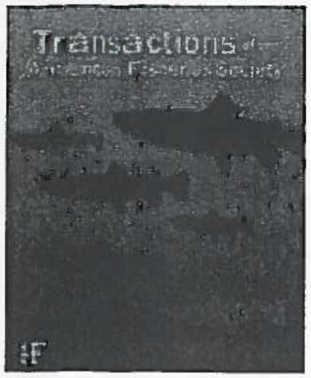
CAC Exhibit ________



Transactions of the American Fisheries Society
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/utaf20

Home Range Size and Seasonal Movement of Juvenile Lake Sturgeon in a Large River in the Hudson Bay Drainage Basin

Cameron C. Barth [a], W. Gary Anderson [a], L. M. Henderson [b] & Stephan J. Peake [b]

[a] Department of Biological Sciences, University of Manitoba, 50 Sifton Road, Winnipeg, Manitoba, R3T 2N2, Canada

[b] Canadian Rivers Institute, Department of Biology, University of New Brunswick, 3 Bailey Drive, Fredericton, New Brunswick, E3B 9P8, Canada

Published online: 15 Dec 2011.

To cite this article: Cameron C. Barth, W. Gary Anderson, L. M. Henderson & Stephan J. Peake (2011) Home Range Size and Seasonal Movement of Juvenile Lake Sturgeon in a Large River in the Hudson Bay Drainage Basin, Transactions of the American Fisheries Society, 140:6, 1629-1641, DOI: 10.1080/00028487.2011.641881

To link to this article: http://dx.doi.org/10.1080/00028487.2011.641881

Transactions of the American Fisheries Society 140:1629–1641, 2011

ISSN: 0002-8487 print / 1548-8659 online
DOI: 10.1080/00028487.2011.641881

ARTICLE

Home Range Size and Seasonal Movement of Juvenile Lake Sturgeon in a Large River in the Hudson Bay Drainage Basin

Cameron C. Barth* and W. Gary Anderson
Department of Biological Sciences, University of Manitoba, 50 Sifton Road, Winnipeg, Manitoba R3T 2N2, Canada

L. M. Henderson and Stephan J. Peake
Canadian Rivers Institute, Department of Biology, University of New Brunswick, 3 Bailey Drive, Fredericton, New Brunswick E3B 9P8, Canada

Abstract

Development of rehabilitation strategies and accurate assessment of anthropogenic impacts relies on a thorough understanding of a species' life history. In the case of the lake sturgeon *Acipenser fulvescens*, a better understanding of the juvenile life history stages is needed to improve conservation efforts for this imperiled species. Home range size and seasonal movement of juvenile lake sturgeon in the Winnipeg River, Manitoba, were examined using mark–recapture and acoustic telemetry. Over a 30-month period (May 2006–October 2008), 5,671 juvenile lake sturgeon (213–879 mm fork length [FL]) were marked with Floy tags and the movements of 23 juvenile lake sturgeon (364–505 mm FL) were monitored by means of acoustic transmitters. Despite the potential for movement over 49 km of naturally connected riverine habitat, the results indicated that juvenile lake sturgeon exhibited strong site fidelity. As determined from the mark–recapture data set, 90.8% of recaptured fish were recaptured less than 2.0 river kilometers (rkm) from their original capture location. Similarly, acoustic telemetry data indicated that 50% of the tagged fish moved 1.5 rkm or less from their initial release locations. Finally, the results of both methodologies indicated that juvenile lake sturgeon rarely move through rapids characterized by high water velocities (>1.5 m/s), complex turbulent flows, boulder and bedrock substrates, and various cross-sectional water depths ranging from 1.0 m to approximately 15.0 m in either an upstream or downstream direction. These results suggest that the year-round habitat requirements for juvenile lake sturgeon can be met in relatively short sections of a large river. Furthermore, owing to strong site fidelity and a lack of movement through rapids, macroscale habitat use in juvenile lake sturgeon occupying large rivers may be dependent on dispersal at either the larval or young of the year life history stages.

The lake sturgeon *Acipenser fulvescens* is found throughout central and eastern 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 native range; however, many populations have suffered dramatic declines owing to various anthropogenic activities such as water pollution and overexploitation (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 alterations (e.g., attributed to hydroelectric development) 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

*Corresponding author: umbarth0@cc.umanitoba.ca
Received December 7, 2010; accepted June 6, 2011
Published online December 15, 2011

history requirements, differences between genetically distinct populations in terms of behavior, habitat use, and movement have become evident, and several knowledge gaps remain, especially with respect to the young 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 overwintering areas. Comparably few studies have characterized home range size and seasonal movement patterns of the lake sturgeon at the juvenile life history stage (Auer 1996; Peterson et al. 2007). Previous studies have focused on movements of young of the year (age 0) (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 Laurentian Great Lakes. Despite these studies, our understanding of seasonal movement patterns, spatial requirements, and 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 Winnipeg River and English River lake sturgeon populations were Designated Unit (DU) 5 by COSEWIC in 2006 (Cleator et al. 2010). This DU was subdivided into nine distinct lake sturgeon management units (MUs) that included populations in the Winnipeg River drainage from the outlet of Lake of the Woods (start of MU 1) to the outlet of the Winnipeg River at Lake Winnipeg (end of MU 9). Lake sturgeon populations in MUs 1–4 (i.e., those between the outlet of the Lake of the Woods in Ontario and the upstream side of Pointe Du Bois generating station [GS] in Manitoba) were assessed as either unknown status or possibly decreasing. Lake sturgeon populations between the Pointe Du Bois GS and the Slave Falls GS (MU 5), and between the Slave Falls GS and the Seven Sisters Falls GS (MU 6), were assessed as healthy. The lake sturgeon population trajectory downstream from the Seven Sisters Falls GS, including MUs 7, 8, and 9, was addressed as unknown (Cleator et al. 2010).

Relatively little published information exists concerning lake sturgeon populations in the Winnipeg River, including this study area, which spans the length of the Winnipeg River between the Slave Falls GS and the Seven Sisters Falls GS (MU 6) (Figure 1). Two spawning areas have been identified for the lake

