were densely aggregated within these areas, comprising the majority of the gill net catch. Additional research effort is required to describe the fish community structure in the areas where juvenile lake sturgeon have been found and this is the focus of the next chapter of this thesis. Finally, additional research is needed to identify diet and seasonal movement and home range size of juvenile lake sturgeon, which are the subject of subsequent chapters.

2.5 References

Alexander, R. D., 1974: The evolution of social behavior. Ann. Rev. Ecol. Syst. **5,** 325-338.

Allen, P. J.; Barth, C. C.; Peake S. J.; Abrahams M. V.; Anderson W. G., 2009: Cohesive social behavior shortens the stress response: the effects of conspecifics on the stress response in lake sturgeon *Acipenser fulvescens* Rafinesque. J. Fish Biol. **74**, 90-104.

Askey, P. J.; Post, J. R.; Parkinson, E. A.; Rivot, E.; Paul, A. J.; Biro, P. A., 2007: Estimation of gillnet efficiency and selectivity across multiple sampling units: A hierarchical Bayesian analysis using mark-recapture data. Fish. Res. **83**, 162-174.

Auer, N. A., 1996: Importance of habitat and migration to sturgeons, with emphasis on lake sturgeon. Can. J. Fish. Aquat. Sci. **53**, 152-160.

Beamish, F. W. J.; Jebbink, J. A.; Rossiter, A.; Noakes, D. L., 1996: Growth strategy of juvenile lake sturgeon (*Acipenser fulvescens*) in a northern river. Can. J. Fish. Aquat. Sci. **53,** 481-489.

Benson, A. C.; Sutton, T. M.; Elliot, R. F.; Meronek, T. G., 2005: Seasonal movement patterns and habitat preferences of age-0 lake sturgeon in the Lower Peshtigo River, Wisconsin. Trans. Am. Fish. Soc. **134**, 1400-1409.

Block, D., 2001: Growth estimates, habitat use, and ecology of the lake sturgeon, *Acipenser fulvescens* Rafinesque, from Round Lake and mature reservoirs in the Winnipeg River. M. Sc. Thesis, University of Manitoba, Winnipeg, MB.

Canadian Council of Ministers for the Environment (CCME)., 1999: Canadian Environmental Quality Guidelines. Canadian Council of Ministers for the Environment, Winnipeg, MB.

Chiasson, W. B.; Noakes, D. L. G.; Beamish, F. W. H., 1997: Habitat, benthic prey and distribution of juvenile lake sturgeon *Acipenser fulvescens* in northern Ontario rivers. Can. J. Fish. Aquat. Sci. **54,** 2866-2871.

Ferguson, M. M.; Duckworth, G. A., 1997: The status and distribution of lake sturgeon, *Acipenser fulvescens*, in the Canadian provinces of Manitoba, Ontario and Quebec: a genetic perspective. Environ. Biol. Fish. **48**, 299-309.

Gross, M. R.; Repka, J.; Robertson, C. T.; Secor, D. H.; Van Winkle, W., 2002: Sturgeon Conservation: Insights from Elasticity Analysis. Am. Fish. Soc. Symp. **28**, 13-30.

Hager M.C.; Helfman, G.S., 1991: Safety in numbers: shoal size choice by minnows under predatory threat. Behav. Ecol. Sociobiol. **29**, 271-276.

Hayes, J.; Werner, R., 2005: Contributing factors in habitat selection by lake sturgeon (*Acipenser fulvescens*). The Research Foundation of the State University of New York. Albany, NY, pp.19.

Holtgren, J. M.; Auer, N. A., 2004: Movement and habitat of juvenile lake sturgeon (*Acipenser fulvescens*) in the Sturgeon River/Portage Lake system, Michigan. J. Freshwat. Ecol. **19,** 419-432.

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

Hubert, W. A., 1996: Passive capture techniques. In: Fisheries techniques (eds B.R. Murphy and D. W. Willis), 2nd edition American Fisheries Society, Bethesda, Maryland, pp. 157 – 192.

Kempinger, J. J., 1996: Habitat, growth, and food of young lake sturgeons in the Lake Winnebago system, Wisconsin. N. Am. J. Fish. Manage. **16**, 102-114.

Levin, A. V., 1988: Characteristics of feeding behavior of juvenile Russian sturgeon, *Acipenser gueldenstaedti*, in relation to food availability. J. Ichthyol. **28,** 41-47.

Lord, K., 2007: Movements and habitat use of juvenile lake sturgeon in the North Channel of the St. Clair River. M. Sc. Thesis, University of Michigan, Ann Arbor, MI, USA.

Nilo, P.; Bolon, A.; Dodson, J.; Dumont, P.; Fortin, R., 2006: Feeding ecology of juvenile lake sturgeon in the St. Lawrence River system. Trans. Am. Fish. Soc. **135**, 1044-1055.

Noakes, D. L. G.; Beamish F. W. H.; Rossiter, A., 1999: Conservation implications of behaviour and growth of the lake sturgeon, *Acipenser fulvescens*, in northern Ontario. Environ. Biol. Fish. **54**, 135-144.

Parsley, M. J.; Beckman, L. G.; McCabe, G., 1993: White sturgeon spawning and rearing habitat in the lower Columbia River downstream of McNary Dam. Trans. Am. Fish. Soc. **122**, 217-228.

Parsley, M. J.; Beckman, L. G., 1994: White sturgeon spawning and rearing habitat in the Lower Columbia River. N. Am. J. Fish. Manage. **14**, 812-827.

Peake, S. J., 1999: Substrate preferences of juvenile hatchery-reared lake sturgeon, *Acipenser fulvescens*. Environ. Biol. Fish. **56**, 367-374.

Podani, J., 2001: SYNTAX 2000 computer programs for data analysis in ecology and systematics. USER'S MANUAL. Scientia Publishing, Budapest, Hungary. pp. 53.

Pulliam, H. R.; Caraco, T., 1984: Living in groups: Is there an optimal group size? In: Behavioural Ecology. Eds: J. R. Krebs and N. B. Davies, Blackwell, Oxford. pp. 122-142.

Richmond, A. M.; Kynard, B., 1995: Ontogenetic behavior of shortnose sturgeon *Acipenser brevirostrum*. Copeia **1995**, 172-182.

Ricker, W. E., 1975: Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. **191**.

Sbikin, Y. N.; Bibikov, N. I., 1988: The reaction of juvenile sturgeons to elements of bottom topography. J. Ichthyol. **28**, 155-160.

Scott, W. B.; Crossman, E. J., 1973: Freshwater Fishes of Canada. Fish. Res. Board Can. **184,** 966 pp.

Secor, D. H.; Anders, P. J.; Van Winkle, W.; Dixon, D. A., 2002: Can we study sturgeons to extinction? What we do and don't know about the conservation of North American Sturgeons. Am. Fish. Soc. Symp. **28**, 3-10.

Smith, K. M.; King, D., 2005: Movement and habitat use of yearling and juvenile lake sturgeon in Black Lake, Michigan. Trans. Am. Fish. Soc. **134,** 1159-1172.

Sokal, R. R.; Rholf, F. J. 1981: Biometry. W. H. Freeman and Company, New York.

St. George, S., 2006: Hydrological dynamics in the Winnipeg River basin, Manitoba. In: Report of activities 2006. Manitoba Geological Survey. pp. 226-230.

Thomas, M. V.; Haas, R. C., 2002: Abundance, age structure, and spatial distribution of lake sturgeon, *Acipenser fulvescens,* in the St. Clair system. J. Appl. Ichthyol. **18,** 495-501.

Thuemler, T. F., 1988: Movements of young lake sturgeons stocked in the Menominee River, Wisconsin. Am. Fish. Soc. Symp. **5,** 104-109.

Wentworth, C. K., 1929: Method of computing mechanical composition types in sediments. Geol. Soc. Am. Bull. **40**, 771-790.

Werner, E. E.; Gilliam, J. F., 1984: The ontogenetic niche and species interactions in size structured populations. Ann. Rev. Ecol. Syst. **15**, 393-425.

Williams, J. E.; Johnson, J. E.; Hendrickson, D. A.; Contreras-Balderas, S.; Williams, J. D.; Navarro-Mendoza, M.; McAllister, D. E.; Deacon, J. E., 1989: Fishes of North America Endangered, Threatened, or of special concern: 1989. Trans. Am. Fish. Soc. **14**, 2-20.

Table 2.1. Total number of fish captured during Spring, (June 12 – 27 July), Summer (August 15 – September 13) and Fall (September 28 – November 6) sampling periods in the Winnipeg River, Manitoba, 2006.

Fish species	*Genus species*	Spring	Summer	Fall	Total	% of total
Lake sturgeon (<530mm FL)	*Acipenser fulvescens*	631	1,044	479	2,154	74.9
Walleye	*Sander vitreus*	69	64	48	181	6.3
Sauger	*Sander canadense*	52	74	24	150	5.2
Lake sturgeon (≥530mm FL)	*Acipenser fulvescens*	76	12	23	111	3.9
White sucker	*Catostomus commersoni*	74	8	17	99	3.4
Shorthead redhorse	*Moxostoma macrolepidotum*	49	1	9	59	2.1
Yellow perch	*Perca fluviatilis*	11	11	4	26	0.9
Trout perch	*Percopsis omiscomaycus*	2	6	10	18	0.6
Mooneye	*Hiodon tergisus*	15	1	2	18	0.6
Burbot	*Lota lota*	5	8	3	16	0.6
Northern pike	*Esox lucius*	7	1	8	16	0.6
Rock bass	*Ambloplites rupestris*	5	2	2	9	0.3
Cisco	*Coregonus artedi*	0	1	4	5	0.2
Smallmouth bass	*Micropterus dolomieu*	4	0	1	5	0.2
Lake whitefish	*Coregonus clupeaformis*	2	0	1	3	0.1
Silver lamprey	*Ichthyomyzon castaneus*	1	1	0	2	< 0.1
Longnose sucker	*Catostomus catostomus*	1	0	0	1	< 0.1
Black crappie	*Pomoxis nigromaculatus*	1	0	0	1	< 0.1
Log perch	*Percina caprodes*	0	0	1	1	< 0.1
Total		1,005	1,234	636	2,875	100.0

Table 2.2. Mean juvenile lake sturgeon CPUE (# of juvenile lake sturgeon/ 22.9 m long gill net/ 24 hours) by mesh size, during three sampling periods in the Winnipeg River, Manitoba, 2006. Does not include sites where juvenile lake sturgeon were absent from the entire gill net gang. Letters denote significant, or lack of significant differences among mesh sizes.

Mesh size	Spring				Summer				Fall				Total	Total	%
(mm)	NS	n	Mean CPUE	m	NS	n	Mean CPUE	m	NS	n	Mean CPUE	m	n	m	m
25	17	31	1.8a	0	67*	534	11.6a	2	18	82	4.8a	0	647	2	0.3
38	--	--	--	--	9*	144	18.2a	2	--	--	--	--	144	2	1.4
51	17	50	2.8a	2	16*	366	24.4a	3	18	184	10.5ab	0	600	5	0.8
76	17	155	9.5b	3	--	--	--	--	18	213	12.4b	2	368	5	1.4
95	17	212	13.1b	9	--	--	--	--	--	--	--	--	212	9	4.2
108	17	183	11.8b	4	--	--	--	--	--	--	--	--	183	4	2.2
Total		631		18		1,044		7		479		2	2,154	27	1.3

*comparisons were only made between gill nets when all mesh sizes were fished in the same gill net gang.

NS = number of gill net sets; n = number of juvenile lake sturgeon captured; m = number of juvenile lake sturgeon mortalities.

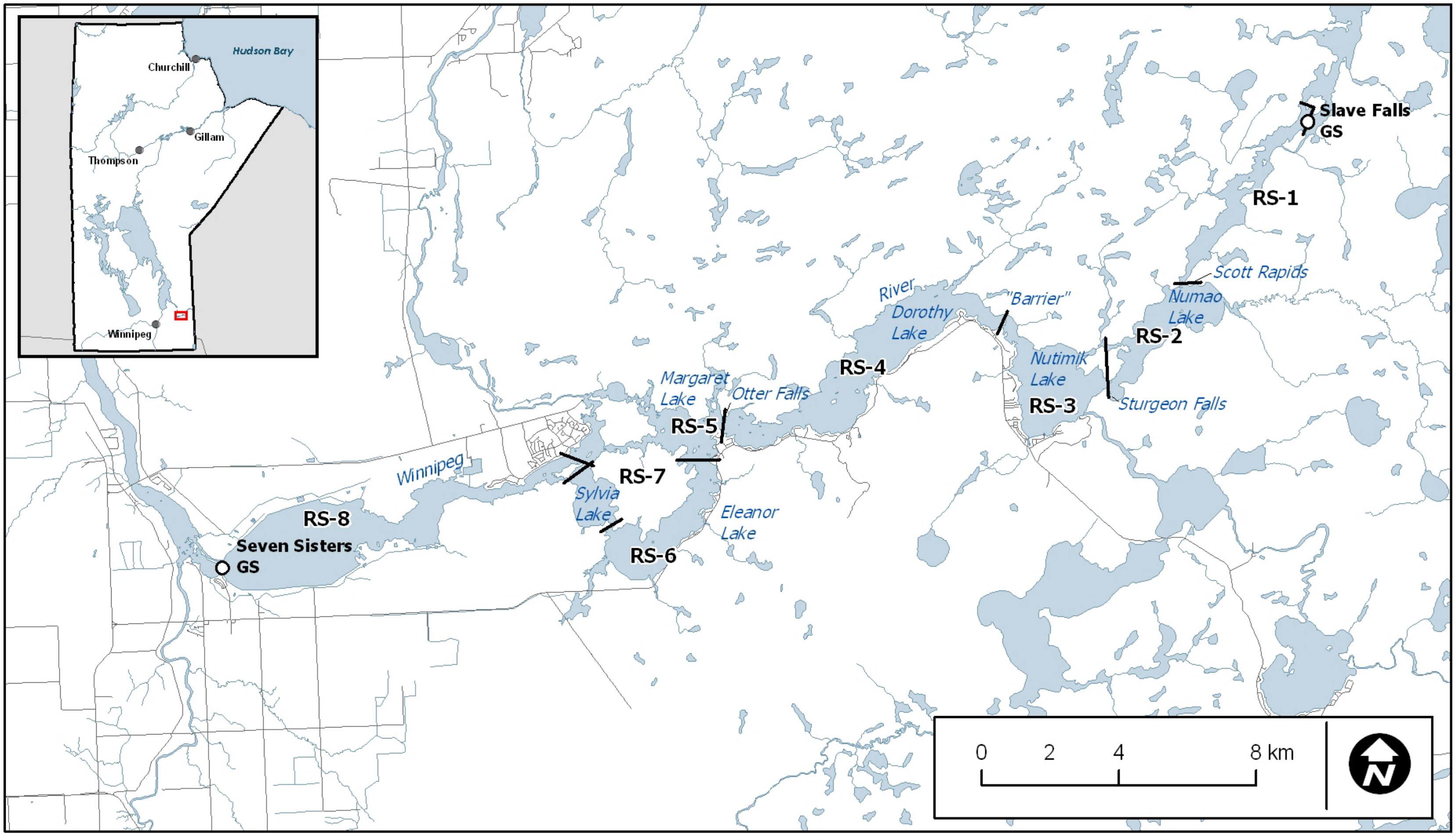

Figure 2.1. The Winnipeg River study area subdivided into eight sections. Section boundaries are based on topography.

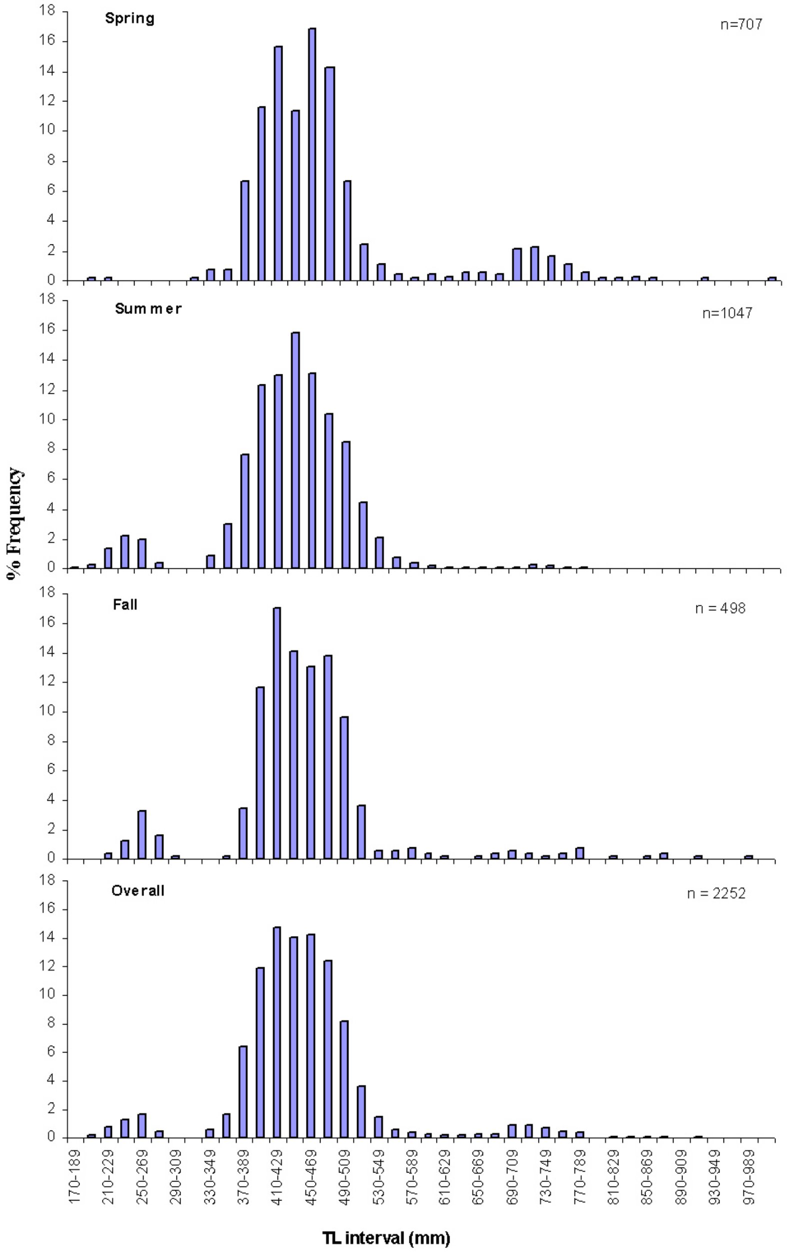

Figure 2.2. Total length (mm) frequency of capture histogram (20 mm intervals) for lake sturgeon captured during each of three sampling periods (spring, summer and fall) and all sampling periods combined in the Winnipeg River, Manitoba, 2006.

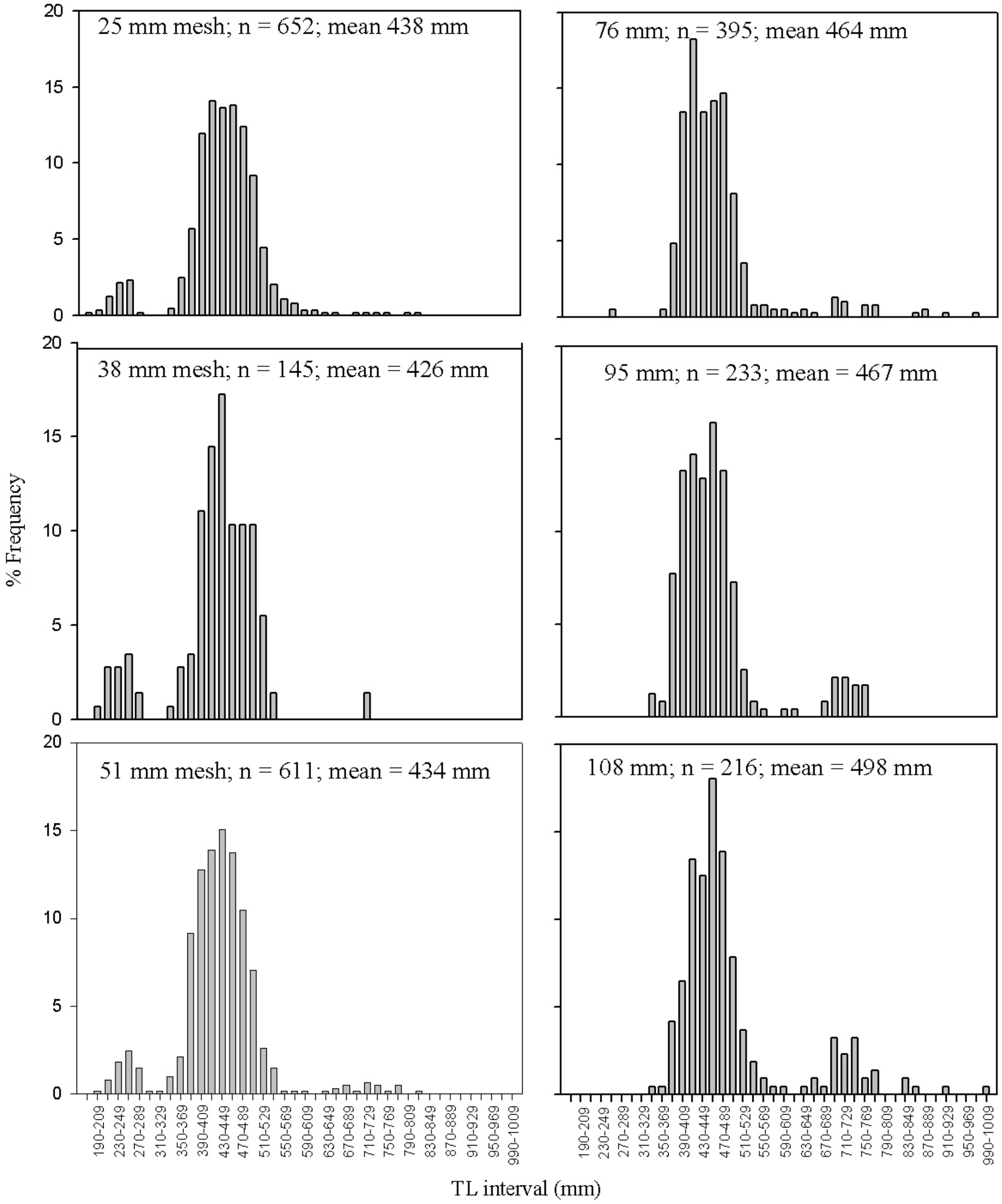

Figure 2.3. Total length (mm) frequency histograms (20 mm intervals) of juvenile lake sturgeon captured in gill nets comprised of 25 mm, 38 mm, 51 mm, 76 mm, 95 mm, and 108 mm mesh in the Winnipeg River, Manitoba, 2006.

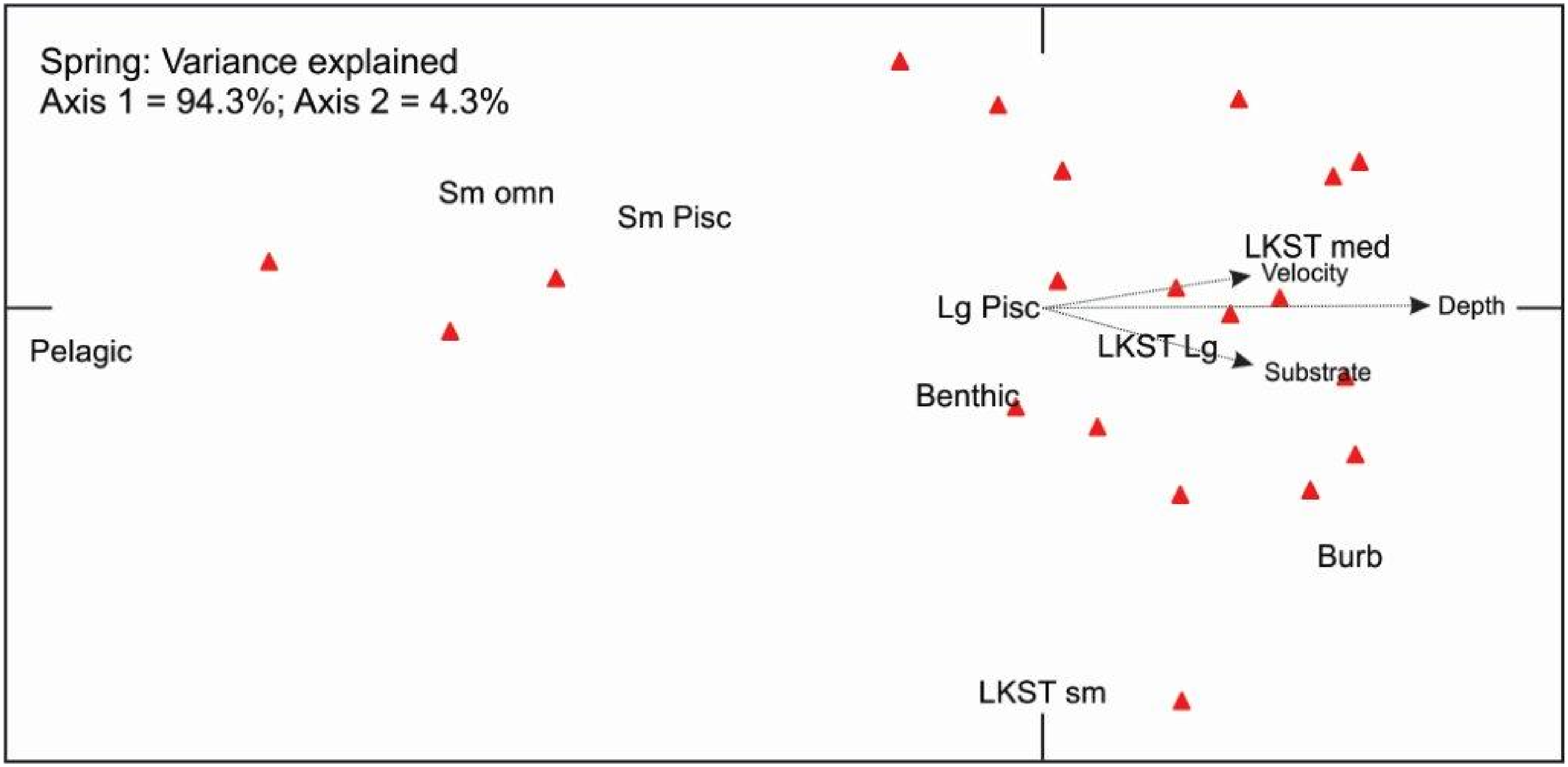

Figure 2.4a. Biplot for canonical correspondence analysis depicting ordination scores for spring gill netting sites (red triangles), functional groups (labelled) and environmental variable (Depth, velocity, substrate) vectors.

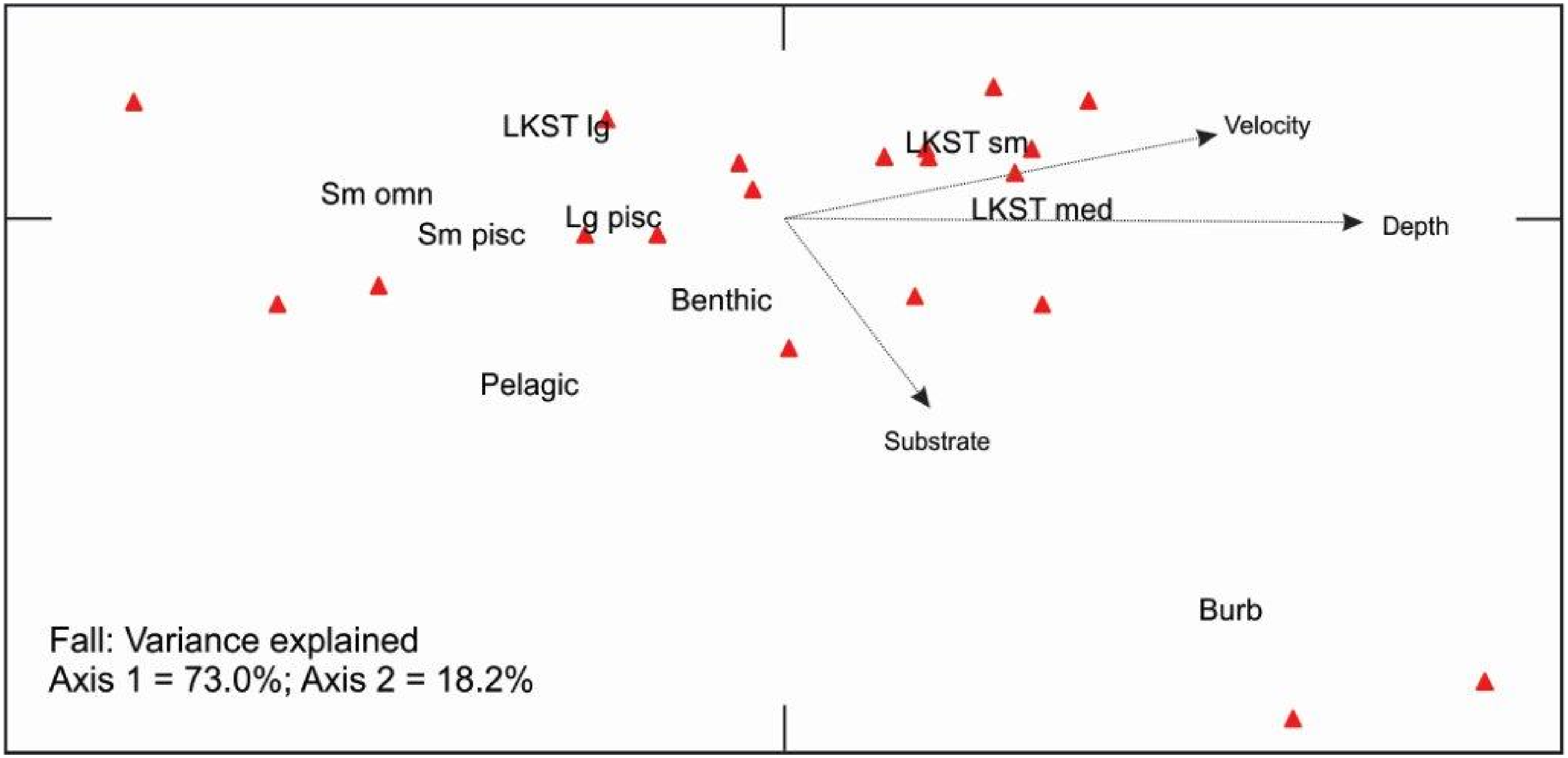

Figure 2.4b. Biplot for canonical correspondence analysis depicting ordination scores for fall gill netting sites (red triangles), functional groups (labelled) and environmental variable (Depth, velocity, substrate) vectors

.

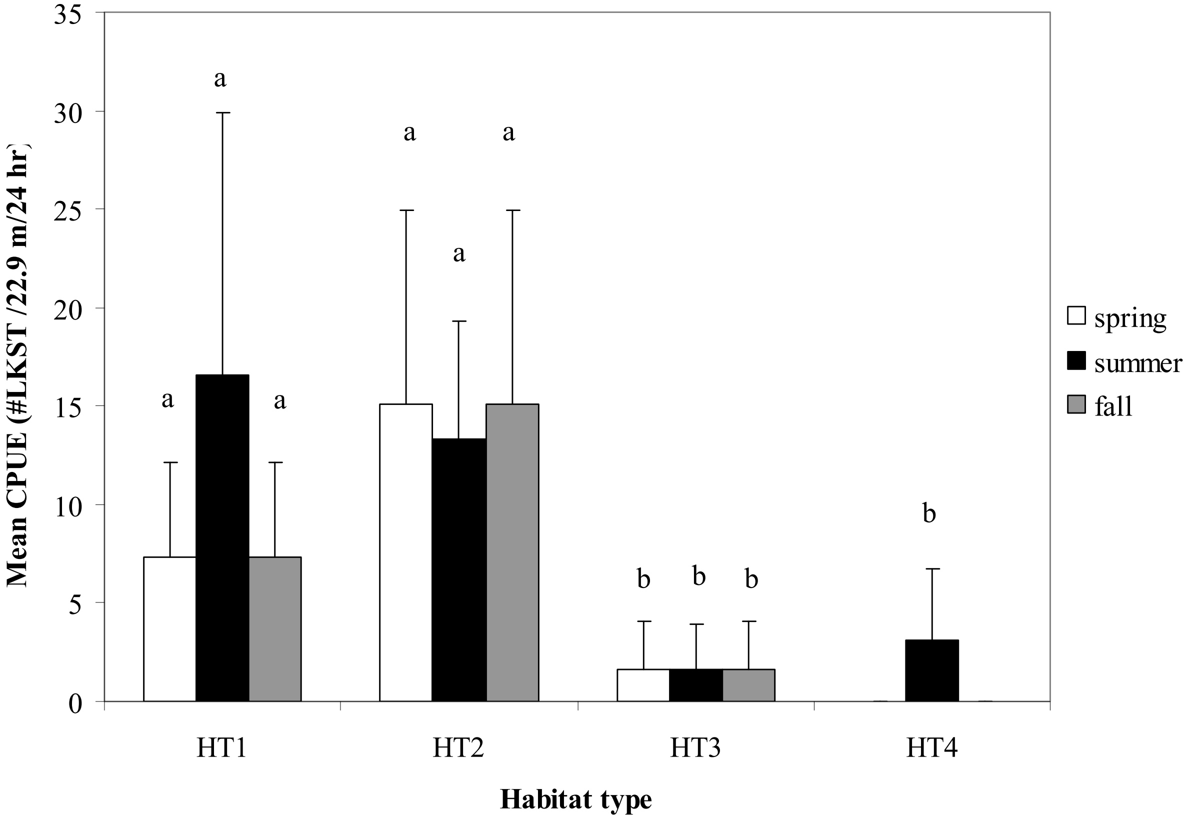

Figure 2.5. **CPUE (# juvenile lake sturgeon/22.9 m net/24 hr) values for juvenile lake sturgeon captured in four habitat types, during three sampling periods in the Winnipeg River, Manitoba, 2006. Values are expressed as a mean ± 1SD. Letters denote significant differences within seasons between habitat types. HT-1 = deep, high velocity, large particle substrate; HT-2 = deep, medium velocity, small particle substrate; HT-3 = shallow, medium velocity, small particle substrate; HT-4 = shallow, high velocity, large particle substrate.**

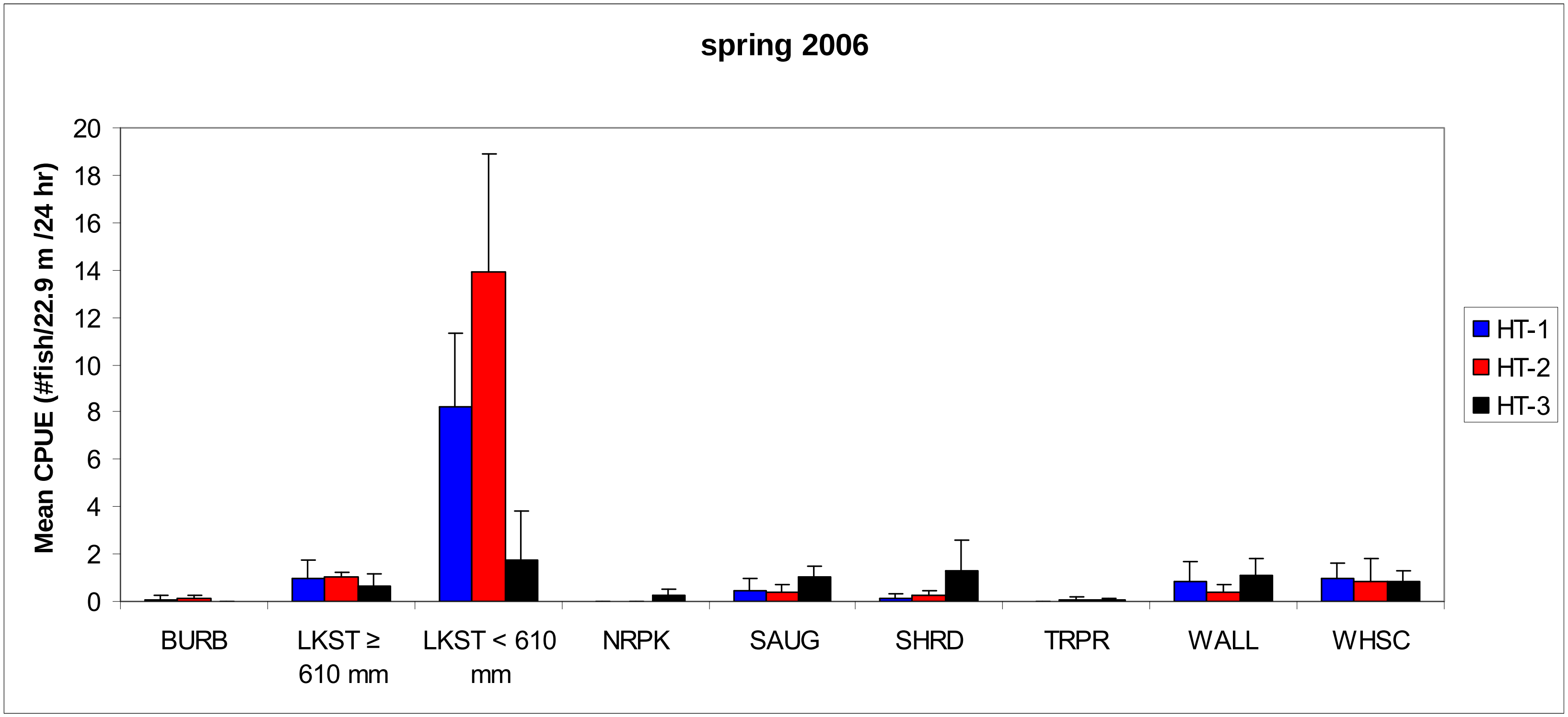

Figure 2.6. CPUE values for selected fish species captured in three habitat types in the Winnipeg River, spring, 2006. Values are expressed as a mean ± 1 SD. BURB = Burbot; LKST = Lake sturgeon; NRPK = Northern pike; SAUG = Sauger; SHRD = Shorthead redhorse; TRPR = Trout perch; WALL = Walleye; WHSC = White sucker.

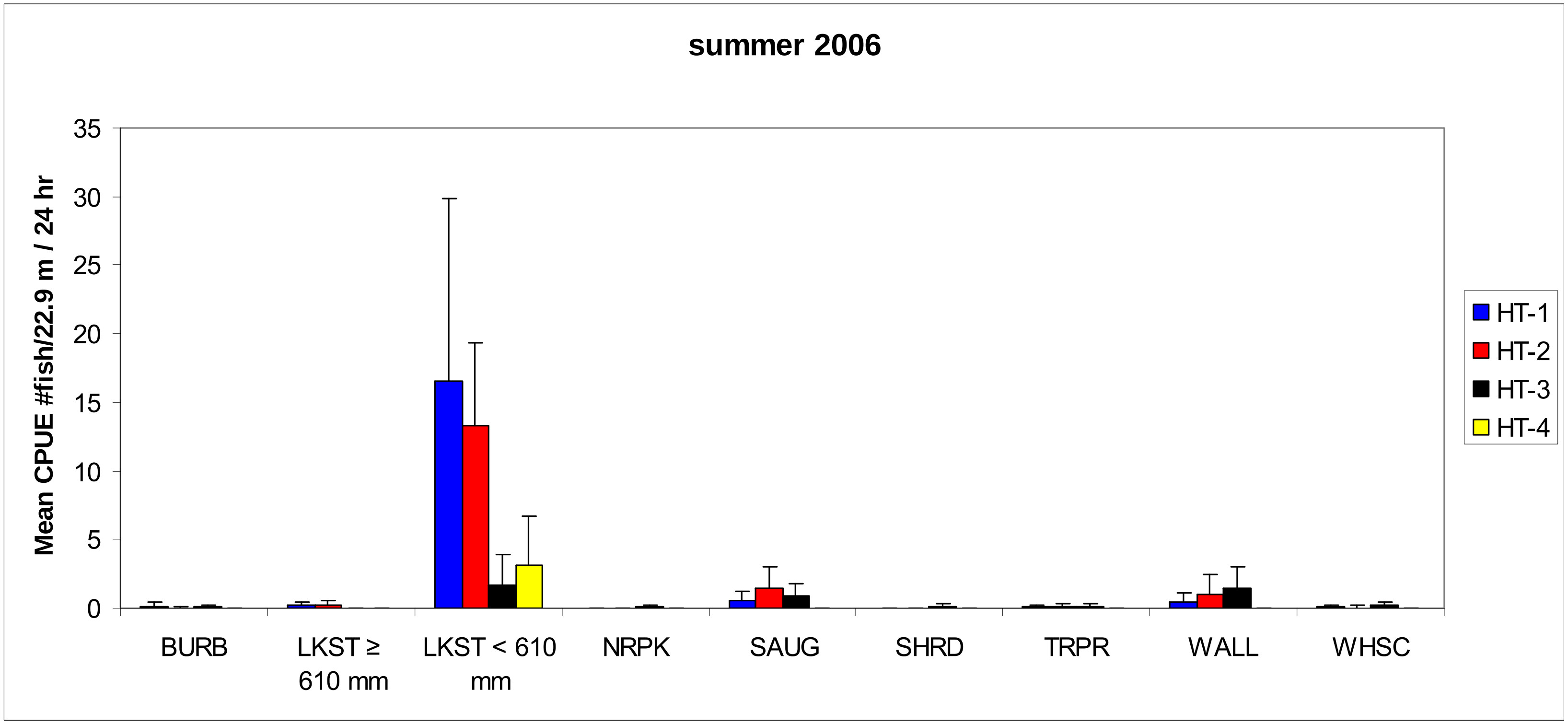

Figure 2.7. CPUE values for selected fish species captured in three habitat types in the Winnipeg River, summer, 2006. Values are expressed as a mean ± 1 SD. BURB = Burbot; LKST = Lake sturgeon; NRPK = Northern pike; SAUG = Sauger; SHRD = Shorthead redhorse; TRPR = Trout perch; WALL = Walleye; WHSC = White sucker.

