MOVEMENT AND HABITAT USE OF LAKE STURGEON (*ACIPENSER FULVESCENS*) IN THE SOUTH SASKATCHEWAN RIVER SYSTEM

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ABSTRACT

Lake Sturgeon (*Acipenser fulvescens*) have experienced declines in numbers throughout their range due to historical overharvesting and more recent habitat degradation. Fragmentation and disruption caused by large dams on the rivers they inhabit have greatly impacted this species. Lake Sturgeon in Alberta are part of an Endangered population as defined by the Committee on the Status of Endangered Wildlife in Canada. The goal of this study was to gather more information on the movement of Lake Sturgeon in the South Saskatchewan River in Alberta and Saskatchewan, to aid conservation. A sample of 123 Lake Sturgeon was tracked in this area for 24.5 months using hydroacoustic telemetry, and a habitat survey gathered depth and substrate data for the study area. Lake Sturgeon had large ranges of movement, and individuals moved the second-highest range on record for this species. Movement varied by season, and adult Lake Sturgeon moved at higher rates and used greater reaches of the river than juveniles. Two possible spawning sites and three overwintering sites were identified, areas which should be left undisturbed by development. The large extent of movement observed in the study area emphasizes the need to leave the South Saskatchewan River system relatively unrestricted by dams and weirs, as blocking movement may have negative impacts on this population of Lake Sturgeon.

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LIST OF ABBREVIATIONS

ASRD – Alberta Sustainable Resource Development
AENV – Alberta Environment
ALSRT – Alberta Lake Sturgeon Recovery Team
ANOVA – Analysis of Variance
COSEWIC – Committee on the Status of Endangered Wildlife in Canada
CWF – Canadian Wildlife Federation
DFO – Department of Fisheries and Oceans Canada
DU – Designatable Unit
ESRD – Alberta Environment and Sustainable Resource Development
GPS – Global Positioning System
kHz - Kilohertz
LKST – Lake Sturgeon
MU – Management Unit
NRCC – National Research Council of Canada
NSERC – Natural Sciences and Engineering Research Council of Canada
PSRB – Partners for the Saskatchewan River Basin
PIT – Passive Integrated Transponder
QTC – Quester Tangent Corporation
rkm – River Kilometer
SE – Standard Error of the Mean
SD - Standard Deviation
SSR – South Saskatchewan River
SSRB – South Saskatchewan River Basin
SWA – Saskatchewan Watershed Authority
TL – Total Length

CHAPTER ONE: INTRODUCTION

Lake Sturgeon Background and Life History

Lake Sturgeon (*Acipenser fulvescens*) are large, long-lived, freshwater fish found in the Hudson Bay, Great Lakes, and Mississippi drainages in North America. They are one of eight species of sturgeon that inhabit North America (Birstein 1993). Lake Sturgeon belong to the Order Acipenseriformes, which includes sturgeon and paddlefish. There are 27 extant species of this order, distributed throughout the north temperate zones of North America, Asia, and Europe. Fossils of this order date back to approximately 200 million years ago (Bemis and Kynard 1997). Members of the Order Acipenseriformes exhibit shared characteristics that include a mainly cartilaginous endocranium, a heterocercal tail, and the notochord being present in adults (Birstein 1993).

Similar to other sturgeon species, Lake Sturgeon lack scales and instead possess a body covered in five rows of bony scutes. These fish grow slowly and can live to be well over 100 years old (Scott and Crossman 1973). All Lake Sturgeon, like other members of their order, spawn in freshwater. These fish complete their entire lifecycle in freshwater throughout most of their range, but inhabit brackish water in the St. Lawrence River, Hudson Bay, and James Bay (Harkness and Dymond 1961). The largest Lake Sturgeon on record came from the Roseau River in Manitoba in 1903, estimated to be over 3 m long and weigh approximately 185 kg (Stewart and Watkinson 2004). Today, Lake Sturgeon of this size are rare, and the large members of this species tend to weigh no more than 40 kg (COSEWIC 2006), a pattern that is typical of most sturgeon populations, where very old, large fish are rarely encountered and populations are dominated by young adult fish (Sulak and Randall 2002). Lake Sturgeon are benthic feeders. They lack teeth and possess a ventral protrusible mouth for ingesting food, as well as four sensory barbels near the mouth used to detect food. Diet can vary by location, and although it is primarily composed of macroinvertebrates, may also include small fish, fish eggs and algae (Houston 1987; Peterson et al. 2007).