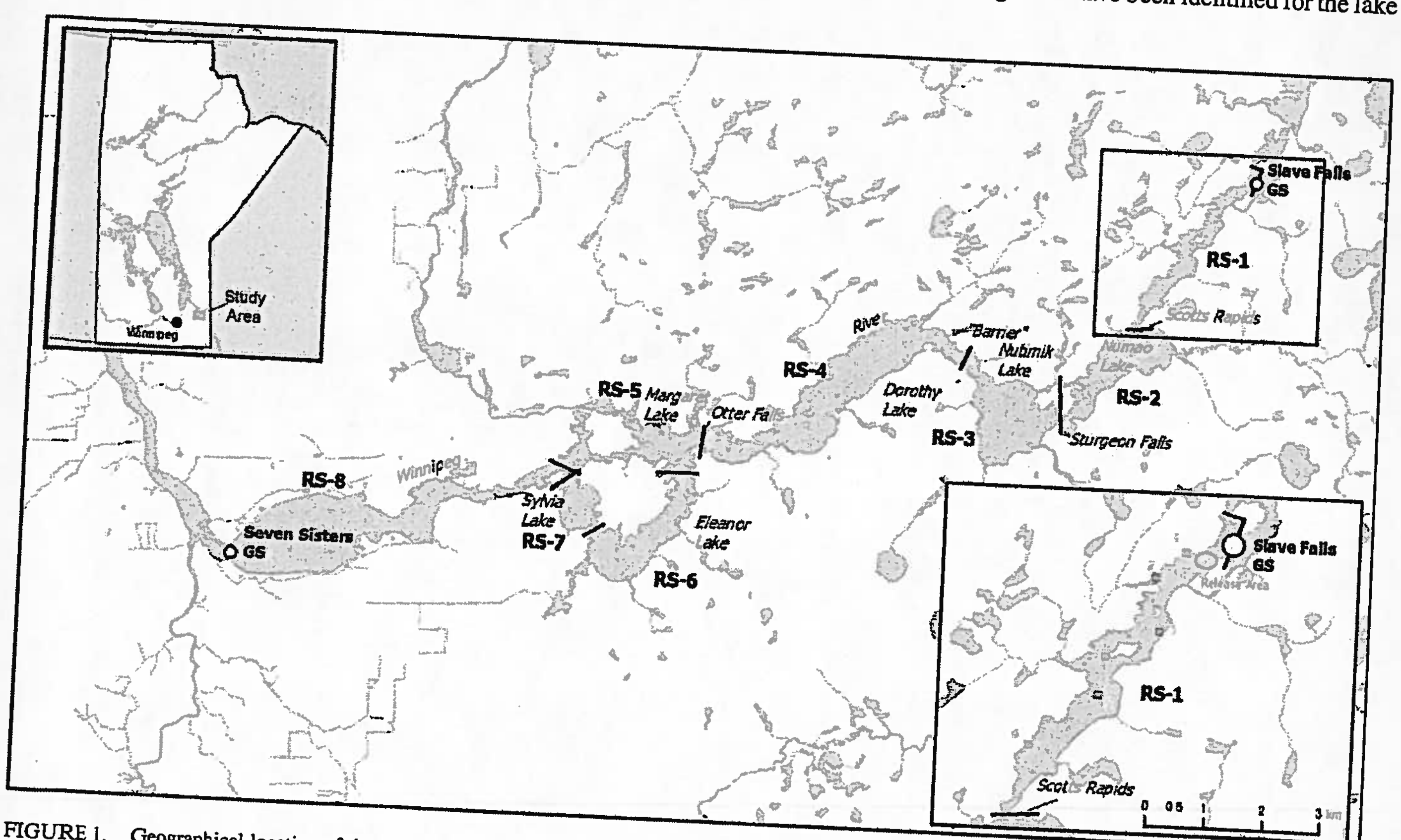


FIGURE 1. Geographical location of the study area. The headwaters of the Winnipeg River are located in northwestern Ontario and the river flows into Lake Winnipeg, Manitoba, in north-central North America. There are eight subdivisions within the study area (RS-1–RS-8); RS-1 was enlarged to illustrate the location of acoustic receivers 1–6 in addition to the release site of juvenile lake sturgeon marked with acoustic tags. RS = river section, GS = generating station. [Figure available online in color.]

sturgeon population in this reach, the first at the base of the Slave Falls GS, and the second just upstream of Nutimik Lake at Sturgeon Falls (Figure 1). Between 1992 and 1997, Jolly–Seber population estimates in MU 6 varied from 3,704 to 20,703 adult lake sturgeon; however, the younger year classes were poorly represented in the catch suggesting that this was an aging population with minimal recruitment (Block 2001). Studies that began during spring 2006, however, indicated that juvenile lake sturgeon were abundant in this reach of the Winnipeg River (Barth et al. 2009). The objectives of present study were to examine home range size and seasonal movements of juvenile lake sturgeon in this reach of the Winnipeg River using two methods, mark–recapture and acoustic telemetry.

METHODS

Study Area

The Winnipeg River is a large river in the Hudson Bay drainage basin that 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 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 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 (established 1931) (50°13′39″N, 95°37′51″W) at the upstream end, and Seven Sisters Falls GS (established 1931) (50°07′09″N, 96°01′03″W) at the downstream end (Figure 1).

The study area is located in the Canadian Shield, with the surrounding landscape being composed 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 in this reach of the Winnipeg River. Although narrow channels with water velocities exceeding 1.0 m/s 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 greater than 1.5 m/s) occur at Scotts Rapids, Sturgeon Falls, the Barrier, and Otter Falls (Figure 1). Both the Slave Falls GS and Seven Sisters Falls GS are operated as run-of-the-river facilities. There are no anthropogenic barriers between the Slave Falls GS and Seven Sisters Falls GS.

To facilitate a better geographic description of the study area, this reach of the Winnipeg River was subdivided into eight river sections (RSs) (Figure 1). Sections were delineated based on river topography with boundary margins located at constrictions of the river that generally coincide with the inlets or outlets, or both, of lakes (lakes being areas where the Winnipeg River widens). These boundary margins were each characterized by water velocities in excess of 1.0 m/s, hard, coarse (>100 mm) substrate, and variable water depths that along a cross-section may range from 1.0 to approximately 15.0 m. Owing to safety concerns, however, detailed water depth and velocity information were not collected from these areas. The most upstream section of the study area, designated as RS-1, measured a total of 6.0 river kilometers (rkm) from Slave Falls at the upstream end to Scotts Rapids. The remaining RSs, from upstream to downstream, include: RS-2, Numao Lake (4.0 rkm long); RS-3, Nutimik Lake (4.0 rkm long); RS-4, Dorothy Lake (9.0 rkm long,); RS-5, Margaret Lake (8.5 rkm long, includes both channels); RS-6, Eleanor Lake (4.5 rkm long); RS-7, Sylvia Lake (2.0 rkm long;); and RS-8, Natalie Lake (11.0 rkm long) (Figure 1).

Water velocities in the main channel of the Winnipeg River were generally 0.2–0.8 m/s in the upstream reaches (i.e., RS-1, RS-2, and RS-3), and less than 0.2 m/s in the main channel of the downstream reaches (RS-4, RS-5, RS-6, RS-7, and RS-8) of the study area. Substrate in the main channel of each river section was influenced by corresponding flow conditions. Substrates consisting of particle sizes larger than 0.063 mm were associated with water velocities greater than 0.2 m/s in RS-1, RS-2, and RS-3, whereas substrates with particle sizes less than 0.063 mm (depositional) were associated with the lower velocities found in the main channel of the lower reaches of the study area (RS-4 to RS–8). Depths measuring less than 5 m are generally found along shorelines or in back bays, and depths of 10–25 m are typical of the main channel. The maximum depth in this study area was approximately 45 m. The study area was classified as mesotrophic, being well oxygenated with moderate nutrient levels, moderate alkalinity (pH 7.5–7.9), and low turbidity (1.5–7.0 nephelometric turbidity units [NTU]) (CCME 1999).