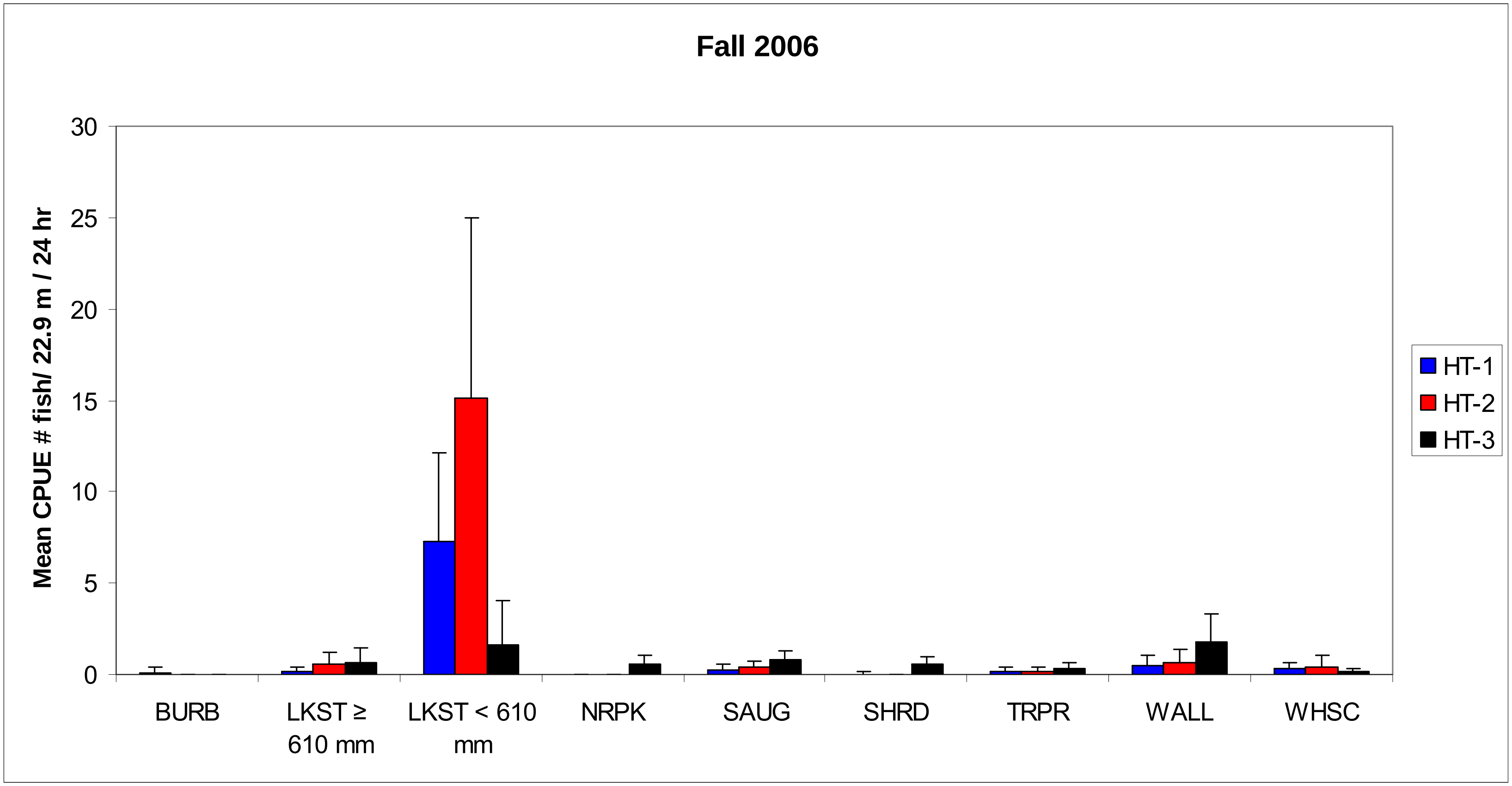

Figure 2.8. CPUE values for selected fish species captured in three habitat types in the Winnipeg River, fall, 2006. Values are expressed as a mean ± 1 SD. BURB = Burbot; LKST = Lake sturgeon; NRPK = Northern pike; SAUG = Sauger; SHRD = Shorthead redhorse; TRPR = Trout perch; WALL = Walleye; WHSC = White sucker.

Chapter 3: Fish community assemblages of the Winnipeg River: biotic interactions with juvenile lake sturgeon

3.0 Chapter Abstract

The purpose of this chapter was to describe the temporal variability of the fish community of the Winnipeg River and examine how biotic interactions may influence habitat selection by juvenile lake sturgeon. Gill nets, comprised of 25, 76, 125 and 203 mm stretched mesh, were used to sample the fish community at four sites (two shallow and two deep) along each of three transects in the Winnipeg River during May, June, July and October, 2007. Descriptive community indices, species rank abundance and principal components analysis suggested that fish community composition and species associations remained stable in both deep and shallow water habitat among sampling months. Deep water habitats were consistently dominated by juvenile lake sturgeon during each month, with the most abundant cohabitant being larger conspecifics. In contrast, shallow water habitat was characterized by relatively high species diversity and species evenness, as in general, several functional groups including benthic foragers, large piscivores, subadult/adult lake sturgeon and juvenile lake sturgeon were found in relatively similar abundances. Principal components analysis suggested that the habitat selection of juvenile lake sturgeon contrasted with that of large piscivorous species, benthic foraging species and small omnivorous species that favored shallow water environments, and was more closely associated with larger conspecifics, burbot and smaller conspecifics, depending on sampling month.

3.1 Introduction

Fish communities in unperturbed aquatic ecosystems have been shaped over evolutionary time by a combination of abiotic features of habitat and biotic mechanisms such as predation and competition. Considerable debate exists among ecologists regarding the relative importance of each in influencing community structure (Connell 1980; Grossman 1982; Ross 1986; Evans et al. 1987; Gelwick and Matthews 1990; Wellborn et al. 1996; Jackson et al. 2001). Developing an understanding of how abiotic environmental characteristics and biotic processes interact to influence fish community dynamics remains a challenge. First, habitat selection, and inter- and intra-specific interactions, may vary in time and space, and among life history stages (Ross 1986; Gelwick and Matthews 1990; Jackson et al. 2001). This necessitates the collection of a large number of samples, from several fish species and life history stages, spread over time and space. Second, quantifying biotic interactions such as predation and competition is complicated by difficulties with determinations of diet due to rapid digestion of some prey types and with difficulties sampling stomach contents in general. For example, sampling stomach contents of fish collected from deep water environments is problematic due to regurgitation and expulsion of contents prior to retrieval (Cortes et al. 1997). Third, it may be difficult to sample all habitats within an ecosystem with the same efficiency, and thus the comparability of data among habitat types may be compromised (Mahon 1980; Grossman et al. 1982; Pegg and Pierce 2002). These difficulties are compounded when considering populations of rare or endangered species because many aspects of their ecology including when, where and why species interact, and the food resources they utilize may be poorly understood (Manly et al. 2002).

Knowledge of seasonal overlap in habitat and resource use among species of fish is essential for examining the degree to which habitat use is influenced by predation and competition (Keast 1977). Community ecologists are often concerned with the degree to which species assemblages, and the nature and importance of biotic interactions, change through time. Grossman (1982) described stochastic and deterministic assemblages, the former being species assemblages in which the rank abundance of species change over time, and the latter describing assemblages in which rank abundances remain constant. Many studies have examined inter-annual stability in fish community structure by examining the within season persistence of communities (Moyle and Vondracek 1985; Matthews et al. 1988; Schlosser and Ebel 1989; Keast and Fox 1990; Gido et al. 2000). Other studies have examined how fish community assemblages vary among seasons (Keast et al. 1978; Tremain and Adams 1995; Hatzenbeler et al. 2000; Wolter and Bischoff 2001).

There is an almost complete lack of understanding pertaining to how biotic processes may have influenced the evolution of habitat preferences at each stage of the lake sturgeon's life cycle. There is a paucity of information on how fish communities were structured prior to both large scale commercial fisheries and hydroelectric development that has altered physical habitat and biotic communities throughout the species' range. Without historical data on species composition and abundance, it is difficult to ascertain how competition and predation may have shaped the evolution of juvenile lake sturgeon habitat use (i.e., past episodes of predation or competition) (Connell 1980). Furthermore, because biotic processes are difficult to study in a field setting, determining the degree to which biotic communities presently influence abundance, mortality, recruitment and habitat use remains a difficult task. As such, very few studies have examined biotic interactions between juvenile lake sturgeon and coexisting fish species. Sandilands (1987) and Beamish et al. (1998) examined habitat utilization and diet overlap in two distinct populations of lake sturgeon occupying small rivers in Ontario, however, both of these studies lacked a temporal aspect. Similarly, very little is known about the influence of predation on young lake sturgeon.

Results of the previous chapter suggested that two distinct fish communities exist in the Winnipeg River, with depth being the primary factor distinguishing them. However, the data set was based mainly on captures from small mesh gill nets ≤ 76 mm (thus larger fish may not have been adequately sampled), and gill net sites and mesh sizes were changed among seasons (thus data sets could not be compared among seasons to examine temporal variability in fish communities). In this thesis chapter, the first objective is to examine temporal variation in the fish community assemblages of the Winnipeg River using consistent sampling locations and methodologies. The second objective is to identify the most prevalent fish species or groups that coexist with juvenile lake sturgeon on a seasonal basis. Finally, the nature and importance of intra and interspecific interactions, and how these interactions may have influenced, or are currently influencing, habitat selection in juvenile lake sturgeon is discussed.

3.2 Materials and Methods

3.2.1 Study Area

The study area consisted of a 41 km long section of the Winnipeg River delineated by the Slave Falls GS at the upstream end, and the Seven Sisters Falls GS at the downstream end (Figure 2.1). The data presented in this chapter were collected from the upstream sections (RS-1, RS-2, RS-3).

3.2.2 Species associations and temporal variability in fish community assemblages

3.2.2.1 Site and sampling period selection

Similar to other studies that have examined temporal variability in fish community assemblages, several sites were selected and repeatedly sampled over several periods using a consistent methodology and similar amounts of sampling effort. Sampling sites were selected along each of three transects of the Winnipeg River and were located approximately 2.5 km, 7.0 km and 12.0 km downstream of the Slave Falls GS. Each transect consisted of four sites: transect 1: sites 1 - 4; transect 2: sites 5 - 8 and transect 3: sites 9 - 12) (Figure 3.1). The criteria for selecting these three transects, and the four sites along each transect, were two fold: 1) the presence of deep (> 13.7 m) and shallow water sites (< 13.7 m) in close proximity, such that each transect consisted of two shallow water sites and two deep water sites; and 2) to provide spatial coverage of the Winnipeg River by sampling in three river sections (RS-1, RS-2 and RS-3). A habitat description for each of the 12 gill net sites is provided in Appendix 3.1. Sampling periods were selected based on changes in water temperature (Appendix 3.2).

3.2.2.2 Fish capture and sampling

The gill net gangs used to sample the fish community were 91.6 m long, and were comprised of four 22.9 m long, 1.8 m deep panels of 25, 76, 127 and 203 mm stretched mesh. On each sampling day, four gill net gangs were set in the evening at each of the four sites along one of the transects. The following morning, nets were pulled and reset along a different transect that evening. Mesh sizes were fished in rotation such that each site received comparable amounts of effort with each mesh size. Therefore, during one sampling period, each of the 12 gill netting sites were fished with four 91.6 m long nets each comprised of the four panels of mesh. Sampling procedures for all fish captured, and a description of the methods and sampling gear used to measure water depth, water velocity, and substrate type were similar to those outlined in sections 2.2.2 and 2.2.3.

3.2.2.3 Species associations – CPUE calculation

Similar to the previous chapter, fish species were classified into one of nine functional groups (i.e., fish species that exploit similar resources in a similar fashion), based on known food and habitat preferences (Carlander 1969; Scott and Crossman 1973). Functional groups included:

1. Burbot (BURB)
2. Sub-adult and adult lake sturgeon measuring ≥ 610 mm TL (lg LKST)
3. Juvenile lake sturgeon measuring between 300 mm TL and 609 mm TL (LKST 300 – 609)
4. Lake sturgeon measuring ≤ 300 mm TL (sm LKST)
5. Benthic foragers (Benthic): (i.e., white sucker, *Catostomus commersoni*, shorthead redhorse, *Moxostoma macrolepidotum*, and lake whitefish, *Coregonus clupeformis*

6. Pelagic foragers (Pelagic) – mooneye, *Hiodon tergisus* and cisco, *Coregonus artedi*

7. Large piscivores (Lg Pisc): walleye, *Sander vitreus*, sauger, *Sander canadensis*, and northern pike, *Esox lucius,* measuring ≥ 250 mm FL

8. Small omnivores (Sm omn): smallmouth bass, *Micropterus dolomieu*, rock bass, *Ambloplites rupestris*, yellow perch, *Perca flavescens*, trout perch *Percopsis omiscomaycus*, and log perch *Percina caprodes*

9. Small piscivores (Sm Pisc) – walleye and sauger measuring < 250 mm FL

CPUE values were calculated for each of the functional groups in shallow and deep water habitat types. CPUE was expressed as:

fish /91.6 m of net/24 hr

where: #fish = the number of fish in a functional group captured per 91.6 m long gill net (comprised of four equal length panels of 25 mm, 76 mm, 127 mm and 203 mm stretched mesh) per 24 hour time period.

3.2.3 Community indices

Community indices of diversity, evenness and dominance are valuable indicators of pattern in community ecology. To identify temporal and spatial pattern in the fish community assemblages of the Winnipeg River mean values for each index were calculated for both shallow and deep water habitat types during each of the four sampling periods. Diversity indices included:

1) the Shannon-Weaver diversity index (H′) (Shannon and Weaver 1948)

$$H' = \sum p_i \ln p_i$$

where p_i = the relative abundance of each species (n_i/N); n_i = the abundance of species i; and N = total number of all individuals.

2) Pielou's Evenness index (J) (Pielou 1966)

$$J = H'/H_{max}$$

where H_{max} is the value of the Shannon-Weaver index when all of the represented species have equal abundances; and H′ is the Shannon-Weaver index function.

3) Dominance (D) was calculated using the percent contribution of the two most numerically dominant species (McNaughton 1968)

$$D = (\%sp1 + \%\ sp2)/100$$

Where: sp1 = most numerically dominant fish species

sp2 = the second most numerically dominant fish species

Calculations were performed using R version 2.8.1, and XLSTAT (Version 2006.2) in Excel (Microsoft Corporation, Redmond, California).

3.2.3.1 Principal components analysis

Associations among functional groups were evaluated using Principal Components Analysis (PCA) because this statistical technique is commonly used to identify patterns of habitat use among species where abundance data has been collected from a variety of sampling locations (Sokal and Rholf 1981; Legendre and Legendre

1998; Quinn and Keough 2002). In this case, PCA was used to determine if species associations remained similar among sampling periods.

Species abundance data from each of the 12 gill netting sites were analyzed using a correlation matrix with a separate analysis for each season. Each analysis was conducted using the raw data since transformation did not significantly improve normality, equality of variance, or relationships between the species. Because inclusion of rare species may blur potential relationships (Gelwick and Matthews 1990), only functional groups with an overall abundance ≥ 1.0% of the overall catch during a particular season were included. This analysis was carried out using XLSTAT (Version 2006.2) in Excel (Microsoft Corporation, Redmond, California).

3.2.3.2 Rank correlation analysis

Rank correlation analysis has been used in many studies to determine the constancy of fish species assemblages between years or seasons (Ross et al. 1985; Gelwick and Matthews 1990). Friedman's rank correlation test with Bonferonni correction for multiple comparisons was used to detect patterns among species ranks at each of the 12 gill netting sites across the four sampling periods. The analysis was carried out using XLSTAT (Version 2006.2) in excel (Microsoft Corporation, Redmond, California).

3.3 Results

Across all sites and sampling periods, 2,780 fish, comprising 17 fish species, including two groups of lake sturgeon, were captured from the 12 sites in 2007 (Table

3.1). Lake sturgeon measuring < 610 mm TL (n = 1,321) comprised 47.5% of the overall catch, while lake sturgeon measuring ≥ 610 mm TL (n = 495) comprised 17.8%. Trout perch (n = 298), walleye (n = 177) and white sucker (n = 151) were the next most abundant species comprising 10.7%, 6.4% and 5.7% of the total catch, respectively. Only 9 of the 17 fish species captured comprised > 1.0% of the total catch (Table 3.1).

Similar to results presented in Chapter 2, differences were observed in fish community composition between deep and shallow water habitat. In deep water, juvenile lake sturgeon 300 - 609 mm TL were the most abundant group comprising between 64.8% and 76.3% of the overall monthly catch (Figure 3.2a) and mean CPUE values were two to four fold greater than sub-adult and adult lake sturgeon (i.e., those measuring > 610 mm TL), the next most abundant functional group (Figure 3.2b). The remaining groups generally comprised < 6.0% of the monthly catch in deep water habitat (Figure 3.2a) and CPUE values were < 2.0 fish/91.6 m net/24 hr, the only exception being the small omnivore group in May (CPUE = 4.5 fish/91.6 m net/24 hr) (Figure 3.2b). In shallow water habitat, the most abundant functional group varied among months. During May, the small omnivore group was the most abundant, comprising 32.7% of the catch (CPUE = 12.5 fish/91.6 m net/24 hr). Sub-adult and adult lake sturgeon ≥ 610 mm TL were the most abundant group captured in June (CPUE = 11.0 fish/91.6 m net/24 hr); RA = 25.1%) and October (CPUE = 4.6 fish/91.6 m net/24 hr; RA = 23.3%), while juvenile lake sturgeon 300 – 609 mm TL were the most abundant group captured in July (CPUE = 10.0 fish/91.6m net/24 hr; RA = 28%)) (figures 3.2a and 3.2b).

Descriptive indices showed a distinct pattern in fish community structure with respect to species diversity, evenness and dominance in both shallow and deep water habitats. In addition, these indices exhibited little variation among months suggesting temporal constancy in the fish community assemblage of the Winnipeg River. Monthly mean Shannon Weaver diversity index values were lower in deep water habitat (monthly mean H value range: 0.93 to 1.08), relative to shallow water habitats (monthly mean H value range: 1.73 to 1.98), (Figure 3.3a). Pielou's evenness index (J) was also lower in deep water habitat (monthly mean J value range: 0.52 to 0.63) relative to shallow water habitat (monthly mean J value range: 0.77 to 0.87) during each month (Figure 3.3b). Dominance index values were higher in deep water habitat (mean D index value range: 0.82 to 0.87), relative to shallow water habitat (mean D index value range: 0.47 – 0.61). Similar to the other indices, dominance index values in each habitat type were similar among months (Figure 3.3c).

Friedman's rank correlation test was used to determine if the rank abundance of functional groups differed significantly among months at each of the 12 sites sampled over the four months. Significant differences in species ranks were observed at only one of the shallow sites (site 2) (Friedman's rank correlation analysis, $P = 0.02$). Non-significant results were found for the remaining 11 sites ($P > 0.05$), further suggesting temporal stability in the fish community composition of the Winnipeg River among sampling months.

Results of principal components analysis also indicated differences between deep and shallow water fish communities and similarities in species associations among months. The first two principal components explained 47.5%, 46.4%, 47.8% and 30.7% of the variation in the data during May, June, July and October, respectively (Figure 3.4). During each month, juvenile lake sturgeon loaded negatively on principal component 1, which consistently contrasted small and large piscivorous fish species, benthic foraging species, and the small omnivore group which loaded positively on principal component 1. During May and June, juvenile lake sturgeon were closely associated with smaller conspecifics, and more closely with larger conspecifics relative to most other groups during each sampling month. Although CPUE values were low for burbot, this species was also rarely captured in shallow water habitats and as such was associated more closely with juvenile lake sturgeon when abundant enough to be included in the analysis.

3.4 Discussion

Although it is generally accepted that abiotic and biotic factors combine to structure fish communities (Bain et al. 1988; Angermeir and Winston 1998), the majority of studies on habitat selection in juvenile lake sturgeon have focused primarily on abiotic factors (chapter 2). The study area on the Winnipeg River provides an excellent opportunity to study species interactions and biotic processes that may influence habitat selection in juvenile lake sturgeon considering their abundance, their dense aggregations, and their preference for deep water habitat. Because there are few published accounts of fish species composition from deep water or main channel environments of large rivers in North America (Dettmers et al. 2001), and few from locations where lake sturgeon are abundant, the data presented in this chapter provide a valuable baseline from which to improve our understanding of how biotic interactions may have, or are currently influencing habitat selection in juvenile lake sturgeon.

3.4.1 Temporal variation in fish community structure

The first objective of this thesis chapter was to determine if fish community composition, and thus potential interspecific interactions, varied on a seasonal basis. I observed consistent patterns in relative abundance, species composition (rank abundance), descriptive index values of diversity, evenness and dominance and similar group associations (principal components analysis) in both deep and shallow water habitats among sampling months. These results strongly suggest that fish communities in both shallow and deep water habitat remained constant across sampling periods. For example, juvenile lake sturgeon were persistent residents of deep water habitat regardless of season. By contrast, other species groups exhibited only transient use of deep water habitat. Similar results were reported in the Mississippi River, USA, where shovelnose sturgeon, *Scaphyrhynchus platorhynchus,* were found to be year round residents of main channel habitat, and coexisting species groups were more commonly associated with littoral zone and backwater habitats (Dettmers et al. 2001).

Seasonal habitat shifts, are commonly observed in lake, stream and river dwelling fish species (Keast et al. 1978; Cunjak 1996). Fish often change habitats and undertake seasonal migrations to find suitable areas for reproduction, foraging, overwintering and refuge from predators (Werner and Gillam 1984; Schlosser 1995). For example, arctic charr, *Salvelinus arcticus,* (Naslund 1990) and grayling, *Thymallus arcticus,* (Craig and Poulin 1975) make seasonal migrations between foraging habitat in small tributaries and overwintering habitat in large rivers. Fish species common to large rivers in the Canadian Shield such as white sucker, walleye and northern pike generally move from shallow near shore areas < 3 m during the open-water season, to deeper waters during late fall and winter at the juvenile life history stage (Rawson 1957; Scott and Crossman 1973; Carlander et al. 1978; Wahl 1995). Results from the Winnipeg River suggest that juvenile lake sturgeon maintain their preference for deep water regardless of season. Considering that lake sturgeon are late to mature, these habitat preferences may persist for several years to a decade, however, further study is necessary to determine when juveniles in this population may utilize alternative habitats.

Qualitative comparisons of fish community data collected during 2006 and 2007 in the Winnipeg River suggests similarities in species composition within both deep and shallow water habitat types among seasons within each year, and within seasons between years (figures 2.7, 2.8 and 2.9, figures 3.2a and 3.2b). Several authors have observed a positive correlation between fish community variability and environmental variability (Matthews and Hill 1980; and Matthews et al. 1988; Hatzenbeler et al. 2000; Oberdorff et al. 2001). For example, rapid fluctuations in water level and flow have been linked to changes in fish community structure and species composition (Grossman et al. 1982; Schlosser 1982; Oberdorff et al. 2001). Run-of-the-river operations, such as the study area on the Winnipeg River, typically do not result in abrupt changes to water levels and flows. As such, deep water habitats of the Winnipeg River can be considered relatively constant environments as they likely experience only gradual changes to abiotic conditions. This may contribute to the constancy in the fish community of the Winnipeg River.

3.4.2 Species Associations and Biotic Interactions

The second and third objectives of this study were to examine species associations and potential biotic interactions among juvenile lake sturgeon and coexisting species, including conspecifics. One of the most interesting findings arising from gill netting studies in the Winnipeg River was the high CPUE's of juvenile lake sturgeon in deep water habitat relative to the comparably low CPUE's of other species groups during each season. Broadly, these results suggest that juvenile lake sturgeon may minimize interspecific competition and predation by being persistent residents of deep water habitat. However, their strict use of deep water may increase intra-specific competition for food. Aspects of intra-specific competition in this study area are discussed further in chapters 4 and 6 of this thesis.

It is also possible (and speculative) that the high densities and dominance of juvenile lake sturgeon in deep water habitat also limits the utilization of these habitats by other fish species through either a direct reduction in foraging opportunities for fish species whose diet may overlap with juvenile lake sturgeon, or an indirect reduction in foraging opportunities for piscivorous fish species such as sauger, northern pike and walleye that may prefer to forage on softer bodied fish species (Reist 1980).

3.4.3 Larger conspecifics

The most abundant cohabitant with juvenile lake sturgeon in deep water habitats during each season was larger conspecifics (Figure 3.2b). In other riverine systems, competition between younger and older lake sturgeon is thought to be minimized by an ontogenetic shift in diet from soft bodied invertebrates to mollusks and crayfish at sizes ranging between 600 and 800 mm TL (see chapter 4). Smith and King (2005) suggested that juvenile lake sturgeon may occupy different habitats to avoid competition with adult lake sturgeon. In this study, CPUE's of lake sturgeon > 610 mm were similar between deep and shallow water habitats, however, the largest mesh size used during this study was 203 mm and therefore, a large proportion of the adult population may not have been susceptible to capture. Further study is needed to examine diet in adult lake sturgeon and determine the size at which ontogenetic changes occur.

Evidence that subadult or adult lake sturgeon forage upon younger, smaller conspecifics has not been reported in the wild and fish have been found to comprise a relatively small proportion of adult lake sturgeon diet (Magnin and Harper 1970; Sandilands 1987). Hence, it is unlikely that subadult or adult lake sturgeon consume large numbers of juvenile lake sturgeon. Predation on larval or YOY lake sturgeon by larger lake sturgeon may occur, but the importance of this interaction is unknown. Cannibalism of eggs by adult lake sturgeon has been noted in the Lake Winnebago system (Bruch and Binkowski 2002) and from the Winnipeg River (see chapter 4).

3.4.4 Benthic foragers

Sandilands (1987) found minimal dietary overlap between lake sturgeon and four other species of benthic feeding fish including lake whitefish, longnose sucker, white sucker and shorthead redhorse in the Kenogami River, Ontario. In this study, shorthead redhorse were found to exhibit the highest degree of dietary overlap with lake sturgeon. In contrast, Beamish et al. (1998) found significant dietary overlap between lake sturgeon, lake whitefish and burbot in the Groundhog and Mattagami rivers, Ontario. In the Winnipeg River, however, abundances of benthic feeding species was higher in shallow water habitats relative to deep water habitats. These data suggest that competition for food may have shaped the niche of both juvenile lake sturgeon and benthic foraging fish species. Juvenile lake sturgeon appear to be more suited to foraging in low light areas with high current, whereas, benthic teleosts may be better adapted to littoral zone environments where superior burst swimming speeds may help in the avoidance of predators.

3.4.5 Large Piscivorous fish species

Piscivory has been suggested as a primary mechanism of influencing fish community assemblages in aquatic ecosystems (Jackson et al. 2001). However, the influence of predation on the early life history stages of lake sturgeon is poorly understood (Barth, unpublished data; Noakes et al. 1999). Several anecdotal reports of predation on YOY sturgeon have been reported. For example, in the Winnipeg River system, two young (presumably YOY) lake sturgeon were found in the gut contents of a burbot during winter 2010 (Ken Kansas, pers comm). Walleye in the Abitibi River, Ontario, were also reported to consume YOY lake sturgeon (EAG 1980, C. Hendry pers comm; as cited in Seyler 1997). In a laboratory setting, channel catfish, *Ictalurus punctatus*, and northern pike minnow, *Phytocheilus oregonensis,* were found to consume white sturgeon, *Acipenser transmontanus,* up to 134 mm TL, whereas larger walleye were found to rarely consume YOY white sturgeon (Gadomski and Parsley 2005a). Gadomski and Parsley (2005b) suggested that predation is a likely cause of mortality in age-0 white sturgeon and that predation rate likely decreases as size increases. In the Winnipeg River, juvenile lake sturgeon larger than 300 mm TL do not appear to be vulnerable to high rates of predation due to their avoidance of shallow water habitat, which minimizes encounters with large piscivorous fish species, and because they possess morphological adaptations (i.e., sharp scutes) that may deter most predators. It is interesting to note, however, that given the present composition of the fish communities in the study area, once juvenile lake sturgeon have attained a size of approximately 300 mm TL, they would be susceptible to predation from only very large walleye and northern pike. Further study is necessary to determine the susceptibility of young lake sturgeon to predation, and the importance that predation may play in influencing mortality.

3.4.6 Burbot

Burbot captured in deep water habitats of the Winnipeg River were found to consume trout perch, crayfish, and ephemeroptera (Barth, unpublished). As previously discussed, YOY lake sturgeon have also been found in the gut contents of burbot from the Winnipeg River. Therefore, burbot may act as both a competitor with, and predator of, YOY or juvenile lake sturgeon. In this study area, burbot comprised a very small proportion of the total catch, and therefore, may not exert significant predation pressure on or influence over habitat selection by juvenile lake sturgeon.

3.4.7 Summary

This work contributes to the understanding of fish community assemblages and species interactions with juvenile lake sturgeon in large impounded river systems. Results suggest that juvenile lake sturgeon may minimize interspecific interactions by occupying deep water, main channel environments where other species groups are less abundant during each season. It is possible that due to several morphological adaptations, juvenile lake sturgeon may be at a competitive advantage to other species in these deep water habitats with high current. Conversely, due to a poor swimming capability relative to other species (Peake 2004), juvenile lake sturgeon may be at a disadvantage when acquiring food and avoiding predation in shallow water habitat. Given the composition of the present day fish community, the habitat use of juvenile lake sturgeon and their apparent susceptibility, or lack thereof, to predation, it seems reasonable to suggest that juvenile lake sturgeon may not utilize shallow water habitats due to either past episodes of predation, past episodes of competition (i.e., with adults or other species) and/or the productivity/foraging opportunities offered by deep water habitat. Presently, little is known about the food availability of deep water habitats, or the food items consumed by juvenile lake sturgeon in deep water habitats on a seasonal basis. This is the subject of the following chapter of this thesis.

3.5 References

Angermeier, P. L.; Winston, M. R., 1998: Local vs Regional influence on local diversity in stream fish communities in Virginia. Ecology **79**, 911-927.

Bain, M. B.; Finn, J. T.; Booke, H. E., 1988: Streamflow regulation and fish community structure. Ecology **69**, 382-392.

Beamish, F. W. H.; Noakes, D. L. G.; Rossiter, A., 1998: Feeding ecology of juvenile lake sturgeon (*Acipenser fulvescens*) in Northern Ontario. Can. Field. Nat. **112**, 459-468.

Bruch, R. M.; Binkowski, F. P., 2002: Spawning behaviour of lake sturgeon (*Acipenser fulvescens*). J. Appl. Ichthyol. **18**, 570-579.

Carlander, K. D., 1969: Handbook of freshwater fishery biology. Iowa State University Press, Ames, IA, USA.

Carlander, K. D.; Campbell, J. C.; Muncy, R. J., 1978: Inventory of percid and esocid habitat in North America. In: Selected Coolwater Fises of North America (ed. R. L. Kendall). American Fisheries Society Publication. Washington D.C., USA. 437p.

Connell, J. H., 1980: Diversity and coevolution of competitors, or the ghost of competition past. Oikos **35**, 131-138.

Cortes, E., 1997: A critical review of methods of studying fish feeding based on analysis of stomach contents: application to elasmobrach fishes. Can. J. Fish. Aquat. Sci. **54**, 726-738.

Craig, P. C.; Poulin, V. A., 1975: Movements and growth of Arctic Grayling (*Thymallus arcticus*) and juvenile Arctic Charr (*Salvelinus alpinus*) in a small arctic stream, Alaska. J. Fish. Res. Board Can. **32**, 689-697.

Cunjak, R. A., 1996: Winter habitat of selected stream fishes and potential impacts from land-use activity. Can. J. Fish. Aquat. Sci. **53**(Suppl. 1), 267-282.

Dettmers, J. M.; Gutreuter, S.; Wahl, D. J.; Soluk, D. A., 2001: Patterns in abundance of fishes in main channels of the upper Mississippi River system. Can. J. Fish. Aquat. Sci. **58**, 933-942.

Evans, D. O.; Henderson, B. A.; Bax, N. J.; Marshall, T. R.; Oglesby, R. T.; Christie, W. J., 1987: Concepts and methods of community ecology applied to freshwater fisheries management. Can. J. Fish. Aquat. Sci. **44**, 448-470.

Gadomski, D. M.; Parsley, M. J., 2005a: Laboratory studies on the vulnerability of white sturgeon to predation. N. Am. J. Fish. Manage. **25**, 667-674.

Gadomski, D. M.; Parsley, M. J., 2005b: Effects of turbidity, light level, and cover on predation of white sturgeon larvae by prickly sculpins. Trans. Am. Fish. Soc. **134**, 369-374.

Gelwick, F. P.; Matthews, W. J., 1990: Temporal and spatial patterns in littoral-zone fish assmblages of a reservoir (Lake Texoma, Oklahoma-Texas, U.S.A.). Environ. Biol. Fish. **27**, 107-120.

Gido, K. B.; Matthews, W. J.; Wolfinbarger, W. C., 2000: Long-term changes in a reservoir fish assemblage: stability in an unpredictable environment. Ecol. Appl. **10**, 1517-1529.

Grossman, G. D., 1982: Dynamics and organization of a rocky intertidal fish assemblage: the persistence and resilience of taxocene structure. Am. Nat. **119**, 611-621.

Grossman, G. D.; Moyle, P. B.; Whitaker, J. O., 1982: Stochasticity in structural and functional characteristics of an Indiana stream assemblage: a test of community theory. Am. Nat. **120**, 423-454.

Hatzenbeler, G. R.; Bozek, M. A.; Jennings, M. J.; Emmons, E. E., 2000: Seasonal variation in fish assemblage structure and habitat structure in the nearshore littoral zone of Wisconsin lakes. N. Am. J. Fish. Manage. **20**, 360-368.

Haxton, T. J.; Findlay, C. S., 2009: Variation in large-bodied fish-community structure and abundance in relation to water-management regime in a large regulated river. J. Fish. Biol. **74**, 2216-2238.

Hoyle, J. A.; Keast, A., 1987: The effect of prey morphology and size on handling time in a piscivore, the largemouth bass (*Micropterus salmoides*). Can. J. Zool. **65**, 1972-1977.

Jackson, D. A.; Peres-Neto, P. R.; Olden, J. D., 2001: What controls who is where in freshwater fish communities - the roles of biotic, abiotic and spatial factors. Can. J. Fish. Aquat. Sci. **58**, 157-170.

Keast, A., 1977: Trophic and spatial interrelationships in the fish species of an Ontario temperate lake. Environ. Biol. Fish. **3**, 7-31.

Keast, A.; Harker, J.; Turnbull, D., 1978: Nearshore fish habitat utilization and species associations in Lake Opinicon (Ontario, Canada). Environ. Biol. Fish. **3**, 173-184.

Keast, A.; Fox, M. G., 1990: Fish community structure, spatial distribution and feeding ecology in a beaver pond. Environ. Biol. Fish. **27**, 201-214.

Lasne, E.; Bergerot, B.; Lek, S.; Laffaille, P. 2007: Fish zonation and indicator species for the evaluation of the ecological status of rivers: example of the Loire Basin (France). *Riv. Res. Applic.* **IN PRESS**.

Legendre, P.; Legendre, L. 1998: Numerical ecology. Elsevier Scientific Publishing Company, Amsterdam.

Mahon, R., 1980: Accuracy of catch-effort methods for estimating density and biomass in streams. Environ. Biol. Fish. **5**, 343-360.

Magnin, E.; Harper, P. P., 1970: Feeding of lake sturgeon (*Acipenser fulvescens*) of the Nottaway River, a tributary of James Bay. Nat. Can. **97**, 73-85.

Manly, B. F. J.; McDonald, L. L.; Thomas, D. L.; McDonald, T. L.; Erickson, W. P., 2002: Resource selection by animals: statistical design and analysis for field studies. Kluwer, Dordrect, Netherlands.

Matthews, W. J.; Hill, L. G., 1980: Habitat partitioning in the fish community of a Southwestern River. Southwest. Nat. **25**, 51-66.

Matthews, W. J.; Cashner, R. C.; Gelwick, F. P., 1988: Stablility and persistence of fish faunas and assemblages in three midwestern streams. Copeia **1988**, 945-955.

Matthews, W. J., 1998: Patterns in freshwater fish ecology. Chapman Hall. New York, New York, USA.

McNaughton, S. J., 1968: Structure and function in California Grasslands. Ecology **49**, 962-972.

Moyle, P. B.; Vondracek, B., 1985: Persistence and structure of the fish assemblage in a small California stream. Ecology **66**, 1-13.

Naslund, I., 1990: The development of regular seasonal habitat shifts in a landlocked Arctic charr, *Salvelinus alpinus* L., population. J. Fish. Biol. **36**, 401-414.

Noakes, D. L. G.; Beamish, F. W. H.; Rossiter, A., 1999: Conservation implications of behaviour and growth of the lake sturgeon, *Acipenser fulvescens*, in northern Ontario. Environ. Biol. Fish. **54**, 135-144.

Oberdorff, T.; Hugueny, B.; Vigneron, T., 2001: Is assemblage variability related to environmental variability? An answer for riverine fish. Oikos **93**, 419-428.

Pegg, M. A.; Pierce, C. L., 2002: Fish community structure in the Missouri and lower Yellowstone rivers in relation to flow characteristics. Hydrobiologia **479**, 155-167.

Pielou, E. C., 1966: The measurment of diversity in different types of biological collections. J. Theor. Biol. **13**, 131-144.

Quinn, G. P.; Keough, M. J., 2002: Experimental design and data analysis for biologists. Cambridge University Press, New York, New York, USA.

Rawson, D. S., 1957: The life history and ecology of yellow walleye, *Stizostedion vitreum*, in Lac la Ronge, Saskatchewan. Trans. Am. Fish. Soc. **86**, 15-37.

Reist, J. D. 1980: Selective predation upon pelvic phenotypes of brook stickleback, *Culea inconstans*, by northern pike, *Esox lucius*. Environ. Biol. Fish. **8**, 255-267.

Ross, S. T., 1986: Resource partitioning in fish assemblages: A review of field studies. Copeia **1986**, 352-388.

Sandilands, A. P., 1987: Biology of the lake sturgeon (*Acipenser fulvescens*) in the Kenogami River, Ontario. In: Proceedings of a workshop on the Lake sturgeon (*Acipenser fulvescens*). Ont. Tech. Rep. Fish. Ser. No. 23 pp. 33 - 46.

Schlosser, I. J., 1982: Fish community structure and function along two habitat gradients in a headwater stream. Ecol. Monogr. **52**, 395-414.

Schlosser, I. J.; Ebel, K. K., 1989: Effects of flow regime and cyprinnid predation on a headwater stream. Ecol. Monogr. **59**, 41-57.

Schlosser, I. J.; 1995: Dispersal, boundary processes, and trophic-level interactions in streams adjacent to beaver ponds. Ecology **76**, 908-925.

Scott, W. B.; Crossman, E. J., 1973: Freshwater Fishes of Canada. Fish. Res. Board Can. **184,** 966 pp.

Seyler, J., 1997. Biology of selected riverine fish species in the Moose River Basin. OMNR, Northeast Science and Technology. Timmins, Ontario. IR-024. 100p.

Shannon, C. E.; Weaver, H. T., 1948: The mathematical theory of communication. University of Illinois Press, Urbana, IL, USA.

Smith, K. M.; King, D., 2005: Movement and habitat use of yearling and juvenile lake sturgeon in Black Lake, Michigan. Trans. Am. Fish. Soc. **134**, 1159-1172.

Sokal, R. R.; Rholf, F. J. 1981: Biometry. W. H. Freeman and Company, New York, New York, USA.

Tremain, D. M.; Adams, D. H., 1995. Seasonal variations in species diversity, abundance and composition of fish communities in the Northern Indian River Lagoon, Florida. Bull. Mar. Sci. **57**, 171-192.

Wahl, D. H., 1995: Effect of habitat selection and behavior on vulnerability to predation of introduced fish. Can. J. Fish. Aquat. Sci. **52**, 382-390.

Wellborn, G. A.; Skelly, D. K.; Werner, E. E., 1996: Mechanisms creating community structure across a freshwater habitat gradient. Ann. Rev. Ecol. Syst. **27**, 337-363.

Werner, E. E.; Gilliam, J. F., 1984: The ontogenetic niche and species interactions in size-structured populations. Ann. Rev. Ecol. Syst. **15**, 393 - 425.

Wolter, C.; Bischoff, A., 2001. Seasonal changes of fish diversity in the main channel of the large lowland River Oder. Regul. River **17**, 595-608.

Table 3.1. Number (n) and relative abundance (RA%) of fish species or group captured, by month, at 12 sites fished in the Winnipeg River study area, 2007.