Lake Sturgeon spawn in the spring, usually between temperatures of 10 - 18°C, but the exact temperature at which spawning begins depends on the reproductive cycles of individual females (Scott and Crossman 1973; Bruch and Binkowski 2002; Peterson et al. 2007). The fish typically spawn over cobble substrate in fast flowing river environments, and may migrate hundreds of kilometers to reach spawning grounds (Bruch and Binkowski 2002). Lake Sturgeon are polygamous and females are extremely fecund, releasing up to a million eggs during a spawning season (Peterson et al. 2007). Males usually spawn every two to three years, but have been observed spawning in consecutive years, while females spawn every three to seven years (Bruch and Binkowski 2002; Forsythe et al. 2011). This periodic spawning allows fish to avoid reproducing in years when conditions are not ideal, and minimizes the effect of a year-class failure on the whole population (Beamesderfer and Farr 1997). After fertilization, the eggs incubate for approximately five to eight days before hatching. The hatched fish drift downstream after emerging, and use their yolk sac for nutrition for nine to eighteen days before they start to feed (Houston 1987). The larval stage typically lasts for several weeks and ends when the sturgeon develop all adult characteristics except for gonads (Peterson et al. 2007). Juvenile Lake Sturgeon are characterized by having spikes on their scutes, however the spikes are lost as the sturgeon mature and grow too large to be threatened by predators (Harkness and Dymond 1961).

Lake Sturgeon do not reach sexual maturity until age 12-15 for males and 20-25 for females (Bruch and Binkowski 2002). The fish gradually accumulate lipid stores as they grow, which eventually provide energy for gonad development and reproduction (Beamish et al. 1996). A delay before reproduction allows the sturgeon to devote all their energy into growing large quickly, which in turn allows them to avoid predation and have a higher survival rate (Beamesderfer and Farr 1997). The growth rate of Lake Sturgeon has been found to be slower at higher latitudes where temperatures are colder (Beamish et al. 1996).

Threats to Lake Sturgeon

Due to human interference, Lake Sturgeon populations today are estimated to be at less than 1% of their historical levels (COSEWIC 2006). Lake Sturgeon were originally only harvested for food by Aboriginal people and were treated as waste fish by others, even being burned as fuel in steamships. However, in the late 19th and early 20th century, commercial harvest began for sturgeon flesh, eggs and swimbladder (Harkness and Dymond 1961). Commercial harvest of Lake Sturgeon led to periods of high catch yields followed by a sharp decrease in catch size, a pattern seen repeatedly in areas with commercial fisheries for this species. Eventually, the overharvest of Lake Sturgeon resulted in decreases in population sizes over most of its range (Houston 1987). Because Lake Sturgeon delay spawning and normally do not spawn every year once they are mature, they are extremely sensitive to overharvest (Beamesderfer and Farr 1997).

For many sturgeon species, reducing fishing pressure on populations has been implemented as a strategy to stop population collapse, and is the easiest variable for managers to control (Boreman 1997). Only a few commercial fisheries for Lake Sturgeon remain, and are well-managed (Pikitch et al. 2005). However, even in areas that have been closed to Lake Sturgeon harvest, population numbers have failed to experience the increase in numbers that have been observed in the closure of fisheries for other species (Auer 1996a), and the lack of recovery of this species has been attributed to habitat degradation.