Fish Capture and Sampling Methodology

Mark–recapture.—From May 2006 to October 2008, juvenile lake sturgeon were captured in gill nets that consisted of various mesh sizes ranging from 25- to 203-mm stretched measure, twisted nylon mesh (Leckies Net and Twine, Winnipeg, Manitoba), equipped with 1-cm-diameter braided float and lead lines. 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. Juvenile lake sturgeon were marked with an individually numbered Floy FD-94-T-bar anchor tag (Floy Tag, Seattle, Washington) applied on the left side of the fish at the base of the dorsal fin by means of a tagging gun (Dennison Mark II, Floy Tag). Lake sturgeon measuring less than 250 mm FL were tagged with individually numbered passive integrated transponder (PIT) tags (12 mm length, 134.2 kHz, Biomark, Boise, Idaho) inserted into the body cavity through a small mid-ventral incision. The PIT tags were scanned after insertion into the fish with a Pocket Reader EX (Biomark). When a lake sturgeon was recaptured, location, Floy tag number, and PIT tag number, 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. This study focused on describing the movement of lake sturgeon measuring less than 879 mm FL. Data collected at lake sturgeon spawning areas in this reach of the Winnipeg River during spring suggest that lake sturgeon in this size-class are sexually immature (C. C. Barth, unpublished data) and are therefore by definition considered to be juveniles.

Acoustic transmitter application.—Between May 29 and May 31, 2007, at water temperatures measuring between 10°C and 11°C, 23 lake sturgeon (364–505 mm FL, 316–665 g) were captured in gill nets and each fish was implanted with a uniquely coded acoustic transmitter that pulsed randomly every 60–180 s. Transmitters (model V9–1 L, VEMCO, Shad Bay, Nova Scotia) had an estimated battery life of 180 d, measured 24 mm in length, and had a mass of 3.6 g, which equated to less than 1.1% of each fish's body mass. Transmitters were programmed with different activation times to avoid confounding detections associated with releasing a large number of tagged fish in the same area. Of the 23 transmitters initially released, four became active immediately, while 9 and 10 of the transmitters were programmed with 4-month (activated in October 2007) and 8-month (activated in February 2008) activation delays, respectively.

The transmitter implantation process followed procedures similar to those outlined in Wagner et al. (2000) and Jepsen et al. (2002). Each lake sturgeon was measured for FL (±1 mm), TL (±1 mm), and body mass (±5 g) before the surgical procedure. Lake sturgeon were brought to shore and anesthetized in approximately 50 L of river water containing 60 mg/L clove oil in ethanol (9:1, ethanol : clove oil) (Anderson et al. 1997). Fish were considered to be fully anesthetized once equilibrium was lost and ventilation had slowed. Anesthetized 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 anterior to the pelvic fins 10–15 mm adjacent to the ventral midline to expose the abdominal cavity. Before insertion through the incision, transmitters were disinfected in ethanol. Incisions were then closed by using polydioxanone (PDS) suture material 3–0 and a CP-2 reverse edge cutting needle (Ethicon, Markham, Ontario). To monitor for complete recovery sturgeon were held overnight in a large, circular tank supplied with flow-through river water before being released. All described procedures were conducted under approved animal care protocols at the University of Manitoba pursuant to the guidelines of the Canadian Council for Animal Care.

Acoustic receivers.—Fish marked with acoustic tags were located by using an array of 44 stationary acoustic receivers (model VR2, VEMCO). Receivers were strategically spaced in the study area in order to maximize coverage of the area and minimize detection area overlap. Acoustic receivers were equipped with an omnidirectional 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 tag detection. For a single omnidirectional 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.

Of the 44 VR2 receivers used to monitor tagged juvenile lake sturgeon, 42 were deployed on May 27, 2007, and the remaining two receivers (1 and 2 located near the Slave Falls GS) were deployed on September 27, 2007 (Figure 1). Before the deployment of receivers 1 and 2, movements of tagged fish in the area immediately downstream from the Slave Falls GS were monitored by a radiolinked Radio/Acoustic Positioning system (VRAP) (VEMCO) that was deployed on May 15, 2007. The 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 by means of a global positioning system (GPS) device (Garmin, model GPS 76, Olathe, Kansas). After approximately 1 year, receivers were retrieved by a scuba diver, downloaded, and subsequently redeployed.

Data Analysis

Mark–recapture.—The number of days between the original mark date and subsequent recapture date were divided into three categories: (1) less than 30 d, (2) between 30 and 365 d, and (3) greater than 365 d. To avoid biasing results towards nonmovement, only fish recaptured more than 30 d after the original tagging date were considered for 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 locations (Gerking 1959). Linear regression was used to determine if a relationship existed between body size (FL) and movement distance within each river section. The number of tags applied and recaptured in each RS was grouped by 50-mm-FL class intervals and distance categories of 0.0–1.0 rkm, 1.1–2.0 rkm, or greater than 2.0 rkm. Finally, a Kruskal–Wallis nonparametric 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 were presented ±1 SD.

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. Seasonal home range estimates reflect the maximum distance in river kilometers that a tagged juvenile lake sturgeon could have moved before 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 farthest upstream and downstream extents 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.

To examine seasonal home range size and seasonal movement patterns, movement distance was measured for each individual fish by time period: (1) spring: May 1 to July 10, 2007 and 2008; water temperature range, 5–18°C; (2) summer: July 11 to September 30, 2007; water temperature range, 15–22°C; (3) fall: October 1 to December 10, 2007; water temperature range, 1–15°C; and (4) winter: December 11, 2007, to April 30, 2008; water temperature range, 1–5°C. A Kruskal–Wallis nonparametric comparison using Dunn's procedure for multiple comparisons was used to examine seasonal differences in home range size as data were nonnormal and heteroscedastic even after transformation. Statistical analyses were conducted using XLSTAT (version 2006.2) in Excel (Microsoft, Redmond, Washington). A significance level of $P < 0.05$ was used for all statistical analyses.

RESULTS

Mark–Recapture

The majority of the effort to mark–recapture juvenile lake sturgeon occurred in the upstream sections of the Winnipeg River study area, particularly RS-1 and RS-2 (Table 1). In 2006, only RS-1 to RS-4 were fished, and most of the effort was expended in RS-1. In 2007, each river section was fished, with RS-1 to RS-4 receiving the majority of the gill-netting effort. In 2008, all river sections were fished, with RS-4 receiving the most effort. Discharge of the Winnipeg River varied between 242 and 2,286 m^3/s (mean 928 m^3/s) during the 30 months of study.

TABLE 1. Gill-netting effort (h) required to mark–recapture juvenile lake sturgeon, by gill-net mesh size and river section (RS) in the reach of the Winnipeg River between the Slave Falls generating station (GS) and the Seven Sisters Falls GS from May 2006 to October 2008. River sections are ordered from upstream to downstream.