	May		June		July		October		Total	
Species	n	RA%	n	RA%	n	RA%	n	RA%	n	RA%
Burbot	11	1.1	13	1.8	2	0.3	12	2.9	38	1.4
Log perch	2	0.2	0	0.0	0	0.0	0	0.0	2	0.1
Lake cisco	2	0.2	1	0.1	5	0.8	0	0.0	8	0.3
Lake sturgeon < 610 mm	485	47.9	330	45.8	351	55.2	155	37.7	1321	47.5
Lake sturgeon > 610 mm	206	20.3	130	18.1	76	11.9	83	20.2	495	17.8
Lake whitefish	0	0.0	0	0.0	3	0.5	9	2.2	12	0.4
Mooneye	10	1.0	3	0.4	9	1.4	15	3.6	37	1.3
Northern pike	13	1.3	5	0.7	2	0.3	4	1.0	24	0.9
Rock bass	4	0.4	7	1.0	11	1.7	10	2.4	32	1.2
Rainbow smelt	0	0.0	0	0.0	0	0.0	1	0.2	1	0.0
Sauger	28	2.8	17	2.4	14	2.2	20	4.9	79	2.8
Shorthead redhorse	18	1.8	10	1.4	37	5.8	17	4.1	82	2.9
Smallmouth bass	0	0.0	0	0.0	3	0.5	1	0.2	4	0.1
Spottail shiner	1	0.1	0	0.0	0	0.0	3	0.7	4	0.1
Trout perch	163	16.1	93	12.9	25	3.9	17	4.1	298	10.7
Walleye	24	2.4	67	9.3	47	7.4	39	9.5	177	6.4
White sucker	41	4.0	40	5.6	48	7.5	22	5.4	151	5.4
Yellow perch	5	0.5	4	0.6	3	0.5	3	0.7	15	0.5
Total	1,013	100.0	720	100.0	636	100.0	411	100.0	2,780	100.0

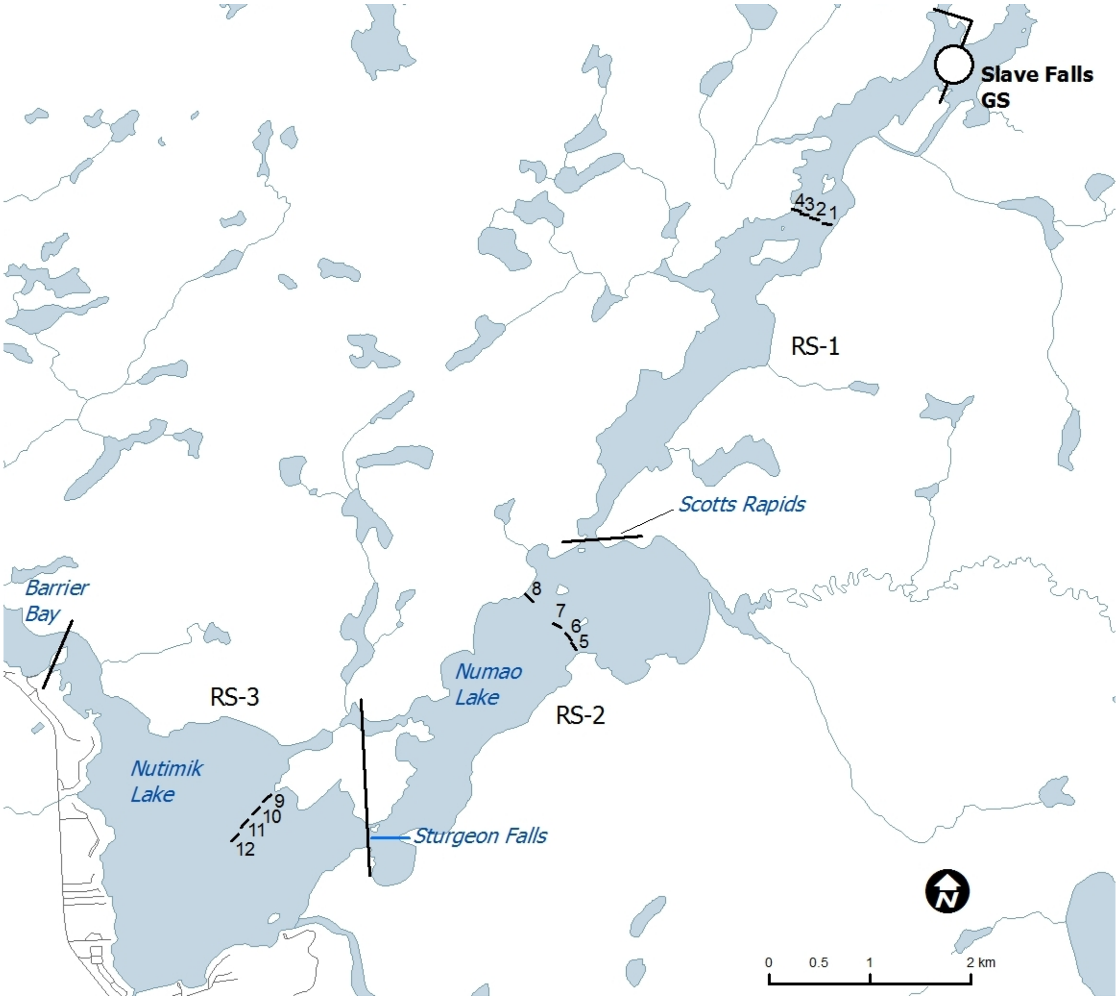

Figure 3.1 **Location of gill netting sites in the upper 14 km of the Winnipeg River study area, 2007. Transect 1 was comprised of gill net sites 1 – 4; Transect 2: gill net sites 5 – 8; Transect 3: gill net sites 9 – 12.**

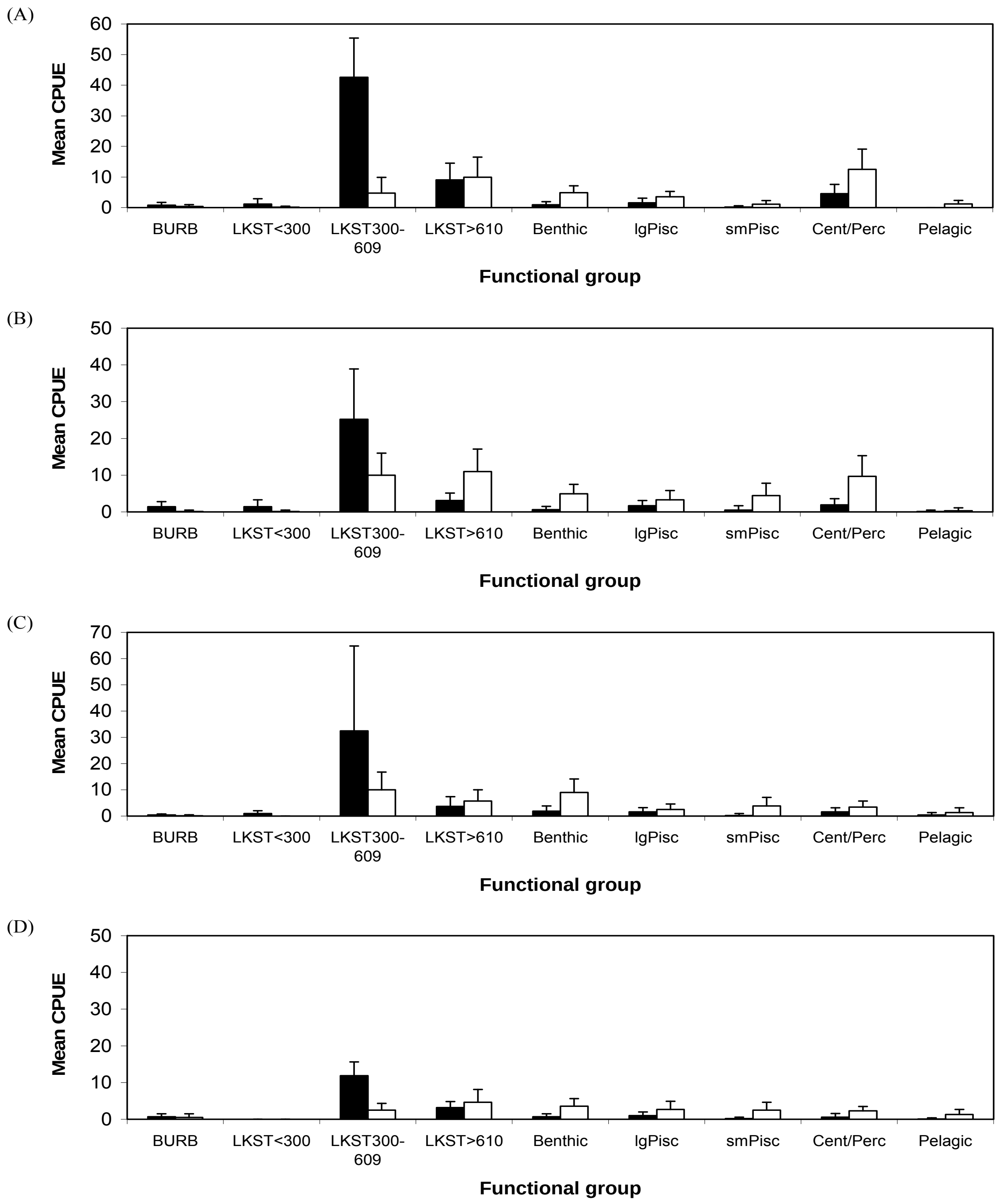

Figure 3.2a Mean CPUE (#fish/91.6 m net/24 hr) of each functional group captured in deep (depth > 13.7 m) or shallow (depth < 13.7 m) habitat during four sampling periods in the Winnipeg River study area, 2007. Filled bars = deep water, unfilled bars = shallow water. A = May, B = June, C = July and D = October.

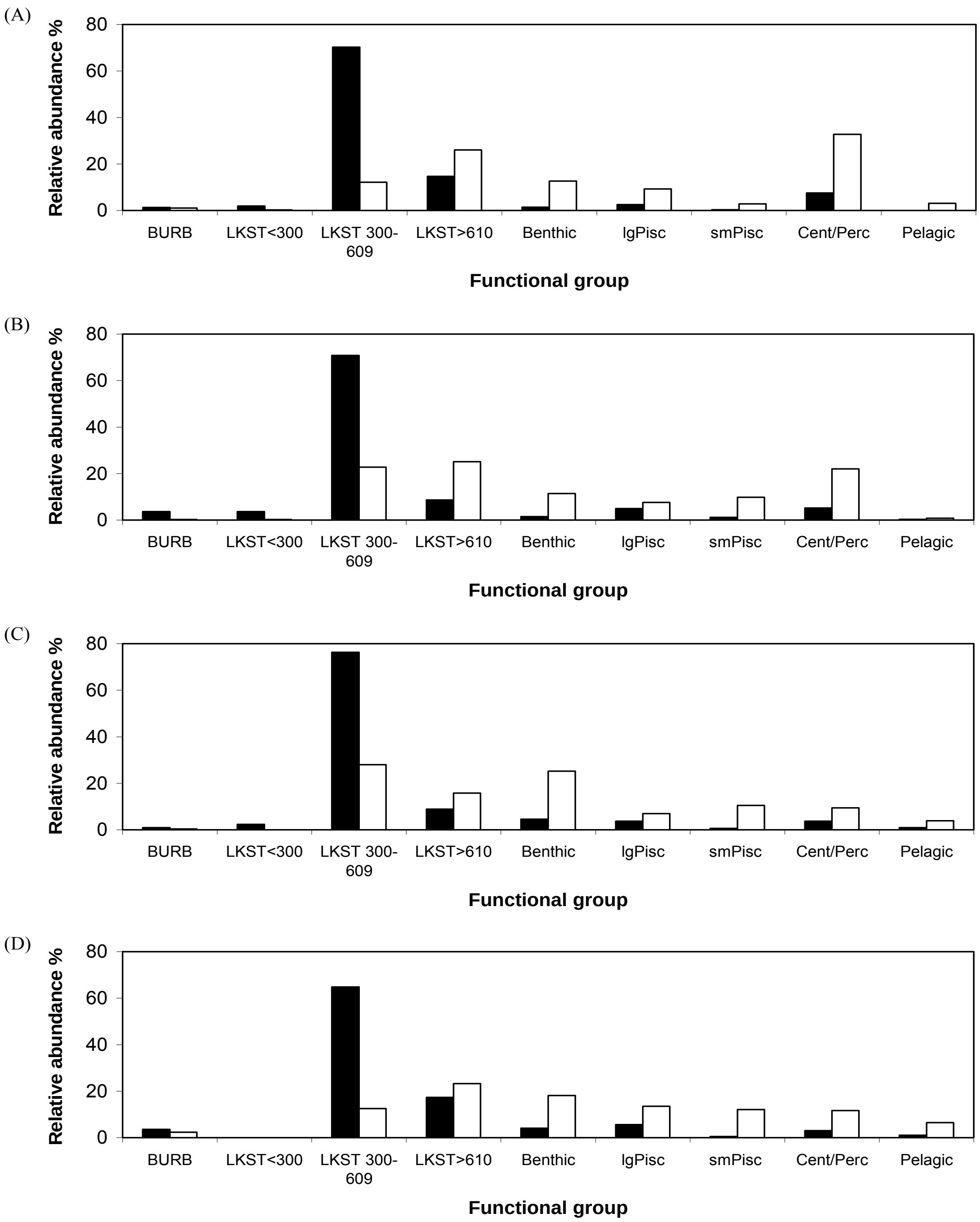

Figure 3.2b. Relative abundance of each functional group captured in deep (depth > 13.7 m) or shallow (depth ≤ 13.7 m) habitat during four sampling periods in the Winnipeg River study area, 2007. Filled bars = deep water, unfilled bars = shallow water habitat. A = May, B = June, C = July and D = October.

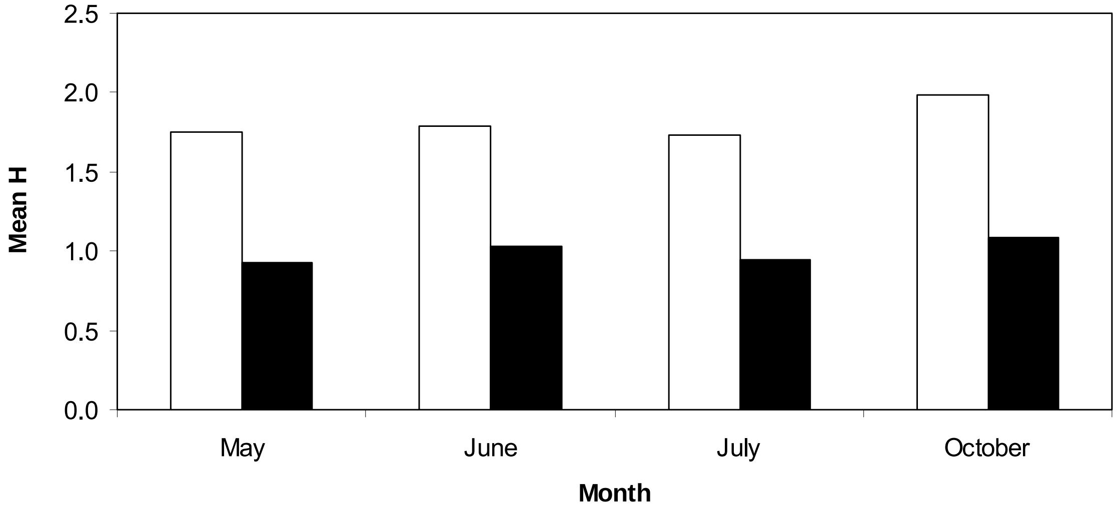

Figure 3.3a. Mean Shannon Weaver (H') diversity index values calculated from 6 deep and 6 shallow water sampling sites fished during four months in the Winnipeg River, 2007. Filled bars denote deep sites, unfilled bars denote shallow sites.

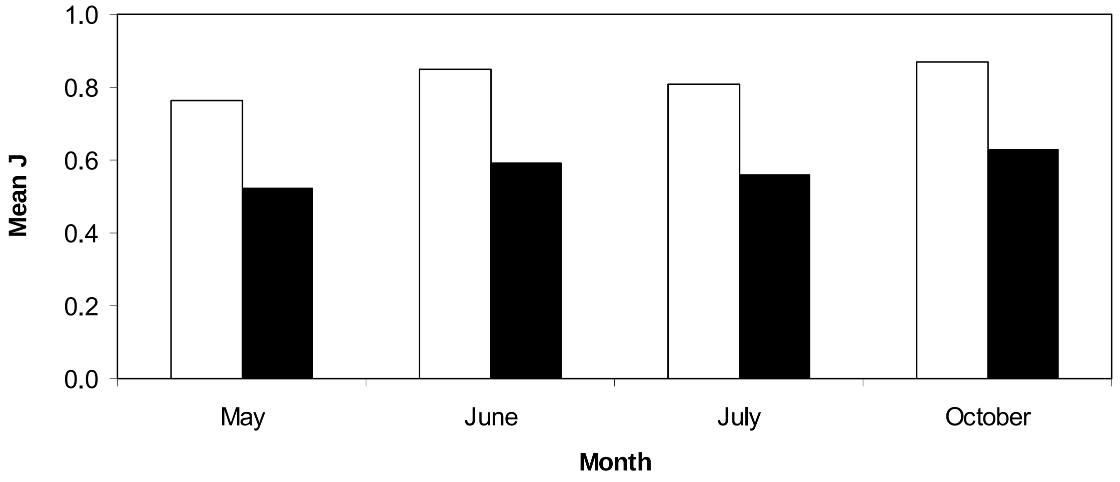

Figure 3.3b. Mean Pielou's eveness index (J) values calculated from 6 deep and 6 shallow water sampling sites fished during four months in the Winnipeg River, 2007. Filled bars denote deep sites, unfilled bars denote shallow sites.

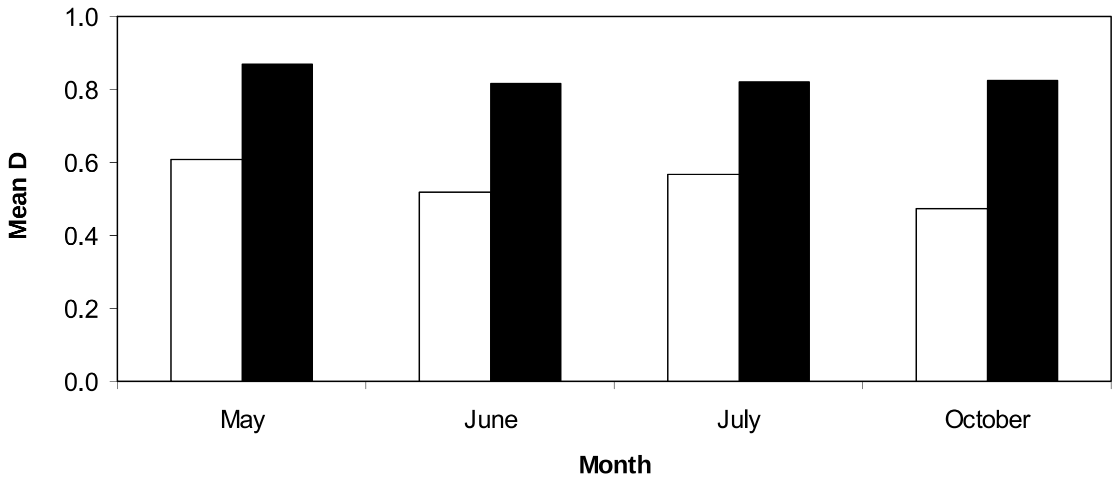

Figure 3.3c. Mean dominance index values (D) calculated from 6 deep and 6 shallow water sampling sites fished during four months in the Winnipeg River, 2007. Filled bars denote deep sites, unfilled bars denote shallow sites.

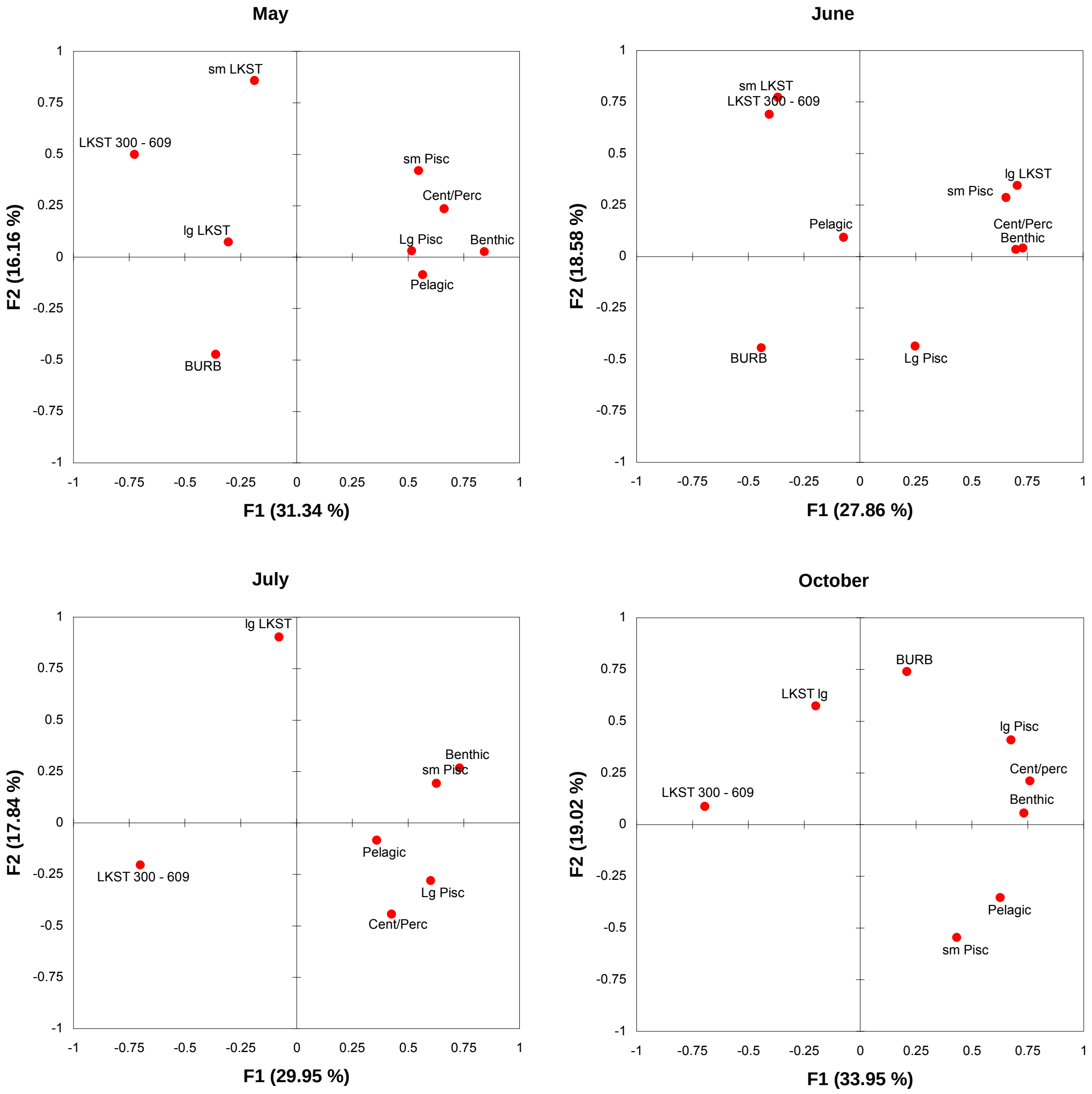

Figure 3.4. Component loadings for functional groups from species abundance data collected at 12 sites during four months in the Winnipeg River, 2007.

Appendix 3.1. Habitat characteristics for 12 gill netting sites set along 3 transects in the Winnipeg River, 2007. Depth – S = Shallow, D = Deep.

Transect #	Site #	River Section	Depth Range (m)	Depth Category	Velocity Range	Substrate type
1	1	RS-1	1.5 - 10.1	S	0.0 - 0.2	Sand
1	2	RS-1	9.6 - 12.5	S	0.1 - 0.2	Sand
1	3	RS-1	17.0 - 25.0	D	0.4 - 0.7	Sand, gravel, cobble
1	4	RS-1	22.8 - 27.2	D	0.4 - 0.7	Cobble > 10 cm, boulder, bedrock
2	5	RS-2	1.5 - 8.8	S	0.0 - 0.3	Sand, gravel, cobble
2	6	RS-2	8.8 - 12.2	S	0.1 - 0.3	Sand, gravel, cobble
2	7	RS-2	18.5 - 24.0	D	0.4 - 0.6	Sand, gravel, cobble
2	8	RS-2	15.8 - 20.5	D	0.1 - 0.2	Sand
3	9	RS-3	1.5 - 7.0	S	0.2 - 0.4	Cobble > 10 cm, boulder, bedrock
3	10	RS-3	7.0 - 13.5	S	0.3 - 0.4	Cobble > 10 cm, boulder, bedrock
3	11	RS-3	13.7 - 18.6	D	0.4 - 0.6	Cobble > 10 cm, boulder, bedrock
3	12	RS-3	18.9 - 22.2	D	0.4 - 0.6	Cobble > 10 cm, boulder, bedrock

Appendix 3.2. Date and water temperatures associated with each of four sampling periods, Winnipeg River, 2007.

Sampling Period	Date	Water temp °C Mean	SD	Range
1	May 4 - 16	7.6	1.0	6.1 - 8.9
2	June 6 - 18	14.5	1.1	13.0 - 16.3
3	July 8 - 20	19.6	0.4	18.0 - 20.2
4	October 10 - 22	11.1	0.5	11.0 - 11.5

SD = Standard deviation

Chapter 4: Seasonal variation in the diet of juvenile lake sturgeon, Acipenser fulvescens, in a large Canadian Shield river

4.0 Chapter Abstract

Knowledge of food resources utilized on a seasonally during each stage of a species' life history is necessary to understand factors influencing habitat selection. Juvenile lake sturgeon, *Acipenser fulvescens,* were captured in gill nets, and gut content samples were collected using a non-lethal gastric lavage methodology from individuals occupying four discrete deep water habitat types, during May, June, July and October (2006-2008). In total, 13,066 prey items belonging to 14 prey groups were collected from 345 juvenile lake sturgeon (251 – 835 mm TL). Juvenile lake sturgeon consumed a low diversity of organisms, as insect larvae from three invertebrate orders, trichoptera, diptera and ephemeroptera, accounted for 97.4% of the total number of prey items recovered, and only six of the prey groups occurred in > 5.0% of the stomachs with contents. Diet of juvenile lake sturgeon was found to vary in relation to season. During May, dipterans (n = 3,175, 77.6%) were the most abundant prey taxa, while Trichopterans were most abundant prey taxa recovered during both June (n = 3,056, 60.4%) and July (n = 2,055, 52.6%). During October, a high proportion (96%) of the juvenile stomachs examined were empty. Based on abundances of prey items found in gut contents of juvenile lake sturgeon, food availability in deep water habitats (depths > 13.7 m) and particle sizes > 0.063 mm was higher relative to deep water habitats characterized by low water velocity (< 0.2 m.s-1), and fine substrate (particle sizes < 0.063 mm) in May and June. In July, the opposite was observed and prey abundance in juvenile lake sturgeon stomachs decreased

with increasing particle size. A positive relationship between size of juvenile lake sturgeon and prey quantity or type was not observed, suggesting that different size/age classes consume similar prey types.

4.1 Introduction

Optimal foraging theory predicts that animals identify and select food resources that not only satisfy their life history requirements, but result in the greatest net benefit to overall fitness (Stephens and Krebs 1986). Studying the composition and diversity of prey items consumed by a predator can provide information on foraging patterns, foraging strategies, food webs, habitat use, prey communities and predator-prey interactions (Hyslop 1980, Amundsen et al. 1996; De Billy De Crespin et al. 2000; Link 2004). Such data can be useful for determining optimal habitats for preservation and remediation, as well as identifying factors affecting the abundance or health of a population (Manly et al. 2002). An understanding of the prey items in a species' diet on a seasonal basis, coupled with knowledge of how the species is distributed in its environment relative to predators, can help improve understanding of abiotic and biotic factors that drive habitat selection at each successive stage of an animal's life-history.

Many abiotic and biotic factors combine to influence the diet of fish species at different life history stages. These include but are not limited to: a) spatial and temporal variations in food availability; b) physical habitat characteristics of the environment; c) life history stage, body size, or sex; and d) differences within and between individual phenotypes (Zaret and Rand 1971; Bridcut and Giller 1995). Percent frequency of occurrence (%F) (# of predators containing the prey item/total number of predators in the group) and the abundance method (where each prey item is represented as a numeric value), are perhaps the most common diet descriptors (Hyslop 1980). Macdonald and Green (1983) suggest that the numerical abundance method provides information on prey acquisition and feeding behavior, while the %F method provides an indication of prey species variability.

Spatial and temporal variations in food availability may influence habitat selection by fish (Werner and Hall 1977; Schafer et al. 2002). In the absence of predators, fish should distribute themselves in similar locations as their prey (Keast and Harker 1977). When predators are present, foraging theory predicts that predation risk and food availability combine to influence habitat selection (Werner and Hall 1988; Lima and Dill 1990). To maximize fitness, fish are predicted to select habitat types based on minimizing the mortality to growth ratio, which changes among habitat types as fish grow (Werner and Gillam 1984; Roff 1992; Werner and Anholt 1993). Body size, therefore, plays a critical role in habitat selection by influencing both predation risk and foraging ability (Werner and Hall 1988). Ontogenetic shifts in diet and habitat use have been observed in a wide variety of fish species from several environments (Keast 1977; Werner and Hall 1988; Persson 1993). For example, many piscivorous fish species switch from invertebrate to fish prey with increasing body size (Werner and Gillam 1984; Olson 1996). Knowledge of the size or age at which ontogenetic changes in habitat use, and diet occur, is critical for the conservation of rare or endangered species so as to ensure that foraging habitat for each life history stage is protected.

Abiotic characteristics of habitat such as depth, water velocity, substrate type and water chemistry, may affect habitat productivity (Keast 1977; Werner and Hall 1977). Dettmers et al. (2001) characterized several distinct aquatic habitat types in large rivers, which included main channel, littoral zone and backwater habitats. Littoral zone and back water habitats are generally considered to be the most productive for aquatic organisms, including fish, due to higher nutrient levels, light, habitat diversity, carbon dioxide and oxygen (Wetzel 1975). Keast and Harker (1977) found that the biomass of both fish and benthic invertebrates decreased with increasing depth in a lake in Ontario, Canada. Conversely, main channel habitats are generally considered to be less productive and less hospitable to aquatic organisms relative to littoral zone areas (Junk et al. 1989). Foraging opportunities for fish in main channel habitats of large North American rivers remains difficult to quantify, however, and is poorly understood. This is primarily the result of inefficient sampling methodologies and a lack of standardized sampling protocols that provide a means of comparison among habitats (Casselman et al. 1990; Dettmers et al. 2001). As a consequence, biologists have been unable to determine with confidence, the importance of main channel habitats to the foraging ecology of riverine fish species.

Acipenserids are considered to be carnivorous at each life history stage (Buddington and Christofferson 1985). After hatching, larval lake sturgeon feed on zooplankton until they are large enough to begin feeding on benthic invertebrate prey (Muir et al. 2000). Diets of young-of-the-year (YOY) lake sturgeon are poorly described. Juveniles are considered opportunists, exhibiting a generalist foraging strategy, consuming small, soft-bodied benthic prey items (Chiasson et al. 1997; Brosse et al. 2000; Nilo et al. 2006). Studies have been conducted in the Lake Winnebago system

(Kempinger 1996; Choudhury et al. 1996); Black Lake, Michigan (Smith and King 2005); the St. Lawrence River system (Hayes and Werner 2005; Nilo et al. 2006) tributaries of James Bay in Quebec (Magnin 1970; Magnin and Harper 1977) and from the Groundhog and Mattagami rivers in northern Ontario (Chiasson et al. 1997; Beamish et al. 1998). Depending on the study area, invertebrates from the orders amphipoda, ephemeroptera, diptera, and trichoptera were the most common prey items. Two of these studies, Beamish et al. (1998) and Nilo et al. (2006), examined the gut contents of juvenile lake sturgeon and the abundance of benthic invertebrate prey simultaneously, to determine prey selectivity.

This chapter examines the diet of juvenile lake sturgeon in relation to size, month and habitat type in the Winnipeg River. Although many studies have examined diet in juvenile lake sturgeon, few have been conducted in large riverine environments, in the northwestern portion of the species range; and considered both season and habitat type simultaneously. Results are particularly relevant to sturgeon populations in large impounded riverine systems in which habitat changes associated with altered river flows and water levels have impacted sedimentation patterns.

4.2 Materials and Methods

4.2.1 Study area

The study area, described in previous chapters, consists of a 41 km long reach of the Winnipeg River delineated by the Slave Falls GS at the upstream end, and the Seven Sisters Falls GS at the downstream end (Figure 2.1). Stomach content sampling was conducted on juvenile lake sturgeon captured in the four furthest upstream sections of this study area (RS-1, RS-2, RS-3 and RS-4) during studies conducted from 2006 – 2008 (Figure 2.1)

4.2.2 Sampling periods and methodology

Stomach content samples were collected from juvenile lake sturgeon during four separate months: May, June, July and October, and from four deep water habitat types defined by particle size (silt/clay, sand, gravel/cobble and bedrock boulder). Fish were captured in gill nets using previously described methods (chapter 2). When fish were removed from the gill net they were placed in a tank supplied with flow through river water. Each fish was weighed (±0.05g) and measured for fork length (FL ±1mm) and total length (TL; ±1mm) and stomach contents were obtained using a modified gastric lavage method (Haley 1998; Brosse et al. 2002). Lake sturgeon were held with a cotton glove, ventral side up, with the snout pointed downwards at approximately a 45 degree angle. Next, a small plastic tube (2 mm internal diameter), connected to a blunted 16 gauge needle and 60 ml syringe, was slowly inserted through the mouth, down the oesophagus and into the stomach. The tubing was deemed to be in the appropriate location when the end of the tube was felt by hand on the ventral surface of the fish. With practice, the appropriate amount of tubing required to reach the stomach was easily determined based on the size of each individual fish. River water was then injected through the tube into the stomach, which caused the fish to regurgitate food items through the mouth. A 500 µm sieve was placed below the mouth of the lake sturgeon to catch expelled food items. More than one syringe full of water was often needed to recover food items. If there were no food items recovered after two full syringes of water, no further attempts were made to recover food, and the stomach was considered empty.

After the lavage procedure, all fish were monitored in a recovery tub for several minutes prior to release. Stomach content samples were preserved in 70% ethanol for subsequent identification in the laboratory.

For each stomach sampled, prey were classified to the lowest taxonomic level practical (usually order) and enumerated. Stomach contents were grouped into the following categories based on taxonomy:

1. Annelida - Hirudinea
2. Annelida - Oligochaeta
3. Crustacea - Microcrustacea (Cladocera, Ostracoda, Copepoda)
4. Crustacea - Amphipoda (Gammaridae, Hyallidae)
5. Crustacea - Decapoda (Crayfish)
6. Insecta - Ephemeroptera
7. Insecta - Odonata
8. Insecta - Trichoptera
9. Insecta - Diptera
10. Insecta - Megaloptera
11. Insecta - Plecoptera
12. Mollusca - Gastropoda

13. Mollusca - Bivalvia

14. Lake sturgeon eggs

4.2.3 Habitat characteristics

Substrate samples were collected in the vicinity of each location that gut content samples were collected using a ponar (225 cm^3). Substrate classifications were based on particle size distribution, modified from Wentworth (1929) as described in chapter 2. Because juvenile lake sturgeon were found to prefer deep water relative to shallow water, stomach content samples were collected only from juvenile lake sturgeon captured in deep water habitats (i.e., > 13.7 m). In chapter 2, deep water habitats were categorized as either, HT-1 which consisted of water velocities > 0.4 m.s-1, and coarse substrate (> 2mm), or HT-2 which consisted of water velocities ranging between 0.2 and 0.4 m.s-1, and fine substrate (< 2 mm). For the purpose of diet analysis, each of these two habitat types were further divided to create four habitat types based on particle size as follows.

- HT-RB – Water depth > 13.7 m, water velocity > 0.4 m.s-1 and particle sizes > 100 mm (i.e., bedrock/boulder)

- HT-GC – Water depth > 13.7 m, water velocity > 0.2 m.s-1 and particle sizes > 2mm and < 100 mm (i.e., gravel and cobble);

- HT-S – Water depth > 13.7 m, water velocity 0.1 – 0.3 m.s-1 and particle sizes > 0.063 mm and < 2mm (i.e., fine and coarse sand).

- HT-SC – Water depth > 13.7 m, water velocity < 0.2 m.s-1 and particle sizes < 0.063 mm (i.e., silt and clay).

4.2.4 Data Analysis

The numeric abundance of each prey category was tabulated for each individual lake sturgeon sampled. Percent frequency of occurrence (%F) was calculated as the number of lake sturgeon that had consumed a prey item, divided by the total number of lake sturgeon in the sample. Standardized abundance values (SA) were calculated for each prey category, in each habitat type by month combination by multiplying the numeric abundance of the prey, by its frequency of occurrence. Standardized abundance values were used in subsequent analyses to avoid biasing results towards prey items that were found in large numbers but occurred in relatively few stomachs. SA data were presented as a mean ± standard deviation (SD). Because the stomachs of fish captured in October were often empty, data from this month were omitted from subsequent analyses.

To determine if a correlation existed between size of juvenile lake sturgeon and prey abundance, the numeric abundance of each invertebrate prey group was regressed against TL in each habitat type by month combination. To examine the influence of month and habitat type on the diet of juvenile lake sturgeon, SA values for each prey type that comprised > 2.0% of the diet were compared among month and habitat type combinations using a one way ANOVA. When significant differences were found among habitat type and month combinations, Tukeys HSD was used to determine which habitat by month combinations were significantly different. Data were log transformed (X+1) (Sokal and Rholf 1981) prior to each analysis to improve normality and homogeneity of variance. Finally, SA values from each prey group that comprised > 2.0% of juvenile lake sturgeon diet were added together, in order to observe potential patterns in invertebrate abundance between habitat type and month. Analyses were carried out using XLSTAT (Version 2006.2) in excel (Microsoft Corporation, Redmond, California). A significance level of $P < 0.05$ was used for all statistical analyses.

4.3 Results

Stomach content samples were collected from 345 juvenile lake sturgeon measuring between 251 mm and 835 mm TL, during four months of the year (May, June, July, October) and four habitat types, which from coarse to fine particle sizes included HT-RB, HT-GC, HT-S, and HT-SC. A total of 13,066 prey items were collected, representing 14 prey groups (Table 4.1). Overall, three invertebrate groups, diptera ($n = 5{,}722$), trichoptera ($n = 5{,}557$), and ephemeroptera ($n = 1{,}445$), combined to represent 97.4% of the numeric abundance of prey items collected during the study (Table 4.1). Dipterans occurred in the highest number of stomachs examined (75.9%), followed by trichopterans (69.0%), ephermeropterans (57.4%) and plecopterans (13.0%). The remaining prey groups were found in ≤ 7.0% of the stomachs with contents (Table 4.1). Of the 345 guts with prey, 86, 147, 110 and 2 were collected in May, June, July, and October, respectively (Table 4.2). The percentage of juvenile lake sturgeon sampled that contained food items ranged from 30.5% to 65.4% in all habitat types from May to July (Table 4.3). In October, recovery of prey items was relatively unsuccessful as contents were found in < 4.0% of the stomachs examined from each habitat type (Table 4.3). The number of gut content samples collected within each month and habitat type combination ranged from 16 to 53 samples.

4.3.1 Diet by month

During May, a total of 4,096 prey items were recovered from 86 juvenile lake sturgeon (Table 4.2). Dipterans (n = 3,175 individuals) were the predominant prey item, found in 87.2% of the stomachs that contained food and comprising 77.2% of the total number prey items collected. Trichopterans (n = 446; %F = 54.7%) and ephemeropterans (n = 402; %F = 59.3%) were numerically less important, but were each found in > 50% of the stomachs examined. The remaining prey groups were found at ≤ 1.0 %F (Table 4.2). During June, 5,061 prey items were recovered from the gut contents of 147 juvenile lake sturgeon. Trichopterans were numerically the most abundant prey group (n = 3,056) comprising 60.4% of the total number of prey items recovered, being found in 74.1% of the stomachs with contents. Dipterans (n = 1,530; %F = 80.3%) and ephemeropterans (n = 337; %F = 47.6%) were both less abundant in the stomachs during June relative to May. The remaining prey groups were found in ≤ 1.7% of the stomachs that contained food. During July, a total of 3,905 prey items were recovered from 110 juvenile lake sturgeon. Similar to June, trichopterans (n = 2,055 individuals) were the dominant prey item recovered, being observed in 74.5% of the stomachs examined and comprising 52.6% of the total number of prey collected. Dipterans (n = 1,011; %F = 60.9%) and ephemeropterans (n = 706; %F = 70.0%) were numerically less important, but were each found in > 60% of the stomachs examined. The remaining prey groups comprised ≤ 0.9% of the prey items collected during this month (Table 4.2). Because only three invertebrate groups (trichoptera, diptera and ephemeroptera) comprised > 2.0% of the total numeric abundance of invertebrate prey during each month, subsequent analyses were limited to these groups.

4.3.2 The influence of body size on diet

Approximately 65% of the juvenile lake sturgeon sampled measured between 400 and 550 mm TL (Figure 4.1). Consumption of the three primary prey groups by juvenile lake sturgeon remained consistent across all sizes of fish sampled (251 - 835 mm TL) as there was not a single case of a juvenile lake sturgeon that consumed large numbers of a rare prey type. Linear regression was used to examine the correlation between TL and the three principal invertebrate prey items separately in each habitat type by month combination (Table 4.4). Significant correlations were found for 6 of the 36 habitat by month combinations. These correlations were considered to be weak given low r^2 values (≤ 0.42) for each test. Positive correlations between size and abundance of prey were found for trichopterans in May and July in gravel/cobble substrates and ephemeropterans in silt/clay substrates in July. Negative correlations between body size and abundance of prey were observed for trichopterans in silt clay substrate in May, dipterans in sand substrate during May and ephemeropterans in sand substrate during July (Table 4.4).