One of the factors limiting the recovery of Lake Sturgeon populations has been lowered water quality caused by human activities (Peterson et al. 2007). Lake Sturgeon habitat can be degraded by activities on the surrounding landscape, such as agriculture, forestry, and road-building; as well as impacts on rivers such as dumping untreated sewage, garbage and pulp mill effluent, which can lead to habitat destruction and decrease in dissolved oxygen levels (Ferguson and Duckworth 1997, Haxton and Findlay 2008). Because Lake Sturgeon are benthic feeders and have long lifespans, they are susceptible to bioaccumulation of toxins (Beamesderfer and Farr 1997). The bodies of Lake Sturgeon also have a high fat content, which makes them susceptible to the accumulation of lipid-soluble toxins (Rousseaux et al. 1995). Lake Sturgeon in heavily polluted areas of the St. Lawrence River had higher incidences of liver damage than those from less-polluted areas, although the damage could not be specifically attributed to contaminants (Rousseaux et al. 1995). Lake Sturgeon eggs can also accumulate toxins, such as PCBs, however the effect of the contaminants on the eggs has not been studied in this species (Rousseaux et al. 1995). Even though water quality guidelines have improved and toxins are banned from use, the accumulation of contaminants already present in the system may be cause for concern.

The construction of dams on the large river systems that Lake Sturgeon inhabit has also been linked to population declines in this species. Because Lake Sturgeon may make long migrations, dams can have a negative effect by blocking Lake Sturgeon from accessing critical habitat. Modelling done on White Sturgeon (*A. transmontanus*) populations has revealed that as river fragmentation increases, the likelihood of sturgeon populations persisting in a river decreases. Fragmentation can create isolated sub-populations of sturgeon, which leads to a decrease in genetic diversity both within and between populations (Jager et al. 2001). Small population sizes can lead to inbreeding, which in turn can lower reproductive output, increase rates of deformities, or increase risk of disease (Hay-Chmielewski and Whelan 1997). When there are fewer individuals in a population, the population is also more susceptible to catastrophic events and the effects of limited food resources (Auer 1996a). Lake Sturgeon in impounded reaches of the Ottawa River are less abundant than in unimpounded reaches of the same river (Haxton and Findlay 2008). One study has suggested that Lake Sturgeon require an unimpeded stretch of river and lake 250-300 km long as a minimum distance to ensure a healthy population (Auer 1996a).

Not only can dams block the access of Lake Sturgeon to spawning grounds, they can also completely eliminate or modify the spawning grounds themselves. The fast-flowing areas where sturgeon historically spawned have disappeared in many systems because dams reduce the amount of free-flowing water in the river and create reservoirs, (Jager et al. 2001). Lake Sturgeon may compensate for this loss of habitat by spawning below hydroelectric dams (Haxton and Findlay 2008). However, spawning below dams is dependent on the amount of water released by the dam and is least impacted if flows are kept near run-of-the-river (Auer 1996b). If too much water is withheld, larger females may not be able to access the spawning sites, thereby decreasing the number of eggs available for fertilization (Auer 1996b). Successful hatching of eggs can also be impacted by fluctuation in water levels below dams (Noakes et al. 1999). If velocity is greatly reduced, Lake Sturgeon eggs may clump together, leading to oxygen deprivation, increased fungal infections, increased predation risk, and therefore decreased survival rates of the eggs (Auer 1996a; Hay-Chmielewski and Whelan 1997). Extreme water fluctuations or temperature changes caused by dams may cause female Lake Sturgeon to resorb their eggs, as conditions are not suitable for spawning (Hay-Chmielewski and Whelan 1997).

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has divided Canadian Lake Sturgeon populations into eight Designatable Units (DUs) based on aquatic ecozones and genetics, assigning a classification to each group based on the risk of extinction. Five groups have been classified as Endangered, with the highest extinction risk: the Western Hudson Bay (DU1), Saskatchewan River (DU2), Nelson River (DU3), Red-Assiniboine River-Lake Winnipeg (DU4), and the Winnipeg River-English River (DU5) populations. The Great Lakes-Upper St. Lawrence (DU8) populations are classified as Threatened, having the second highest risk of extinction. The Lake of the Woods-Rainy River (DU6) and Southern Hudson Bay-James Bay (DU7) populations are listed as Special Concern and are considered to have the lowest extinction risk (COSEWIC 2006). The Lake Sturgeon is also under consideration to be added to the federal Species at Risk Act list by Fisheries and Oceans Canada (DFO 2007).

Lake Sturgeon in Alberta

The province of Alberta represents the Lake Sturgeon's westernmost range in North America (Scott and Crossman 1973). Lake Sturgeon populations in Alberta belong to DU2, as defined by COSEWIC, and are therefore considered to be part of an Endangered population; however, the Alberta subpopulations seem to be at a lower risk than other subpopulations within the DU (Cleator et al. 2010). Declines in population size in DU2 are attributed to over-fishing by commercial fisheries and negative impacts caused by dams and other barriers (Cleator et al. 2010). Within DU2, management units (MUs) have been established for smaller areas within the larger drainage basins.