River section	Mesh size (mm)								
	25	38	51	76	95	108	127	203	Total hours
				2006					
RS-1	1,497.5	93.7	915.6	750.1	402.0	402.0	402.0		4,462.8
RS-2	670.9	105.7	307.8	107.9	107.9	107.9	107.9		1,516.0
RS-3	314.2								314.2
RS-4	141.0								141.0
RS-5									0.0
RS-6									0.0
RS-7									0.0
RS-8									0.0
				2007					
RS-1	3,009.7		122.7	856.8			878.4	925.4	5,792.9
RS-2	2,004.0		164.0	899.7			889.2	984.4	4,941.2
RS-3	1,442.1			905.6			908.2	976.8	4,232.8
RS-4	423.6			386.4			390.0	401.2	1,601.2
RS-5	149.6			149.6			149.6	149.6	598.4
RS-6	161.3			161.3			161.3	161.3	645.2
RS-7	154.6			154.6			154.6	154.6	618.4
RS-8	157.8			157.8			157.8	157.8	631.2
				2008					
RS-1	930.7		220.4	105.5			86.8	86.8	1,430.1
RS-2	1,676.9		256.5	283.5			174.9	174.9	2,566.7
RS-3	1,233.4		73.4	138.8			102.4	102.4	1,650.3
RS-4	1,714.5		346.9	949.2			832.0	832.0	4,674.6
RS-5	84.5			84.5			84.5	84.5	338.0
RS-6	114.5			114.5			114.5	114.5	458.0
RS-7	83.6			83.6			83.6	83.6	334.6
RS-8	103.7			103.7			103.7	103.7	414.9

TABLE 2. Number of juvenile lake sturgeon marked (n_M) and recaptured (n_R) by river section (RS) and year in the reach of the Winnipeg River between the Slave Falls generating station (GS) and the Seven Sisters Falls GS from May 2006 to October 2008. River sections are ordered from upstream to downstream.

			n_R		
River section	Year	n_M	2006	2007	2008
RS-1	2006	1,561	156	122	54
	2007	688		96	27
	2008	224			7
RS-2	2006	585	15	46	49
	2007	825		37	52
	2008	813			23
RS-3	2006	78			1
	2007	353		6	3
	2008	266			4
RS-4	2006	1			1
	2007	34			9
	2008	211			6
RS-5	2006				
	2007	3			
	2008	8			
RS-6	2006				
	2007	4			
	2008	8			
RS-7	2006				
	2007	3			
	2008	6			
Total n		5,671	171	307	236

In total, 5,671 tags (Floy and PIT tags combined) were applied to lake sturgeon measuring less than 879 mm FL between May 2006 and October 2008 (Tables 2 and 3). The majority of the tags were applied to fish in RS-1, followed by RS-2 and RS-3, and 78% were applied to lake sturgeon measuring less than 530 mm FL (Table 3). Fewer tags were applied to sturgeon in sections RS-5, RS-6, and RS-7 throughout the 30 months of study (Tables 2 and 3), and lake sturgeon were absent from the gill-net catches in the most downstream section of the study area, RS-8. A total of 714 marked juvenile lake sturgeon were recaptured during the study: $n = 171$ in 2006, $n = 307$ in 2007, and $n = 236$ in 2008. The majority of the recaptures occurred in RS-1 ($n = 462$), followed by RS-2 ($n = 222$), RS-4 ($n = 16$), and RS-3 ($n = 10$). Lake sturgeon measuring less than 530 mm FL formed the majority of recaptures and the greatest percentage of recaptures by river section occurred in RS-1 (Table 3). There is no provision for upstream fish passage at either Slave Falls GS or Seven Sisters Falls GS, but it is possible for fish in the study area to pass the Seven Sister Falls GS in a downstream direction either over the spillway or through the turbines. During the study period, however, there were no reports of fish being recaptured downstream from the Seven Sisters Falls GS.

Using juvenile lake sturgeon recaptured after 30 d posttagging only, a linear relationship was not observed between the number of days between recapture events and distance moved (rkm) ($P = 0.06$, $r^2 = 0.01$; Figure 2). Over the 30-month study period, only 7 of the 714 recaptured juvenile lake sturgeon traversed river section boundary margins (Table 4). Furthermore, of these seven fish, only one traversed a river section boundary in an upstream direction (moving from RS-2 to RS-1), while six traversed a river section boundary in a downstream direction

TABLE 3. Number of juvenile lake sturgeon marked (M) and recaptured (R) by fork length (mm) and river section (RS) in the reach of the Winnipeg River between the Slave Falls generating station (GS) and the Seven Sisters Falls GS, Manitoba, from May 2006 to October 2008. River sections are ordered from upstream to downstream. Percent recaptures for each size class (%R) are calculated as (M/R) × 100; the percentages of recaptured fish for each river section (%M/R) are calculated as (total M/total R) × 100.

	Fork length interval (mm)													
River Station	<279		280–329		330–379		380–429		430—479		480–529		530—579	
	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
RS-2	35	3	73	7	452	44	867	95	520	57	99	12	4	0
RS-3	1	0	4	0	7	1	82	0	177	4	248	5	134	3
RS-4	0	0	0	0	4	0	2	0	5	0	34	1	56	2
RS-5	4	0	0	0	0	0	0	0	0	0	1	0	0	0
RS-6	0	0	0	0	0	0	0	0	0	0	1	0	0	0
RS-7	0	0	0	0	0	0	0	0	0	0	1	0	0	0
RS-8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	124	11	128	17	1,116	151	1,923	303	1,054	157	419	23	221	9
% R		8.9		13.3		13.5		15.8		14.9		5.5		4.1

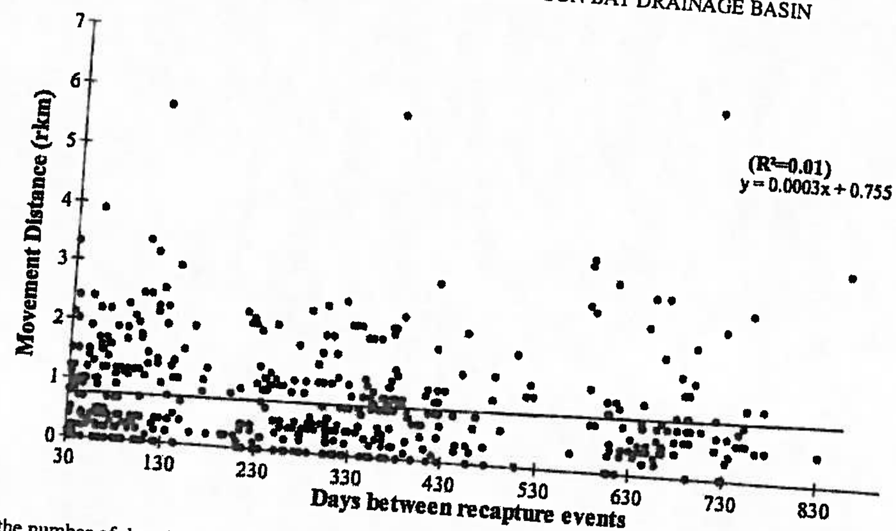


FIGURE 2. Scatterplot of the number of days between recapture events and distance moved (rkm) between recapture events for the 714 juvenile lake sturgeon recaptured in the reach of the Winnipeg River between Slave Falls GS and Seven Sisters Falls GS, Manitoba, May 2006–October 2008.

(one moved from RS-1 to RS-2, two moved from RS-2 to RS-3, and three moved from RS-3 to RS-4). Fish recaptured in RS-4 exhibited the longest overall mean movement distance (1.44 rkm), followed by RS-1 (0.96 rkm), RS-3 (0.71 rkm), and RS-2 (0.60 rkm) (Table 4). Although sample sizes were unequal, home range sizes of juvenile lake sturgeon in RS-1 and RS-4 were significantly greater than RS-2 (Kruskal–Wallis test: $P < 0.0001$).

Due to the limited spatial extent of juvenile lake sturgeon movements between original capture and recapture locations, and differences between the timing of original mark and recapture dates, it was difficult to identify seasonal movement patterns using the mark–recapture data set within each RS. However, within each river section, a high proportion (60.0%, 86.1%, 100.0%, and 71.4% in RS-1, RS-2, RS-3, and RS-4, respectively) of the recaptured juvenile lake sturgeon were recaptured less than 1.0 rkm from their original tagging location (Figure 3), and further, in all RSs combined, 90.8% of the recaptured fish were recaptured less than 2.0 rkm from their original tagging location. A linear relationship between body size (FL) and movement distance (home range size) was not observed for juvenile lake sturgeon within RS-1, RS-2, RS-3, or RS-4 (Figure 4).