4.3.3 Diet by Month and Habitat type

The mean SA of trichopterans collected from juvenile lake sturgeon stomachs in June over sand (JN-HT-S) (37.5 ±45.3) was significantly greater than all other month by habitat type combinations with the exception of silt/clay in July (JL-HT-SC) (34.2 ±45.3) and sand in July (JL-HT-S) (16.0 ± 2.8) (ANOVA, $P < 0.001$, Tukey's HSD, $P < 0.05$) (Figure 4.2). Trichopterans were found in low abundances in stomachs of juvenile lake sturgeon collected over silt/clay substrate in May (M-HT-SC) and June (JN-HT-SC), mean SA = 0.4 ± 0.7 and SA = 1.5 ± 4.8, respectively. The SA of dipterans in juvenile lake sturgeon stomachs sampled over sand (M-HT-S) (39.7 ±44.3) and gravel/cobble (M-HT-GC) (SA = 56.5 ±76.9) in May were significantly greater than all other habitat type by month combinations with the exception of boulder/bedrock (M-HT-RB) (17.2 ± 25.1) in May (ANOVA, $P < 0.001$, Tukeys HSD, $P < 0.03$) (Figure 4.2). In general, the SA of dipterans was high in May and low in all habitat by month combinations in May and June (Figure 4.2). The SA of ephemeropterans in silt/clay in July (JL-HT-SC) (8.5 ± 2.6) was significantly greater than three habitat types in June (JN-HT-SC; 1.0 ± 2.2), (JN-HT-S; 1.0 ± 1.7) and (JN-HT-GC; SA = 1.1 ± 1.5) (ANOVA, $P < 0.01$, Tukey's HSD, $P < 0.03$) (Figure 4.2).

Combined SA values from the three invertebrate groups were also compared among habitat types and month combinations (Figure 4.3). During May, the SA value of invertebrates in M-HT-SC (11.0 ±13.2) was lower relative to M-HT-S (45.5 ±47.5), M-HT-GC 61.4 ±79.5) and M-HT-RB (25.7 ±32.5) (Figure 4.3). The same trend was observed in June, as the SA of invertebrates in JN-HT-SC (10.6 ±18.8) was lower relative to JN-HT-S (44.3 ±47.2), JN-HT-GC (26.2 ±40.5) and JN-HT-RB (18.9 ±22.1). These data suggest that the predominant invertebrate groups in juvenile lake sturgeon diets were not as abundant in fine substrate types during May and June. However, during July, the opposite trend was observed where the abundance of prey was highest in JL-HT-SC (54.8 ±43.5), decreasing with increasing particle sizes JL-HT-S (25.1 ± 30.8), JL-HT-GC (12.2 ± 16.8) and JL-HT-RB (7.1 ±5.9) (Figure 4.3). Combined SA values were also consistently among the lowest observed in boulder/bedrock substrate and amongst the highest in sand substrate during each month.

4.4 Discussion

Preliminary analysis of micro-scale movements of juvenile lake sturgeon suggests that movements may occur over a very limited spatial scale (Barth unpublished, and Chapter 5); and the habitats of the Winnipeg River are relatively homogenous over relatively large spatial scales. As a result, it is reasonable to assume that the substrate over which each sturgeon was captured reflects the food resources available in that substrate type.

The diet of juvenile lake sturgeon occupying deep water habitats in the Winnipeg River consisted primarily of trichopterans, dipterans and ephemeropterans which combined, comprised 97.4% of the total number of prey items recovered. Overall, juvenile lake sturgeon diet consisted of 14 prey groups, however, only six were found in > 5.0% of the stomachs examined. These results are similar to previously published accounts. For example, in Lake Nipigon, Ontario, juvenile lake sturgeon consumed mainly ephemeropteran and dipteran larvae (Harkness and Dymond, 1961). Magnin and Harper (1970) studied the food habits of four age groups of lake sturgeon ranging in age from 3 – 46 years in Lake Wasanipi and Wasanipi River, tributaries of James Bay during June. Over 90% of the food items recovered from the smallest two size groups (3 – 5 years of age, 340 – 495 mm TL; and 6 – 10 years of age, 480 – 670 mm TL), consisted of the orders trichoptera, diptera, and ephemeroptera. Furthermore, trichopterans were found to comprise > 65% of prey items collected in June (Magnin and Harper 1970), a result that parallels the findings of this study. In the Groundhog and Mattagami rivers, Ontario, trichopterans, dipterans and ephemeropterans combined to represent 76.7% of the food items recovered from juvenile lake sturgeon between June and August (Beamish et al.

1998). However, unlike this study, ephemeropterans were the most abundant prey group comprising 65.8% of the total numeric abundance of prey (Beamish et al. 1998). Conversely, Nilo et al. (2006) (300 µm screen) reported that juvenile lake sturgeon from the St. Lawrence River, Quebec, had a very diverse diet of 74 prey taxa (family level), 50 of which were found in greater than 5% of the stomachs sampled. These authors suggest that juvenile lake sturgeon in the St. Lawrence River may consume a greater diversity of prey items relative to other systems due to the highly productive and diverse nature of the invertebrate fauna in the St. Lawrence River system.

The predominant prey items (trichopterans, dipterans and ephemeropterans) consumed by juvenile lake sturgeon in the Winnipeg River and other studies described above, differ from the diet of juveniles in the south and eastern portions of their North American range with respect to the relative importance of the order amphipoda, (class crustacea) particularly microcrustaceans or malacostracans in the diet. Kempinger (1996) found that juvenile lake sturgeon (267 – 749 mm TL) in Lake Winnebago, Wisconsin, consumed mainly larval dipterans, however, amphipods were of secondary importance comprising > 40% of the total food items collected from 81 individuals. Similarly, depending on season, Hayes and Werner (2005) found that either dipterans (chironomid larvae) or amphipods (gammarids) were the most important prey items collected from juvenile lake sturgeon (300 – 651 mm) in the St. Lawrence River. Guilbard et al. (2002) reported that the preferred dietary item for juvenile lake sturgeon in the St. Lawrence estuarine transitional zone (ETZ) was gammarids, and additionally, Nilo et al. (2006) found that gammarids comprised > 80% of the prey items found in juvenile lake sturgeon stomachs examined at five sites in the St. Lawrence River between June and November.

By comparison, amphipods comprised < 1.0% of the overall number of prey items recovered from juvenile stomachs in this study, suggesting that this prey group was either selected against, or were present in relatively low densities in the deep water habitat that juvenile lake sturgeon occupy in this study area. Invertebrate sampling from the Winnipeg River approximately 10 km upstream of this study site suggested that amphipods, particularly malacostracans belonging to the families Gammaridae or Hyallidae, were 40 – 50 fold higher at shallow water sites (< 3.0 m) relative to deep water sites (Gill and Wyn 2008, unpublished). These data suggest that amphipods may comprise a relatively small proportion of juvenile lake sturgeon diet in this study area due to their low abundance in deep water habitats.

Although not a single juvenile lake sturgeon sampled in this study was found to have consumed fish, fish were reported to comprise a portion of juvenile lake sturgeon diet in the St. Lawrence River estuarine transitional zone (ETZ), Quebec (Guilbard et al. 2007). This is not unusual as juveniles of other sturgeon species, such as pallid sturgeon, *Scaphyrhinchus albus,* in the Missouri River exhibit a piscivorous diet while shortnose sturgeon, *Scaphyrhinchus platorhynchus*, in the same river system fed primarily on aquatic invertebrates (Gerrity et al. 2006). During the present study, one juvenile lake sturgeon, sampled during early June 2007, was found to have consumed lake sturgeon eggs. Consumption of lake sturgeon eggs by adult lake sturgeon has also been observed in this system (Barth, unpublished) and in the Lake Winnebago system by Bruch and Binkowski (2002). Cannibalism of eggs, larvae, or YOY lake sturgeon may be one mechanism by which densities of adult and juvenile fish may influence recruitment. This avenue of research has received little study.

4.4.1 Ontogeny of lake sturgeon and relation to diet

A strong relationship between the body size (TL) of juvenile lake sturgeon and prey type or quantity was not observed. Explaining this result is difficult because it could be expected that larger fish would consume larger quantities of prey. However, relatively few stomach samples were collected from juvenile lake sturgeon > 700 mm TL (i.e., 6% of fish sampled) (Figure 4.1). In addition, a consistent pattern was not observed between body size and prey abundance in each habitat type by month combination (Table 4.4). One possible explanation is that larger lake sturgeon may not be actively foraging in deep water habitat and may be simply moving between foraging locations. Further research is necessary to understand how body size influences the diet of lake sturgeon in this study area.

Several authors have observed an ontogenetic shift in diet when lake sturgeon reach lengths ranging between 600 and 800 mm (TL). Hayes and Werner (2005) found that lake sturgeon shifted their diet from insect larvae, to bivalves, when fish measured approximately 700 mm TL in the St. Lawrence River, Quebec. Guilbard et al. (2007) found that mollusks comprised an important part of the diet at the subadult life stage (> 600 mm), but were rarely found in juvenile stomachs (i.e., < 600 mm) in the St. Lawrence River estuarine transitional zone (ETZ), Quebec. Sandilands (1987) reported that juvenile lake sturgeon fed mostly on trichopterans and odonates in the Kenogami River, Ontario, however, they began to select for crayfish as they approached 800 mm TL. In the Chibougamau River, Quebec, lake sturgeon measuring between 835 and 1070 mm TL mainly consumed gastropods and bivalves which combined to represent 60.4% of the diet (Magnin 1977). An ontogenetic shift in diet of lake sturgeon in the Winnipeg

River was not apparent in this study. Future studies on the Winnipeg River lake sturgeon population should include diet sampling of larger juvenile and adult fish.

4.4.2 Prey selectivity

Juvenile lake sturgeon are often classified as a benthic generalist that consumes mainly small, soft-bodied invertebrates that live on or in the sediment (Harkness and Dymond 1961; Magnin and Harper 1970; Magnin 1977; Kempinger 1996, Beamish et al. 1998; Guilbard et al. 2007). Because detailed benthic or drifting invertebrate sampling was not conducted congruent with stomach content sampling during this study, it is difficult to support or refute this statement. However, benthic and drifting invertebrates were sampled from May – October (2006 – 2008) in the Winnipeg River in the vicinity (i.e., both upstream and downstream) of the Pointe Du Bois GS, located approximately 8 km upstream of the Slave Falls GS (Gill and Wyn 2008, unpublished; Gill et al. 2008, unpublished; Gill 2009, unpublished). These studies suggested that the diversity the benthic invertebrate community was low, as the orders diptera and ephemeroptera accounted for > 75% of the total number of organisms collected during each year. Similarly, drifting invertebrate diversity was low as insect larvae from the orders trichoptera, diptera and ephemeroptera, combined to comprise 67% and 76% of the total number of drifting invertebrates captured in 2006 and 2007, respectively. Given these results, it seems reasonable to suggest that juvenile lake sturgeon in the Winnipeg River are also opportunistic foragers.

Two studies have correlated benthic invertebrate abundance with prey abundance in the diet of juvenile lake sturgeon to determine selection for, or avoidance of, particular prey types. In the Groundhog and Mattagami rivers in Ontario, Beamish et al. (1998) suggested that ephemeropteran larvae were selected for, whereas dipterans and trichopterans were abundant in the substrate but rarely found in juvenile lake sturgeon stomachs. In the St. Lawrence River, Quebec, Nilo et al. (2006) found that malacostracans and ephemeropteran nymphs were the only two prey groups selected for at each of four sampling sites. Trichopteran larvae were selected for at three sites, and dipteran larvae were selected for at only one. Both studies indicated that larval ephemeroptera were positively selected by juvenile lake sturgeon. It is possible that larval ephemeroptera were selected for because they are larger, and have a higher energetic content relative to members of the orders trichoptera or diptera (Salonen et al. 1976).

Based on benthic invertebrate abundance data and congruent sampling of juvenile lake sturgeon stomachs, Nilo et al. (2006) suggested that drifting invertebrates may not only represent a major food source for juvenile lake sturgeon, but that drifting invertebrates may be selected for. Because large numbers of invertebrates drift during May, June and July in the Winnipeg River, and because the composition of invertebrate drift is similar to the diet of juvenile lake sturgeon, it is likely that juvenile sturgeon diet is comprised of both benthic and drifting invertebrate prey. However, determining the relative importance of the drifting and benthic invertebrates to the diet of juvenile lake sturgeon was not possible since the three predominant prey groups found in the contents of juvenile lake sturgeon stomachs were the same invertebrate groups that comprised the majority of the benthic and drifting invertebrate abundance in the Winnipeg River (Gill and Wyn 2008, unpublished; Gill et al. 2008, unpublished; Gill 2009, unpublished).

4.4.3 Seasonal diet variability

At least 30% of the lake sturgeon sampled from each habitat type during May, June and July were found to contain food items, however, in October, a high proportion (96%) of the stomachs sampled were empty. These data suggest a significant reduction in foraging by juvenile lake sturgeon in October. Both benthic and drifting invertebrate abundance in the Winnipeg River was 4 – 20 fold less in October relative to other months of the year (Gill and Wyn 2008, unpublished; Gill et al. 2008, unpublished; Gill 2009; unpublished). Although foraging opportunities may have been significantly reduced during October, it is unlikely that juvenile lake sturgeon ceased feeding. Similar studies have recovered food items from juvenile lake sturgeon via gastric lavage during fall (Kempinger 1996; Hayes and Werner 2005; Guilbard et al. 2007). However, the fish collection methods used in those studies facilitated immediate stomach sampling and recovery of diet items. In my study, however, fish remained in gill nets for up to several hours prior to sampling and digestion or regurgitation of a limited volume of food items may have reduced sampling success. Indeed, Guilbard et al. (2007) observed a greater success rate when sampling stomachs of lake sturgeon captured by trawling compared to those captured in gill nets during fall.

Nearly every author that has investigated temporal aspects of juvenile lake sturgeon diet has noted seasonal shifts in the importance of prey items. The abundance of dipterans in the stomachs of juvenile lake sturgeon during May suggests that this prey group may be more available relative to June and July in substrate types > 2 mm. Guilbard et al. (2007) and Hayes and Werner (2005) also observed a decrease in the proportion of dipterans from spring to fall in the diet of juvenile lake sturgeon. In June and July, trichopterans were the most abundant prey group found in the stomachs of juvenile lake sturgeon from the Winnipeg River, especially in lake sturgeon sampled over sand substrates during June and silt/clay substrates during July. Trichopterans also were found to comprise a high proportion of juvenile diet in June in the Nottaway River (Magnin 1970).

4.4.4 Optimal foraging habitat for juvenile lake sturgeon

During May and June combined, standardized abundance values of the three main invertebrate groups combined (Figure 4.2) were relatively high in fish captured in habitats characterized by particle sizes > 0.063 mm, particularly sand and gravel/cobble substrates. Concurrently, relatively few prey were recovered from fish caught over silt/clay substrates. These data suggest that faster flowing areas of rivers or impoundments may be more productive for invertebrates (combination of both benthic and drifting) during May and June, and thus may offer more suitable foraging habitat. A correlation between mean standardized abundance values and CPUE of juvenile lake sturgeon (RS-1 and RS-2) in similar habitat/month combinations is evident (Figure 4.4), suggesting that juvenile lake sturgeon distribution in deep water habitat may be affected by food availability. Furthermore, these data suggest that sand and gravel/cobble substrates may be more productive relative to more coarse substrates.

Potential differences in food availability among months and habitats may be a factor influencing the distribution and abundance of juvenile lake sturgeon. Young-of-the-year lake sturgeon in the Winnipeg River and other locations are known to feed primarily on dipterans (Kempinger 1996; Henderson, unpublished data). Based on contents of lake sturgeon stomachs, dipterans appear to be relatively unavailable during May and June over fine substrate types. It is possible that higher abundance of dipterans over sand and gravel/cobble substrates during spring improves YOY survival in these habitat types. Due to an extended winter period when YOY foraging activity is likely low, food availability during spring may be critical for survival of YOY lake sturgeon by preventing starvation, or by affecting energetic expenditures to search for food, making them more susceptible to predation by large piscivorous fish. Because juvenile lake sturgeon were found to be more abundant in upstream sections of the study area (Chapter 6) that are dominated by sand and gravel/cobble substrates, relative to downstream sections of the study area that are dominated by fine depositional substrates, this is a possible mechanism explaining the abundance differences (see Chapter 6).

4.4.5 Summary

Juvenile lake sturgeon fed mainly upon three invertebrate orders (trichoptera, diptera and ephemeroptera) regardless of body size, in deep water habitats of the Winnipeg River. The quantity of invertebrate prey in stomachs varied with season and substrate type. Considering the high degree of dietary overlap among lake sturgeon size/age classes, the limited diversity of prey items consumed, and the density of juvenile lake sturgeon in deep water habitat types, a high potential for intra-specific competition for food may exist. Optimal foraging habitat may be comprised of substrates such as sand and gravel/cobble during May and June, and finer substrates may be more productive for invertebrates during July. However, before conclusions can be made regarding optimal foraging habitat a comprehensive invertebrate sampling study that includes the collection of both benthic and drifting invertebrates in several different habitat types is required.

Also, information on seasonal movement (Chapter 5) and growth (Chapter 6) in this population is necessary to further understand habitat selection in juvenile lake sturgeon.

4.5 References

Amundsen, P. A.; Gabler, H. M.; Staldvik, F. J., 1996: A new approach to graphical analysis of feeding strategy from stomach contents data - modification to the Costello (1990) method. J. Fish. Biol. **48**, 607-614.

Beamish, F. W. H.; Noakes, D. L. G.; Rossiter, A., 1998: Feeding ecology of juvenile lake sturgeon (*Acipenser fulvescens*) in Northern Ontario Can. Field Nat. **112**, 459-468.

Bridcut, E. E.; Giller, P. S., 1995: Diet variability and foraging strategies in brown trout (*Salmo trutta*): an analysis from subpopulations to individuals. Can. J. Fish. Aquat. Sci. **52**, 2543-2552.

Brosse, L.; Lepage, M.; Dumont, P., 2000: First results on the diet of the young Atlantic sturgeon *Acipenser sturio* L., 1758 in the Gironde estuary. Bol. Inst. Esp. Oceanogr. **16**, 75-80.

Brosse, L.; Dumont, P.; Lepage, M.; Rochard, E., 2002: Evaluation of a gastric lavage method for sturgeons. N. Am. J. Fish. Manage. **22**, 955-960.

Bruch, R. M.; Binkowski, F. P., 2002: Spawning behaviour of lake sturgeon (*Acipenser fulvescens*). J. Appl. Ichthyol. **18**, 570-579.

Buddington, R. K.; Christofferson, J. P., 1985: Digestive and feeding characteristics of the chondostreans. Environ. Biol. Fish. **14**, 31-41.

Casselman, J. M.; Penczak, T.; Carl, L.; Mann, R. H. K.; Holcik, J.; Woitowich, W. A., 1990: An evaluation of fish sampling methodologies for large-river systems. Pol. Arch. Hydrobiol. **37**, 521-552.

Chiasson, W. B.; Noakes, D. L. G.; Beamish, F. W. H., 1997: Habitat, benthic prey and distribution of juvenile lake sturgeon (*Acipenser fulvescens*) in northern Ontario rivers. Can. J. Fish. Aquat. Sci. **54**, 2866-2871.

Choudhury, A.; Bruch, R.; Dick, T. A., 1996: Helminths and food habits of lake sturgeon Acipenser fulvescens from the Lake Winnebago system, Wisconsin. Am. Midl. Nat. **135**, 274-282.

Cortes, E., 1997: A critical review of methods of studying fish feeding based on analysis of stomach contents: application to elasmobrach fishes. Can. J. Fish. Aquat. Sci. **54**, 726-738.

De Crespin De Billy, V.; Doledec, S.; Chessel, D., 2000: Biplot presentation of diet composition data: an alternative for fish stomach contents analysis. J. Fish. Biol. **56**, 961-973.

Dettmers, J. M.; Gutreuter, S.; Wahl, D. J.; Soluk, D. A., 2001: Patterns in abundance of fishes in main channels of the upper Mississippi River system. Can. J. Fish. Aquat. Sci. **58**, 933-942.

Gerrity, P. C.; Guy, C. S.; Gardner, W. M., 2006: Juvenile Pallid sturgeon are piscivorous: A call for conserving native cyprinids. Trans. Am. Fish. Soc. **135**, 604-609.

Haley, N. 1998: A gastric lavage technique for characterizing diets of sturgeons. N. Am. J. Fish. Manage. **18**, 978-981.

Harkness, W. J. K.; Dymond, J. R., 1961: The lake sturgeon. Ontario. Department of Lands and Forests, Toronto, Ontario, Canada.

Hayes, J.; Werner, R., 2005: Contributing factors in habitat selection by lake sturgeon (*Acipenser fulvescens*). The Research Foundation of the State University of New York. Albany, NY, pp.19.

Hyslop, E. J., 1980: Stomach content analysis - a review of methods and their application. J. Fish. Biol. **17**, 411-429.

Junk, W. J.; Bayley, P. B.; Sparks, R. E., 1989. The flood pulse concept in river-floodplain systems. In D. P. Dodge [ed] Proceedings of the international large river symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106.

Keast, A., 1977: Trophic and spatial interrelationships in the fish species of an Ontario temperate lake. Environ. Biol. Fish. **3**, 7-31.

Keast, A.; Harker, J., 1977: Fish distribution and benthic invertebrate biomass relative to depth in an Ontario lake. Environ. Biol. Fish. **2**, 235-240.

Kempinger, J. J., 1996: Habitat, growth, and food of young lake sturgeons in the Lake Winnebago system, Wisconsin. N. Am. J. Fish. Manage. **16**, 102-114.

Lima, S. L., Dill, L. M., 1990. Behavioral decisions made under the threat of predation: a review and prospectus. Can. J. Zool. **68**, 619-640.

Link, J. S., 2004: Using fish stomachs as samplers of the benthos. Mar. Ecol-Prog. Ser. **269**, 265-275.

Macdonald, J. S.; Green, R. H.; 1983: Redundancy of variables used to describe importance of prey species in fish diets. Can. J. Fish. Aquat. Sci. **40**, 635-637.

Magnin, E. 1977: Growth, diet and fecundity of lake sturgeon (*Acipenser fulvescens*) of the Grand River [Quebec] watershed. Nat. Can. **104**, 419-427.

Magnin, E.; Harper, P. P., 1970: Feeding of lake sturgeon (*Acipenser fulvescens*) of the Nottaway River, a tributary of James Bay. Nat. Can. **97**, 73-85.

Manly, B. F. J.; McDonald, L. L.; Thomas, D. L.; McDonald, T. L.; Erickson, W. P., 2002: Resource selection by animals: statistical design and analysis for field studies. Kluwer Academic Publishers, Dordrect, Netherlands.

Muir, W. D.; McCabe, G. T.; Parsley, M. J.; Hinton, S. A., 2000: Diet of first-feeding larval and young-of-th-year White sturgeon in the Lower Columbia River. Northwest Sci. **74**, 25-33.

Nilo, P.; Tremblay, S.; Bolon, A.; Dodson, J.; Dumont, P., 2006: Feeding ecology of juvenile lake sturgeon in the St. Lawrence river system. Trans. Am. Fish. Soc. **135**, 1044-1055.

Olson, M. H., 1996: Ontogenetic niche shifts in largemouth bass: variability and consequences for first-year growth. Ecology **77**, 179-190.

Persson, L., 1993: Predator-mediated competition in prey refuges: The importance of habitat dependent prey resources. Oikos **68**, 12-22.

Roff, D. A., 1992. Life history evolution. Champman and Hall, London, UK.

Salonen, K.; Sarvala, J.; Hakala, I.;Viljanen, M., 1976: The relation of energy and organic carbon in aquatic invertebrates. Limnol. Oceanogr. **21**, 724-730.

Sandilands, A. P., 1987: Biology of the lake sturgeon (*Acipenser fulvescens*) in the Kenogami River, Ontario. In: Proceedings of a workshop on the Lake sturgeon (*Acipenser fulvescens*). Ont. Tech. Rep. Fish. Ser. No. 23 pp. 33 - 46.

Schafer, L. N.; Platell, M. E.; Valesini, F. J.; Potter, I. C., 2002: Comparisons between the influence of habitat type, season and body size on the dietary compositions of fish species in nearshore marine waters. J. Exp. Mar. Biol. Ecol. **278**, 67-92.

Smith, K. M.; King, D., 2005: Movement and habitat use of yearling and juvenile lake sturgeon in Black Lake, Michigan. Trans. Am. Fish. Soc. **134**, 1159-1172.

Sokal, R. R.; Rholf, F. J., 1981: Biometry. W. H. Freeman and Company, New York.

Stephens, D. W.; Krebs, J. R., 1986: Foraging Theory. Princeton University Press, Princeton, New Jersey.

Waters, T. F., 1972: The drift of stream insects. Ann. Rev. Entomol. **17**, 253-272.

Wentworth, C. K., 1929: Method of computing mechanical composition types in sediments. Geol. Soc. Am. Bull. 40, 771-790.

Werner, E. E.; Hall, D. J., 1977: Competition and habitat shift in two sunfishes (Centrarchidae). Ecology **58**, 869-876.

Werner, E. E.; Gillam, J. F., 1984: The ontogenetic niche and species interactions in size-structured populations. Ann. Rev. Ecol. Syst. **15**, 393-425.

Werner, E. E.; Hall, D. J., 1988: Ontogenetic shifts in Bluegill: The foraging rate-predation risk trade-off. Ecology **69**, 1352-1366.

Werner, E. E.; Anholt, B. R., 1993: Ecological consequences of the trade-off between growth and mortality rates mediated by foraging activity. Am. Nat. **142**, 242-272.

Wetzel, R. G., 1975: Limnology. W. B. Saunders Company, Philadelphia, PA, USA.

Zaret, T. M.; Rand, A. S., 1971: Competition in tropical stream fishes: Support for the competitive exclusion principle. Ecology **52**, 336 - 342.

Table 4.1. Overall number of prey (n), percent frequency (%F) and percent of total for each invertebrate taxa found in the stomachs of 345 juvenile lake sturgeon sampled in the Winnipeg River, between May 2006 and July 2008.

Prey **Taxon**	**%F**	**n**	**Percent of total**
Trichoptera	69.0	5,557	42.5
Diptera	75.9	5,722	43.8
Ephemeroptera	57.4	1,445	11.1
Decapoda	3.2	14	0.1
Hirudinea	2.9	11	0.1
Odonata	3.5	14	0.1
Plecoptera	13.0	131	1.0
Amphipoda (Microcrustacea)	7.0	54	0.4
Annelida (Oligochaeta)	0.3	1	0.0
Amphipoda (e.g., Gammaridae)	4.9	33	0.3
Bivalvia (Pelecypoda)	5.2	48	0.4
Gastropoda	2.0	17	0.1
Megaloptera	1.2	6	0.0
Sturgeon eggs	0.3	13	0.1
All taxa		13,066	100.0

Table 4.2. Number (n), percent frequency of occurrence (%F) and percent monthly total (%t) of prey taxa found in the stomachs (st) of 345 juvenile lake sturgeon sampled in the Winnipeg River (2006 - 2008), by sampling month.

Prey	May st = 86			June st = 147			July st = 110			October st = 2		
Taxon	%F	n	%t	%F	n	%t	%F	n	%t	%F	n	%t
Trichoptera	54.7	446	10.9	74.1	3,056	60.4	74.5	2,055	52.6	0.0	0	0.0
Diptera	87.2	3,175	77.6	80.3	1,530	30.2	60.9	1,011	25.9	100.0	6	100.0
Ephemeroptera	59.3	402	9.8	47.6	337	6.7	70.0	706	18.1	0.0	0	0.0
Decapoda	1.2	1	0.0	0.7	1	0.0	8.2	12	0.3	0.0	0	0.0
Hirudinea	3.5	3	0.1	3.4	6	0.1	1.8	2	0.1	0.0	0	0.0
Odonata	1.2	1	0.0	3.4	7	0.1	5.5	6	0.2	0.0	0	0.0
Plecoptera	9.3	12	0.3	11.6	84	1.7	18.2	35	0.9	0.0	0	0.0
Amphipoda (Microcrustacea)	18.6	42	1.0	3.4	8	0.2	2.7	4	0.1	0.0	0	0.0
Annelida (Oligochaeta)	0.0	0	0.0	0.7	1	0.0	0.0	0	0.0	0.0	0	0.0
Amphipoda (e.g. Gammaridae)	3.5	3	0.1	1.4	2	0.0	10.9	28	0.7	0.0	0	0.0
Bivalvia (Pelecypoda)	5.8	9	0.2	2.7	4	0.1	8.2	35	0.9	0.0	0	0.0
Gastropoda	0.0	0	0.0	2.0	6	0.1	3.6	11	0.3	0.0	0	0.0
Megaloptera	0.0	0	0.0	2.7	6	0.1	0.0	0	0.0	0.0	0	0.0
Sturgeon eggs	0.0	0	0.0	0.7	13	0.3	0.0	0	0.0	0.0	0	0.0
All taxa		4,094	100.0		5,061	100.0		3,905	100.0		6	100.0

Table 4.3. Summary of juvenile lake sturgeon diet by habitat type and month in the Winnipeg River. Table includes: sample size (n), number of empty stomachs (MT), % with contents (% con), mean total standardized abundance (SA), standard deviation (SD), mean number of taxa (nt), and frequency of occurence (%F) for each of the three main invertebrate prey groups (dip = diptera; tri = trichoptera; eph = ephemeroptera), found in juvenile lake sturgeon stomachs collected in the four habitat types in the Winnipeg River.

	n	MT	% con	All prey SA	SD	Mean (nt)	SD	SA Tri	SD	Tri %F	SA Dip	SD	Dip %F	SA Eph	SD	Eph %F
HT-SC																
May	17	9	65.4	11.0	13.2	2.1	1.2	0.4	0.7	41	3.9	5.3	94	6.7	8.5	47
June	34	33	50.7	10.6	18.8	2.1	1.2	1.5	4.8	38	8.1	17.0	94	1.0	2.2	41
July	18	10	64.3	54.8	43.5	3.2	1.2	34.2	45.3	78	12.2	16.4	100	8.5	10.9	72
October	-	1	0.0	-		-		-		-	-		-	-		-
HT-S																
May	18	41	30.5	45.5	47.5	2.3	0.8	1.5	3.0	44	39.7	44.3	100	4.3	5.4	67
June	47	67	41.2	44.3	47.2	2.4	1.2	37.5	45.3	87	5.7	8.5	70	1.0	1.7	47
July	53	71	42.7	25.1	30.8	2.6	1.4	16.0	20.2	79	5.2	16.1	49	3.8	7.7	72
October	-	12	0.0	-		-		-		-	-		-	-		-
HT-GC																
May	27	26	50.9	61.4	79.5	2.6	1.2	3.4	4.5	56	56.5	76.9	89	1.5	1.8	59
June	39	73	34.8	26.2	40.5	2.6	1.1	10.5	15.2	90	14.5	32.0	87	1.1	1.5	56
July	23	45	33.8	12.2	16.8	2.3	1.5	4.4	6.3	70	3.6	6.9	48	4.2	8.8	65
October	1	25	3.8	-		-		-		-	-		-	-		-
HT-RB																
May	24	54	30.8	25.7	32.5	2.6	1.2	5.9	9.3	71	17.2	25.1	71	2.6	4.9	63
June	27	31	46.6	18.9	22.1	2.1	0.9	12.3	18.2	74	5.4	8.8	70	1.2	2.4	44
July	16	33	32.7	7.1	5.9	2.5	1.4	1.8	2.1	63	2.4	2.9	75	3.0	4.5	69
October	1	28	3.4	-		-		-		-	-		-	-		-

Total SA = Total standardized abundance. Calculated as the sum of the means of all three predomiant prey groups.

Table 4.4. Linear regression relating size (TL) of juvenile lake sturgeon and number of each of the three primary invertebrate prey by month and habitat type combination in the Winnipeg River 2006 – 2008.

	n	Tri Pval	Sig	r^2	Cor	Dip Pval	Sig	r^2	Cor	Eph Pval	Sig	r^2	Cor
M-HT-SC	17	0.08	N	0.18		0.93	N	0.01		0.27	N	0.08	
M-HT-S	18	0.17	N	0.11		0.04	*	0.24	-	0.01	*	0.34	-
M-HT-GC	27	0.01	*	0.28	+	0.23	N	0.06		0.50	N	0.02	
M-HT-RB	24	0.10	N	0.12		0.67	N	0.01		0.26	N	0.06	
JN-HT-SC	34	0.59	N	0.01		0.31	N	0.03		0.21	N	0.05	
JN-HT-S	47	0.13	N	0.05		0.74	N	0.01		0.06	N	0.08	
JN-HT-GC	39	0.82	N	0.01		0.50	N	0.01		0.61	N	0.01	
JN-HT-RB	27	0.67	N	0.01		0.29	N	0.03		0.86	N	0.01	
JL-HT-SC	18	0.04	*	0.23	-	0.12	N	0.15		0.03	*	0.27	+
JL-HT-S	53	0.87	N	0.01		0.07	N	0.06		0.63	N	0.01	
JL-HT-GC	23	0.01	*	0.42	+	0.45	N	0.03		0.84	N	0.01	
JL-HT-RB	16	0.10	N	0.18		0.43	N	0.05		0.69	N	0.01	

n = sample size;
Tri = trichoptera
Dip = diptera
Eph = ephemeroptera
Sig = Significance
(N) = not significant
* = sig. correlation
Cor = Corrleation (+) = positive, (-) negative
r^2 = Coefficient of determination

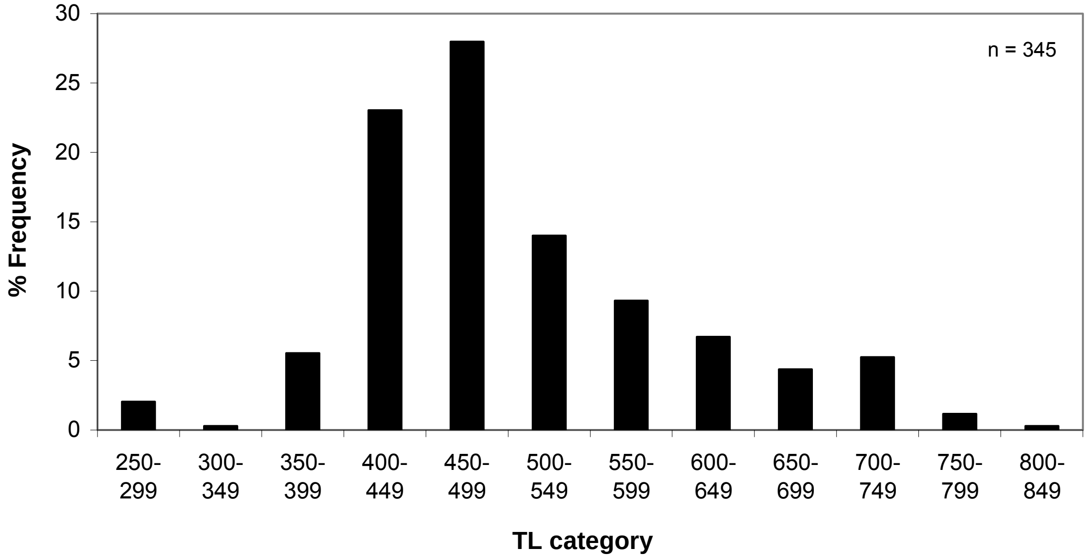

Figure 4.1. Size frequency distribution of 345 juvenile lake sturgeon collected for stomach samples in the Winnipeg River, 2006 - 2008.

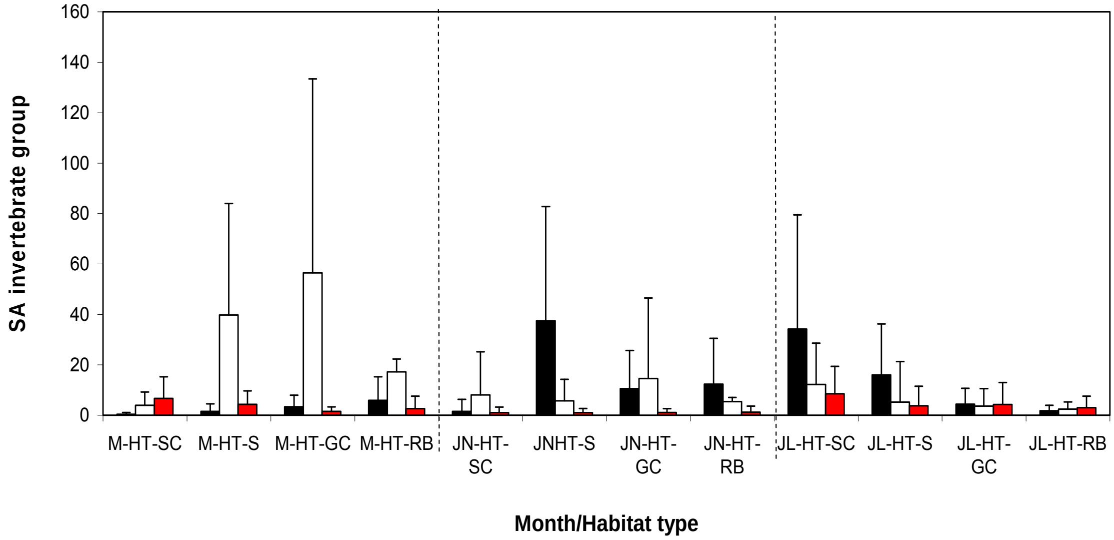

Figure 4.2. Standardized abundance (SA) of the three principal invertebrate prey groups found in juvenile lake sturgeon stomachs collected from each of the 12 month by habitat type combinations from the Winnipeg River (2006 - 2008). Data is presented as a mean SA ± SD. Trichopterans = filled bars; Dipterans = unfilled bars; Ephemeropterans = red bars. M = May; HT = Habitat type; SC = silt/clay; S = sand; GC = Gravel/Cobble; RB = Rock/Boulder.

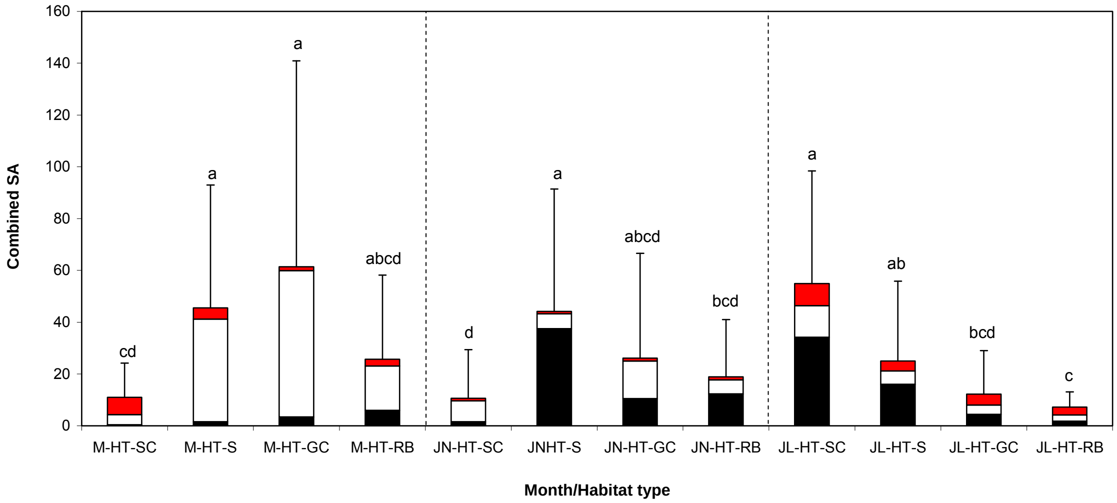

Figure 4.3. Combined standardized abundance (SA) values (sum of SA of each principal invertebrate taxa) by habitat type and month combination from juvenile sturgeon stomachs sampled in the Winnipeg River, 2006 - 2008. Data is presented as a mean combined SA ± SD. Trichopterans = filled bars; Diptera = unfilled bars; Ephemeroptera = red bars. Letters denote significant differences, or lack of significant differences between groups. M = May; HT = Habitat type; SC = silt/clay; S = sand; GC = Gravel/Cobble; RB = Rock/Boulder.

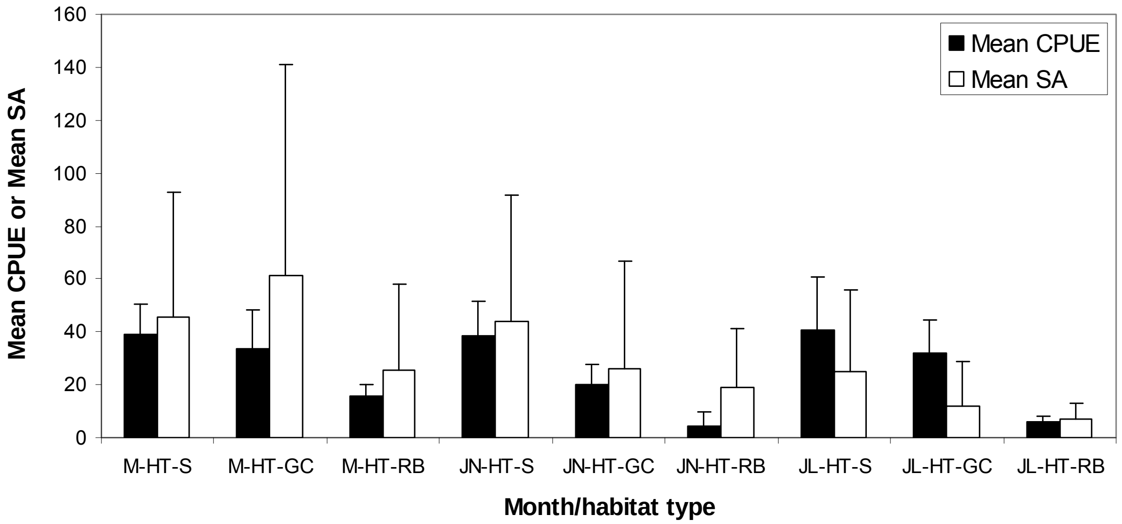

Figure 4.4. Mean CPUE (#LKST/91.6 m net/24 h) and mean standardized abundance values for juvenile lake sturgeon in each habitat by month combination in the Winnipeg River, 2007. CPUE data from sites fished in 2007, including mean CPUE of juvenile lake sturgeon from fish captured in RS-1 and RS-2 only.