In Alberta, Lake Sturgeon are found only in the North and South Saskatchewan river systems. Sturgeon in Alberta are hypothesized to have originally been part of a large population that extended from Alberta to Manitoba; however, the construction of dams for hydroelectric power and water storage for irrigation on the Saskatchewan River system led to fragmentation into smaller subpopulations (McLeod et al. 1999). In 1967, construction of Gardiner Dam on the South Saskatchewan River was completed, and the flow of the river was significantly altered. Downstream, the dam caused higher flows in the winter and lower flows in the spring and summer than in the undammed river; while upstream, Lake Diefenbaker, a reservoir of about 430 km^2, was created(Martz et al. 2007; SWA 2011). Due to the construction of the Gardiner Dam, Lake Sturgeon in the North and South Saskatchewan rivers in Alberta cannot intermix and as a result are considered to be two sub-populations (ASRD 2002).

Lake Sturgeon in the South Saskatchewan River upstream of Gardiner belong to MU2. Lake Sturgeon numbers in the Alberta portion of this management unit are believed to be increasing (Cleator et al. 2010). In the South Saskatchewan River system, Lake Sturgeon have been caught in the mainstem of the South Saskatchewan River, as well as its tributaries: the Oldman, Bow and Red Deer rivers (Haugen 1969). It is unknown to what extent, if any, Lake Sturgeon pass downstream over Gardiner Dam.

The North Saskatchewan River Lake Sturgeon population belongs to MU1. In the North Saskatchewan River system, along with being found in the mainstem, Lake Sturgeon are found in the Brazeau River (McLeod et al. 1999). Lake Sturgeon in the North Saskatchewan River are able to migrate into Saskatchewan, and individuals tagged in Alberta have been recaptured in the mainstem of the Saskatchewan River east of Prince Albert, as well as in the South Saskatchewan River downstream of the Gardiner Dam (ALSRT 2011). It is thought that the population size of Lake Sturgeon in the Alberta portion of MU1 are stable (Cleator et al. 2010).

Up until 1940, Lake Sturgeon in Alberta were harvested both commercially and recreationally, although the number harvested was not as high as those in other provinces (Stewart 2009). From 1940 to 1968, the fishery was closed due to concerns of the impact of overfishing. In 1968, sport fishing was once again allowed, with catch limits implemented (McLeod et al. 1999; Saunders 2006). Various regulations were introduced after the re-opening of the fishery, such as size limit increases and requirements for special licenses. Harvest of Lake Sturgeon in Alberta was eventually banned in 2004 for the North Saskatchewan River and 2006 for the South Saskatchewan River; however, catch-and-release angling is still permitted (Saunders 2006, ALSRT 2011).

Population abundance of catchable Lake Sturgeon for both the North and South Saskatchewan River system has been estimated using data from previous mark-recapture studies. The population of the South Saskatchewan River system upstream of the

Gardiner Dam is estimated to be approximately 6400 individuals (Paul 2013). Abundance estimates in the North Saskatchewan system are much lower, with an estimated mean of 820 individuals in the upper section of the river and 2300 individuals in the lower section (ALSRT 2011).

South Saskatchewan River Basin

The South Saskatchewan River Basin (SSRB) is part of the larger Saskatchewan River Basin sub-basin, which is in turn part of the Saskatchewan-Nelson River Basin, the largest drainage basin in the Canadian Prairies (Cohen 1991). The Saskatchewan River system originates in the Rocky Mountains and ends at Lake Winnipeg. In total, the Saskatchewan River Basin is a catchment for an area greater than 405 million km^2 (PSRB 2009). This river basin extends through the provinces of Alberta, Saskatchewan and Manitoba as well as part of the Rocky Mountains in Montana. Approximately three million people live in the Saskatchewan River Basin, with over 2.4 million of those people living in Alberta, in the corridor from Edmonton to Calgary (PSRB 2009).