TABLE 3. Extended.

Fork length interval (mm)														
580–629		630–679		680–729		730–779		780–829		830–879		Total		
M	R	M	R	M	R	M	R	M	R	M	R	M	R	%M/R
73	8	92	10	40	3	23	1	43	2	28	1	2,473	462	18.7
19	1	45	3	56	0	17	0	19	0	17	0	2,223	222	10.0
25	0	7	1	1	0	1	0	2	0	8	0	697	14	2.0
71	8	53	5	15	0	4	0	1	0	1	0	246	16	6.5
1	0	1	0	3	0	1	0	0	0	0	0	11	0	0.0
0	0	4	0	5	0	1	0	1	0	0	0	12	0	0.0
0	0	2	0	5	0	0	0	1	0	0	0	9	0	0.0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
189	17	204	19	125	3	47	1	67	2	54	1	5,671	714	
	9.0		9.3		2.4		2.1		3.0		1.9		7.9	

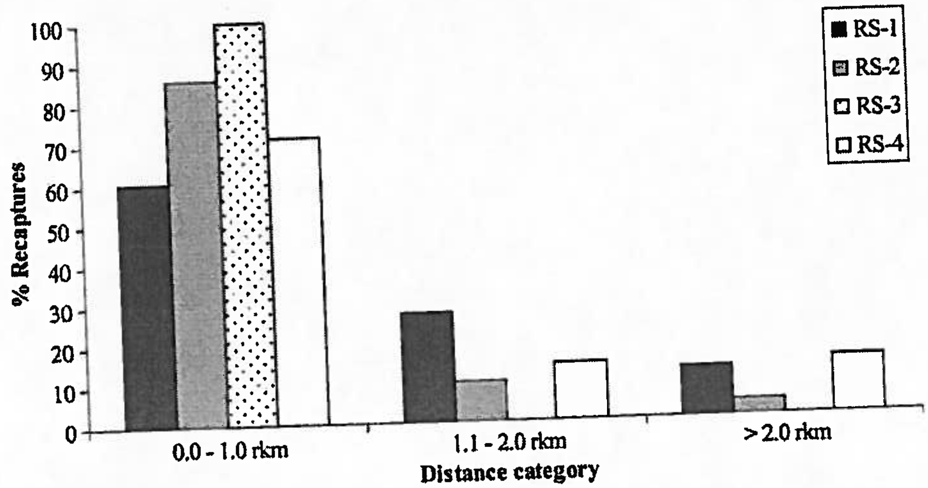


FIGURE 3. Percentage of recaptured juvenile lake sturgeon by distance category (0.0–1.0, 1.1–2.0, and >2.0 rkm) and river section (RS-1 [black], RS-2 [gray], RS-3 [stippled], and RS-4 [white]) in the reach of the Winnipeg River between Slave Falls GS and Seven Sisters Falls GS, Manitoba, May 2006–October 2008.

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 from the Slave Falls GS (Figure 1). 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 d (mean = 131 ± 61 d).

Far less movement was observed from the tagged juvenile lake sturgeon relative to what was expected during the planning phase of the study. Of the 44 acoustic receivers located throughout the study area, only the nine (located in RS-1 and RS-2 only) most upstream receivers located any of the 23 fish marked with acoustic tags. Two of the 23 tagged juvenile lake sturgeon were omitted from further analysis due to either transmitter malfunction or downstream displacement immediately following the surgical procedure. A third juvenile lake sturgeon moved downstream out of RS-1 and into RS-2. This fish was relocated in RS-2 the day the transmitter was programmed to activate. Due to the activation delay, the timing of the downstream movement through Scotts Rapids into RS-2 cannot be determined. With the exception of the initial downstream movement, this juvenile lake sturgeon with an acoustic tag remained exclusively in the upstream end of RS-2, exhibiting movement distances of less than 2.0 km during winter 2007–2008 and spring 2008. Therefore, the subsequent results section is based on the movements of the 20 juvenile lake sturgeon carrying acoustic tags that remained in RS-1.

In total, six stationary receivers were used to monitor the movements of the tagged juvenile lake sturgeon in RS-1 (Figure 1). 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 receivers 3 and 4 (rkm 2.5–2.6), and between receivers 5 and 6 (rkm 3.9–4.8). Of the 20 juvenile lake sturgeon with acoustic tags, 10 remained in the vicinity of the capture and release location and were

TABLE 4. Number (n) of recaptured juvenile lake sturgeon by the number of days between original marking and recapture; mean movement distance (MD), SD, and range between capture and recapture locations; and the number of individuals that moved between river sections (BRS) in the reach of the Winnipeg River between the Slave Falls generating station (GS) and the Seven Sisters Falls GS from May 2006 to October 2008. River sections (RS) are ordered from upstream to downstream; different letters after means indicate significant differences between groups (Kruskal–Wallis test; $P < 0.05$).

River section	Days between mark and recapture				Mean MD (rkm)	SD	Range (rkm)	RS length (rkm)	BRS
	<30	30–365	>365	>30 d					
RS-1	119	243	100	343	0.96 z	1.07	0.0–6.2	6.0	1
RS-2	35	108	79	187	0.61 y	0.60	0.0–3.3	4.0	2
RS-3	4	6	4	10	0.71 zy	0.71	0.0–2.2	4.0	1
RS-4	2	12	2	14	1.44 z	2.00	0.1–5.8	9.0	3
Total n recaptured	160	369	185	554					7