Chapter 5: Seasonal movement and home range size of juvenile lake sturgeon, *Acipenser fulvescens*, in a large river in the Hudson Bay drainage basin

5.0 Chapter Abstract

In the case of the lake sturgeon, *Acipenser fulvescens*, a better understanding of the juvenile life history stages is urgently needed to improve conservation efforts for this imperiled species. Seasonal movement and home range size of juvenile lake sturgeon in the Winnipeg River, Manitoba, Canada, were examined using mark and recapture and acoustic telemetry. Over a 30-month period (May 2006 – October 2008), 5,671 juvenile lake sturgeon (213 mm – 879 mm FL) were marked with Floy-tags and the movements of 23 juvenile lake sturgeon (364 – 505 mm FL) were monitored using acoustic transmitters. Despite the potential for movement over 41 km of available habitat, juvenile lake sturgeon were highly sedentary and exhibited strong site fidelity as 90.8% of recaptured fish were recaptured less than 2.0 rkm from their original capture location. Similarly, acoustic telemetry data indicated that 60% of the tagged fish moved 1.8 rkm or less from their initial release location. Finally, results indicated that juvenile lake sturgeon rarely traversed habitats characterized by shallow water depths (< 5 m), high water velocities (> 1.5 m.s^{-1}), complex turbulent flows and large boulder and bedrock substrate in either an upstream or downstream direction.

5.1 Introduction

The lake sturgeon, *Acipenser fulvescens*, is one of eight sturgeon species found in North America, and is the only sturgeon species endemic to the Hudson Bay drainage basin. Similar to other species of sturgeon worldwide, lake sturgeon were historically abundant throughout their North American range, however, many populations have suffered dramatic declines owing to various anthropogenic activities (Birstein 1993; Beamesderfer and Farr 1997). Currently, few abundant populations remain, and the species is considered threatened throughout most of its range in the United States (Williams et al. 1989) and has been designated as endangered in Western Canada by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (COSEWIC 2006). Largely driven by concerns that overexploitation and habitat alteration are continuing to stress remaining populations, lake sturgeon research has increased substantially over the last several decades. Although studies have led to an improved understanding of the species' life history requirements, differences among genetically distinct populations in behaviour, habitat use, and movement are evident, and several knowledge gaps remain, especially with respect to the early life history stages (Secor et al. 2002).

Seasonal movement patterns and home range size have been studied in adult lake sturgeon occupying several riverine systems (Hay-Chmielewski 1987; Sandilands 1987; Fortin et al. 1993; Auer 1996; Rusak and Mosindy 1997; McKinley et al. 1998; Knights et al. 2002; Borkholder et al. 2002; Haxton 2003; Lallaman et al. 2008). These studies have primarily documented the timing, periodicity and spatial extent of movements from feeding to spawning, and/or overwintering areas. Comparatively fewer studies have characterized seasonal movement patterns and home range size of the lake sturgeon at the juvenile life history stage (Auer 1996; Peterson et al. 2007). Those studies that have been conducted have examined movements of young-of-the-year (YOY) (Benson et al. 2005), hatchery-reared juveniles (Thuemler 1988; Smith and King 2005) or wild juveniles (Kempinger 1996; Holtgren and Auer 2004; Smith and King 2005; Lord 2007) occupying small river and lake environments in tributaries of the Great Lakes. Despite these studies, our understanding of seasonal movement patterns, spatial requirements and/or home range size of the juvenile life history stage of the lake sturgeon remains limited, especially in larger riverine environments outside of the Great Lakes drainage basin. The present study aimed to determine seasonal movement and home range size in juvenile lake sturgeon in the Winnipeg River, a large northern river that is part of the Hudson Bay drainage basin.

5.2 Materials and methods

5.2.1 Study area

The Winnipeg River flows 260 km in a northeasterly direction from its headwaters in northern Minnesota, through Lake of the Woods to its outlet at Lake Winnipeg, draining an area of approximately 150,000 km^2. Monthly discharges are typically between 500 m^3/s and 1,500 m^3/s, although peaks as high as 3,000 m^3/s have been observed (St. George 2006). Between 1895 and 1951, eight hydroelectric dams were constructed on the river, two in Ontario and six in Manitoba. Flows are regulated by the Lake of the Woods Control Board mainly at the Norman Dam, the most upstream hydroelectric generating station (GS) built at the river's outlet on Lake of the Woods, Ontario. This study was conducted from May 2006 to October 2008, in an impounded reach of the Winnipeg River in Manitoba bordered by the Slave Falls GS (est 1931) (50º13'39N, 95º37'51W) at the upstream end, and Seven Sisters Falls GS (est 1931)

(50º07’09N, 96º01’03W) at the downstream end (referred to as the study area) (Figure 2.1). Both GS’s are operated as run-of-the-river, and upstream fish passage does not exist at either GS.

To facilitate a better geographic description of the study area, this reach of the Winnipeg River was subdivided into eight river sections (RS) (Figure 2.1). Section boundaries were delineated based on river topography, with margins being located at sets of rapids, constrictions of the river, or inlets and/or outlets of lakes (lakes being areas where the Winnipeg River widens). The most upstream section, denoted RS-1, measured a total of 6.0 river kilometers (rkm; 0 – 6.0) from Slave Falls at the upstream end to Scotts Rapids. The remaining RS’s, from upstream to downstream, include: RS-2: Numao Lake (4.0 rkm long, rkm 6.0 – 10.0); RS-3: Nutimik Lake (4.0 rkm long, rkm 10.0 -14.0); RS-4: Dorothy Lake (9.0 rkm long, rkm 14.0 – 22.0); RS-5: Margaret Lake (5.0 rkm long; rkm 22.0 – 27.0); RS-6: Eleanor Lake (4.5 rkm long, rkm 22.0A – 26.5A); RS-7: Sylvia Lake (2.0 rkm long; rkm 26.5A – 28.5A); and RS-8: Natalie Lake (11 rkm long, rkm 27.0 – 38.0) (Figure 2.1).

5.2.2 Fish capture and sampling methodology

5.2.2.1 Mark and recapture

From May 2006 to October 2008, juvenile lake sturgeon were captured in gill nets comprised of various mesh sizes ranging from 25 mm to 305 mm stretched, twisted nylon mesh (Leckies Net and Twine, Winnipeg, Manitoba, Canada), equipped with a 1 cm diameter braided float and lead line. For each lake sturgeon captured, location (Garmin GPS, model #GPS 76, Olathe, Kansas) fork length (FL) (±1 mm), and total length (TL)

(±1 mm) were recorded. A sub-sample of juvenile lake sturgeon were weighed (±5 g) and marked with an individually numbered Floy FD-94-T-bar anchor tag (Floy Tag Inc., Seattle, WA, USA) applied on the left side of the fish at the base of the dorsal fin using a tagging gun (Dennison Mark II, Floy Tag Inc., Seattle, WA, USA). Lake sturgeon measuring less than 250 mm FL were tagged with individually numbered Passive Integrated Transponders (PIT tags) (12 mm length, 134.2 kHz, Biomark, Boise, Idaho) inserted into the body cavity through a small mid-ventral incision. PIT tags were scanned following insertion into the fish using a Pocket reader EX (Biomark, Boise, Idaho). When a lake sturgeon was recaptured, location, number of Floy and/or PIT tag, along with TL, FL and mass were recorded. Fish were not marked a second time upon recapture unless the initial Floy tag was loose or damaged. As this study focused on describing the movement of juvenile lake sturgeon, only lake sturgeon that measured < 879 mm FL were considered in the analysis as lake sturgeon measuring < 879 mm FL in the Winnipeg River are known to be immature (Barth, unpublished).

5.2.2.2 Acoustic transmitter application

Between May 29 and May 31, 2007, 23 lake sturgeon (364 – 505 mm FL; mass 316 – 665 g) were captured in gill nets and each was implanted with a uniquely coded acoustic transmitter that pulsed randomly every 60 – 180 seconds. Transmitters (model #V9-1L, VEMCO LTD., Shad Bay, Nova Scotia) had an estimated 180 day battery life, measured 24 mm in length, and had a mass of 3.6 g, which equated to < 1.1% of each fish's body mass. Transmitters were programmed with different activation times in order to avoid code collisions associated with releasing a large number of tagged fish in the same area. Of the 23 transmitters initially released, four became active immediately, while nine and 10 of the transmitters were programmed with 4 month (activated in October 2007) and 8 month (activated in February 2008) activation delays, respectively.

Each lake sturgeon was measured for FL (±1 mm), TL (±1 mm) and body mass (±5 g) prior to the surgical procedure. The transmitter implantation process followed similar procedures outlined in Wagner et al. (2000) and Jepsen et al. (2002). Lake sturgeon were brought to shore and anaesthetized in approximately 50L of river water containing 60 mg/L clove oil (9 parts ethanol to 1 part clove oil) (Anderson et al. 1997). Fish were considered to be fully anaesthetized once equilibrium was lost and ventilation had slowed. Anaesthetized fish were placed ventral side up on a V-shaped cradle lined with styrofoam that was kept moist. The gills of the fish were continually bathed in freshwater supplied by a submersible pump (placed in the river), until the procedure was complete. An incision 0.8 – 1.2 cm long was made posterior to the pelvic fins 10 – 15 mm adjacent to the midline to expose the abdominal cavity. Prior to insertion through the incision, transmitters were disinfected in ethanol. Incisions were then closed using PDS suture material 3-0, with a CP-2 reverse edge cutting needle (Ethicon, Markham, Ontario, Canada). In order to monitor for a complete recovery, sturgeon were held overnight in a large circular tank supplied with flow through river water prior to being released.

5.2.2.3 Acoustic receivers

Acoustically tagged fish were located using an array of 44 stationary acoustic receivers (Model #VR2, VEMCO Ltd., Shad Bay, Nova Scotia). Receivers were strategically spaced in the study area to maximize coverage of the area and minimize detection area overlap. Acoustic receivers were equipped with an omni-directional hydrophone that continually monitored for transmitted acoustic pulses from active transmitters within its range of detection. Each receiver logged the transmitter code number, as well as the date and time associated with each valid detection. For a single omni-directional receiver, the probability that a signal would be recorded was proportional to the distance between transmitter and receiver (Simpfendorfer et al. 2002). In this study, the maximum detection radius of each VR2 receiver was estimated at 350 m (C. McDougall, unpublished).

Forty-two of the 44 VR2 receivers used to monitor tagged juvenile lake sturgeon were deployed on May 27, 2007, with the remaining two receivers (#72 and #74 located near the Slave Falls GS) being deployed on September 27, 2007 (Figure 5.1). Prior to the deployment of receivers #72 and #74, movements of tagged fish in the area immediately downstream of the Slave Falls GS were monitored by a radio-linked Radio/Acoustic Positioning system (VRAP) (VEMCO Ltd, Shad Bay, Nova Scotia), that was deployed on May 15, 2007. VR2 receivers were bolted to 22.9 kg concrete blocks with the hydrophone oriented toward the surface to ensure that the hydrophone remained stationary and elevated from the river bottom. Acoustic receivers were lowered to the river bottom at depths ranging between 3.0 and 10.0 m, and released without an attached float. The location of each receiver was determined using a GPS (Garmin, model# GPS 76, Olathe, Kansas). After approximately one year, receivers were retrieved by a scuba diver, downloaded, and subsequently redeployed.

5.2.3 Data Analysis

5.2.3.1 Mark and recapture

The number of days between original mark date, and subsequent recapture date, were divided into three categories: i) < 30 days; ii) between 30 and 365 days; and iii) > 365 days. To avoid biasing results towards non-movement only fish recaptured > 30 days after the original tagging date were considered in the analysis of movements and calculation of home range size (Fortin et al. 1993). Home range size was measured for each recaptured juvenile lake sturgeon as the shortest linear distance by water between original capture and recapture location (Gerking 1959). If an individual fish was recaptured on more than one occasion, then the distance between the two most distant capture and recapture locations was used. The number of tags applied and recaptured in each RS was grouped by 50 mm FL class intervals and distance category of 0.0 – 1.0 rkm, 1.1 – 2.0 rkm, or > 2.0 rkm. Linear regression was used to determine if a relationship existed between body size (FL) and movement distance within each river section. Finally, a Kruskal-Wallis non-parametric test using Dunn's procedure for multiple comparisons was used to determine if the home range size of juvenile lake sturgeon differed among sections of the study area. Mean values are presented ± 1 SD.

5.2.3.2 Acoustic telemetry

Providing an accurate estimate of home range size using the acoustic telemetry data set was difficult due to gaps in the detection area of the receiver array, and the omni-directional nature of VR2 receivers which only indicate the presence of a tagged fish within the detection range of the receiver. Overall and seasonal home range estimates reflect the maximum distance in rkm that a tagged juvenile lake sturgeon could have moved prior to being located by an adjacent receiver, accounting for both the detection radius of each receiver, and gaps in the receiver array. For example, seasonal home range size was calculated as the total distance between receivers at the furthest upstream and downstream extent of an individual's movement range, and adding 700 m to account for the 350 m detection radius of each receiver plus any distance outside the detection radius of adjacent receivers to account for movement potential. Blind spots in the receiver array were located between the Slave Falls GS and receiver #1 (rkm 0.0 - 0.3), between receiver #2 and receiver #3 (rkm 1.5 – 1.8), between receiver #3 and #4 (rkm 2.5 – 2.6), and between receiver #5 and #6 (rkm 3.9 – 4.8) (Figure 5.1).

To examine seasonal home range size and seasonal movement patterns, movement distance was measured for each individual fish by time period: i) Spring: May 1 to July 10, 2007; water temperature range 5ºC - 18ºC; ii) Summer: July 11 to September 30, 2007; water temperature range 15ºC - 22ºC; iii) Fall: October 1 to December 10 2007; water temperature range 1ºC - 15ºC; and iv) Winter: December 11 , 2007 to April 30, 2008; water temperature range 1ºC - 5ºC. A Kruskal-Wallis non-parametric comparison using Dunn's procedure for multiple comparisons was used to examine seasonal differences in home range size as data were non-normal and heteroscedastic even following transformation. Statistical analyses were conducted using XLSTAT (Version 2006.2) in Excel (Microsoft Corporation, Redmond, California). A significance level of $P < 0.05$ was used for all statistical analyses.

5.3 Results

5.3.1 Mark and recapture

In total, 5,671 tags (Floy and PIT combined) were applied to lake sturgeon measuring < 879 mm FL between May 2006 and October 2008 (Table 5.1). The majority of the tags were applied in RS-1, followed by RS-2 and RS-3, and 78% were applied to lake sturgeon less than 530 mm FL (Table 5.1). Fewer tags were applied in the downstream sections of the study area, indeed, throughout the 30 months of study, lake sturgeon were absent from gill net catches in the most downstream section, Natalie Lake (RS-8). A total of 714 marked juvenile lake sturgeon were recaptured during the study, with the majority of the recaptures occurring in RS-1, followed by RS-2, RS-4, and RS-3. Unsurprisingly, fish < 530 mm FL formed the majority of recaptures and the greatest percentage of recaptures by river section occurred in RS-1 (Table 5.1).

Using only fish recaptured > 30 days post-tagging (Table 5.2), a linear relationship was not observed between the number of days between recapture events and distance moved (rkm) ($P = 0.06$, $r^2 = 0.01$). Over the 30-month study period, only seven of the 714 recaptured juvenile lake sturgeon were found to traverse river section boundaries (Table 5.2). Of these seven, only one traversed the study area boundaries in an upstream direction. Fish recaptured in RS-4 exhibited the longest overall mean movement distance, followed by RS-1, RS-3, and RS-2 (Table 5.2). Although sample sizes were unequal, home range size differed significantly among river sections (Kruskal Wallis, $P < 0.0001$).

Due to the limited spatial extent of juvenile lake sturgeon movements and differences between the timing of original mark and recapture dates, it was difficult to identify seasonal movement patterns using the mark and recapture data within each RS. In all RS's combined, 90.8% of the recaptured juvenile lake sturgeon were recaptured less than 2.0 rkm from their original tagging location (Figure 5.2). Of the 343 fish that were originally marked in RS-1 and subsequently recaptured > 30 days after the original tagging date, 60.6% moved less than 1.0 rkm from their original tagging location. Similarly, 86.1%, 100.0%, and 71.4% of the marked fish were recaptured < 1.0 rkm from their original tagging location in RS-2, RS-3, and RS-4, respectively (Figure 5.3). A linear relationship between body size (FL) and movement distance (home range size) was not observed for juvenile lake sturgeon within any RS.

5.3.2 Acoustic telemetry

Twenty-three juvenile lake sturgeon were implanted with V9 acoustic transmitters between May 29 and May 31, 2007. Each fish was captured and released in the same area located approximately 0.5 rkm downstream of rkm 0, the Slave Falls GS (Figure 5.2). Tagged juvenile lake sturgeon had a mean FL of 425 ± 33 mm (range: 364 – 505 mm) and a mean mass of 456 ± 86 g (range: 316 – 665 g). The data set from these 23 juvenile lake sturgeon consisted of 663,945 relocations with a mean of 28,867 ± 27,704 valid detections for each individual fish (range: 60 – 104,511). The number of days relocated for each fish varied from 3 to 232 days (mean = 131 ± 61 days) (Appendix 5.1). Three fish were omitted from further analysis due to transmitter malfunction, or downstream displacement following surgical procedures and the subsequent results section is based on the movement of 20 acoustically tagged fish that remained in RS-1.

Ten of the acoustically tagged juvenile lake sturgeon remained in the vicinity of the capture and release location, being relocated exclusively by the two furthest upstream receivers. These fish utilized 1.5 rkm or less over the period their transmitters were active (Table 5.3). The second general pattern, observed in nine of the remaining 10 fish, was the downstream dispersal (> 3.0 rkm) from the release location to the downstream portion of RS-1. Five of these nine sturgeon moved as far downstream as receiver #64, potentially using the entire length of RS-1. Overall mean movement distance for acoustically tagged juvenile lake sturgeon was 3.2 ± 1.9 rkm (Table 5.3). A weak linear correlation was observed between home range size and body size (FL) (linear regression; $P = 0.03$; $r^2 = 0.24$).

The number of active transmitters varied among seasons as 19 were active during spring, four during summer, 11 during fall, and 15 during winter (Table 5.3). Mean home range size did not differ significantly between seasons (Kruskal Wallis; $P = 0.38$) (Table 3). This result may not be surprising considering half the acoustically tagged juvenile lake sturgeon remained in the vicinity of their capture and release location, and 16 of the 20 tagged individuals were relocated by only two receivers for > 88% of their total relocation days (Table 5.4); however, some seasonal movement patterns were observed. During fall, five juvenile lake sturgeon moved downstream from where they were located during summer, or were first relocated > 3 rkm downstream from their initial release location when their transmitters became active. During winter, 13 of the 15 acoustically tagged sturgeon were relocated by either one receiver or two adjacent receivers for the entire winter period (Table 5.4). Finally, during spring, five acoustically tagged juvenile lake sturgeon moved from downstream overwintering locations, upstream to the Slave Falls GS between May 15 and May 29, 2008.

5.4 Discussion

In the present study, acoustic telemetry led to a more detailed examination of spatial and temporal movements of juvenile lake sturgeon, while mark and recapture simultaneously allowed for the examination of movements from a large number of fish over multiple years. Both methodologies were effective at providing home range estimates; however, some consideration of potential biases and uncertainties associated with each should be considered. First, unequal sampling effort occurred between and within different sections of the study area. The majority of the acoustic telemetry and mark and recapture work was conducted in RS-1 and RS-2, (i.e., the upstream reaches of the study area). Although this limits our understanding of juvenile lake sturgeon movements in the downstream reaches, it allows for a detailed examination of movements in the upstream reaches where juvenile lake sturgeon are known to be most abundant (Barth, unpublished). Secondly, there are limits to the level of precision or accuracy associated with the use of the acoustic telemetry. Due to uncertainties associated with blind spots in the receiver array, home range size estimates essentially represented the maximum distance in rkm that a juvenile could have moved prior to being detected. As a consequence, home range size was likely overestimated for most fish.

Regardless of these uncertainties, the results indicate that juvenile lake sturgeon in the Winnipeg River exhibit high site fidelity and occupy small home ranges in relatively short river sections. These results suggest that the year-round habitat requirements for juvenile lake sturgeon in large rivers can be met in relatively short river sections. Within the Great Lakes watershed, three studies have also found that juvenile lake sturgeon exhibit a high degree of site fidelity and occupy relatively small home range areas. Holtgren and Auer (2004) tracked four juvenile (220 – 830 mm FL) lake sturgeon in the Sturgeon River/Portage Lake system, Michigan, and found that fish moved an average of 15.5 km (+/- 7.2 SD) over an 83-day period (total linear movement), and occupied a mean home range area of 11.0 km^2 (+/- 9.9 SD). Lord (2007) implanted transmitters into nine juvenile lake sturgeon (582 cm – 793 mm TL) in the St. Clair River, Michigan, and found that juvenile sturgeon occupied home range areas that varied between 0.8 km^2 and 10.8 km^2 over two years of study. Finally, Smith and King (2005) estimated home range size over a four-month period (July – October) for five juvenile lake sturgeon (785 – 1135 mm TL), in Black Lake, Michigan, and home range area varied between 4.79 km^2 and 7.27 km^2.

Taken together, these results suggest that juvenile lake sturgeon may occupy smaller home ranges when compared with other species of similar length. Jordan et al. (2006) used radio telemetry to study movement of hatchery raised juvenile pallid sturgeon, *Scaphyrhinchus albus*, (520 – 613 mm FL) in the Missouri River below the Fort Randall dam. Results indicated that pallid sturgeon remained near their stocking site, using on average 8.3 rkm during the first year of study. However, in the subsequent two years, mean range of movement was greater, averaging 29.3 and 28.9 rkm. In a subsequent telemetry study, home range size of juvenile pallid sturgeon (mean FL 511 ± 29 mm) on the Missouri River varied between 1.1 rkm and 73.9 rkm, and for shovelnose sturgeon, *Scaphyrhinchus platorynchus,* (mean FL 497 ± 29 mm) between 0.7 rkm and 41.5 rkm over a 4 – 9-month period (Gerrity et al. 2008).

One of the most surprising results of this study was the limited upstream or downstream movement of juvenile lake sturgeon through natural sets of rapids such as Scotts Rapids, Sturgeon Falls, and Barrier Bay (Figure 2.1). Movement through Scotts Rapids and Sturgeon Falls, where water depth is generally < 5.0 m and water velocities are > 1.5m.sec^{-1}, was practically non-existent; however, movement through Barrier Bay where water velocity is similar but water depth is greater (i.e., > 10 m) was still low but more frequent relative to Scotts Rapids and Sturgeon Falls. These results suggest that transitions in habitat, specifically shallow (< 5.0 m), fast flowing rapids, may act as natural barriers to juvenile lake sturgeon movement in this study area.

The notion that habitat breaks and boundaries in continuous habitat are linked to fish movement and home range size has been reported in a number of marine reef dwelling fish species such as Cunner, *Tautogolabrus adspersus,* Coral trout, *Plectropomus leopardus,* Kelp bass, *Paralabrax clathratus,* and California sheephead, *Semicossyphus pulcher* (Bradbury et al. 1995; Zeller 1997; Lowe et al. 2003; Topping et al. 2005). For example, deep, sandy expanses of habitat were found to act as natural boundaries to the movements of Kelp bass and California sheephead (Lowe et al. 2003; Topping et al. 2005). Similarly, home range size in Cunner was related to bottom relief such as boulders and crevices as fish would not enter open, sandy areas devoid of cover (Bradbury et al. 1995). The present study suggests that the length of river between sets of rapids, or the length of continuous deep water habitat, may similarly affect home range size and movement of juvenile lake sturgeon.

Core areas of habitat use, defined as smaller areas within an animal's home range that are used more frequently, have been observed in several fish species including adult lake sturgeon from two populations (Borkholder et al. 2002; Knights et al. 2002). A high proportion of the acoustically tagged juvenile lake sturgeon in this study were relocated by adjacent receivers (Table 5.4), which supports the notion that juvenile lake sturgeon in the Winnipeg River also occupy core areas of habitat use within their home range. Additionally, the home range size estimate in RS-1 was lower (0.96 ± 1.07 rkm) using the mark and recapture data set relative to the acoustic telemetry data set (3.2 ± 1.9 rkm) (tables 2 and 3). Occupation of a core area may explain this result as fish may have a higher probability of capture and recapture inside their core area.

Establishing a seasonal movement pattern for juvenile lake sturgeon in this population was difficult because the majority of the tagged fish exhibited high site fidelity and remained in the vicinity of their original tagging location. In the Great Lakes watershed, several studies have documented the downstream movement of YOY lake sturgeon during fall (Thuemler 1988; Kempinger 1996; Holtgren and Auer 2004; Benson et al. 2005). Benson et al. (2005) suggested that the purpose of the downstream movement was to locate areas of low water velocity that may offer more suitable overwintering refuges. Similarly, in this study several acoustically tagged juvenile lake sturgeon moved downstream during fall. It is possible that these downstream movements were also made in relation to a water velocity gradient, as water velocities are generally lower in the downstream portion of RS-1. During winter, a high proportion (87%) of tagged juvenile lake sturgeon were relocated by either one or two receivers for the entire season and, additionally, the number of days that these fish were not relocated was greater relative to the other seasons (Table 5.3). These data suggest that activity rate may be reduced and that fish were even more sedentary during this period. Lastly, during spring, several acoustically tagged juvenile lake sturgeon moved upstream to the Slave Falls GS either prior to or during the period that lake sturgeon were known to have spawned in the area. Since juvenile lake sturgeon have been found to consume sturgeon eggs in this study area (Barth, unpublished), it is possible that these movements were undertaken for the purposes of foraging on eggs deposited by spawning adults, or accompanying adults to the spawning ground, a behaviour that has been observed in other sturgeon populations (Peterson et al. 2002).

Evidence to suggest a correlation between body size and home range size in the present study was inconclusive as significant linear relationships were not observed within any RS using the mark and recapture data set, while a weak relationship was observed using the acoustic telemetry data set. However, home range size has been linearly related to body size in several species of fish from both freshwater (Minns 1995; Keeley and Grant 1997) and marine environments (Morrissey and Gruber 1993; Kramer and Chapman 1999). Smith and King (2005) suggested a linear relationship between movement distance and body size in juvenile lake sturgeon in Black Lake, Michigan. These authors found that juveniles longer than 90 cm TL (range: 90 – 113.5 cm) displayed longer daily movements and occupied larger home ranges than juveniles measuring less than 90 cm (range: 78.5 – 79.5 cm). It is possible that if sub-adult or adult lake sturgeon had been included in this study then a relationship between home range size and body size may have become more apparent. However, adult lake sturgeon from several different populations have also been reported as largely sedentary (Threader and Brousseau 1986; Sandilands 1987; Fortin et al. 1993) and a few studies have also suggested that adults remain within a river basin despite the potential for both upstream and downstream movements (Borkholder et al. 2002; Haxton 2003). Further research is needed in this population to determine the size or age at which lake sturgeon expand their home range, and/or begin to traverse constrictions of the Winnipeg River.

Food availability and seasonal change in habitat productivity are additional factors that may influence home range size in fish populations. Minns (1995) suggested that riverine fish species occupy smaller home ranges than fish in lakes because food resources may be continually delivered by river currents, thus reducing the amount of area and time necessary to search for food. However, foraging in areas of higher water velocity, and potentially larger quantities of drifting food items, must be traded off with the energy expended to retain position in areas of higher flow. Although thought of as poor swimmers, sturgeons have been described as a species that are morphologically adapted for bottom holding, a behaviour employed to conserve energy while holding position in the current (Adams et al. 1999; Peake 2004). Bottom holding may provide an advantage for exploiting the food resources in main channel environments of large riverine systems and provide a plausible explanation for the observed limited home range size.

A final, potentially important influence over home range size is predation risk and the capacity of the home range to provide refuge from predators. It is possible that juvenile lake sturgeon occupy small home ranges to reduce the risk of predation through familiarity with escape routes (Stamps 1995), or shelter. However, many of the habitat types that juveniles occupy in the Winnipeg River study area, (i.e., flat expanses of sand, gravel) (Barth et al. 2009), lack obvious areas of refuge. Therefore, predator avoidance for lake sturgeon in this habitat would require a relatively good burst swimming capacity, which has not been examined closely in sturgeons, but is thought to be poor relative to other pelagic species (Peake 2004); adoption of a cryptic form that facilitates escape through non-detection; a reliance on body armour (i.e., sharp scutes) to deter predators; and/or living in groups which can either confuse the predator or bet hedge by reducing an individuals' probability of being captured. Predator avoidance may well have contributed to habitat selection in juvenile lake sturgeon as the observed limited movement of juveniles through habitat transitions suggest that juvenile lake sturgeon may be at a disadvantage relative to other pelagic species in shallower, near shore habitats where predators are found in higher abundance (Barth et al. 2009).

Development of effective management and conservation strategies for lake sturgeon relies upon an understanding of the processes that influence survival at each life history stage. However, improving this understanding in juvenile lake sturgeon is difficult for several reasons. First, few abundant populations of lake sturgeon remain to facilitate detailed study. Secondly, lake sturgeon inhabit a diversity of habitats, ranging from large rivers to smaller tributaries systems across a wide latitudinal gradient. Due to the diversity of abiotic and biotic conditions that lake sturgeon encounter throughout their range, studies from a number of populations are necessary to improve our understanding. Thirdly, juvenile lake sturgeon, at least in the Winnipeg River, have been shown to congregate in deep water habitats that are difficult to accurately sample (Barth et al. 2009), my study has shown that sturgeon rarely move through rapids or transitions in habitat. These results have important implications for population estimation and habitat assessment since juvenile lake sturgeon may be abundant yet difficult to locate without significant amounts of sampling effort, and suitable juvenile rearing areas could be underutilized if larvae or young-of-the-year do not disperse to these areas. Finally, further study within this population is needed to determine the relative condition and growth rate of this population, and the size or age at which juvenile lake sturgeon increase their home range size and/or begin to move through sets of rapids. Studies on other populations are also required to determine if these movement patterns are similar across the species range.

5.5 References

Adams, S. R.; Hoover, J. J.; Kilgore, K. J., 1999: Swimming endurance of juvenile Pallid sturgeon, *Scaphyrhnchus albus*. Copeia **1999**, 802-807.

Anderson, W. G.; McKinley, R. S.; Colavecchia, M., 1997: The use of clove oil as an anaesthetic for rainbow trout and its effect on swimming performance. N. Am. J. Fish. Manage. **17**, 301-307.

Auer, N. A., 1996: Importance of habitat and migration to sturgeons, with emphasis on lake sturgeon. Can. J. Fish. Aquat. Sci. **53**, 152-160.

Barth, C. C.; Peake, S. J.; Allen, P. J.; Anderson, W. G., 2009: Habitat utilization of juvenile lake sturgeon, *Acipenser fulvescens*, in a large Canadian river. J. Appl. Icthyol. **25** (Suppl.2), 18-26.

Beamesderfer, R. C. P.; Farr, R. A., 1997: Alternatives for the protection and restoration of sturgeons and their habitat. Environ. Biol. Fish. 48, 407-417.

Benson, A. C.; Sutton, T. M.; Elliot, R. F.; Meronek, T. G., 2005: Seasonal movement patterns and habitat preferences of age-0 lake sturgeon in the Lower Peshtigo River, Wisconsin. Trans. Am. Fish. Soc. **134**, 1400-1409.

Birstein, V. J., 1993. Sturgeons and paddlefishes: threatened fishes in need of conservation. Cons. Biol. **7**, 773-787.

Borkholder, B. D.; Morse, S. D.; Weaver, H. T.; Hugill, R. A.; Linder, A. T.; Schwartzkopf, L. M.; Perrault, T. E.; Zacher, M. J.; Frank, J. A., 2002: Evidence of a year-round resident population of lake sturgeon in the Kettle River, Minnesota, based on radio-telemetry and tagging. N. Am. J. Fish. Manage. **22**, 888-894.

Bradbury, C.; Green, J. M.; and Bruce-Lockhart, M., 1995: Home range of female Cunner *Tautogolabrus adspersus* (Labridae), as determined by ultrasonic telemery. Can. J. Zool. **73**, 1268-1279.

COSEWIC. 2006. COSEWIC assessment and update status report on the lake sturgeon *Acipenser fulvescens* in Canada. Committeee on the Status of Endangered Wildlife in Canada. Ottawa. (www.sararegistry.gc.ca/status/status_e.cfm).

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

Gerking, S. D., 1959: The restricted movement of fish populations. Biol. Rev. **34**, 221-242.

Gerrity, P. C.; Guy, C. S.; Gardner, W. M., 2008: Habitat use of juvenile pallid sturgeon and shovelnose sturgeon with implication for water-level management in a downstream reservoir. N. Am. J. Fish. Manage. **28**, 832-843.

Hay-Chmielewski, E. M., 1987: Habitat preferences and movements patterns of the lake sturgeon in Black Lake, Michigan. M. Sc. Thesis. University of Michigan, Ann Arbour, MI, USA.

Haxton, T., 2003: Movement of lake sturgeon, (*Acipenser fulvescens*), in a natural reach of the Ottawa River. Can. Field. Nat. **117**, 541-545.

Holtgren, J. M.; Auer, N. A., 2004: Movement and habitat of juvenile lake sturgeon (*Acipenser fulvescens*) in the Sturgeon River/Portage Lake system, Michigan. J. Freshwat. Ecol. **19**, 419-432.

Jepsen, N.; Koed, A.; Thorstad, E. B.; Baras, E., 2002: Surgical implantation of telemetry transmitters in fish: how much have we learned? Hydrobiologia **483**, 239-248.

Jordan, G. R.; Klumb, R. A.; Wanner, G. A.; Stancill, W. J., 2006: Poststocking movements and habitat use of hatchery-reared juvenile Pallid sturgeon in the Missouri River below Fort Randall Dam, South Dakota and Nebraska. Trans. Am. Fish. Soc. **135**, 1499-1511.

Keeley, E. R.; Grant, J. W. A., 1995: Allometric and environmental correlates of territory size in juvenile Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. **52**, 186-196.

Kempinger, J. J., 1996: Habitat, growth, and food of young lake sturgeons in the Lake Winnebago system, Wisconsin. N. Am. J. Fish. Manage. **16**, 102-114.

Knights, B. C.; Vallazza, J. M.; Zigler, S. J.; Dewey, M. R., 2002. Habitat and movement of lake sturgeon in the Upper Mississippi River system, USA. Trans. Am. Fish. Soc. **131**, 507-522.

Kramer, D. L.; Chapman, M. R., 1999. Implications of fish home range size and relocation for marine reserve function. Environ. Biol. Fish. **55**, 65-79.

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

Lord, K., 2007: Movements and habitat use of juvenile lake sturgeon in the North Channel of the St. Clair River. M. Sc. Thesis, University of Michigan, Ann Arbor, MI, USA.

Lowe, C. G.; Topping, D. T.; Cartamil, D. P.; Papastamatiou, Y. P., 2003: Movement patterns, home range, and habitat utilization of adult Kelp bass *Paralabrax clathratus* in a temperate no-take marine reserve. Mar. Ecol. Prog. Ser. **256**, 205-216.

McKinley, S. R.; Van Der Kraak, G.; Power, G., 1998: Seasonal migrations and reproductive patterns in the lake sturgeon, *Acipenser fulvescens*, in the vicinity of hydroelectric stations in northern Ontario. Environ. Biol. Fish. **51**, 245-256.

Minns, C. K., 1995: Allometry of home range size in lake and river fishes. Can. J. Fish. Aquat. Sci. **52**, 1499-1508.

Morrissey, J. F.; Gruber, S. H., 1993: Home range of juvenile Lemon Sharks, *Negaprion brevirostris*. Copeia **1993**, 425-434.

Peake, S. J., 2004: An evaluation of the use of critical swimming speed for determination of culvert water velocity criteria for smallmouth bass. Trans. Am. Fish. Soc. **133**, 1472-1479.

Peterson, D.; Gunderman, B.; Vecsei, P., 2002. Lake sturgeon of the Manistee River: a current assessment of spawning stock size, age and growth. Am. Fish. Soc. Symp. **28**, 175-182.

Peterson, D.; Vesci, P.; Jennings, C. A., 2007: Ecology and biology of the lake sturgeon: a synthesis of current knowledge of a threatened North American Acipenseridae. Rev. Fish. Biol. Fisheries **17**, 59-76.

Rusak, J. A.; Mosindy, T., 1997: Seasonal movements of lake sturgeon in the Lake of the Woods and the Rainy River, Ontario Can. J. Zool. **74**, 383-395.

Sandilands, A. P., 1987: Biology of the lake sturgeon (Acipenser fulvescens) in the Kenogami River, Ontario. In: Proceedings of a workshop on the Lake sturgeon (*Acipenser fulvescens*). Ont. Tech. Rep. Fish. Ser. No. 23 pp. 33 - 46.

Secor, D. H.; Anders, P. J.; Van Winkle, W.; Dixon, D. A., 2002: Can we study sturgeons to extinction? What we do and don't know about the conservation of North American Sturgeons. Am. Fish. Soc. Symp. **28**, 3-10.

Simpfendorfer, C. A.; Heupel, M. R.; Hueter, R. E., 2002: Estimation of short-term centers of activity from an array of omni-directional hydrophones and its use in studying animal movements. Can. J. Fish. Aquat. Sci. **59**, 23-32.

Smith, K. M.; King, D., 2005: Movement and habitat use of yearling and juvenile lake sturgeon in Black Lake, Michigan. Trans. Am. Fish. Soc. **134**, 1159-1172.

Stamps, J., 1995. Motor learning and the value of familiar space. Am. Nat. **146**, 41-58.

St. George, S., 2006: Hydrological dynamics in the Winnipeg River basin, Manitoba. In: Report of activities 2006. Manitoba Geological Survey. pp. 226-230.

Threader, R.; Brousseau, C. S., 1986: Biology and Management of the Lake Sturgeon in the Moose River, Ontario. N. Am. J. Fish. Manage. **6**, 383-390.

Thuemler, T. F., 1988: Movements of young lake sturgeons stocked in the Menominee River, Wisconsin. Am. Fish. Soc. Symp. **5**, 104-109.

Topping, D. T.; Lowe, C. G.; Caselle, J. E., 2005: Home range and habitat utilization of California sheephead, *Semicossyphus pulcher* (Labridae), in a temperate no-take marine reserve. Mar. Biol. **147**, 301 – 311.

Wagner, G. N.; Stevens, E. D.; Byrne, P., 2000: Effects of suture type and patterns on surgical wound healing in rainbow trout. Trans. Am. Fish. Soc. **129**, 1196-1205.

Williams, J. E.; Johnson, J. E.; Hendrickson, D. A.; Contreras-Balderas, S.; Williams, J. D.; Navarro-Mendoza, M.; McAllister, D. E.; Deacon, J. E., 1989: Fishes of North America Endangered, Threatened, or of special concern: 1989. Trans. Am. Fish. Soc. **14**, 2-20.

Zeller, D. C., 1997: Home range and activity patterns of the coral trout *Plectropomus leopardus* (Serranidae). Mar. Ecol. Prog. Ser. **154**, 65-77.

Table 5.1. Number of fish marked (M) and recaptured (R), by fork length (mm), and river section (RS) of the Winnipeg River study area, May 2006 - October 2008. Percent recaptures for each size class (%R) calculated as (M/R)*100. Percent of recaptured fish for each river section (%M/R) calculated as (total M/total R)*100.Table includes multiple recaptures.

	Fork length interval (mm)																												
	< 279		280-329		330-379		380-429		430-479		480-529		530-579		580-629		630-679		680-729		730-779		780-829		830-879		Total		%M/R
RS	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	
RS-1	84	8	51	10	653	106	972	208	352	96	35	5	27	4	73	8	92	10	40	3	23	1	43	2	28	1	2473	462	18.7
RS-2	35	3	73	7	452	44	867	95	520	57	99	12	4	0	19	1	45	3	56	0	17	0	19	0	17	0	2223	222	10.0
RS-3	1	0	4	0	7	1	82	0	177	4	248	5	134	3	25	0	7	1	1	0	1	0	2	0	8	0	697	14	2.0
RS-4	0	0	0	0	4	0	2	0	5	0	34	1	56	2	71	8	53	5	15	0	4	0	1	0	1	0	246	16	6.5
RS-5	4	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	3	0	1	0	0	0	0	0	11	0	0.0
RS-6	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	4	0	5	0	1	0	1	0	0	0	12	0	0.0
RS-7	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	5	0	0	0	1	0	0	0	9	0	0.0
RS-8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Total	124	11	128	17	1116	151	1923	303	1054	157	419	23	221	9	189	17	204	19	125	3	47	1	67	2	54	1	5671	714	
% R		8.9		13.3		13.5		15.8		14.9		5.5		4.1		9.0		9.3		2.4		2.1		3.0		1.9		7.9	

Table 5.2. Number of recaptured juvenile lake sturgeon collected at different time intervals, mean movement distance (MD) (rkm) (± 1 SD) and number of individuals that moved between river section (BRS) in the Winnipeg River, May 2006 - October 2008. Letters represent significant, or lack of significant differences among groups. A significance level of P < 0.05 was used.