The SSRB consists of four major sub-basins: the South Saskatchewan, Bow, Oldman, and Red Deer sub-basins. The South Saskatchewan River (SSR) is formed from the confluence of the Bow and Oldman Rivers, known locally as the Grand Forks, approximately 10 kilometers north of Grassy Lake, Alberta. It flows east into Saskatchewan until joining with the North Saskatchewan River to form the Saskatchewan River, just east of Prince Albert, Saskatchewan. The Red Deer River enters the SSR just east of the Alberta-Saskatchewan border. The Oldman and Bow basins contribute the most water to the mean flow of the SSR, at 38% and 43%, respectively, while the Red Deer contributes 18% and the lower SSRB contributes 0.7% (AENV 2003). The SSRB drainage encompasses approximately 150 000 km^2 and stretches over three geographic regions: Cordillera, Foothills, and Great Plains (Martz et al. 2007). Lake Diefenbaker is the largest body of water in the drainage (Martz et al. 2007).

The SSRB contains the urban centers of Calgary, Red Deer, Lethbridge, and Medicine Hat, Alberta, all of which are major point sources of pollution in the basin (North/South Consultants Inc. 2007). Water in the SSRB is removed for both consumptive and non-consumptive uses such as agriculture, municipal use, forestry, and oil and gas development. Of the over 20 000 water licenses in the Saskatchewan River Basin, all but a few hundred are for the SSRB (PSRB 2009). The high amounts of water withdrawn from the system have led to Alberta Environment recommending that no new water removal licenses be issued for the SSRB, to ensure that there is enough water available to meet future demands, and due to concerns over decreasing health of aquatic and riparian environments (AENV 2006). Despite concerns over pollution from urban centers, the water quality of the mainstem of the SSR is considered to be good, based on available data (North/South Consultants Inc. 2007).

Thesis Project

The goal of this project was to monitor movement of Lake Sturgeon in the South Saskatchewan River system in Alberta and Saskatchewan. Data collected from the monitoring were used to determine the extent of movement through the system, compare movements of adults and juveniles, and determine the effect of season, diel period, and other environmental factors on Lake Sturgeon migration. Areas of critical habitat in the system, such as feeding, overwintering, and possible spawning sites were identified, and a habitat survey of part of the system was conducted. The results of the study are presented in Chapter 2 of this thesis.

CHAPTER TWO: MOVEMENT AND HABITAT USE OF LAKE STURGEON IN THE SOUTH SASKATCHEWAN RIVER SYSTEM

Abstract

Lake Sturgeon movement and habitat use were monitored in the South Saskatchewan River Basin in Alberta and Saskatchewan, Canada. Acoustic telemetry was used to monitor 123 Lake Sturgeon from August of 2010 to the end of September 2012, with continuing tagging efforts until August of 2011. Movement was monitored in the Oldman, Bow, Red Deer and South Saskatchewan Rivers. Tagged fish were detected in all four rivers included in the approximately 1100 river kilometer (rkm) study area. Lake Sturgeon made long migrations throughout the study area, with the maximum range of 687.8 rkm being the second-highest range ever recorded for this species. Lake Sturgeon movement varied seasonally, with the highest rate of movements in the spring and the lowest rate of movements in the winter. In general, adult fish had greater ranges and moved at a higher rate than did juveniles. Lake Sturgeon moved more during the night than during the day. Three overwintering sites and two suspected spawning areas were identified in the study area. This study is the most comprehensive study to date on Lake Sturgeon in the South Saskatchewan River system, and will aid in management efforts for this population.

Introduction

Lake Sturgeon behaviour has been studied in many systems, with focus on the migration and habitat use. Lake Sturgeon inhabit large river systems where suitable resources may be widely spatially dispersed, and members of this species often migrate long distances to utilize those resources (Beamesderfer and Farr 1997). Reasons for migration include feeding, reproduction, or avoiding unsuitable conditions such as freezing or drought (Cleator et al. 2010). The large rivers inhabited by Lake Sturgeon are often impacted by dams that block migration, which may have detrimental effects on populations (Houston 1987; Auer 1996a; Hay-Chmielewski and Whelan 1997).