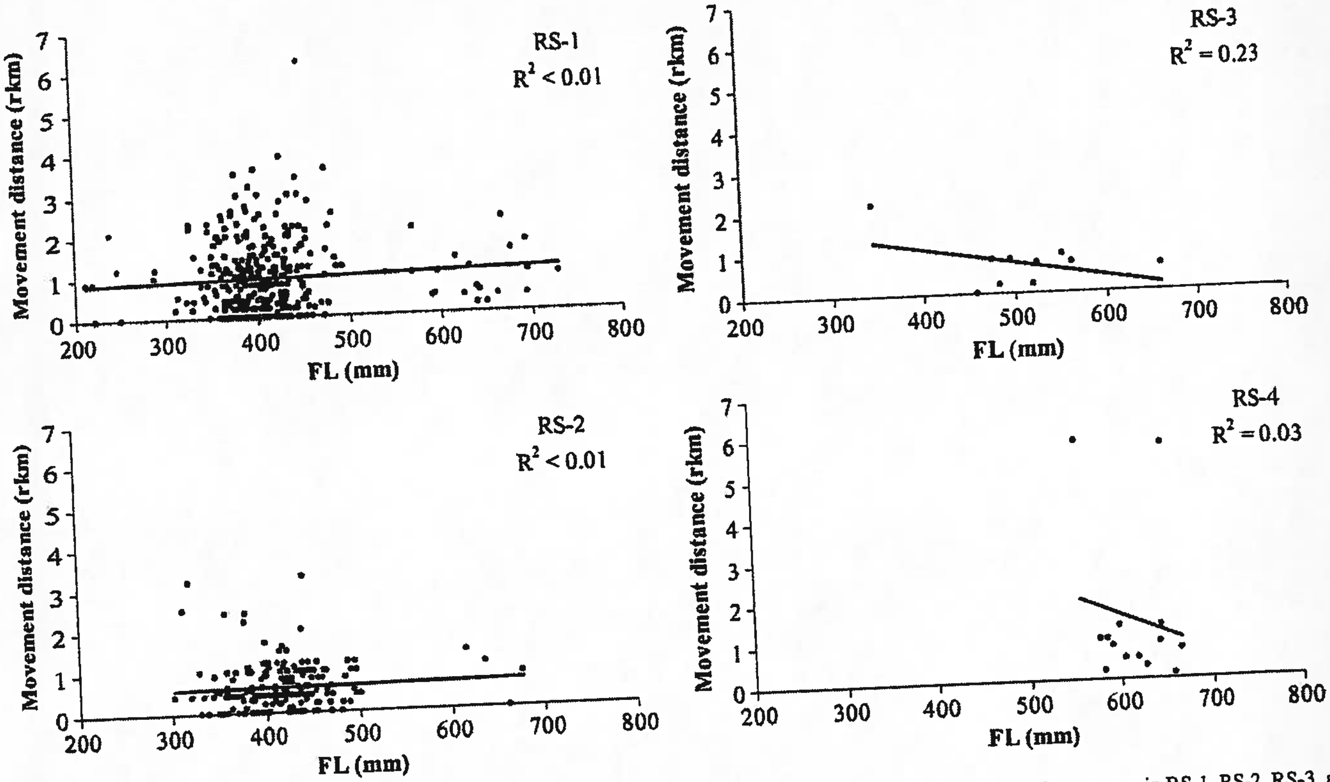


FIGURE 4. Scatterplots of fork length (FL, mm) versus movement distance (rkm) between recapture events for juvenile lake sturgeon in RS-1, RS-2, RS-3, and RS-4 in the Winnipeg River study area, 2006–2008.

relocated exclusively by the two farthest upstream receivers. These fish used 1.5 rkm (or less) over the period their transmitters were active (Figure 5). 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 juvenile lake sturgeon were relocated as far downstream as receiver 6 (Figure 5).

The number of tagged juvenile lake sturgeon with active transmitters in RS-1 varied among seasons as 19 were active during spring (four during spring 2007 and 15 during spring 2008), four during summer 2007, 11 during fall 2007, and 15 during winter 2007–2008 (Figure 5). Mean home range size was 2.5 rkm during spring, 1.7 rkm during summer, 2.3 rkm during fall, and 1.9 rkm during winter. Significant differences in home

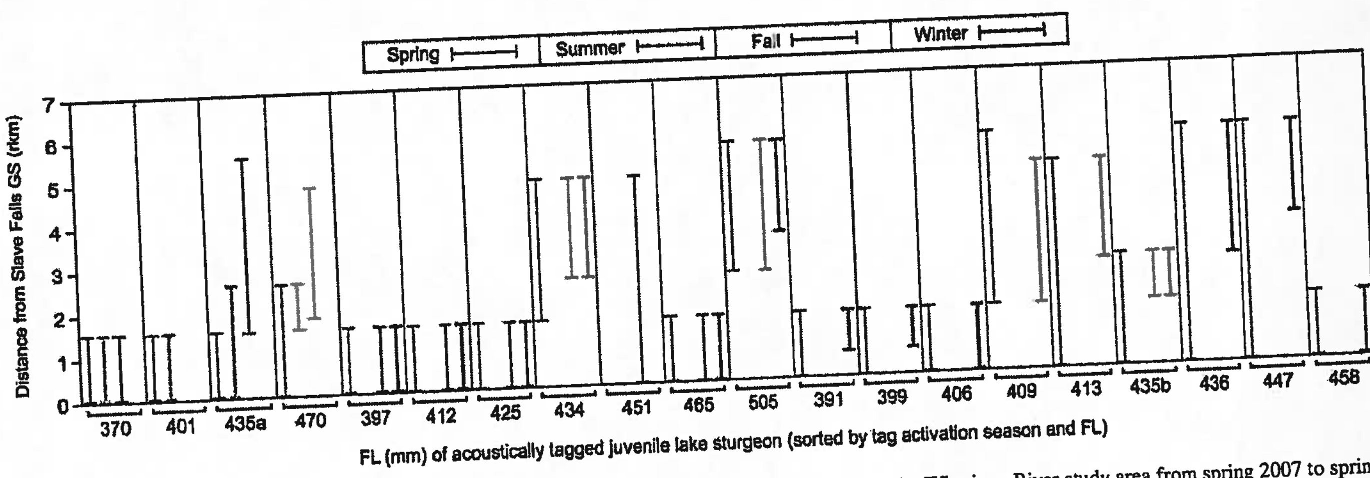


FIGURE 5. Seasonal range of movement for 20 juvenile lake sturgeon with acoustic tags in RS-1 in the Winnipeg River study area from spring 2007 to spring 2008. Juvenile lake sturgeon are grouped by season of tag application and FL. Distances on the *y*-axis provide the distance (rkm) from the Slave Falls GS, denoted as rkm 0. Bars represent the maximum distance (rkm) that a tagged juvenile lake sturgeon could bave moved before being located by an adjacent receiver. [Figure available online in color.]

range size were not found among seasons (Kruskal–Wallis test: $P = 0.38$). This result may not be surprising considering half the juvenile lake sturgeon with acoustic tags remained in the vicinity of their capture and release location (Figure 5), and 16 of the 20 tagged individuals were relocated by only two receivers for more than 88% of the days they were relocated. Finally, a relationship between size (FL) and home range size was not evident during any of the seasons, which also may not be surprising given the limited length range of tagged fish (364–505 mm FL).

Although half of the lake sturgeon with acoustic tags remained within 1.5 rkm of their release location, 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 more than 3.0 rkm downstream from their initial release location when their transmitters became active. During winter, 13 of 15 juvenile lake sturgeon with acoustic tags were relocated by either only one receiver or two adjacent receivers for the entire winter period. Finally, between May 15 and May 29, 2008, five juvenile lake sturgeon with acoustic tags moved upstream from downstream overwintering locations to receiver 1 located approximately 0.6 rkm from the Slave Falls GS.

DISCUSSION

Simultaneous use of mark–recapture and acoustic telemetry methods during the present study allowed for a greater understanding of juvenile lake sturgeon movements within the Winnipeg River study area. Although results obtained from both methodologies were similar, acoustic telemetry led to a more detailed examination of the extent of spatial and temporal movements within a river section, while mark–recapture allowed for the examination of movements from a large number of tagged fish over multiple years and emphasized the limited movement of juvenile lake sturgeon between the river sections. Both methodologies were effective at providing home range estimates; however, before interpretation of the results, some consideration of the potential biases and uncertainties associated with each methodology for estimating home range size should be considered. One aspect of bias was the unequal amount of sampling effort that occurred among and within sections of the study area. The majority of the acoustic telemetry and mark–recapture work was conducted in RS-1 and RS-2, (i.e., the upstream reaches of this study area). Although this may limit our understanding of juvenile lake sturgeon movements in the downstream reaches of the study area, it allows for a detailed examination of movements in the upstream reaches where juvenile lake sturgeon are known to be most abundant (C.C.B., unpublished data). Secondly, the level of precision or accuracy associated with the use of the either methodology must be acknowledged. Due to uncertainties associated with blind spots in the receiver array, home range size estimates essentially represented the maximum distance in river kilometers that a juvenile lake sturgeon could have moved before being detected by an adjacent receiver. As a consequence, home range size was probably overestimated for most of the fish with acoustic tags. Conversely, mark–recapture probably underestimated home range size because movements that occur during the time elapsed between the initial mark and the subsequent recapture periods are unknown, and fish may occupy core areas within their home range thereby increasing the probability of being marked and recaptured within the core area.