	Days between mark and recapture				Mean MD*	SD	Range	RS length	BRS
RS	< 30	30 - 365	> 365	Total > 30	(rkm)		(rkm)	(rkm)	
RS-1	119	243	100	343	0.96 (a)	1.07	0.0 - 6.2	6.0	1
RS-2	35	108	79	187	0.61 (b)	0.60	0.0 - 3.3	4.0	2
RS-3	4	6	4	10	0.71 (ab)	0.71	0.0 - 2.2	4.0	1
RS-4	2	12	2	14	1.44 (a)	2.00	0.1 - 5.8	9.0	3
Total	160	369	185	554	0.84	0.80	0.0 - 6.2		7

* Mean MD only includes fish captured > 30 days from original tagging date.

Table 5.3. Movement distance, by season, for 20 acoustically tagged juvenile lake sturgeon in the Winnipeg River, 2007 and 2008. Data expressed in river kilometers +/- 1 SD. DNR = days not relocated.

	Movement distance (rkm)				
Code #	Overall	Spring	Summer	Fall	Winter
2056	1.5	1.5	-	-	1.5
2057	5.5	5.5	-	-	2.9
2058	1.5	1.5	-	-	0.9
2059	1.5	1.5	-	-	1.5
2060	5.5	3.6	-	-	3.0
2061	5.5	5.5	-	-	2.3
2063	4.8	4.8	-	-	2.3
2064	1.5	1.5	-	-	0.9
2065	1.5	1.5	-	1.5	1.5
2066	4.8	3.0	-	2.3	2.5
2068	5.5	2.9	-	2.9	2.2
2069	1.5	1.5	-	1.5	1.5
2070	4.8	-	-	4.8	-
2071	1.5	1.5	-	1.5	1.5
2072	1.5	1.5	-	1.5	1.5
2073	2.4	2.4	-	0.9	0.9
2075	1.5	1.5	1.5	-	-
2078	1.5	1.5	1.5	1.5	-
2080	4.8	2.4	0.9	3.0	-
2081	5.5	1.5	2.4	3.6	-
Mean	3.2(a)	2.5(a)	1.6(a)	2.3(a)	1.8(a)
SD	1.9	1.4	0.6	1.2	0.7
Range	1.5 - 5.5	1.5 - 5.5	0.9 - 2.4	0.9 - 4.8	0.9 - 3.0
Mean DNR	37.1	5.4	1.8	7.7	36.5
SD	42.6	5.6	2.9	11.4	39.1

Table 5.4. Number of relocation (R) days, by receiver, and percentage of relocation days by one and two receivers (%R days 1 rec, %R days 2 rec) for each of 20 acoustically tagged juvenile lake sturgeon in the Winnipeg River, 2007 and 2008. Note: Number R days by each receiver may not add up to total R days because fish may have been relocated by more than 1 receiver on a given day.

	Receiver #						Total R days	%R days 1 rec	%R days 2 rec
Code #	74	72	70	69	67	64			
2056	109	149	-	-	-	-	258	57.8	100.0
2057	41	28	1	8	57	15	150	38.0	65.3
2058	8	81	-	-	-	-	89	91.0	100.0
2059	148	133	-	-	-	-	281	52.7	100.0
2060	-	-	4	159	159	4	326	48.8	97.5
2061	58	59	1	4	24	19	165	35.8	70.9
2063	3	5	2	90	102	-	202	50.5	95.0
2064	49	152	-	-	-	-	201	75.6	100.0
2065	184	231	-	-	-	-	415	55.7	100.0
2066	-	-	4	48	166	-	218	76.1	98.2
2068	-	-	-	16	95	28	139	68.3	88.5
2069	151	49	-	-	-	-	200	75.5	100.0
2070	10	11	16	16	12	-	65	24.6	49.2
2071	23	39	-	-	-	-	62	62.9	100.0
2072	201	145	-	-	-	-	346	58.1	100.0
2073	24	26	156	-	-	-	206	75.7	88.3
2075	78	78	-	-	-	-	156	50.0	100.0
2078	105	120	-	-	-	-	225	53.3	100.0
2080	16	16	176	3	2	-	213	82.6	90.1
2081	75	75	30	26	31	58	295	25.4	50.8

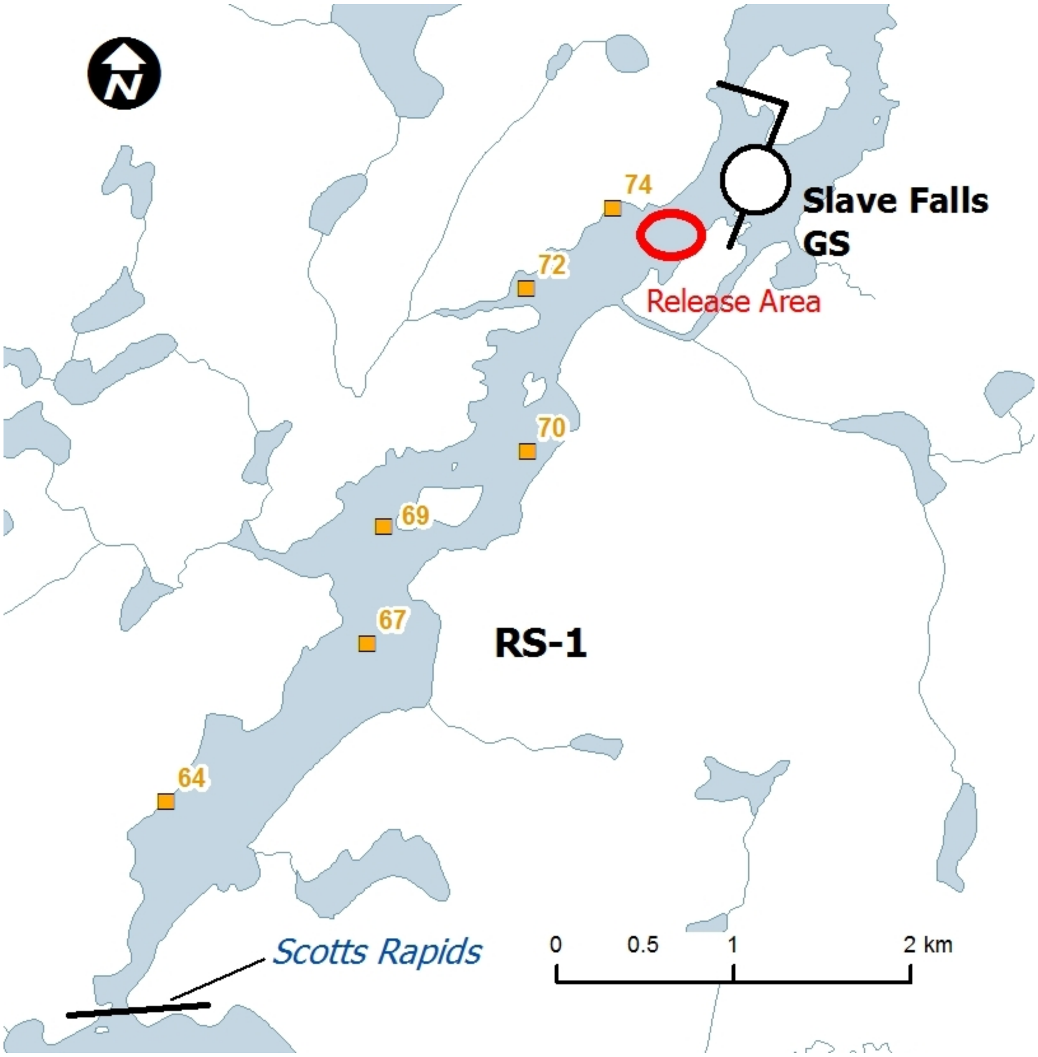

Figure 5.1. Location of the six stationary VR-2 receivers used to monitor movements of 20 acoustically tagged juvenile lake sturgeon in RS-1 of the Winnipeg River study area, 2007 and 2008.

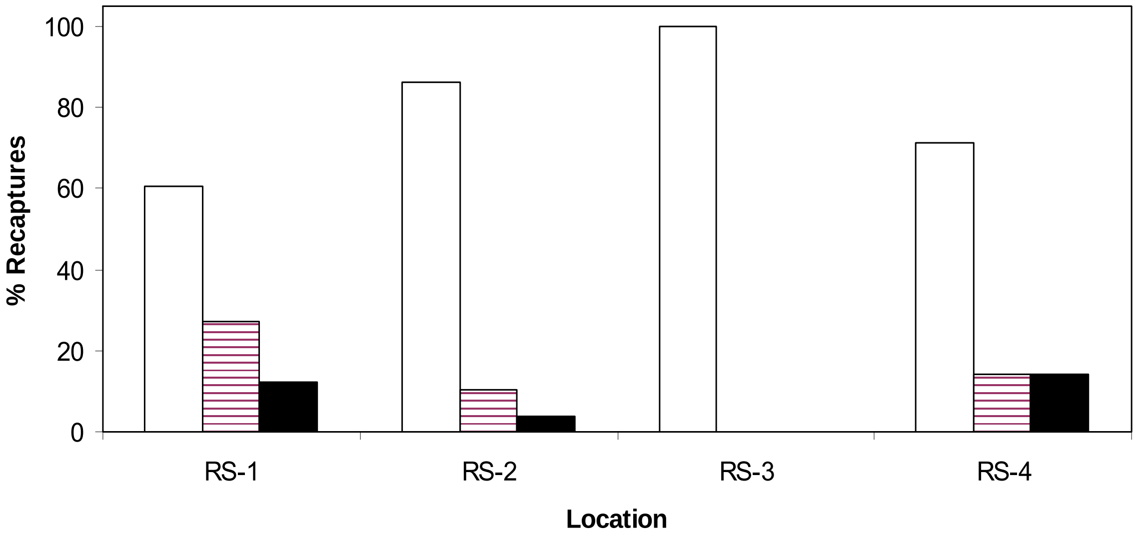

Figure 5.2. Percentage of recaptured juvenile lake sturgeon by distance category, 0.0 - 1.0 rkm (unfilled bars), 1.1- 2.0 rkm (horizontal line bars) and > 2.0 rkm (filled bars) in each of four river sections in the Winnipeg River study area, 2006 - 2008.

Appendix 5.1. Biological characteristics and tracking information for lake sturgeon tagged with acoustic transmitters in the Winnipeg River, 2007. Tag weight (TW) to fish weight (FW), date released (DR), #R (#relocations), days R (days relocated).

Code #	FL (mm)	TL (mm)	Mass (g)	% TW to FW	DR	# R	# Days R	Date FD	Date LD
2055	364	395	359	1.0	30-May-07	44,832	108	05-Feb-08	03-Jul-08
2056	458	515	535	0.7	31-May-07	57,581	149	03-Feb-08	10-Jul-08
2057	436	492	450	0.8	30-May-07	10,334	109	04-Feb-08	10-Jul-08
2058	399	441	316	1.1	30-May-07	4,232	81	08-Feb-08	10-Jul-08
2059	406	460	419	0.9	30-May-07	22,907	150	03-Feb-08	10-Jul-08
2060	409	468	418	0.9	31-May-07	104,511	159	03-Feb-08	10-Jul-08
2061	447	505	490	0.7	30-May-07	30,188	96	14-Feb-08	10-Jul-08
2062	433	484	479	0.8	31-May-07	60	3	03-Feb-08	05-Feb-08
2063	413	461	427	0.8	31-May-07	34,142	125	03-Feb-08	19-Jun-08
2064	391	453	367	1.0	31-May-07	34,864	153	03-Feb-08	10-Jul-08
2065	412	473	369	1.0	31-May-07	87,332 (3,198*)	232	01-Oct-07	12-Jun-08
2066	434	489	508	0.7	31-May-07	15,689	167	01-Oct-07	07-Jun-08
2067	425	483	487	0.7	31-May-07	1,454	76	01-Jun-07	10-Dec-07
2068	505	562	665	0.5	31-May-07	36,094	177	01-Oct-07	09-Jun-08
2069	465	534	547	0.7	31-May-07	6,085 (34*)	158	15-Oct-07	11-May-08
2070	451	514	524	0.7	31-May-07	7,901 (316*)	42	01-Oct-07	18-Nov-07
2071	397	453	358	1.0	31-May-07	268	45	08-Oct-07	23-May-08
2072	425	489	482	0.7	31-May-07	24,173 (751*)	214	01-Oct-07	27-May-08
2073	435	487	475	0.8	31-May-07	9592	183	07-Oct-07	14-Jun-08
2075	401	455	353	1.0	29-May-07	5,154 (5,154*)	68	01-Jun-07	02-Sep-07
2078	370	414	375	1.0	29-May-07	28,546 (6694*)	116	02-Jun-07	27-Mar-08
2080	470	536	585	0.6	31-May-07	60,492	193	01-Jun-07	10-Dec-07
2081	435	493	497	0.7	31-May-07	37,514 (2,864*)	217	01-Jun-07	10-Dec-07
Total						663,945			
Mean	425	481	456			28,876	131		
SD	33	38	86			27704	61		

* = number of relocations by the VRAP system.

Chapter 6: Variation in abundance and biological characteristics of juvenile lake sturgeon, Acipenser fulvescens, within an impounded reach of a large river

6.0 Chapter Abstract

Juvenile lake sturgeon rarely move among eight sections of a 41 km long impoundment on the Winnipeg River (Chapter 5), suggesting that juvenile lake sturgeon exist as behaviorally isolated subpopulations in this study area. The purpose of this chapter was to describe and compare the abundance and biological characteristics among subpopulations of juvenile lake sturgeon in the Winnipeg River study area. Mean CPUE's of juvenile lake sturgeon occupying upstream sections (RS-1, RS-2 and RS-3) were significantly greater than downstream sections (RS-4, RS-5, RS-6, RS-7 and RS-8) (Kruskal Wallis, Dunn's $p < 0.0001$). Condition factor and growth were inversely related to abundance as subpopulations occupying RS-1 and RS-2 exhibited lower condition and slower growth, relative to subpopulations in RS-3 (moderate) and RS-4 to RS-7, combined (highest) (ANCOVA, $P < 0.0001$, Tukeys HSD, $P < 0.0001$). Biotic factors such as environmental productivity, and/or interspecific competition for food, may be responsible for the differences in growth among subpopulations. Further, the limited movement of juveniles and their unequal abundance and distribution, suggests that the distribution and/or mortality of lake sturgeon at the egg, larval, and/or young-of-the-year life history stages, may be responsible for the observed differences among sections of the study area. Examination of size frequency data suggests that lake sturgeon recruitment is sporadic. Data suggest that between 2004 and 2008, recruitment appears to have occurred

in 2005 and 2008 only. Implications of these results on growth and recruitment of lake sturgeon in large impounded rivers is discussed.

6.1 Introduction

The lake sturgeon, *Acipenser fulvescens,* is reknowned for its large body size and unique life history traits such as longevity, intermittent spawning, late age at maturity, high fecundity and slow growth (Scott and Crossman 1973; Birstein 1993; Kempinger 1996). These life history traits are thought to make lake sturgeon slow to recover following population declines. Throughout their North American range, which includes the Hudson Bay, Mississipi and Great Lakes drainage basins (Figure 1.1), few abundant populations of lake sturgeon remain. Because over-harvest and habitat alterations continue to threaten remaining populations, research studies that identify factors influencing growth and mortality are urgently needed to prevent further population declines and facilitate recovery strategies.

Fisheries management decisions are typically based on data sets comprised of quantifiable biological characteristics such as length, body mass, and age. Collection of these data enables the derivation of important metrics such as condition factor, growth rate, mortality rate and yield per recruit models that can assist in the comprehension of the key ecological or anthropogenic factors that may influence a fish population (Campana 2001; Lorenzen and Enberg 2001). For threatened and endangered species it can be difficult to establish these relationships, and as a consequence, identifying ecological factors that directly influence the abundance or health of a population may prove difficult. Empirical information on the young life history stages of lake sturgeon are lacking for most populations, making it difficult to develop population models (Jager et al. 2000; Pine et al. 2001), understand factors that influence mortality and year-class strength, or identify management options that benefit population growth and improve conservation efforts (Secor et al. 2002; Gross et al. 2002).

Several studies have attempted to identify factors that influence growth and recruitment in lake sturgeon. Condition factor and growth were compared among several lake sturgeon populations throughout their range in attempts to determine the primary extrinsic factors that influence growth (Threader and Brousseau 1986; Fortin et al. 1993; Beamish et al. 1996; Fortin et al. 1996; Power and McKinley 1997). Results suggest that abiotic factors such as temperature, latitude, longitude, pH, salinity, and conductivity as well as biotic factors such as environmental productivity and competition are the primary factors influencing growth in this species. Far less attention has been given to abiotic or biotic factors that influence recruitment. Nilo et al. (2006) suggested that water temperatures and flows during June were the primary factors influencing year-class strength in the St. Lawrence River, Quebec, although correlations have also been drawn between year-class strength and the strength of the previous years cohort (Nilo et al. 1997). Strong year classes have also been positively correlated with spring flows in several species of sturgeon including Russian sturgeon, *Acipenser guldenstadti*, (Khoroshko 1972) and white sturgeon, *Acipenser transmontanus*, (Kholhorst et al. 1991).

In previous chapters, juvenile lake sturgeon were found to be highly abundant in the Winnipeg River study area, preferring deep water habitats with detectable (> 0.2 m.s-1) current (Chapter 2). Juvenile lake sturgeon were found at high densities in deep water, dominating the fish community with few potential interspecific interactions (Chapter 3). Juvenile lake sturgeon were also found to forage predominantly on larval invertebrates of the orders Ephemeroptera, Trichoptera and Diptera (Chapter 4). Finally, investigations of seasonal movement determined that juvenile lake sturgeon exist as behaviorally isolated subpopulations, rarely moving between sections of the study area separated by rapids (Chapter 5). The primary objective of this chapter was to describe the abundance and biological characteristics of juvenile lake sturgeon subpopulations in this study area. A second objective of this chapter was to determine the relative strength of year-classes based on size frequency distributions developed from catch data collected between 2006 – 2008. The final objective was to examine the ecological factors that may be responsible for variation in growth and/or recruitment among subpopulations of juvenile lake sturgeon. In particular, I examined the potential role of interspecific competition and variation in substrate type.

6.2 Materials and Methods

6.2.1 Study Area

The study area consisted of a 41 km long impoundment on the Winnipeg River delineated by the Slave Falls GS at the upstream end and the Seven Sisters Falls GS at the downstream end (Figure 2.1). The study area was divided into eight sections based on river topography, with boundary margins being located at sets of rapids, river constrictions, or inlets and/or outlets of "lakes" (Figure 2.1). A more detailed description of the study area is provided in chapter 2.

6.2.1.1 Physical characteristics of the study area

Hydrological characteristics of a riverine environment facilitate the deposition and transport of sediments thus influencing the characteristics of fish habitat (Baxter 1977; Nelson 2005). In most riverine environments, including hydroelectric reservoirs or impoundments, there exists a predictable relationship between water velocity and substrate where higher water velocities are associated with coarse substrates, and lower velocities are associated with areas of finer, depositional substrate types. Water velocities and substrate in the main channel of the Winnipeg River in the upstream sections of the study area (including RS-1, RS-2 and RS-3) consist of water velocities ranging from 0.2 – 1.5 m.s-1 and particle sizes generally > 2 mm. Conversely, main channel habitats in downstream sections of the study area (including RS-4, RS-5, RS-6, RS-7 and RS-8) consist mainly of water velocities < 0.2 m.s-1 and depositional substrates comprised of particles sizes < 2 mm. It should be noted that water velocities in excess of 1.0 m.s-1 and substrates comprised of particle sizes > 2 mm can be found in the downstream sections of the study area, however, these areas are generally limited to inlets and outlets of lakes (see Figure 2.1).

6.2.2 Juvenile lake sturgeon sampling

6.2.2.1 Abundance

Gill nets were set in each of the eight study area sections during fall 2008 to examine the abundance of juvenile lake sturgeon in the study area. Each was 91.6 m long and comprised of four different panels of mesh (25, 76, 125 and 203 mm stretched), each 22.9 m long. Each gill net sampling site was characterized by depths > 13.7 m and water velocities ≥ 0.1 m.s-1. Substrate type however, varied among sampling sites due to the availability of substrate types that exist along the longitudinal axis of this impoundment (see section 6.2.1.1). Gillnet gangs were set in the evening and pulled the following morning with set durations generally lasting between 13 and 17 hours.

6.2.2.2 Biological statistics

Lake sturgeon were captured in the study area from May 2006 – October 2008. Fork length (FL) (mm) and total length (TL) mm were measured for each fish, while mass (g) and aging structures were collected from a sub-sample of the catch. See the methods section of chapter 2 and chapter 3 for a more complete description of the gill netting methodology and fish sampling procedures.

Marginal pectoral fin rays were used to provide age estimates for juvenile lake sturgeon. Pectoral fin rays provide accurate age estimates in lake sturgeon < 14 years of age (Bruch et al. 2009). Pectoral fin rays were removed from all incidental mortalities by running a knife along the anterior edge of the pectoral fin to the base, and cutting around the base of the pectoral fin at the articulation (Cuerrier 1951). For live lake sturgeon, a 1 cm long portion of the leading edge of the pectoral fin ray, close to the articulation (Haxton and Findlay 2008) was removed for age analysis. All fin rays were cut within 6.4 mm of the articulation as recommended by Cuerrier (1951). Pectoral fins were air-dried for at least 90 days prior to being sectioned (65 – 80 micrometer) with a low speed isomet saw (Struers, Mississauga, Ontario, Canada). Sections were then mounted on a clear plastic slide and covered with clear cytoseal (Cytoseal 60, Thermo scientific, Waltham, Massachusettes). Age estimates were obtained by counting annuli from a cross section of the basal section of the first pectoral fin ray as outlined in Roussow (1957). Translucent and opaque zones on the fin ray cross section were observed, with the translucent zones representing summer growth (Probst and Cooper 1955) and opaque zones representing winter growth (Noakes et al. 1999). Under a low magnification with transmitted light, opaque zones were counted (Figure 6.1). I assigned age estimates to each fin ray by interpreting each structure, double blind, three times. Where discrepancies existed, I re-examined the structure before assigning the final age.

6.2.3 Data analysis

6.2.3.1 Abundance of juvenile sturgeon and other functional groups

To assess potential intra and interspecific competition, CPUE values were calculated for each functional group of fish (functional groups described in chapter 2 and 3) captured at each gill netting site. Mean CPUE values (± 1 SD) were calculated and presented for each functional group within each river section. CPUE was expressed as:

fish /91.6 m of net/24 hr

where: # fish = the number of fish in a particular functional group captured per 91.6 m long gill net (comprised of four equal length panels of 25 mm, 76 mm, 127 mm and 203 mm stretched mesh) per 24 hour time period. Because nets were set for durations less than 24 hours, catches were arithmetically adjusted to the 24 hour period.

Mean CPUE values of each functional group, were compared between upstream (consisting of RS-1, RS-2 and RS-3) and downstream (RS-4, RS-5, RS-6, RS-7 and RS-8) sections of the study area. Because data could not be normalized even following transformation, a non-parametric Mann-Whitney test was used to make the comparisons. A significance level of $P < 0.05$ was used for all statistical analyses.

6.2.4 Condition factor and length-mass relationship

Condition factor and length-mass relationships were developed for each subpopulation of juvenile lake sturgeon using all lake sturgeon for which both TL and body mass were collected over the three year study period. Condition factor was calculated using the following equation:

$$K = W \text{ X } 10^5 / TL^3$$

where: K = condition factor; W = body mass (g); and TL = total length (mm) (after Fulton 1911, in Ricker 1975). Mean condition factor was calculated for each section of the study area by 50 mm TL intervals. This 50 mm interval was selected based on the magnitude of change in K among the size classes of juvenile lake sturgeon.

Total length – mass equation parameters were estimated for juvenile lake sturgeon subpopulations occupying distinct sections of the study area. Linear regressions were performed on log transformed data and described by the following equation:

$$\log (M) = (b) \log (TL) + a$$

where M = body mass (g), TL = total length (mm), a = intercept and b = slope or growth rate (Ricker 1975). Analysis of covariance (ANCOVA), with Tukey's test for multiple comparisons, was used on log values to determine if significant differences existed among length-mass relationships among juvenile lake sturgeon subpopulations.

6.2.5 Growth

Length-at-age relationships were developed for sub-populations of juvenile lake sturgeon in the study area. To determine if these relationships differed among sections of the study area, data were log transformed and compared using ANCOVA with Tukey's test for multiple comparisons.

6.2.6 Length-frequency - Year class strength

Length-frequency histograms were developed for subpopulations of juvenile lake sturgeon by year (2006, 2007, and 2008), using TL measurements collected from juvenile lake sturgeon captured after July 10. Sturgeon were grouped by 20 mm total length (TL) class intervals beginning with the 120 – 139 mm size class. The 20 mm size interval was deemed appropriate given the large sample sizes collected from upstream sections of the study area. Only fish captured after July 10 were used to develop the histograms because most of the growth that would have occurred during that year is completed by that time (Barth, unpublished). Size frequency distributions developed using fish captured following the completion of growth during that year, can provide important information on year class strength (Koeller et al. 1986). Length frequency histograms, and length at age relationships for lake sturgeon aged between 0 and 2 years were used to identify relative cohort strength over a five year period (2004 – 2008). Only small fish or the younger ages were used to identify the relative strength of a cohort because growth was found to be relatively consistent during the first two years in this study area.

Each analysis was carried out using XLSTAT (Version 2006.2) in excel (Microsoft Corporation, Redmond, California).

6.3 Results

6.3.1 Abundance of juvenile lake sturgeon and other functional groups

Between September 18 and October 1st, 2008, 44 sites were fished with gill nets in eight sections of study area for a total of 773.2 hours (hr) (Table 6.1). In total, 518 fish were captured, comprised of 10 fish species. Lake sturgeon (n = 294) comprised over half of the total catch (56.8%), followed by walleye, (n = 74, 14.3%), white sucker, (n = 37; 7.1%), trout perch, (n = 36; 6.9%), sauger, (n = 31; 6.2%) and burbot, (n = 30; 6.2%) (Table 6.1). The remaining fish species, lake whitefish, shorthead redhorse, northern pike and yellow perch each comprised less than 5% of the overall catch. Lake sturgeon were captured in each river section with the exception of RS-8, comprising over 86% of the catch in RS-1, RS-2 and RS-3, and 40.0% or less of the catch in each of RS-4, RS-5, RS-6 and RS-7.

Mean CPUE values were calculated for each functional group from the fall 2008 gill net catch by study area section (Figure 6.2). Mean CPUE (# fish/91.6 m net/24 hr) of juvenile lake sturgeon measuring 300 – 610 mm TL was 16.3 (SD = 11.5), 28.1 (SD = 12.5) and 5.8 (SD 3.7) in RS-1, RS-2 and RS-3, respectively. These CPUE values were significantly greater relative to mean CPUE values in each of RS-4, RS-5, RS-6 and RS-7 that were each < 0.5 (Kruskal Wallis, Dunn’s p < 0.0001). As the CPUE values of juvenile lake sturgeon decreased along the longitudinal axis of the study area, CPUE values of other functional groups generally increased. For example, mean burbot CPUE was 0.0 in RS-1, RS-2 and RS-3 but was 2.5 (SD = 2.1), 0.5 (SD = 0.7), 1.7 (SD = 1.0), 1.2 (SD = 1.3) and 1.7 (SD = 2.1) in RS-4, RS-5, RS-6, RS-7 and RS-8 respectively. Similarly, the mean CPUE of large piscivorous fishes was 1.1 (SD = 1.2), 1.5 (SD = 1.3) and 0.6 (SD = 1.0) in RS-1, RS-2 and RS-3, respectively, but relatively higher in all downstream sections at 4.6 (SD = 3.9), 3.9 (SD = 1.6), 4.9 (SD = 2.5), 3.4 (SD = 2.5) and 5.3 (SD = 2.9).

With the exception of juvenile lake sturgeon (described above), due to small sample sizes, and high variances, statistical tests were not performed to compare mean CPUE values of other functional groups among sections of the study area. Instead, mean CPUE values were compared among functional groups from upstream (RS-1, RS-2 and RS-3) and downstream (RS-4, RS-5 RS-6, RS-7 and RS-8) sections of the study area combined. The decision to combine and compare CPUE values between these sections was based on similarities in fish community composition, in particular juvenile lake sturgeon. Mean CPUE values of larger conspecifics (i.e., lake sturgeon measuring > 610 mm TL) were similar between upstream (2.54 SD = 1.75) and downstream (2.60 SD = 5.00) sections of the study area (Figure 6.3) (Mann-Whitney, P = 0.07). The mean CPUE values of the remaining species groups were found to be significantly higher in downstream sections of the study area relative to upstream sections. For example, mean CPUE's of burbot (D/S mean = 1.6, SD = 1.6; U/S mean = 0.0, SD = 0.0), large piscivorous fish (D/S mean 4.5, SD = 2.7; U/S mean = 1.1, SD = 1.2) and small omnivores (D/S mean 1.8, SD = 3.4; U/S mean 0.0, SD = 0.0) (Mann-Whitney, P < 0.011, all tests) were all significantly higher in downstream sections of the study area (Figure 6.3).

6.3.2 Biological statistics

To describe and compare biological statistics among juvenile lake sturgeon subpopulations, groups occupying the downstream sections (RS-4, RS-5, RS-6 and RS-7) of this study area were combined due to similarities in size, condition factor, and length-at-age (Kruskal-Wallis, Dunn's procedure $P > 0.05$).

6.3.2.1 Condition Factor

Mean condition factor for lake sturgeon in size classes < 349 mm TL varied between 0.36 and 0.41 however, few fish < 400 mm TL were captured outside RS-1 and RS-2 (Table 6.2). In size classes of lake sturgeon measuring > 350 mm TL, mean condition factor varied between 0.40 and 0.62 depending on RS. Mean condition factor was consistently lowest in juvenile lake sturgeon captured in RS-1 and RS-2, moderate in RS-3 and highest in RS-4 – RS-7 combined. Condition factor generally increased with size of juvenile lake sturgeon in RS-1, RS-2 and RS-3 (Table 6.2), a trend that is consistent with findings from other populations (Fortin et al. 1993; Beamish et al. 1996; Power and McKinley 1997).

Mass-TL relationships were developed and compared among lake sturgeon captured in RS-1, RS-2, RS-3 and RS-4 – RS-7 combined (Figure 6.4a-d). Growth coefficients (b, slope) differed significantly between isolated groups of sturgeon being highest in RS-4 – RS-7 combined, (3.40), followed by RS-3 (3.21), and finally, RS-1 (3.17) and RS-2 (3.15) which were grouped similarly (ANCOVA $P < 0.0001$, Tukey's HSD, $P < 0.0001$) (Table 6.3).

6.3.2.2 Age and Growth

Aging structures were collected from 225 lake sturgeon measuring between 216 mm TL and 1000 mm TL. Ages ranged between 1 and 27 years (Table 6.4). Length-at-age data were presented from four subpopulations of juvenile sturgeon that occupied RS-1, RS-2, RS-3, and RS-4 – RS-7 combined. High variability in length-at-age between juvenile lake sturgeon was observed between sections of the study area. For example, the TL of a juvenile sturgeon at age five varied between 382 mm TL (RS-1) and 742 mm TL (RS-4-RS-7), and the length of six year old fish varied between 416 mm TL in RS-1 to 888 mm TL in RS-4 – RS-7 (Figure 6.5a). Similar to the mass-TL relationship, growth of juvenile lake sturgeon was most rapid in RS-4 – RS-7, moderate in RS-3 and slowest in RS-1 and RS-2 (ANCOVA, $P < 0.0001$, Tukey’s HSD, $P < 0.0001$) (Figure 6.5b). A positive correlation was also observed between growth and river section distance from the Slave Falls GS.

6.3.3 Size distribution and year class strength

Attempts to determine cohort strength in upstream sections of the impoundment were confounded by slow growth rates that made it difficult to assign ages to juvenile lake sturgeon > 3 years of age based on length. Therefore, to determine the relative strength of a cohort, length frequency data and known length at age relationships of juvenile sturgeon < 3 years of age, were used to qualitatively determine the strength of year classes between 2004 and 2008.

Young-of-the-year lake sturgeon, measuring from 130 to 175 mm, were captured in the study area for the first time in 2008 (figure 6.6, figure 6.7, figure 6.8). This result suggests that the 2006 and 2007 cohorts were either weak or absent, while the 2008 cohort was, in relative terms, stronger. Evidence to suggest that recruitment of the 2005 cohort is shown in the 2006 catch data, as juvenile sturgeon measuring between 210 and 287 mm TL (one year old), were captured during fall (Figure 6.6). Finally, the 2004 cohort also appears to be weak or absent, as evidenced by a lack of fish measuring between 278 and 379 mm TL, which would correspond to 2 year old fish in RS-1 and RS -2 (Figure 6.6). In summary, for the five years in which we have data (2004 and 2008), evidence suggests that successful recruitment to the YOY life history stage may have only occurred in 2005 and 2008. Results were similar for each subpopulation, as a particular year class was not evident in one subpopulation, but absent from another. Although juvenile abundance is highly unequal within this study area, these results suggest that at least some of the factors influencing recruitment may be similar across subpopulations.

6.4 Discussion

Results presented in the previous chapter indicated that juvenile lake sturgeon rarely move between sections of this 41 km long study area on the Winnipeg River, thereby existing as behaviorally isolated sub-populations separated only by transitions in habitat (Chapter 5). The results presented in this chapter indicate that this behavioural isolation has led to observable differences in abundance, condition factor and growth of these sub-populations. To the authors' knowledge, these differences in abundance and population parameters have not been previously observed within a sturgeon population separated only by rapids. Intraspecific variation in growth and condition, however, have been observed among populations of shovelnose sturgeon, *Scaphyrhynchus* *platorhynchus*,, white sturgeon, *Acipenser transmontanus*, and lake sturgeon occupying the same river system or cascading reservoir systems (Beamesderfer et al. 1995; Everett et al. 2003; Haxton and Findlay 2008). The magnitude of the observed differences in abundance and growth among the juvenile lake sturgeon subpopulations, and the inverse correlation observed between abundance and condition factor and growth is striking. Finally, the decreasing trend in abundance observed along the longitudinal axis of this study area, strongly suggests that at least some of the abiotic or biotic factors that influence recruitment in lake sturgeon differ among sections of this impoundment.

6.4.1 Abundance and distribution of juvenile lake sturgeon in impoundments

Deep water habitats of the three most upstream sections of this study area were dominated by juvenile lake sturgeon, and other species groups were far less abundant. Similarly, other studies have also observed a greater abundance of juvenile lake sturgeon in upstream, higher gradient areas of rivers or impoundments. For example, in the Lake Winnebago system, Wisconsin, Bruch (1999) suggested that “up river lakes” provide nursery habitat for lake sturgeon, and that as fish attain larger sizes, they move downstream. Similarly, in the Ottawa River, Haxton (in review), found that the catch probability of juvenile lake sturgeon was highest in the upper third of impounded river reaches. Conversely, data from a 350 km long unimpounded reach of the St. Lawrence River (Mailhot et al. in press), suggested that juvenile nursery areas are located in the downstream reaches, and that as fish grow towards sexual maturity, they move upstream, closer to spawning areas. The differences observed in the abundance of juvenile lake sturgeon among sections of this study area, and the potential affinity of juvenile lake sturgeon for upstream sections of impoundments, but lower reaches of unimpounded rivers requires further study.

6.4.1.1 Potential explanations for abundance differences

Binckley and Resetarits (2005) suggest that distribution and abundance patterns can arise from either habitat selection (i.e., perceived fitness driven by past selection), or random dispersal followed by non-random mortality. Explaining the observed distribution of juvenile lake sturgeon in this study area however, cannot simply be attributed to a selection of, or preference for, high gradient, non-depositional substrate. This is because juvenile lake sturgeon rarely move between habitat transitions, and therefore their distribution must be determined prior to the juvenile life stage. For this reason, the distribution of juvenile lake sturgeon in this study area must be attributed to either differential distribution or differential mortality at either the egg, larval or YOY life history stages.

Differential distribution

Possibly, the majority of lake sturgeon spawn in upstream sections of this study area, and therefore, larval distribution is non-random and skewed towards upstream areas. This would occur if larvae settle out quickly and do not drift extensively from spawning areas. Another possibility is that larval lake sturgeon use water velocity and substrate cues to select for particular habitat types and these habitat types only exist in the upstream sections of this study area. For example, Gessner et al. (2008) observed a positive selection for gravel substrate in larval Atlantic sturgeon (*Acipenser oxyrinchus*).

Since coarse substrate types such as gravel predominantly exist in the upstream sections of this impoundment, a similar preference in larval lake sturgeon might also produce the observed distribution.

Differential mortality

Differential mortality of larval or YOY lake sturgeon may also provide an explanation for the observed distribution of juvenile lake sturgeon in this study area. Deep water habitats of upstream sections of the study area were dominated by juvenile lake sturgeon, however, downstream river sections were more species diverse and abundances of functional groups such as burbot, benthic foragers, large piscivores, and small omnivores were higher than in upstream sections (Figure 6.3). The observed pattern of increasing species richness from upstream to downstream has been reported in many studies on large rivers (Huet 1949, Lowe-McConnell 1975; Horwitz 1978; Schlosser 1982, Thiel et al. 1995; Matthews 1998; Aarst and Neinhuis 2003; Ibarra et al. 2005; McGarvey and Hughes 2008) and has been attributed to changes in physical characteristics. It is possible that higher abundances of predators in downstream sections may directly increase the mortality of larval or YOY lake sturgeon.

Larval lake sturgeon mortality may also be higher due to either decreased foraging success, or a lack of required food items in depositional substrates, which predominate in the downstream sections. Larval lake sturgeon have been associated with sand and gravel substrates in several studies from the Great Lakes, however, the suitability of depositional substrates remains unknown.

6.4.2 Condition and growth

The trends observed in the abundance of juvenile lake sturgeon along the longitudinal axis of the impoundment were inversely related to the trends observed with respect to condition factor and growth. Juvenile lake sturgeon captured in RS-1 and RS-2 exhibited the lowest condition factors and slowest growth, while moderate condition factor and moderate growth were exhibited by juvenile lake sturgeon captured in RS-3, and the highest condition and most rapid growth were observed in juveniles captured in RS4 – RS-7 (Table 6.2 and Figure 6.5b). The similarity between higher condition factor and more rapid growth is not surprising considering that these two traits have been shown to be related in brown trout, *Salmo trutta*, as heavier individuals have been found to grow faster than individuals of the same length that are lighter (Ellis and Gowing 1957).

Although growth and condition factor were highly variable between subpopulations of juvenile lake sturgeon in the study area, the range of values reported were similar to those reported from other populations. For example, in the St. Lawrence and Ottawa rivers, condition factor of lake sturgeon measuring > 700 mm TL varied between 0.51 and 0.63 (Fortin et al. 1993), and condition factor in lake sturgeon measuring between 400 and 700 mm TL in Lake St. Francis, Ontario (Cuerrier and Roussow 1951) varied between 0.61 and 0.72. Condition factor values reported in these studies were similar to those observed in the downstream sections of this study area. In contrast, condition factor of juvenile lake sturgeon that measured between 300 and 650 mm TL, in the Kenogami River (Ecologistics 1987 in Ontario Ministry of Natural Resources 2009) varied between 0.36 and 0.47. These values are comparable to juvenile sturgeon occupying upstream sections of the Winnipeg River study area. Growth was also highly variable among sections of the study area. For example, length-at-age data from juvenile lake sturgeon in upstream sections were similar to a slow growing population found in a small river, the Kenogami River, Ontario, Canada (Figure 6.10). Conversely, faster growing fish in the downstream sections of the study area exhibited growth rates comparable to faster growing, more southerly populations found in the Lake Winnebago system (Bruch 2009).

Differences in growth among sections of the Winnipeg River study area can also be inferred from length-frequency histograms that exhibit a clear shift to the right (figures 6.6, 6.7 and 6.8). Size classes < 610 mm TL are poorly represented in downstream sections of the study area and this can be attributed to the relatively rapid growth rates that allow for individuals grow to, or exceed, 610 mm TL by age 4 - 6. In contrast, it may take over 10 years for juvenile lake sturgeon in upstream sections of the study area to attain a length of 610 mm TL (Figure 6.5a). It is apparent that in upstream sections of the study area, slow juvenile growth increases the abundance of smaller sized juvenile lake sturgeon. Interestingly, length-at-age information collected from adult lake sturgeon in this study area from 1982 – 2005 (Manitoba Water Stewardship, unpublished data) (Figure 6.11) suggests a high variability in length at age across fish that are several decades old. These data suggest that a growth bottleneck may have existed in this population for at least the last 50 years. (Note: The adult lake sturgeon aged and shown Figure 6.11 were captured in RS-2 and RS-3 only).

6.4.2.1 Factors affecting condition and growth

Explaining the ecological factors responsible for the observed differences in condition factor and growth among subpopulations of juvenile lake sturgeon requires an identification of factors that influence condition and growth in lake sturgeon, and a determination of which factors differ among sections of this study area. Previous studies suggest that abiotic factors such as latitude (mean annual temperature), longitude, and water chemistry as well as biotic factors such as food availability and competition may influence growth in lake sturgeon. The most commonly cited factor influencing growth of fish, including sturgeon, is latitude. By comparing length-at-age data between lake sturgeon populations, several authors have associated decreased growth with increasing latitude (Threader and Brousseau 1986; Mosindy 1987; Fortin et al. 1996). Latitudinal differences obviously do not exist between groups of juvenile lake sturgeon in this study area, yet as shown in Figure 6.5b, large differences were observed.