Lake Sturgeon movement can be variable; however, some common patterns have been documented for this species. Adult Lake Sturgeon may exhibit seasonal movement patterns, with a general trend of increased movement in the spring and summer compared to fall and winter (Hay-Chmielewski 1987; Rusak & Mosindy 1997; Trested et al. 2011). Adult Lake Sturgeon undergoing long migrations in the spring to reach spawning habitat with rocky substrate and high water velocity have been observed in multiple systems (Bruch & Binkowski 2002; Auer 1996a). Descriptions of juvenile Lake Sturgeon movement patterns are often conflicting. Some studies have found that they do not exhibit seasonal movement (Smith & King 2005; Barth et al. 2011), but season has been shown to influence depth selection (Altenritter et al. 2013). Movements may even differ among individuals of the same size in the same system (Smith and King 2005).

Lake Sturgeon in multiple river systems exhibit site fidelity, migrating throughout the system but returning to core areas where they spend much of their time (Knights et al.

2002; Haxton 2003; Barth et al. 2011), although this pattern is not seen in all systems (Hay-Chmielewski 1987). In areas where their range includes both lentic and lotic habitat, Lake Sturgeon may migrate between lake and river, or remain in the river year-round (Rusak and Mosindy 1997; Auer 1999; Borkholder et al. 2002; Boase et al. 2011; Trested et al. 2011). Migration and arrival at spawning habitat have been linked to the period of the lunar cycle (Forsythe et al. 2012), and movement may be influenced by time of day, water temperature, and water discharge (Lallaman et al. 2008; Forsythe et al. 2012).

Lake Sturgeon habitat use has been studied in many areas. Juvenile Lake Sturgeon appear to prefer depths greater than 9 meters, if available (Holtgren and Auer 2004; Smith and King 2005; Barth et al 2009). Lake Sturgeon generally prefer substrates of small particle size, such as silt, sand, clay, gravel and organic substrates (Chiasson et al. 1997; Peake 1999; Knights et al. 2002; Holtgren and Auer 2004; Smith and King 2005; Trested et al. 2011). While adult Lake Sturgeon may use the same habitat as juveniles (Trested et al. 2011), it has been suggested that juveniles use different habitats to avoid competition with adults (Smith and King 2005).

Despite some similar observations of Lake Sturgeon movement trends in different river systems, the variation observed, both across and within these systems, makes it difficult to apply knowledge of Lake Sturgeon migration behaviour from one system to another in order to implement management strategies. It is therefore necessary to become familiar with the behaviour of specific populations, especially at-risk populations, in order to understand and protect them.

The goal of this study was to examine the movement patterns of Lake Sturgeon in the South Saskatchewan River system, Alberta and Saskatchewan, Canada, using hydroacoustic telemetry. Whereas there have been a few studies on the movement of Lake Sturgeon in this area (Saunders 2006), it was unknown to what extent sturgeon migrate throughout the South Saskatchewan River system. Lake Sturgeon were known to congregate at certain areas in the river, based on information from anglers and previous movement studies; however, it was unknown if most individuals mainly stayed in these locations or made wide-ranging movements throughout the system. The methods employed in this study allowed sturgeon to be tracked continuously in multiple locations, something that had not been previously completed. To better understand movement and habitat choices of Lake Sturgeon, a habitat survey was also completed during the project to characterize the reaches of the South Saskatchewan River system where tagged Lake Sturgeon were detected.

Methods

Study Area

The study area consisted of a section of the South Saskatchewan River (SSR) system stretching from southern Alberta into southwestern Saskatchewan and included reaches of four rivers: the South Saskatchewan, Bow, Oldman and Red Deer rivers (Figure 2.1). The SSR is formed by the confluence of the Bow and Oldman rivers at what is referred to as the Grand Forks. The study area included the SSR from its origin at the Grand Forks downstream to the upstream portion of Lake Diefenbaker at Saskatchewan Landing (473 rkm), the Bow River from the Grand Forks upstream to the Bassano Dam, an irrigation dam blocking upstream fish movement (172 rkm), the Oldman River from the Grand Forks upstream to the Oldman Dam, another irrigation dam that blocks fish passage (322 rkm), and the Red Deer River upstream from the confluence of the Red Deer River and the SSR (135 rkm). There was no barrier to movement at the farthest upstream receiver location in the Red Deer River; however, it was difficult to find access locations with sufficient depths for equipment deployment upstream and so this site was selected as the upstream cut-off. On the Oldman River, there were two weirs that were potential barriers to Lake Sturgeon movement: one in the City of Lethbridge, 158 rkm upstream of the Grand Forks, and one 290 rkm upstream of the Grand Forks. In total, the study area included just over 1100 rkm. Based on observations in other river systems, it was predicted that Lake Sturgeon would exhibit long migrations and that rate of movement and distance travelled would be greatest in the spring.