Despite 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 during each season. Furthermore, as evidenced by the low proportion of tagged fish moving between river sections, and half of the fish with acoustic tags remaining in less than 1.5 rkm of riverine habitat for the duration their tags were active, 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 ± 7.2 km (mean ± SD) over an 83-d period (total linear movement) and occupied a mean home range area of 11.0 ± 9.9 km^2. Lord (2007) implanted transmitters into nine juvenile lake sturgeon (582–793 mm TL) in the St. Clair River, Michigan, and found that juvenile sturgeon occupied home range areas that varied between 0.8 and 10.8 km^2 over 2 years of study. Finally, Smith and King (2005) estimated home range size over a 4-month period (July–October) for five juvenile lake sturgeon (785–1,135 mm TL) in Black Lake, Michigan, and home range area varied between 4.79 and 7.27 km^2.

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 the Barrier (Figure 1). These results suggest that rapids, characterized by high water velocities (>1.5 m/s), coarse boulder and bedrock substrate, and water depths that may range from 1.0 m to approximately 15.0 m, limit the upstream and downstream movement and home range size of juvenile lake sturgeon in this study area. As such, the length of river between sets of rapids is probably a primary factor influencing home range size and movement of juvenile lake sturgeon. Indeed the mark–recapture data suggest a correlation between river section length and home range size (Table 4).

To our knowledge, the finding that movement and home range in juvenile lake sturgeon is limited by rapids has not been previously reported in the literature. Several studies on adult lake sturgeon, however, have suggested high site fidelity to a particular river basin or river reach (Threader and Brousseau 1986; Fortin et al. 1993; Borkholder et al. 2002; Haxton 2003). For example, Threader and Brousseau (1986) in the Moose River, Ontario, and Fortin et al. (1993) in the St. Lawrence and

Ottawa rivers, Quebec, found that of the majority of lake sturgeon marked and subsequently recaptured, 80% and 70%, respectively, were recaptured within 5 km of their original tagging locations. Conversely, Knights et al. (2002) reported that movements of adult lake sturgeon varied from 3 to 198 km in the upper Mississippi River, and documented the upstream and downstream movement through navigation dams. Despite differences in river topography and genetics among populations, studies on adult and juvenile lake sturgeon suggest the occupation of small home range areas relative to the quantity of available habitat.

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 juvenile lake sturgeon with acoustic tags in this study were relocated by two adjacent receivers, which supports the notion that juvenile lake sturgeon in the Winnipeg River also occupy core areas within their home range. Additionally, the home range size estimate using the mark–recapture data set in RS-1 was lower relative to the home range estimate obtained using the acoustic telemetry data set during each season. Occupation of a core area may explain this result as fish would have a higher probability of capture and recapture inside their core area, while acoustic telemetry would capture less frequent movements of fish outside the core area that were not detected by mark–recapture.

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 age-0 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 five juvenile lake sturgeon with acoustic tags moved downstream during fall or before the onset of 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 (88%) 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 (i.e., time spent in the blind spots of the receiver array) was greater relative to the other seasons. These data suggest that activity rate may be reduced during this period. Lastly, during spring five juvenile lake sturgeon with acoustic tags moved upstream to the vicinity of the Slave Falls GS either before or during the period that lake sturgeon were known to have spawned in the area. It is possible that these lake sturgeon were accompanying adults to the spawning ground, a behavior 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–recapture data set, or during any season 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. Those authors found that juveniles longer than 900 mm TL (range, 900–1,135 mm) displayed longer daily movements and occupied larger home ranges than juveniles measuring less than 900 mm (range, 785–795 mm). Because most of the data presented in the study was collected from fish measuring less than 680 mm FL, and the acoustic telemetry data were collected from a relatively narrow size range of fish, it is possible that if a higher number of larger juvenile 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. For example, adult lake sturgeon are known to move between river sections in this study area (H. Labadie, unpublished data). Clearly, further research is needed to determine the size or age at which lake sturgeon in this population expand their home range and begin to move through rapids in the Winnipeg River.

Interestingly, in addition to the limited movement through rapids, juvenile lake sturgeon in the Winnipeg River were rarely found at water depths less than 7 m (Barth et al. 2009). Although the ecological rationale for these behaviors is not fully understood, one potential cost associated with occupying shallow water habitat or moving through rapids is the threat of predation. Predator avoidance may well have contributed to habitat selection in juvenile lake sturgeon and the observed limited movement of juveniles through rapids, since juvenile lake sturgeon may be at a disadvantage relative to other pelagic species in shallow, nearshore habitats or high velocity eddies near rapids where potential predators are often found in high abundance (Barth et al. 2009). However, this explanation seems unlikely since predation on post-age-0 lake sturgeon larger than 200 mm FL has not been documented in the wild despite several studies (Noakes et al. 1999; Carrofino et al. 2010; C.C.B., unpublished data), and laboratory studies conducted on larval and age-0 white sturgeon *A. transmontanus* suggested that susceptibility to predation decreased with increasing size (Gadomski and Parsley 2005). Finally, few predatory species, with the exception of large walleye *Sander vitreus* and northern pike *Esox lucius*), exist in the Winnipeg River that would attempt to consume an armored juvenile lake sturgeon measuring more than 200 mm FL. Clearly, further study is needed to determine why shallow or high flow environments limit movement of juvenile lake sturgeon in this study area.

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 considered as poor swimmers, sturgeons have been described as a species that are morphologically adapted for bottom holding, a behavior 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. Conversely, the availability of food may also explain some of the movements observed by juvenile lake sturgeon in this study. As previously discussed, five juvenile lake sturgeon moved upstream to the Slave Falls GS during the time when adult lake sturgeon were spawning in the area. Since juvenile lake sturgeon have been found to consume sturgeon eggs in this study area (C.C.B., unpublished data), it is possible that these movements were undertaken for the purposes of foraging on eggs deposited by spawning adults.

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, an abundance of juvenile lake sturgeon have not been observed in studies on other populations. Secondly, lake sturgeon inhabit a diversity of habitats, ranging from large rivers to smaller tributaries across a wide latitudinal gradient that includes three different watersheds. 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 may occupy habitats or swiftly flowing rivers that may be difficult to sample accurately (Secor et al. 2002). This study has shown that in large rivers lake sturgeon exhibit high year-round site fidelity and rarely move through rapids. These results have several important implications for population estimation and habitat assessment. For example, juvenile lake sturgeon may be abundant yet difficult to locate without significant amounts of sampling effort. Also, population estimates may be biased due to a lack of random mixing of juveniles within the population. Further, suitable areas of juvenile lake sturgeon habitat could exist but may be underexploited if larvae or age-0 fish do not disperse to these areas, and juvenile lake sturgeon do not move to these areas due to high site fidelity. Finally, further study within this population is needed to determine the size or age at which lake sturgeon increase their home range size and begin to move through rapids. Studies on other lake sturgeon populations are also required to determine if these movement patterns are similar across the species' range.