A similar argument can be made for properties of water such as pH and conductivity, which have also been positively related to growth in lake sturgeon through inter-population comparison (Fortin et al. 1996). Water chemistry parameters (i.e., pH, conductivity, turbidity, nutrients, major ions and metal) have been found to be relatively similar among sampling locations along the entire length of the Winnipeg River between Pointe Du Bois GS and the outlet of the river at Lake Winnipeg (Environment Canada 2006). Further, water temperature data, collected periodically in conjunction with gillnetting during this study, were found to be similar along the length of the immediate study area, as would be expected considering the lack of a significant, or numerous tributaries, the short residence time of water in reservoir, and the similarities in climactic factors.

Other factors, including exploitation (harvest) rate and genetic differences are also unlikely to play a role in influencing the observed growth rate differences among lake sturgeon subpopulations. Fortin et al. (1993) suggested that exploitation may have been responsible for differences in biological statistics between three populations of lake sturgeon occupying the Ottawa and St. Lawrence rivers. Exploitation rate, however, is thought to be low in this study area on the Winnipeg River (D. Leroux pers comm), and is thus unlikely to influence differences in growth between subpopulations of juvenile lake sturgeon. Lastly, it is highly unlikely that genetic differences could cause the differences in growth given the observed unimpeded movement of adults between sections of the study area (Labadie, unpublished) and the relatively short distances between spawning areas.

To summarize, due to similarities in abiotic conditions, and because exploitation rate or genetic differences offer poor explanations for the observed differences in growth among subpopulations, biotic factors such as food availability and/or intra- or interspecific competition are the most plausible explanations for observed differences in growth rates. It should be noted that food availability and competition are not mutually exclusive because it is recognized that an increased abundance of consumers is inversely correlated to available resources. For this reason, it is difficult to distinguish between the two factors in studies on wild populations (Arendt 1997). Diana et al. (2003) suggested that lake sturgeon raised in a laboratory have the capacity for rapid growth and concluded that food was the factor limiting growth in most wild populations. Growth limiting densities, however, are uncommon in wild populations (Cushing 1975; Pitcher 1992; Barrett 1999), and evidence that competition or density influences growth in wild populations is difficult to attain. As such, most studies simply note a correlation (Cowx 1988). For example, Haxton and Findlay (2008) found that growth rates in lake sturgeon were more rapid in less densely populated impounded reaches of the Ottawa River. Based on the observed density differences, these authors suggest that density-dependent growth compensation may be occurring between reaches of the Ottawa River. Although inverse correlations between CPUE and growth are suggestive, Matthews (1986) argued that only evidence obtained through manipulative experiments can convincingly demonstrate that competition may affect the availability of resources. Therefore, it cannot be conclusively determined that intra-specific competition is indeed responsible for observed differences in growth.

Although it cannot be conclusively shown that intra-specific competition is the primary factor influencing observed differences in growth among subpopulations of juvenile lake sturgeon, several lines of evidence support the notion that it does play an important role. First, this study meets criteria suggested by Lobon-Cervia (2005) where optimal conditions for determining the role of density in influencing growth occurs in populations of fish that experience similar water temperatures, low mortality rates and extreme density differences. Further, Barrett (1999) suggested that in cases where food resources are limited, growth rate differences among isolated populations should reflect the different ratios of population density to food availability. Although the availability of food was not quantified in my study, the growth coefficient was inversely proportional to abundance (Figure 6.9). Finally, juvenile diet was found to be similar among several size/age groups of sturgeon (Chapter 4). Considering the densities of juvenile sturgeon occupying upstream sections of this study area, it is reasonable that density plays a role in influencing growth of juvenile lake sturgeon.

6.4.3 Density-dependent habitat selection

Regardless of the factors responsible for the growth rate differences among sections of the Winnipeg River, it is unknown why juvenile lake sturgeon do not disperse downstream into areas that may benefit their growth. Ideal free distribution (IFD) theory (Fretwell and Lucas 1970) predicts that individuals should distribute themselves among habitats such that overall fitness is maximized (Morris 1987), and mean individual fitness is equal among available habitats (Tregenza 1995; Holt and Barfield 2001; Haugen et al. 2006). Given the magnitude of the growth rate differences observed among isolated groups of juvenile lake sturgeon in the study area it appears that juvenile lake sturgeon do not adhere to the IFD. Alternatively, slow growing juvenile lake sturgeon may be trading off slower growth for increased survival. Therefore, two possibilities will be discussed, non-compliance (maladaptive habitat selection) and compliance (fitness is indeed equal between sections) with the IFD.

6.4.3.1 Non-compliance with the IFD (maladaptive habitat selection)

It is counterintuitive that juvenile lake sturgeon avoid downstream dispersal, as their growth, and fitness should benefit by dispersing downstream. Other studies have also suggested that habitat selection in juvenile sturgeon cannot be fully explained by food availability. For example, Chiasson et al. (1997) found that juvenile lake sturgeon were most abundant at the confluence of the Groundhog and Mattagami rivers, where prey were only moderately abundant. Similarly, Nilo et al. (2006) suggested that juvenile lake sturgeon aggregate locally, and the aggregations cannot be fully explained by food availability.

The behavior exhibited by juvenile lake sturgeon in the Winnipeg River and their failure to move through habitat transitions represents a deviation from at least one of the key IFD assumptions. The IFD assumes that animals have "perfect information" concerning the availability of resources in their environment (Trezgenda 1995). However, because juvenile lake sturgeon do not move between sections of the study area, they cannot have ideal knowledge of resource levels in their surroundings. Therefore, the sedentary behavior is responsible for the deviation from at least one assumption of the IFD, and this decision may be considered maladaptive if indeed downstream dispersal would benefit fitness under present day environmental conditions.

In contrast, an ecological trap occurs when environmental change (often human induced) alters cues that animals use to assess habitat quality (Gates and Gysel 1978). Hydroelectric developments on the Winnipeg River have resulted in significant changes to fish habitat, and it is possible that cues used to select habitat on a macroscale (i.e., between sections of this study area) have been altered. It is likely however, that these cues pertain to either the passive drifting phase of the lake sturgeon, or the YOY phase, because juveniles have evolved behavior not to move, and thus do not select habitat on a macroscale. Habitat characteristics such as water velocity and substrate may act as important cues in macro-scale habitat selection by drifting sturgeon larvae (Gessner et al. 2008).

If the sedentary behavior exhibited by juvenile lake sturgeon is maladaptive under present day conditions, then why is this behavior so engrained in this species at this life history stage? One plausible explanation is that sedentary behavior evolved in large riverine environments as an adaptive mechanism to exploit relatively short sections of river in an environment where fish passage through natural sets of rapids may not have been possible. Because passage is now possible through many of these "flooded" natural sets of rapids, and because spawning locations may have been lost due to flooding, juvenile fish may be limited in terms of their dispersal to areas near to or immediately downstream of spawning areas. Secondly, there may have been a cost associated with dispersal at the juvenile life history stage, such as increased predation (Smith and King 2005). In contrast, possible benefits of limited larval dispersal include predator avoidance, avoidance of competition with adults in downstream environments far from spawning areas (Smith and King 2005), or the benefit of bet hedging by remaining in groups near spawning areas. Hydroelectric development therefore, may not only have reduced the availability of spawning habitat, but also the available rearing habitat, since sedentary behavior and settling out quickly near spawning areas precludes the use of suitable rearing habitats in downstream river reaches.

6.4.3.2 Compliance to the IFD

A second possibility is that fitness in juvenile lake sturgeon is equal among sections of the impoundment (i.e., juveniles are indeed distributed according to the IFD) and that evolution of the low dispersal behavior is adaptive. Tradeoffs are numerous in ecology, and the growth – mortality tradeoff is one of the most common (Roff 1992). The adaptive significance of slow growth and maintaining station in a location with a large number of conspecifics could be to increase survival, ensuring that a "reservoir" of juvenile fish exist to replenish the population (Booth 1995). As previously discussed in chapter 3, living at higher densities in their preferred deep water habitats may reduce interspecific interactions either directly through exclusion of species that overlap in diet with sturgeon, or by reduction in foraging opportunities for large piscivorous fish through exclusion of other prey species.

The costs and benefits of group living have been the subject of many ecological studies. For example, the Allee effect, where positive correlation between population density and population growth rate are observed, or, inverse density dependence (depensation), where at low population densities, individual growth or survival declines, have been described for many animal taxa, including fish (Allee 1949; Courchamp et al. 1999, Stephens and Sutherland 1999). The abiotic and biotic (i.e., fish communities) conditions that existed when life history traits were evolving in lake sturgeon are not well understood. Reports by First Nations people and early settlers suggest that very high abundances of lake sturgeon existed prior to the extreme commercial harvests and hydroelectric developments of the modern era. Because the species was abundant historically, and because lake sturgeon have been described as gregarious by several authors (Auer 1999; Secor et al. 2002), it is possible that Allee effects influenced the evolution of this species. Further, it is plausible that living at high densities provided fitness benefits to this species. However, the potential fitness benefits that lake sturgeon derive from existing in groups has not been examined, and with populations generally existing at such low levels, further study is difficult. The most common benefits derived from the Allee effect include protection from predators or group foraging, however, neither have been observed in lake sturgeon.

6.4.4 Year class strength

Length frequency histograms suggest that recruitment to this lake sturgeon population was sporadic, and between 2004 and 2008 recruitment may only have occurred in 2005 and 2008. Cohorts from the 2004, 2006 and 2007 year classes appear to be weak or absent. Average discharge of the Winnipeg River during May was 1,145, 1,534, 1,299, 476 and 980 cms, from 2004 – 2008, respectively suggesting that flow variations cannot solely account for these differences.

The reason for success or failure of year-classes in lake sturgeon is unknown and could be related to several environmental or biotic factors. Year-class strength in many sturgeon species has been related to environmental conditions such as temperature and flow (Nilo et al. 1997). Nilo et al. (1997) suggested that higher flows may result in a greater dispersion of larval lake sturgeon, resulting in reduction of density-dependant mortality (competition). Everett et al. (2003) suggested that recruitment and year class strength in shovelnose sturgeon may be related to available resources. Interestingly, Nilo et al. (1997), when using a subset of data collected from the St. Lawrence River (1980 – 1991), observed a negative correlation between year class strength and the strength of the previous year class. These authors suggest that density dependent interactions among year classes may be an important factor influencing cohort strength.

6.4.5 Summary and implications of results:

Dispersal or mortality of either the egg, larval or YOY life history stages may be one of the principle ecological mechanisms responsible for the observed distributional pattern of juvenile lake sturgeon in my study area. Research is needed to explain why recruitment is so different between sections of this study area. By focusing research on this question, a significant contribution towards conservation and rehabilitation of this species can be made. The following chapter details potential studies that would help to address these questions.

Density dependent interactions, including interactions between life-history stages, may be particularly relevant for a species such as the lake sturgeon. The sedentary behavior, limited movement through rapids, and strict preference for deep water environments suggests an evolved behavior to remain in groups at the juvenile life history stage. Findings included in this chapter suggest living at high densities may incur a cost of reduced growth. Reductions in growth however, may be traded off with increased survival. Although difficult to examine in a field setting, future studies should address the potential costs and benefits associated with a group existence in lake sturgeon. It is possible that conservation of this species will require considerable effort if survival of young is related to population density.

Heterogeneity in biological characteristics within this population of lake sturgeon raises uncertainty with respect to factors that influence the growth and condition of juvenile lake sturgeon in riverine environments. Results suggest that previous studies examining growth among populations may well be overly simplistic as results presented in this chapter indicate that dramatic differences in lake sturgeon can occur within the same waterbody in the absence of barriers to movement.

Finally, results presented in this and other chapters of this thesis have raised many important questions that, if answered, may provide a significant contribution towards conservation, rehabilitation and management of this species. In the final chapter of this thesis, priority research questions are identified and discussed.

6.5 References

Allee, W. C.; 1949: Principals of Animal Ecology: Saunders, Philadelphia, PA, USA.

Allen, P. J.; Barth, C. C.; Peake, S. J.; Abrahams, M. V.; Anderson, W. G., 2009: Cohesive social behavior shortens the stress response in lake sturgeon *Acipenser fulvescens*. J. Fish. Biol. **74**, 90-104.

Arendt, J. D., 1997: Adaptive intrinsic growth rates: an integration across taxa. Q. Rev. Biol. **72**, 149-177.

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

Auer, N. A.; Baker, E. A., 2002: Duration and drift of larval lake sturgeon in the Sturgeon River, Michigan. J. Appl. Ichthyol. **18**, 557-564.

Barrett, N. S., 1999: Food availability is not a limiting factor in the growth of three Australian temperate reef fishes. Environ. Biol. Fish. **56**, 419-428.

Beamesderfer, R. C. P.; Rien, T. A.; Nigro, A. A., 1995: Differences in the dynamics and potential production of impounded and unimpounded white sturgeon populations in the Lower Columbia River. Trans. Am. Fish. Soc. **124**, 857-872.

Beamish, F. W. J.; Jebbink, J. A.; Rossiter, A.; Noakes, D. L. D., 1996: Growth strategy of juvenile lake sturgeon (*Acipenser fulvescens*) in a northern river. Can. J. Fish. Aquat. Sci. **53**, 481-489.

Birstein, V. J., 1993: Sturgeons and paddlefishes: threatened fishes in need of conservation. Conserv. Biol. **7**, 773-787.

Booth, D. J.; 1995: Juvenile groups in a coral-reef damselfish: density-dependent effects on individual fitness and population demography. Ecology **76**, 91-106.

Bruch, R.; Campagna, S. E.; Davis-Foust, S. L.; Hansen, M. L.; Janssen, J., 2009: Lake sturgeon age validation using bomb radio carbon and known-age fish. Trans. Am. Fish. Soc. **138**, 361-372.

Campagna, S. E., 2001: Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation models. J. Fish. Biol. **59**, 197-242.

Chen, Y.; Jackson, D. A.; Harvey, H. H., 1992: A comparison of von Bertalanffy and polynomial functions in modelling fish growth data. Can. J. Fish. Aquat. Sci. **49**, 1228-1249.

Chiasson, W. B.; Noakes, D. L. G.; Beamish, F. W. H., 1997: Habitat, benthic prey and distribution of juvenile lake sturgeon (*Acipenser fulvescens*) in northern Ontario rivers. Can. J. Fish. Aquat. Sci. **54**, 2866-2871.

Courchamp, F.; Clutton-Brock, T.; Grenfell, B., 1999: Inverse density dependence and the Allee effect. Trends Ecol. Evol. **14**, 405-410.

Cowx, I. G., 1988: Distribution and variation in the growth of the roach (*Rutilus rutilius*) and dace (*Leuciscus leuciscus*), in a river catchment in south-west England J. Fish. Biol. **33**, 59-72.

Cragg-Hine, D.; Jones, J. W., 1969: The growth of dace (*Leuciscus leuciscus*), roach (*Rutilus rutilus*) and chub (*Squalius cephalus*) in Willow Brook, Northhamptonshire. J. Fish. Biol. **1**, 59-82.

Cuerrier, J. P., 1951: The use of pectoral fin rays for determining age of sturgeon and other species of fish. *The Canadian Fish Culturist*, 10-18.

Cushing, D. H., 1975: Marine ecology and fisheries. Cambridge University Press, London, UK.

Diana, J. S.; Webb, P. W.; Essington, T., 2003: Growth and appetite of juvenile lake sturgeon *Acipenser fulvescens*. Michigan Department of Natural Resources. Fisheries research report #2063.

Ellis, R. J.; Gowing, H., 1957: Relationship between food supply and condition of wild brown trout, *Salmo trutta* Linnaeus, in a Michigan stream. Limnol. Oceanogr. **2**, 299-308.

Everett, S. R.; Scarnecchia, D. L.; Power, G. J.; Williams, C. J., 2003: Comparison of age and growth of shovelnose sturgeon in the Missouri and Yellowstone rivers. N. Am. J. Fish. Manage. **23**, 230-240.

Fretwell, S. D.; Lucas, H. L., 1970: On territorial behavior and other factors influencing habitat selection in birds. I. Theoretical development. Acta Biotheor. **19**, 16-36.

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

Fortin, R.; Dumont, P.; Guennette, S., 1996: Determinants of growth and body condition lake sturgeon (*Acipenser fulvescens*). Can. J. Fish. Aquat. Sci. **53**, 1150-1156.

Gates, J. E.; Gysel, L. W., 1978: Avian nest dispersion and fledging success in field-forest ecotones. Ecology **59**, 871-883.

Gessner, J.; Kamerichs, C. M.; Kloas, W.; Wuertz, S., 2008: Behavioural and physiological responses in early life phases of Atlantic sturgeon (*Acipenser oxyrinchus* Mitchill) towards different substrates. J. Appl. Ichtyol. **25**, 83-90.

Gross, M. R.; Repka, J.; Robertson, C. T.; Secor, D. H., 2002: Sturgeon Conservation: Insights from elasticity analysis. Am. Fish. Soc. Symp. **20**, 184-200.

Harkness, W. J. K.; Dymond, J. R., 1961: The lake sturgeon. Ontario. Department of Lands and Forests, Toronto, Ontario, Canada.

Haugen, T. O.; Winfield, I. J.; Vollestad, L. A.; Fletcher, J. M.; James, J. B.; Stenseth, N. C., 2006: The ideal free pike: 50 years of fitness-maximizing dispersal in Windermere. Proc. R. Soc. B **273**, 2917-2924.

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

Haxton, T. 2008. A synoptic review of the history and our knowledge of lake sturgeon in the Ottawa River. Southern Science and Information Technical Report SSI #126, 31p.

Holt, R. D.; Barfield, M., 2001: On the relationship between the ideal free distribution and the evolution of dispersal. In Dispersal (Eds. J. Colbert; E. Danchin; E. Dhondt; J. D. Nichols, Oxford University Press, Oxford, pp. 83-95.

Jager, H. I.; Lepla, K.; Chandler, J.; Bates, P.; Van Winkle, W., 2000: Population viability analysis of white sturgeon and other riverine fishes. Environ. Sci. Policy S483-S489.

Kempinger, J. J., 1996: Habitat, growth, and food of young lake sturgeons in the Lake Winnebago system, Wisconsin. N. Am. J. Fish. Manage. **16**, 102-114.

Khoroshko, P. N., 1972. The amount of water in the Volga basin and its effect on the reproduction of sturgeons (Acipenseridae) under conditions of normal and regulated discharge. J. Ichthyol. **12**, 608-616.

Koeller, P. A.; Hurley, P. C. F.; Perley, P.; Neilson, J. D., 1986: Juvenile fish surveys on the scotian shelf: Implications for year-class size assessments. ICES J. Mar. Sci. **43**, 59-76.

Lebreton, G. T. O.; Beamish, F. W. H.; McKinley, S. R., eds. 2004: Sturgeons and Paddlefish of North America. Kluwer Academic Publishers. Netherlands.

Lobon-Cervia, J., 2005: Spatial and temporal variation in the influence of density dependence on growth of stream living brown trout (*Salmo trutta*). Can. J. Fish. Aquat. Sci. **62**, 1231-1242.

Lorenzen, K.; Enberg, K., 2001: Density-dependent growth as a key mechanism in the regulation of fish populations: evidence from among-population comparisons. P. R. Soc. London **269**, 49-54.

Morris, D. W., 1987: Tests of density-dependent habitat selection in a patchy environment. Ecol. Monogr. **57**, 269-281.

Nelson, P. A., 2005: Ecology of sympatric catostomid fishes in a glaciated riverine system: habitat, food, and biogeography. Ph D thesis, University of Manitoba, Winnipeg, Manitoba, Canada. 97p.

Nilo, P.; Dumont, P.; Fortin, R., 1997: Climatic and hydrological determinants of year-class strength of St. Lawrence River lake sturgeon (*Acipenser fulvescens*). Can. J. Fish. Aquat. Sci. **54**, 774-780.

Nilo, P.; Tremblay, S.; Bolon, A.; Dodson, J.; Dumont, P., 2006: Feeding ecology of juvenile lake sturgeon in the St. Lawrence river system. Trans. Am. Fish. Soc. **135**, 1044-1055.

Noakes, D. L. G.; Beamish, F. W. H.; Rossiter, A., 1999: Conservation implications of behaviour and growth of the lake sturgeon, *Acipenser fulvescens*, in northern Ontario. Environ. Biol. Fish. **54**, 135-144.

Pauly, D., 1979: On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. J. Const. int. Explore. Mer. **39**, 175-192.

Pine, W. E.; Allen, M. S.; Dreitz, V. J., 2001: Population viability of the Gulf of Mexico sturgeon: Inferences from capture-recapture and age-structured models. Trans. Am. Fish. Soc. **130**, 1164-1174.

Power, M.; McKinley, R. S., 1997: Latitudinal variation in lake sturgeon size as related to thermal opportunity for growth. Trans. Am. Fish. Soc. **126**, 549-558.

Power, M. E.; Dietrich, W. E., 2002: Food webs in river networks. Ecol. Res. **17**, 451-471.

Probst, R. T.; Cooper, E. L., 1955: Age, growth and production of the lake sturgeon (*Acipenser fulvescens*) in the Lake Winnebago region, Wisconsin. Trans. Am. Fish. Soc. **84**, 207-227.

Przyblski, M., 1996: Variation in fish growth characteristics along a river course. Hydrobiologia **325**, 39-46.

Scott, W. B.; Crossman, E. J., 1973: Freshwater Fishes of Canada. Fish. Res. Board Can. **184,** 966 pp.

Ricker, W. E., 1975: Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. **191**.

Roff, D. A., 1992. Life history evolution. Champman and Hall, London, UK.

Rossiter, A.; Noakes, D. L. G.; Beamish, F. W. H., 1995: Validation of age estimation for the lake sturgeon. Trans. Am. Fish. Soc. **124**, 777-781.

Roussow, G., 1957: Some considerations concerning sturgeon spawning periodicity. J. Fish. Res.Bd. Can. **14**, 553-572.

Santoul, F.; Cayrou, J.; Mastrorillo, S.; Cereghino, R., 2004: Spatial patterns of the biological traits of freshwater fish communities in south-west France. J. Fish. Biol. **66**, 301-304.

Secor, D. H.; Anders, P. J.; Van Winkle, W.; Dixon, D. A., 2002: Can we study sturgeons to extinction? What we do and don't know about the conservation of North American Sturgeons. Am. Fish. Soc. Symp. **28**, 3-10.

Shepherd, T. D.; Litvak, M. K., 2004: Density-dependent habitat selection and the ideal free distribution in marine fish spatial dynamics: considerations and cautions. Fish. Fish. **5**, 141-152.

Smith, K. M.; King, D., 2005: Movement and habitat use of yearling and juvenile lake sturgeon in Black Lake, Michigan. Trans. Am. Fish. Soc. **134**, 1159-1172.

Stephens, P. A.; Sutherland, W. J.; Freckleton, R. P., 1999: What is the Allee effect? Oikos **87**, 185-190.

Threader, R.; Brousseau, C. S., 1986: Biology and Management of the Lake Sturgeon in the Moose River, Ontario. N. Am. J. Fish. Manage. **6**, 383-390.

Tregenza, T., 1995: Building on the ideal free distribution. Adv. Ecol. Res. **26**, 253-302.

Vannote, R. L.; Minshall, G. W.; Cummins, K. W.; Sedell, J. R.; Cushing, C. E., 1980: The river continuum concept. Can. J. Fish. Aquat. Sci. **37**, 130-137.

Table 6.1. Number of fish species captured in each of eight sections of the Winnipeg River study area fall, 2008. Gill nets were 91.6 m long and comprised of 25 mm, 76 mm, 127 mm, and 203 mm stretched mesh, that were each 22.9 m long.

	Number	GNG effort	Fish species											
RS	of sites	(hr)	BURB	LKST	LKWH	NRPK	SAUG	SHRD	TRPR	WALL	WHSC	YLPR	Total n	RA LKST
RS-1	5	86.8	-	70	-	-	1	-	-	3	-	-	74	95
RS-2	5	91.4	-	115	-	-	1	-	-	5	5	-	126	91
RS-3	6	102.4	-	42	-	1	-	-	-	2	4	-	49	86
RS-4	6	106.3	11	26	6	1	2	-	2	17	5	-	70	37
RS-5	5	84.5	2	14	-	-	4	-	-	10	5	-	35	40
RS-6	6	114.5	8	17	-	-	5	-	9	20	7	-	66	26
RS-7	5	83.6	4	10	-	-	6	2	11	7	3	-	43	23
RS-8	6	103.7	7	0	1	-	13	1	14	10	8	1	55	0
Total	44	773.2	32	294	7	2	32	3	36	74	37	1	518	NA
RA			6.2	56.8	1.4	0.4	6.2	0.6	6.9	14.3	7.1	0.2	100.0	NA

GNG = Gill net gang; RS = River section; RA = Relative abundance; RA (%LKST); BURB = Burbot; LKST = Lake sturgeon; LKWH = Lake whitefish; NRPK = Northern pike; SAUG = Sauger; SHRD = Shorthead redhorse; TRPR = Trout perch; WALL = Walleye; WHSC = White sucker; YLPR = Yellow perch

Table 6.2. Mean condition factor and standard deviation (SD) by 50 mm TL size class intervals for all lake sturgeon captured in seven sections of the Winnipeg River, 2006 - 2008. Condition factors of lake sturgeon from RS-4 – RS-7 were combined due to similarities between individuals in these river sections.

	River section (all years combined)											
	RS-1			RS-2			RS-3			RS4-RS-7 combined		
	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
150-199	4	0.36	0.03	1	-	-	-	-	-	7	0.40	0.08
200-249	23	0.36	0.04	21	0.37	0.07	-	-	-	-	-	-
250-299	48	0.36	0.05	6	0.37	0.06	-	-	-	-	-	-
300-349	2	0.41	0.03	13	0.39	0.06	1	-	-	-	-	-
350-399	78	0.40	0.04	181	0.42	0.06	5	0.43	0.03	2	0.51	0.09
400-449	420	0.40	0.04	443	0.42	0.04	17	0.44	0.05	1	-	-
450-499	403	0.41	0.03	458	0.42	0.01	90	0.46	0.05	1	-	-
500-549	153	0.41	0.04	194	0.42	0.03	120	0.48	0.05	1	-	-
550-599	21	0.41	0.03	52	0.42	0.03	98	0.48	0.05	12	0.58	0.07
600-649	21	0.43	0.06	6	0.42	0.03	64	0.49	0.04	30	0.62	0.08
650-699	25	0.45	0.04	14	0.45	0.05	17	0.49	0.05	50	0.58	0.08
700-749	36	0.44	0.04	25	0.48	0.05	1	-	-	55	0.60	0.06
750-799	24	0.42	0.06	27	0.46	0.06	1	-	-	32	0.60	0.05
800-849	1	-	-	15	0.46	0.04	-	-	-	11	0.57	0.05
850-899	3	0.42	0.02	7	0.47	0.03	-	-	-	3	0.55	0.01
> 900	-	-	-	3	0.37	0.06	-	-	-	2	0.56	0.03
Overall	1261	0.40	0.02	1466	0.43	< 0.01	414	0.47	0.03	207	0.58	< 0.01

Table 6.3. Mass-TL relationship (log (M) = (b) log TL + a) for lake sturgeon captured in RS-1, RS-2, RS-3 and RS-4 - RS-7, in the Winnipeg River study area, 2006 - 2008. Differences between slopes were tested using ANCOVA with Tukey's HSD test for multiple comparisons.

	Equation: log M = log TL*b + a				Difference between slopes			
River section	n	B	a	r^2	1	2	3	4
RS-1	1261	3.17	-8.85	0.98	-	NS	***	***
RS-2	1466	3.15	-8.78	0.97	NS	-	***	***
RS-3	414	3.21	-8.91	0.93	***	***	-	***
RS-4 - RS-7, combined	208	3.40	-9.37	0.98	***	***	***	-

n=sample size

b=slope

a = intercept

r^2 = correlation coefficient

*** $P < 0.0001$

Table 6.4. Mean total length-at-age (±SD) for lake sturgeon captured in RS-1, RS-2, RS-3 and RS-4 - RS-7 in the Winnipeg River, 2006 - 2008. Individuals from RS-4 – RS-7 were combined due to similarities in length-at-age.

	RS-1			RS-2			RS-3			RS-4 - RS-7		
age	n	mean TL	SD	n	mean TL	SD	n	mean TL	SD	n	mean TL	SD
1	6	253	23.6	1	256							
2	7	327	32.9	4	283	62.7	1	370		2	391	1.4
3	2	417	66.5	2	375	21.2	2	443	101.9	3	488	81.4
4	3	467	29.9	5	378	23.5	3	501	6	2	627	59.2
5	12	433	43.2	6	453	44.4	9	510	30.3	9	658	56.4
6	14	469	35.6	5	470	34.8	11	532	38.5	21	722	76.5
7	9	487	23	1	496		3	614	34.3	17	766	53.6
8	4	497	32.1	7	520	28.7	5	587	86.5	5	715	49.6
9	1	458		1	520		13	612	37.1	2	746	113.1
10							6	616	37.7	1	799	
11	1	467										
12	1	712										
13	1	731		1	504							
14	2	741	8.5									
15				2	970	70.7						
16	3	731	33.9									
17							1	997				
18				1	732							
19												
20	1	1000		2	760	0						
21												
22	1	778										
23	1	788										
24												
25												
26												
27	1	896		1	740							

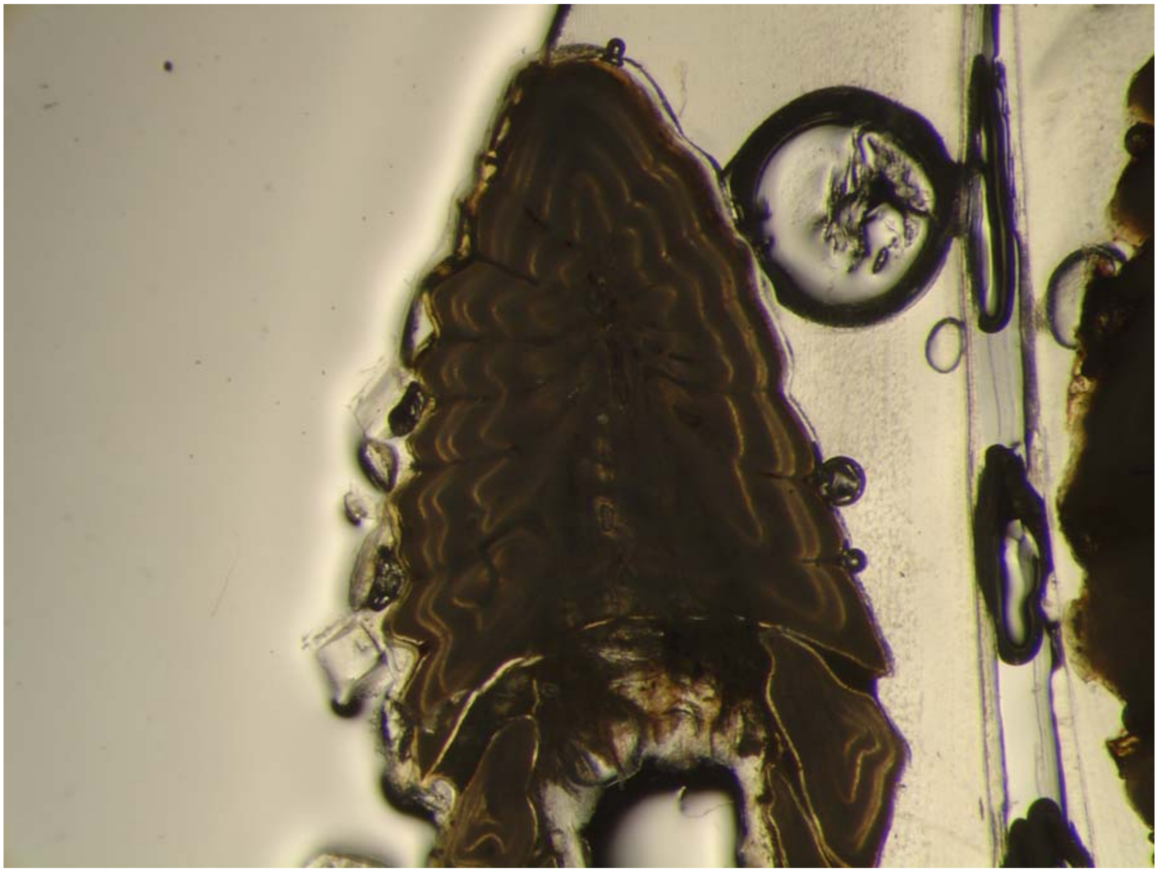

Figure 6.1. Photograph of a lake sturgeon pectoral fin cross section under magnification.

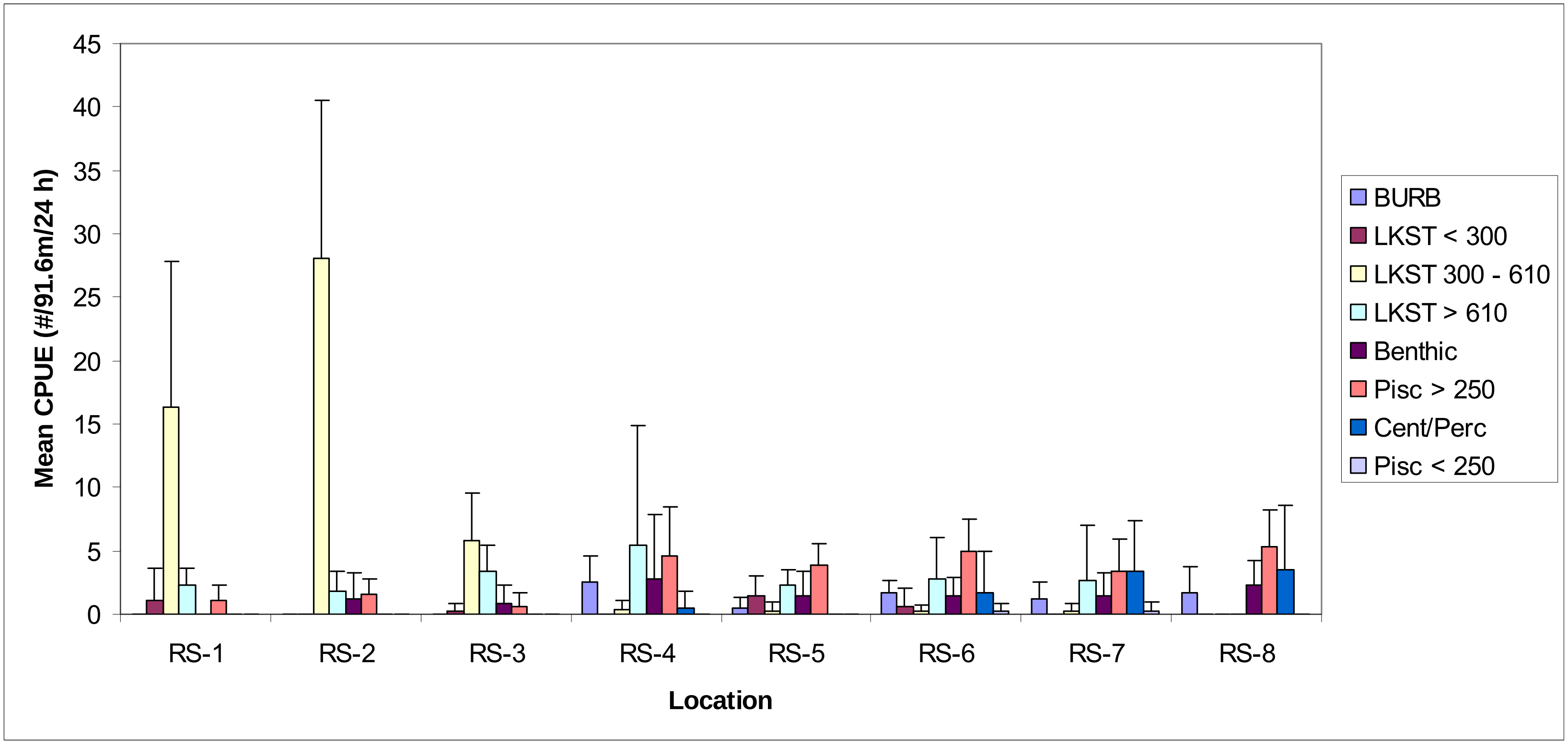

Figure 6.2. Mean CPUE (# fish/91.6 m net/24 hr) of each functional group, by river section, based on abundance data collected from 44 gill net sites sampled in the Winnipeg River, fall, 2008.

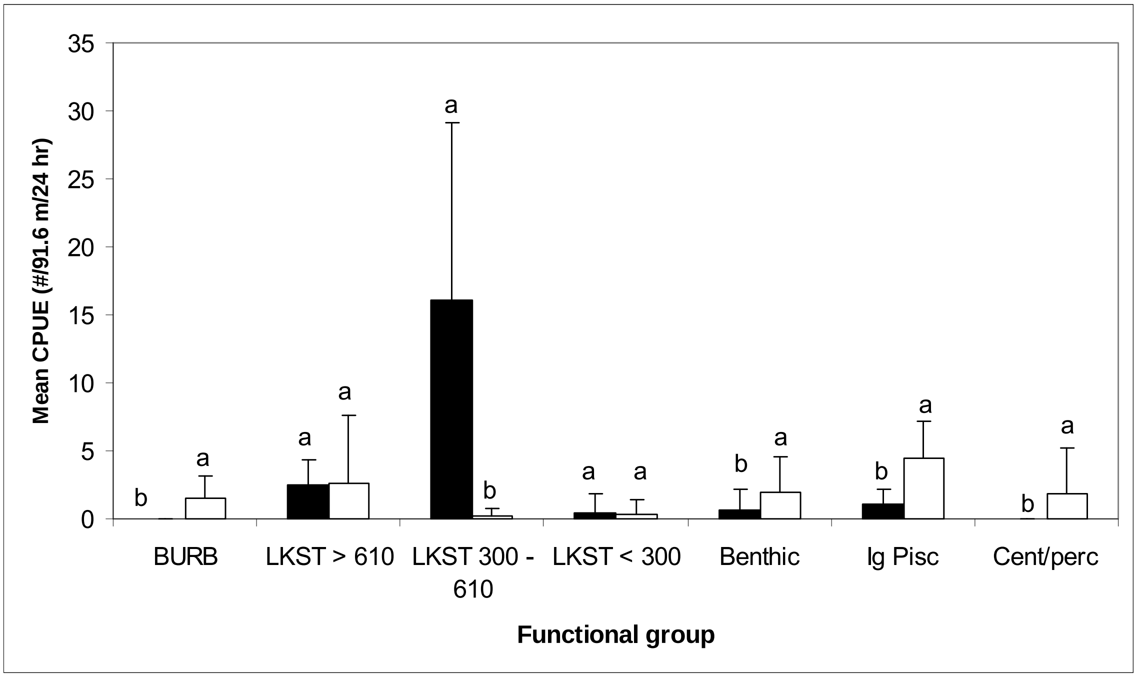

Figure 6.3. Mean CPUE (# fish/91.6 m/24 hr) values for 7 functional groups based on gill net catches at 44 sites in the Winnipeg River, fall, 2008. Error bars denote standard deviation. Filled bars denote upstream sections (RS-1 – RS-3), unfilled bars denote downstream sections (RS-4 – RS-8). Mann Whitney non-parametric tests were used to determine statistical differences between groups. Letters denote significant, or lack of significant differences between groups.

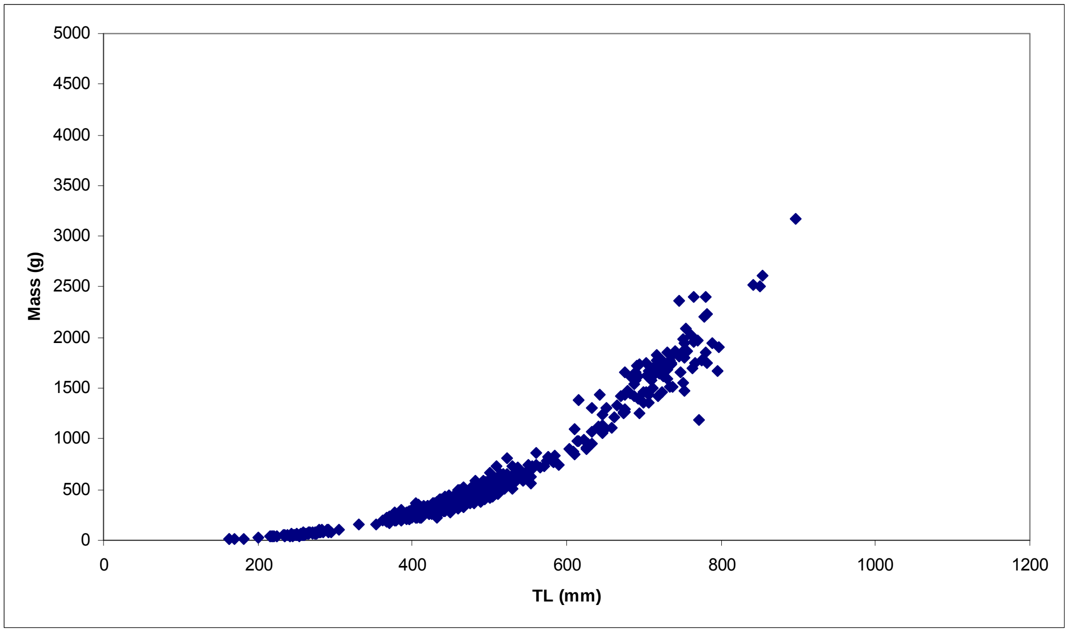

Figure 6.4a. Scatterplot of total-length (TL) (mm) vs mass (g) data collected from lake sturgeon captured in RS-1, 2006 - 2008.