Acoustic Tagging

Lake Sturgeon were captured on baited hooks on rods and set-lines. All Lake Sturgeon captured received an external numbered Floy Tag (FloyTag Inc., Seattle WA) as well as a subcutaneous Passive Integrated Transponder (PIT) tag (Biomark, Boise ID) to facilitate identification of recaptured fish. Floy tags were inserted at the base of the dorsal fin, while PIT tags were injected under the third dorsal scute. Fork length, total length (TL) and girth were recorded for all Lake Sturgeon.

Vemco (Bedford, Nova Scotia) V16 coded acoustic transmitters were implanted surgically into the body cavity of Lake Sturgeon in the field. The transmitters had a diameter of 16 mm, were 68 mm long and weighed 24 g in air. They transmitted a unique code at random intervals with an average delay of 60 seconds (minimum 30 seconds, maximum 90 seconds) at a frequency of 69 kHz and had a battery life of approximately five years. Lake Sturgeon were immobilized using a clove oil solution as an anesthetic during transmitter implantation (Anderson et al. 1997; Barth et al. 2011). Fish were placed in the clove oil solution until movement ceased and respiration had slowed. Once immobilized, the sturgeon were placed on a V-shaped measuring board lined with a piece of wetted foam. All surgery tools and transmitters were disinfected with ethanol prior to surgery. Throughout surgery, the gills of the Lake Sturgeon were bathed in fresh river water. An incision approximately 3-4 cm long was cut on the left ventral surface of the fish, slightly posterior to the pectoral girdle. After the acoustic tag was inserted, the incision was closed with 2-3 interrupted sutures (Ethicon PDS II Suture, CP-2 Reverse Cutting Needle). Following surgery, fish were placed in a tub of fresh river water to recover until they had regained equilibrium and exhibited swimming motions. The sturgeon were then released back into the river at the location of capture. Surgically implanting the transmitter typically took around five minutes and the time from anesthetization to release typically did not exceed 20 minutes.

Sex and maturity of Lake Sturgeon receiving transmitters (tagged sturgeon) were not determined, except for two females with free-running eggs in the body cavity and one male expelling milt. Fish with a TL greater than 1150 mm were classified as adults while fish 626-1150 mm were classified as juveniles. This cut-off was determined by previous age-maturity data collected by Alberta Sustainable Resource Development (ASRD; T. Clayton, personal communication). In order to tag as many true juveniles as possible, effort was put into choosing Lake Sturgeon that still retained juvenile characteristics, such as small size, sharp scutes and pointed snout. All sturgeon that were classified as juveniles were weighed to ensure that the transmitter would not account for more than 2% of body weight (Winter 1983; Baras and Lagardere 1995). No Lake Sturgeon weighing less than 1500 g was implanted with a transmitter.

Lake Sturgeon were captured and tagged in two periods: August to September 2010 and May to August 2011. A total of 336 Lake Sturgeon were captured during the study, with 123 receiving transmitters. Tagged Lake Sturgeon were captured at ten different locations in the study area (Figure 2.1). Effort was made to spread out tagging locations throughout the study area, but was limited by river access as well as angling success. As a result, the numbers of fish tagged at different locations was not evenly distributed. Thirty-four Lake Sturgeon were implanted with transmitters in 2010, with the remaining 89 tagged in 2011. All Lake Sturgeon were tagged in Alberta.