ACKNOWLEDGMENTS

Ray Lafantasie, Holly Labadie, Jon Peake, Claire Hrenchuk, Carl Bradley, and Christine Lacho are graciously thanked for their assistance in the field. Michael Patterson, Darren Gillis, and three anonymous reviewers are also thanked for kind reviews of previous versions of this manuscript. Jarod Larter is acknowledged for his assistance in the creation of the study area maps. Support for this research was provided by Manitoba Hydro and NSERC (CRDPJ 321520–05) to S.J.P. and W.G.A.

REFERENCES

Adams, S. R., J. J. Hoover, and K. J. Kilgore. 1999. Swimming endurance of juvenile pallid sturgeon, *Scaphyrhnchus albus*. Copeia 1999:802–807.

Anderson, W. G., R. S. McKinley, and M. Colavecchia. 1997. The use of clove oil as an anaesthetic for rainbow trout and its effect on swimming performance. North American Journal of Fisheries Management 17:301–307.

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

Barth, C. C., S. J. Peake, P. J. Allen, and W. G. Anderson. 2009. Habitat utilization of juvenile lake sturgeon, *Acipenser fulvescens*, in a large Canadian river. Journal of Applied Ichthyology 25(Supplement 2):18–26.

Beamesderfer, R. C. P., and R. A. Farr. 1997. Alternatives for the protection and restoration of sturgeons and their habitat. Environmental Biology of Fishes 48:407–417.

Benson, A. C., T. M. Sutton, R. F. Elliot, and T. G. Meronek. 2005. Seasonal movement patterns and habitat preferences of age-0 lake sturgeon in the Lower Peshtigo River, Wisconsin. Transactions of the American Fisheries Society 134:1400–1409.

Birstein, V. J. 1993. Sturgeons and paddlefishes: threatened fishes in need of conservation. Conservation Biology 7:773–787.

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. Master's thesis. University of Manitoba, Winnipeg.

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

Carrofino, D. C., T. M. Sutton, R. F. Elliot, and M. C. Donofrio. 2010. Predation on early life stages of lake sturgeon in the Peshtigo River, Wisconsin. Transactions of the American Fisheries Society 139:1846–1856.

CCME (Canadian Council of Ministers of the Environment). 1999. Canadian environmental quality guidelines, updated to 2011. CCME, Winnipeg, Manitoba.

Cleator, H., K. A. Martin, T. C. Pratt, C. C. Barth, B. Corbett, M. Duda, and D. Leroux. 2010. Information relevant to a recovery potential assessment of Lake Sturgeon: Winnipeg River–English River populations (DU5). Canadian Science Advisory Secretariat, Department of Fisheries and Oceans, Research Document 2010/084, Winnipeg, Manitoba.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006. COSEWIC assessment and update status report on the lake sturgeon *Acipenser fulvescens* in Canada. COSEWIC, Ottawa. Available: http://dsp-psd.pwgsc.gc.ca/collection_2007/ec/CW69-14-484-2007E.pdf. (November 2011).

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

Gadomski, D. M., and M. J. Parsley. 2005. Laboratory studies on the vulnerability of young white sturgeon to predation. North American Journal of Fisheries Management 25:667–674.

Gerking, S. D. 1959. The restricted movement of fish populations. Biological Reviews 34:221–242.

Hay-Chmielewski, E. M. 1987. Habitat preferences and movement patterns of the lake sturgeon in Black Lake, Michigan. Master's thesis. University of Michigan, Ann Arbor.

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

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

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

Keeley, E. R., and J. W. A. Grant. 1997. Allometric and environmental correlates of territory size in juvenile Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 52:186–196.

Kempinger, J. J. 1996. Habitat, growth, and food of young lake sturgeons in the Lake Winnebago system, Wisconsin. North American Journal of Fisheries Management 16:102–114.

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

Kramer, D. L., and M. R. Chapman. 1999. Implications of fish home range size and relocation for marine reserve function. Environmental Biology of Fishes 55:65–79.

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

Lord, K. 2007. Movements and habitat use of juvenile lake sturgeon in the north channel of the St. Clair River. Master's thesis. University of Michigan, Ann Arbor.

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

Minns, C. K. 1995. Allometry of home range size in lake and river fishes. Canadian Journal of Fisheries and Aquatic Sciences 52:1499–1508.

Morrissey, J. F., and S. H. Gruber. 1993. Home range of juvenile lemon sharks, *Negaprion brevirostris*. Copeia 1993:425–434.

Noakes, D. L. G., F. W. H. Beamish, and A. Rossiter. 1999. Conservation implications of behaviour and growth of the lake sturgeon, *Acipenser fulvescens*, in northern Ontario. Environmental Biology of Fishes 54:135–144.

Peake, S. J. 2004. An evaluation of the use of critical swimming speed for determination of culvert water velocity criteria for smallmouth bass. Transactions of the American Fisheries Society 133:1472–1479.

Peterson, D. L., B. Gunderman, and P. Vecsei. 2002. Lake sturgeon of the Manistee River: a current assessment of spawning stock size, age, and growth. Pages 175–182 *in* W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society, Symposium 28, Bethesda, Maryland.

Peterson, D. L., P. Vecsei, and C. A. Jennings. 2007. Ecology and biology of the lake sturgeon: a synthesis of current knowledge of a threatened North American Acipenseridae. Reviews of Fish Biology and Fisheries 17: 59–76.

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

Sandilands, A. P. 1987. Biology of the lake sturgeon (*Acipenser fulvescens*) in the Kenogami River, Ontario. Pages 33–46 *in* C. H. Oliver, editor. Proceedings of a workshop on the lake sturgeon (*Acipenser fulvescens*). Ontario Technical Report Fisheries Series 23, Toronto.

Secor, D. H., P. J. Anders, W. Van Winkle, and D. A. Dixon. 2002. Can we study sturgeons to extinction? What we do and don't know about the conservation of North American sturgeons. Pages 3–10 *in* W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society, Symposium 28, Bethesda, Maryland.

Simpfendorfer, C. A., M. R. Heupel, and R. E. Hueter. 2002. Estimation of short-term centers of activity from an array of omni-directional hydrophones and its use in studying animal movements. Canadian Journal of Fisheries and Aquatic Sciences 59:23–32.

Smith, K. M., and D. King. 2005. Movement and habitat use of yearling and juvenile lake sturgeon in Black Lake, Michigan. Transactions of the American Fisheries Society 134:1159–1172.

St. George, S. 2006. Hydrological dynamics in the Winnipeg River basin, Manitoba. Pages 226–230 *in* Report of activities 2006. Manitoba Geological Survey, Winnipeg.

Threader, R., and C. S. Brousseau. 1986. Biology and management of the lake sturgeon in the Moose River, Ontario. North American Journal of Fisheries Management 6:383–390.

Thuemler, T. F. 1988. Movements of young lake sturgeons stocked in the Menominee River, Wisconsin. Pages 104–109 *in* R. D. Hoyt, editor. Eleventh annual larval fish conference. American Fisheries Society, Symposium 5, Bethesda, Maryland.

Wagner, G. N., E. D. Stevens, and P. Byrne. 2000. Effects of suture type and patterns on surgical wound healing in rainbow trout. Transactions of the American Fisheries Society 129:1196–1205.

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