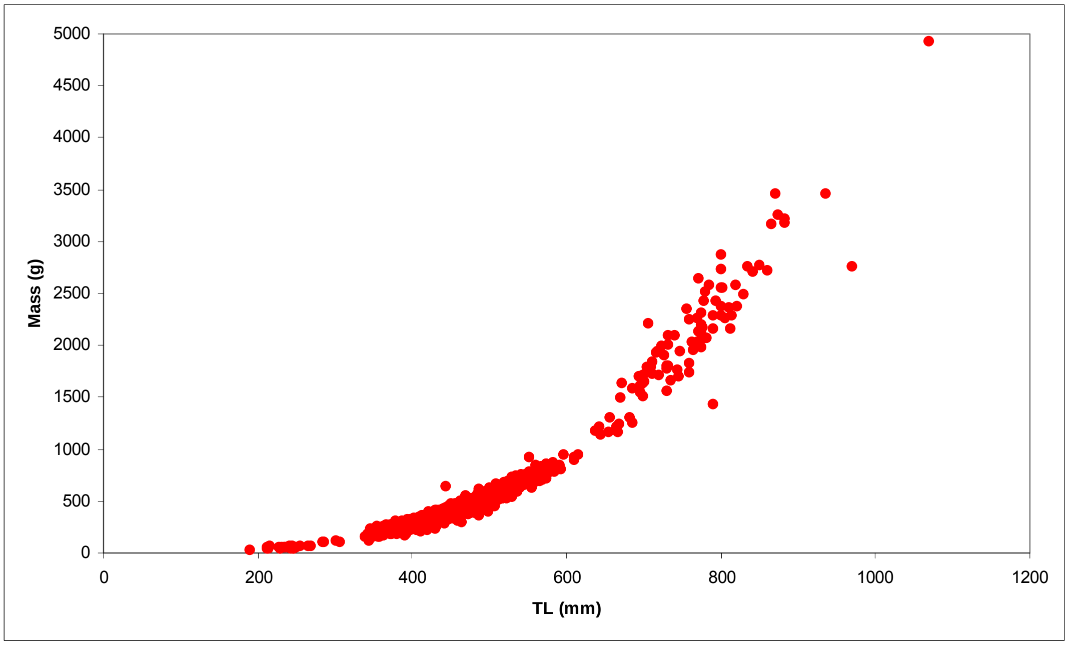

Figure 6.4b. Scatterplot of total length (TL) (mm) vs mass (g) data collected from lake sturgeon captured in RS-2, 2006 - 2008.

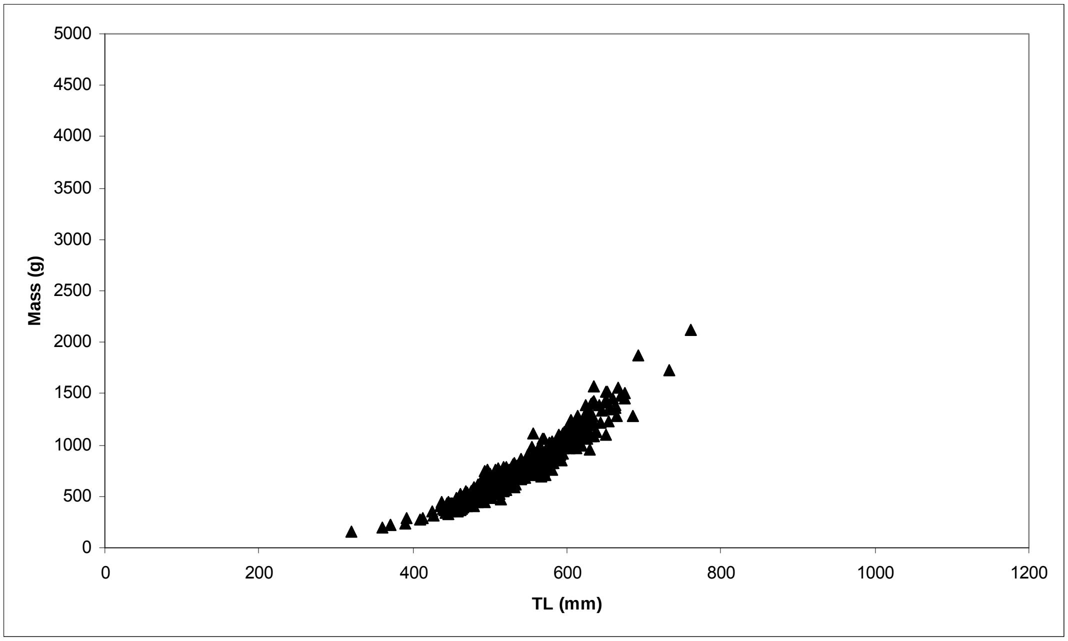

Figure 6.4c. Scatterplot of total length (TL) (mm) vs mass (g) data collected from lake sturgeon captured in RS-3, 2006 - 2008.

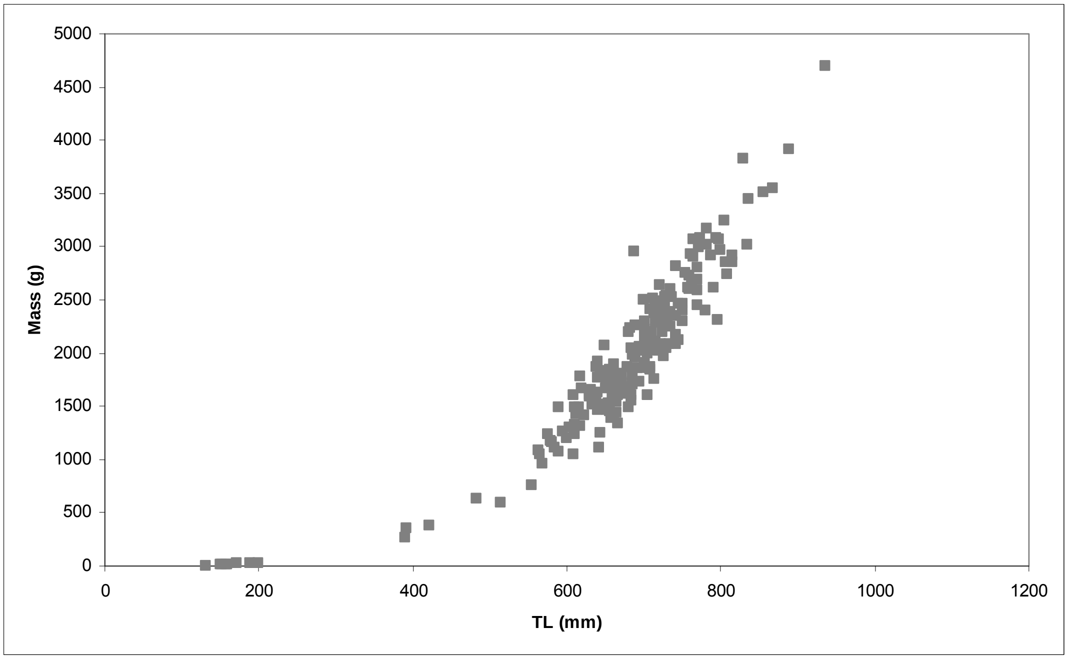

Figure 6.4d. Scatterplot of total length (TL) (mm) vs mass (g) data collected from lake sturgeon captured in RS-4 – RS-7 combined, 2006 – 2008.

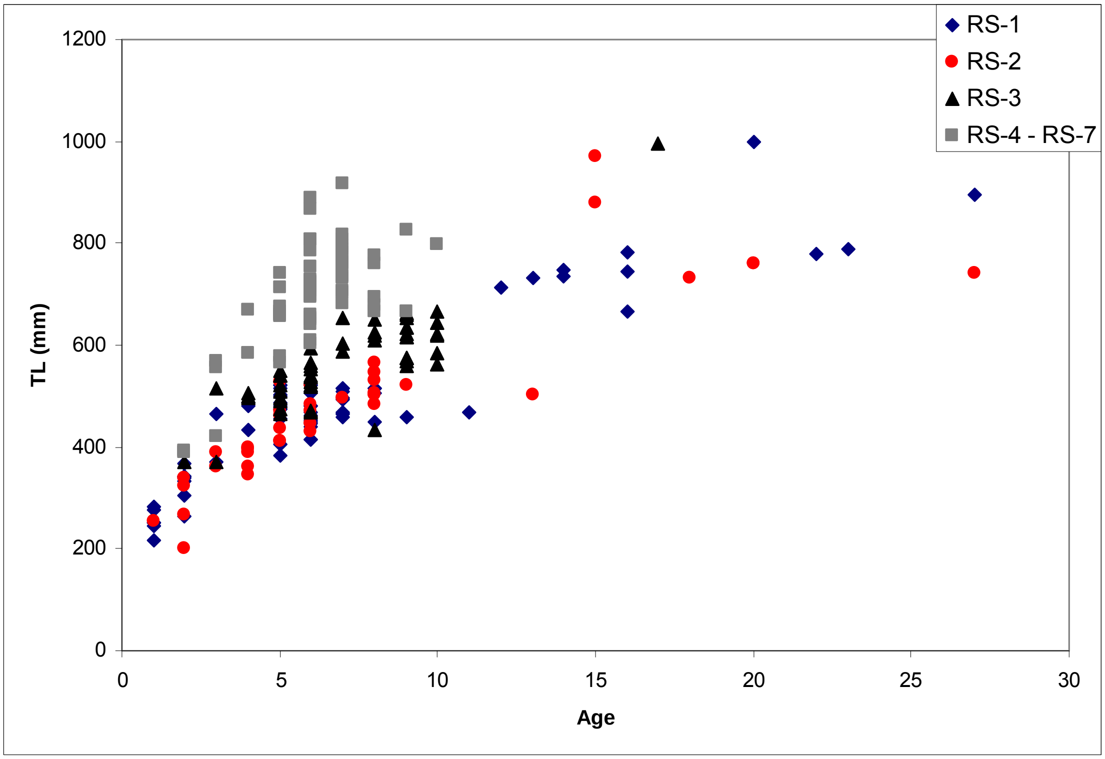

Figure 6.5a. Scatterplot of total length (TL) (mm) vs age data collected from lake sturgeon in RS-1, RS-2, RS-3, RS-4 - RS-7, combined, in the Winnipeg River study area, 2006 - 2008.

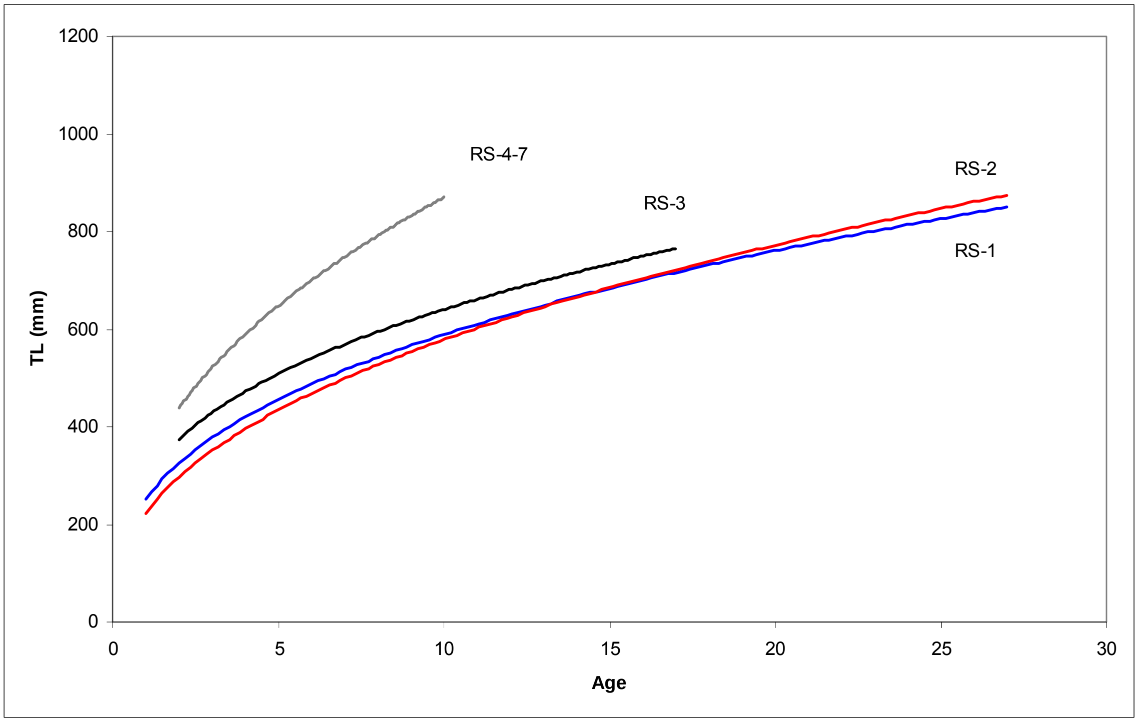

Figure 6.5b. Power relationship established from length-at-age data from juvenile lake sturgeon captured in each section of the Winnipeg River study area, 2006 - 2008.

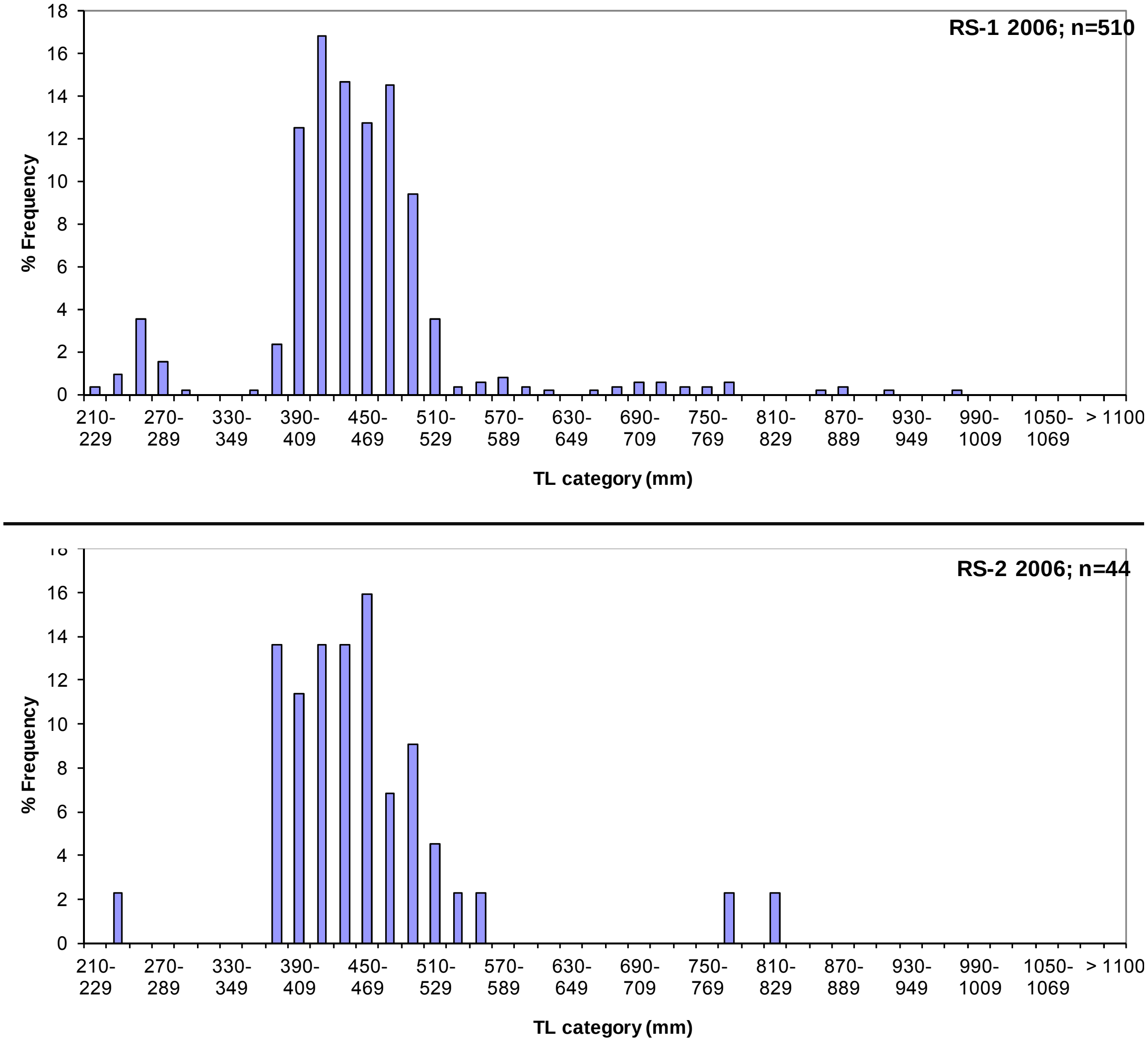

Figure 6.6. Length-frequency distributions, by 20mm length class intervals, for lake sturgeon captured in RS-1 and RS-2 between July 10 and November 8, 2006 in the Winnipeg River.

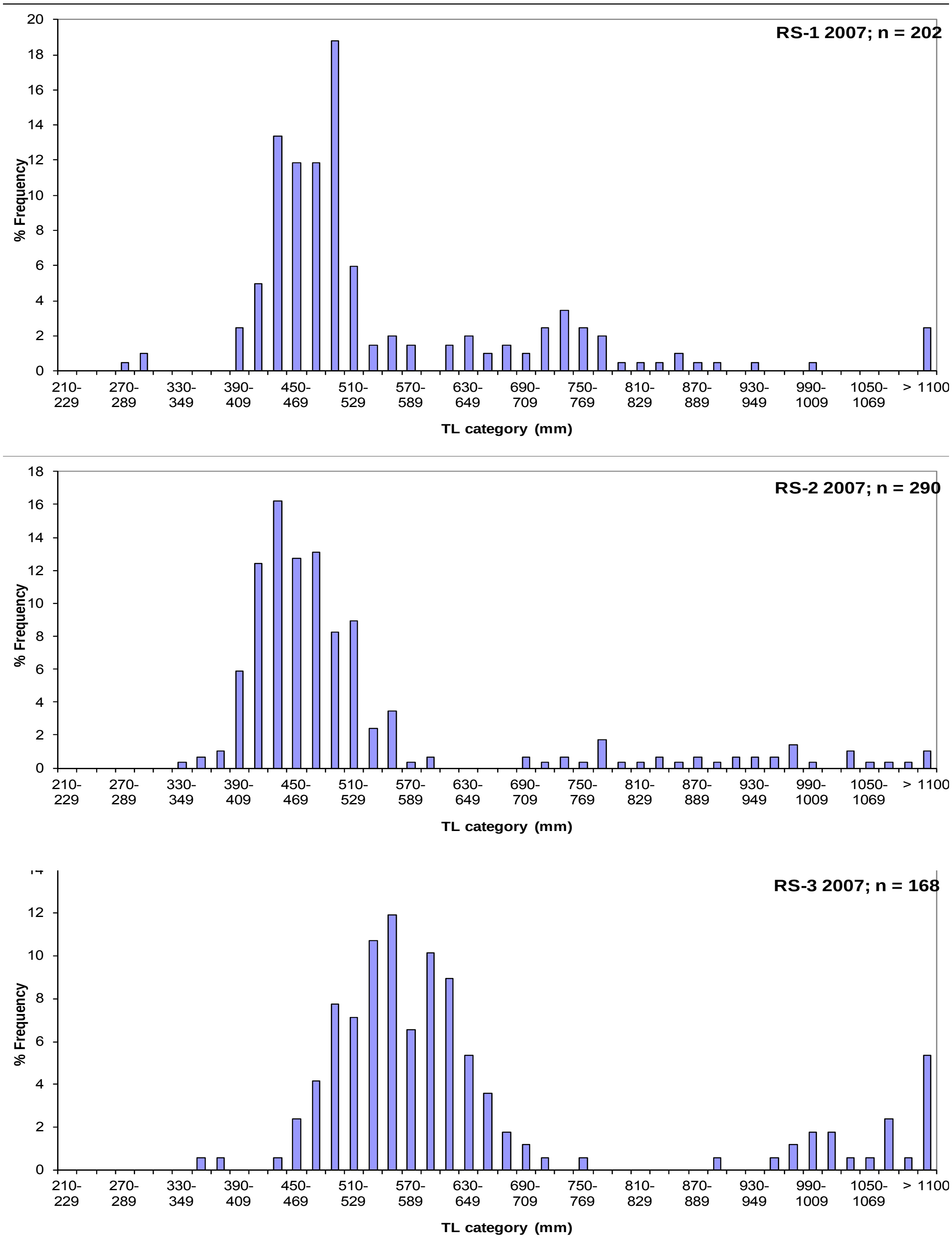

Figure 6.7. Length-frequency distribution, by 20 mm TL intervals, for lake sturgeon captured in RS-1, RS-2 and RS-3 of the Winnipeg River between July 10 and 1 November, 2007.

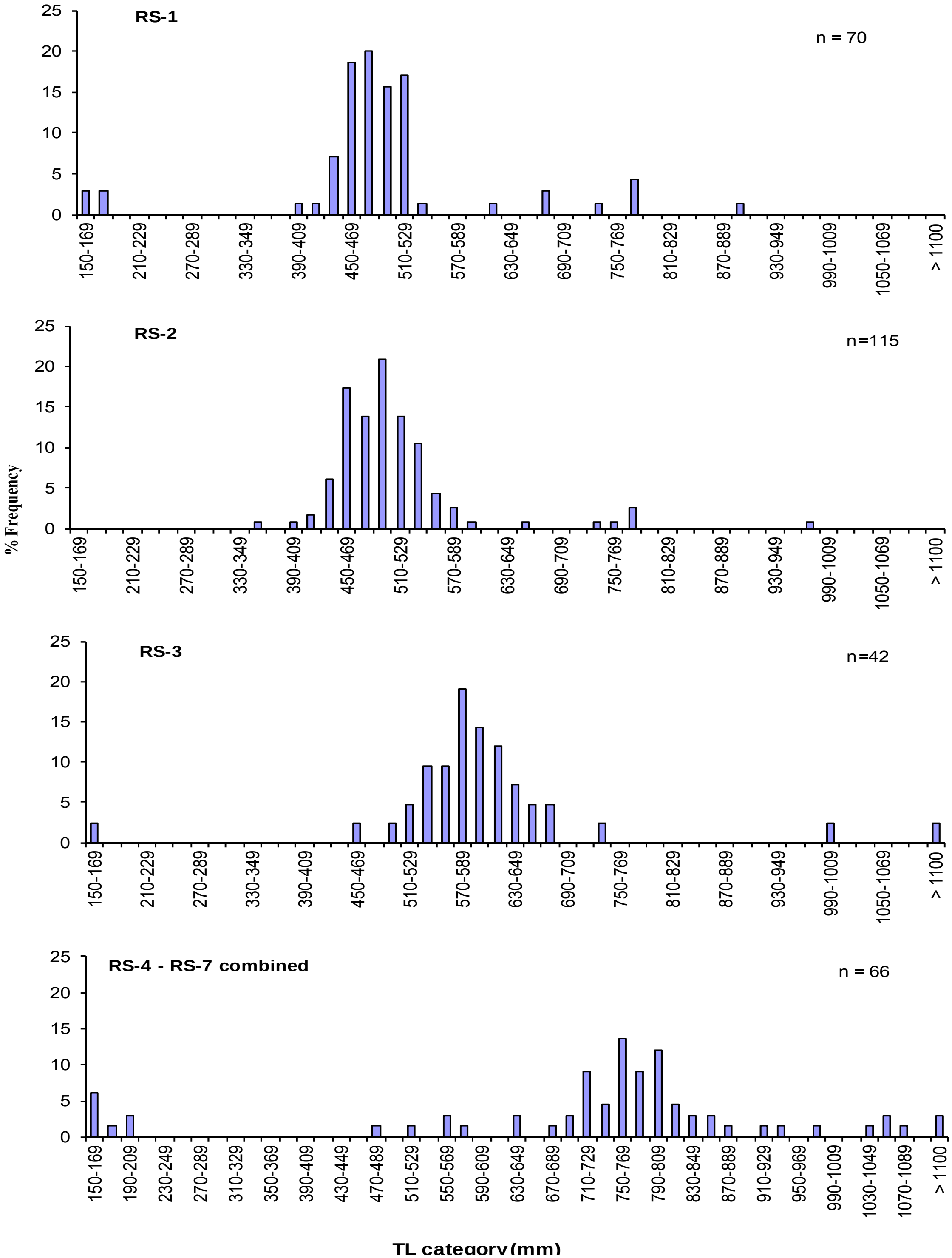

Figure 6.8. Length-frequency distribution, by 20 mm TL intervals, for lake sturgeon captured in RS-1, RS-2, RS-3 and RS-4 - RS-7 combined in the Winnipeg River after July 10, 2008. Gillnets were comprised of 25, 76, 127 and 203 mm mesh.

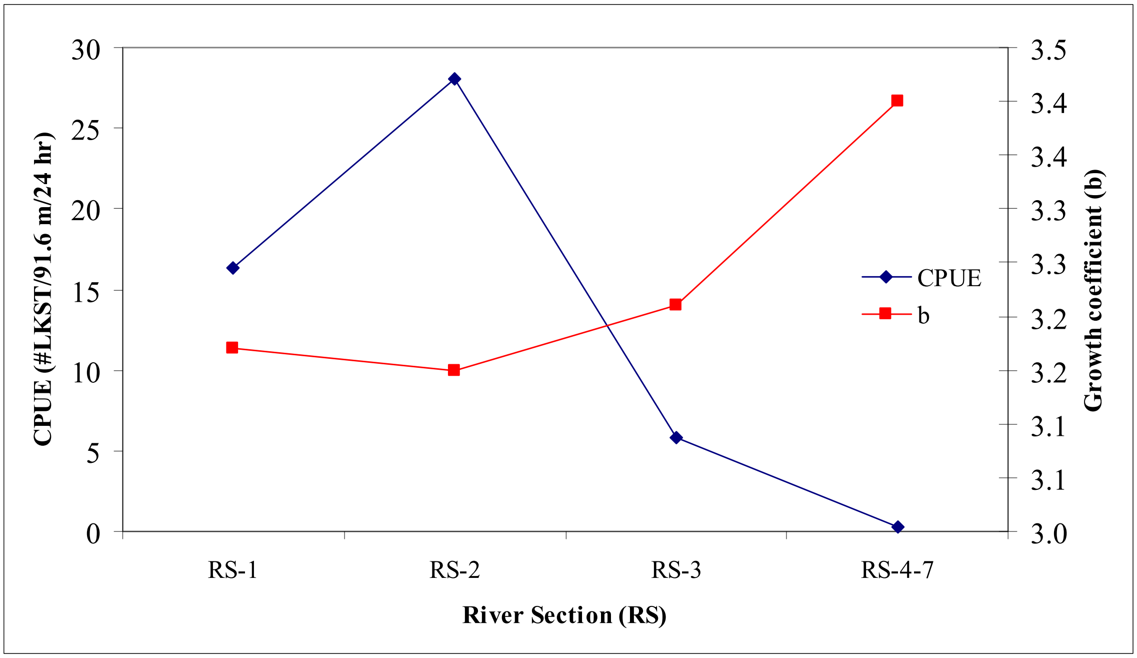

Figure 6.9. Relationship between mean catch per unit effort (CPUE #LKST/91.6 m/24 hr) (fall 2008 data) and the growth coefficient (b) of juvenile lake sturgeon (< 610 mm TL) captured in RS-1, RS-2, RS-3 and RS-4 – RS-7, combined, in the Winnipeg River study area.

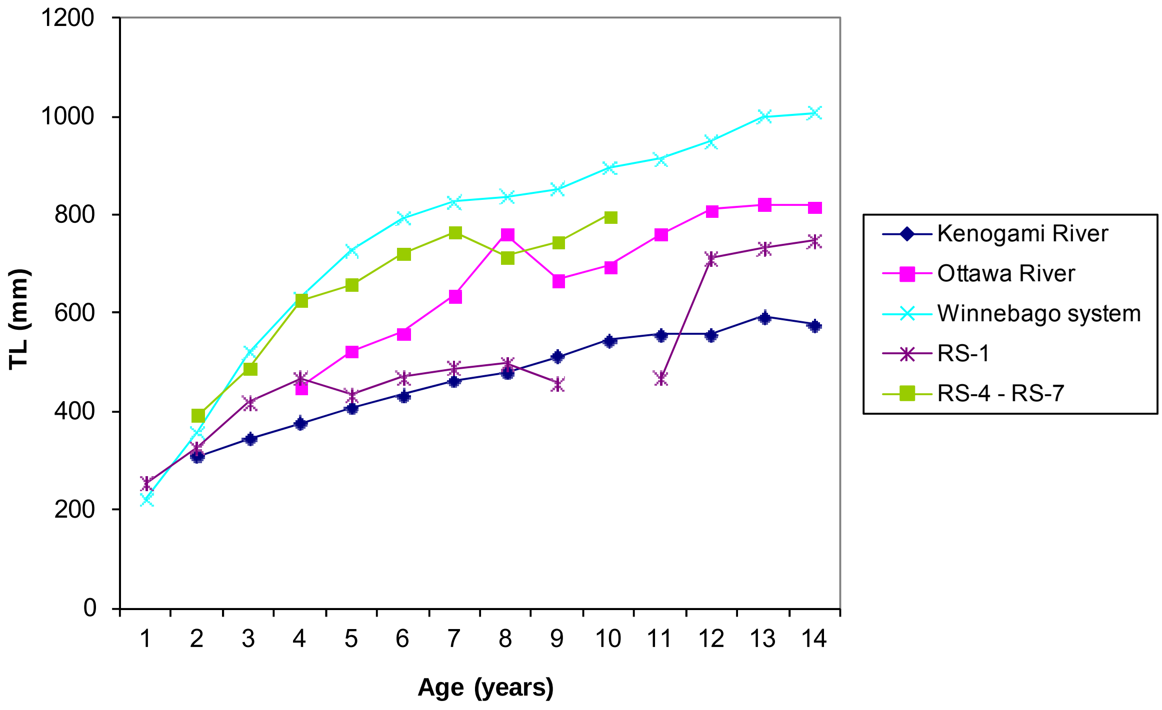

Figure 6.10. Mean length at age data from selected lake sturgeon populations in North America. (Kenogami River - Ecologistics (1987), Ottawa River - Haxton (2004), Lake St. Francis (Cuerrier 1955), Winnebago system (Bruch 2009)).

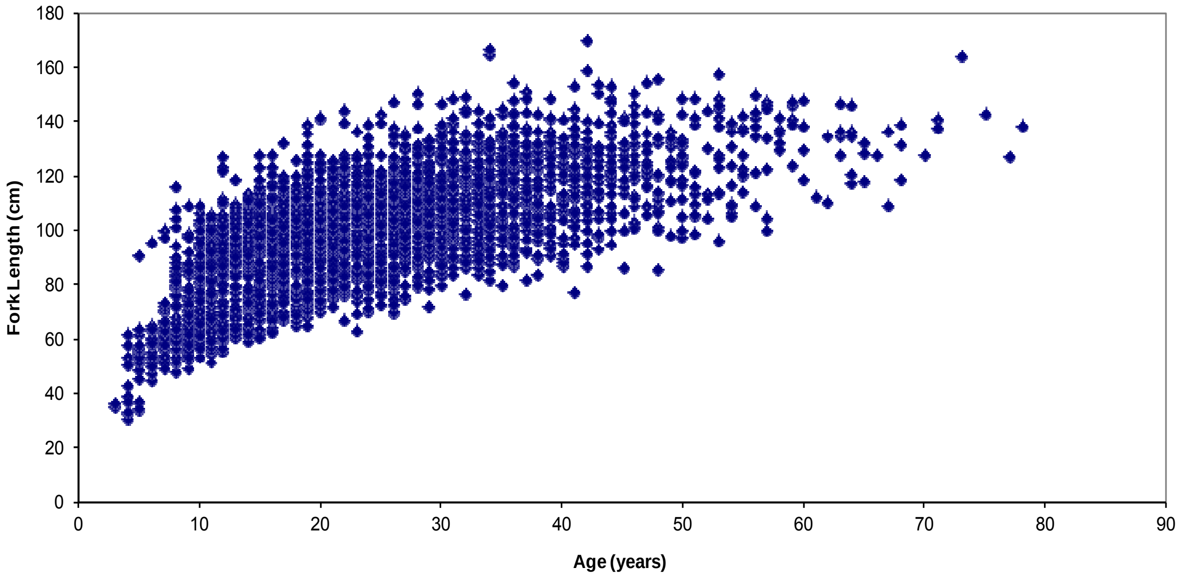

Figure 6.11. Scatterplot of fork length (cm) vs age data collected from lake sturgeon captured in the Winnipeg River between Slave Falls GS and Seven Sisters Falls GS between 1983 and 2005. Data provided by Manitoba Water Stewardship.

Chapter 7. Future research directions

7.1 Research Questions

Studies in the Winnipeg River highlighted dramatic abundance, condition factor and growth differences among subpopulations of juvenile lake sturgeon along the longitudinal axis of the 41 km long study area (Chapter 6). While earlier chapters of this thesis provided baseline data to describe habitat preferences (Chapter 2), potential biotic interactions (Chapter 3), diet (Chapter 4), and movements (Chapter 5) that combine to shape habitat selection and distribution of juvenile lake sturgeon within the study area, many unanswered questions remain with respect to factors influencing the distribution and abundance of juvenile lake sturgeon. Below, several research questions are identified to further elucidate principle biotic and abiotic factors influencing recruitment of lake sturgeon in large riverine environments. Results obtained from these studies could significantly improve impact assessment and conservation and management decisions for this threatened species.

Question #1: Location and relative importance of spawning areas in impoundments

Lake sturgeon have specific spawning habitat requirements, often spawning in areas of swift water at the base of falls, rapids or hydroelectric generating stations (Bruch and Binkowski 2002). However, physical conditions at spawning locations have been shown to be highly variable in terms of depth, water velocity and substrate. Optimal spawning habitats are thought to consist of rock or cobble substrates, combined with turbulent and complex flows where water velocities measure between 0.9 and 1.5 m.s-1 (Harkness and Dymond 1961; Brousseau 1987; LaHaye et al. 1992; Threader et al. 1998; Bruch and Binkowski 2002; Peterson et al. 2007). Auer (1996) suggested that hydroelectric dams affect the quantity and quality of available spawning habitat for sturgeon by inundating natural rapid areas and reducing water velocities. Research is needed to test this idea in large rivers such as the Winnipeg or Nelson rivers in Manitoba. In the Winnipeg River study area, it is possible that juvenile lake sturgeon abundance is driven primarily by the availability of spawning habitat, which under present day conditions may only exist in upstream sections. It is unknown if the location and relative importance of spawning areas changes following impoundment, or if lake sturgeon can adjust to altered flow regimes and move to alternate spawning areas located further upstream. This study could be conducted over a two-three week period in the Winnipeg River study area during spring. Gill nets could be set at each potential spawning location along the longitudinal axis of the impoundment to determine the relative abundance of spawning lake sturgeon. Results of this study would have important implications for assessing impacts of hydroelectric generating stations on spawning habitat availability and for spawning habitat creation following development of a hydroelectric station.

Question #2: Spatial extent of larval lake sturgeon drift in large, impounded rivers

Although several studies have attempted to quantify dispersal distance and estimate the proportion of larvae that drift various distances from spawning areas (D’Amours et al. 2001; Auer and Baker 2002; Holtgren and Auer 2004) these studies were not conducted in large impounded rivers where water velocities have been altered due to hydroelectric development. It is possible that in large impounded rivers, larval lake sturgeon do not drift extensive distances from spawning areas, and as a result, larval lake sturgeon may be distributed only in areas near spawning locations. Furthermore, it is possible that the altered flow regime in impoundments, which in general reduces water velocities, limits the downstream dispersal of larval lake sturgeon. To examine the spatial extent of larval drift in impoundments, and the effect of hydraulic conditions on larval dispersal, drift nets could be set along the longitudinal axis of the Winnipeg River study area. If the study was conducted in conjunction with the spawning habitat study described above, larval lake sturgeon abundance could be quantified and the extent of larval drift estimated relative to the abundance of spawning fish.

Question #3: Suitability of depositional substrate for larval lake sturgeon

One of the most significant impacts of impoundment is the alteration/reduction of river flows and the concomitant increase in depositional substrate in downstream sections of impoundments. Previous studies have documented larval lake sturgeon occupying sand or gravel substrates (Kempinger 1996; Benson et al. 2005), however, there has not been a study that has assessed the suitability of depositional substrate for the growth and survival of larval lake sturgeon. This question is of primary importance because if depositional substrate is indeed unsuitable, large portions of impounded rivers may no longer provide suitable habitat for larval lake sturgeon. For example, it is possible that the distribution of juvenile fish in the Winnipeg River study area is driven by poor larval survival in downstream sections of the impoundment. Three studies could be used to answer this question: 1) laboratory based investigations using protocols similar to Gessner et al. (2008) to address habitat selection in larval lake sturgeon; 2) mesocosms with different substrates to address predation and the foraging efficiency of larval lake sturgeon over different substrates; and 3) field based investigations to measure prey abundance in depositional substrate.

Question #4: Mortality of lake sturgeon larvae and YOY due to predation

This final question is more difficult to address, but its potential importance to the abundance and survival of the young life history stages of lake sturgeon cannot be ignored. It is possible that one of the main factors affecting the abundance of lake sturgeon post-impoundment is the alteration of the fish community. In general, river impoundment generally increases the abundance of predatory fish species such as walleye and northern pike. In the Winnipeg River, juvenile lake sturgeon abundance was negatively correlated with other fish species and juvenile habitat selection also suggested a general avoidance of other species. These data suggest that predation may have indeed played a role in shaping their habitat selection. Field studies designed to address the predation question however, have proven unreliable due to emulsion of stomach contents from fish removed from deep water habitat, and digestion rates that may preclude the identification of small fish. Clearly, new and innovative methodologies are needed to address this question in the wild.

7.2 Conclusions

This thesis has described in depth, seasonal community structure, distribution, habitat use, diet and behaviour of juvenile lake sturgeon in a large riverine environment. The data presented will form a baseline for future hypotheses driven research such as the questions outlined above. While collection and analysis of such data to answer these questions is logistically challenging, nonetheless they should be considered priority research questions that have the potential to provide significant insight into factors influencing abundance and recruitment to lake sturgeon populations in large river systems across North America. Furthermore, they will increase our knowledge of factors that drive the ecology of Acipeneserids in large river systems throughout the world. Finally, addressing these research questions will aid in the protection of remaining populations and thus ensure the continued existence of the enigmatic and culturally iconic lake sturgeon.

7.3 References

Auer, N. A., 1996: Importance of habitat and migration to sturgeons, with emphasis on lake sturgeon. Can. J. Fish. Aquat. Sci. 53, 152-160.

Auer, N. A.; Baker, E. A., 2002: Duration and drift of larval lake sturgeon in the Sturgeon River, Michigan. J. Appl. Ichthyol. 18, 557-564.

Benson, A. C.; Sutton, T. M.; Elliot, R. F.; Meronek, T. G., 2005: Seasonal movement patterns and habitat preferences of age-0 lake sturgeon in the Lower Peshtigo River, Wisconsin. Trans. Am. Fish. Soc. 134, 1400-1409.

Brousseau, C. S., 1987: The lake sturgeon (*Acipenser fulvescens*) in Ontario. In: Proceedings of a workshop on the lake sturgeon (*Acipenser fulvescens*). Ontario Ministry of Natural Resources Fisheries Technical Report Series 23, Maple, Ontario pp. 2-9.

Bruch, R. M.; Binkowski, F. P., 2002: Spawning behaviour of lake sturgeon (*Acipenser fulvescens*). J. Appl. Ichthyol. 18, 570-579.

D'Amours, J.; Thibodeau, S.; Fortin, R., 2001: Comparison of lake sturgeon (*Acipenser fulvescens*), *Stizostedion* spp., *Catostomus* spp., quillback (*Carpoides cyprinus*) and mooneye (*Hiodon tergisus*) larval drift in Des Prairie River, Quebec. Can. J. Zool. 79, 1472-1489.

Gessner, J.; Kamerichs, C. M.; Kloas, W.; Wuertz, S., 2008: Behavioural and physiological responses in early life phases of Atlantic sturgeon (*Acipenser oxyrinchus* Mitchill) towards different substrates. J. Appl. Ichtyol. 25, 83-90.

Harkness, W. J. K.; Dymond, J. R., 1961: The lake sturgeon. Ontario. Department of Lands and Forests, Toronto, Ontario, Canada.

Holtgren, J. M.; Auer, N. A., 2004: Movement and habitat of juvenile lake sturgeon (*Acipenser fulvescens*) in the Sturgeon River/Portage Lake system, Michigan. J. Freshwat.Ecol. 19, 419-432.

Kempinger, J. J., 1996: Habitat, growth, and food of young lake sturgeons in the Lake Winnebago system, Wisconsin. N. Am. J. Fish. Manage. 16, 102-114.

LaHaye, M.; Branchaud, M.; Gendron, M.; Vendon, R.; Fortin, R., 1992: Reproduction, early life history, and characteristics of the spawning grounds of the lake sturgeon (*Acipenser fulvescens*) in Des Prairies and l'Assomption rivers, near Montreal, Quebec. Can. J. Zool. 70, 1681-1689.

Peterson, D.; Vesci, P.; Jennings, C. A., 2007: Ecology and biology of the lake sturgeon: a synthesis of current knowledge of a threatened North American Acipenseridae. Rev. Fish. Biol. Fisher. 17, 59-76.

Threader, R.; Brousseau, C. S., 1986: Biology and Management of the Lake Sturgeon in the Moose River, Ontario. N. Am. J. Fish. Manage. 6, 383-390.