Acoustic Receivers

Vemco VR2W hydroacoustic receivers were used to detect transmitting Lake Sturgeon. The VR2Ws consisted of an omnidirectional hydrophone, data logger, and lithium battery housed in a waterproof, pressure-resistant PVC case. Batteries were replaced approximately every 12 months to ensure the receivers were constantly recording. When a transmitter transmitted a signal and was in detection range of a receiver, the date, time, and transmitter number were stored in the internal memory of the receiver. The receivers were attached to a vertical piece of rebar on a 35 kg square concrete pad with two rebar handles. When deployed in the river, the top of the hydrophone was positioned approximately 40 cm above the bottom of the river. A smaller concrete cinder block was attached to the receiver base by at least 10 m of rope and was deployed downstream of the receiver. The locations of receivers and cinderblocks were recorded using a Garmin GPSMap 76CSX handheld GPS unit (Garmin Limited, Olathe, Kansas). To retrieve the receivers, a hook was dragged across the river-bottom between the receiver base and cinder block until the rope was snagged and the receiver could be lifted. Receivers were retrieved from the river two or three times a year to upload detection data.

River kilometers of the study area were determined using Garmin Mapsource software (Version 6.16.3) to measure distances down the centre of the river channels on a digital map of the study site (TOPO Canada 4.00). The Grand Forks was assigned a value of 0 rkm. Measurements upstream in the Bow and Oldman rivers were positive and rkm downstream in the SSR were negative. For the Red Deer River, rkm were measured as the positive distance upstream of the Red Deer Forks. Receiver locations were assigned a position to the nearest tenth of a rkm after being imported into Mapsource from the handheld GPS unit.

The number of receivers deployed fluctuated seasonally, with more deployed in the open water season and fewer through the ice cover season. The maximum number of receivers deployed in the study area at the same time was 53. Numbers were also impacted by loss of receivers. Receivers were placed in depths over 2 m whenever possible to avoid damage by ice and debris, however, this depth was not always available in the study area, especially in the Oldman, Red Deer and Bow rivers. In locations where depths greater than 2 m could not be found, receivers were removed from the river in the fall and replaced in the same location after ice-off in the spring. Receivers were first deployed in August of 2010, with additional locations being added as the study progressed. In areas that had been previously identified as locations where sturgeon congregated (i.e. known fishing holes), receivers were clustered together to maximize detection probability. For the rest of the study area, effort was made to distribute the receivers evenly; however, this was not always possible due to limited river access.

Range testing was performed in 2010 and 2011 in order to determine detection distances of receivers. The detection range of receivers can be affected by water velocity, type of substrate, and proximity to riverbanks (Bergé et al. 2012). Results from the range testing on the acoustic receivers indicated a maximum detection range of 0.5 km; however, when the data from all receivers were examined, it was determined that under ideal conditions, the same transmission from a tagged fish was often detected by two receivers up to 1.9 km apart in the mainstem of the SSR. This distance was used as the maximum detection range of receivers in the South Saskatchewan, Bow, and Oldman rivers. The detection range was better in Lake Diefenbaker. Under ideal conditions, the same transmission from a tagged fish could often be detected by receivers 2.9 rkm apart. To ensure that all calculations were based on real movement by Lake Sturgeon and not detection ranges, all detections at locations less than 2 km (rivers) or 3 km (Lake Diefenbaker) from previous detected locations were removed from the dataset.

Habitat Assessment

Water temperatures at various locations in the study area were collected with HOBO temperature loggers (Onset Computer Corporation, Bourne MA) attached to receiver bases. Seasons were defined by water temperature, similar to other studies (Rusak and Mosindy 1997; Barth et al. 2011; Shaw et al. 2013). Spring was defined as the period of rising temperatures (2°C to 15°C) from March 21 to June 20. Summer was when temperatures ranged from 16°C to the maximum temperatures, June 21 to

September 30. Fall was the period of dropping water temperatures (15°C to 2°C) from October 1 to Nov 14. Winter was characterized as stable cold temperatures (2°C and lower) and occurred between November 15 and March 20. In determining seasonal cut-offs, temperatures from the receiver just upstream of the Red Deer Forks in the SSR at rkm -296 were used because this receiver had a temperature logger attached and remained in the river year-round.

Sunset and sunrise data as well as number of daylight hours for Medicine Hat, which represented the midpoint of the study area, were downloaded from the National Research Council of Canada (NRCC) website (NRCC, accessed Dec 10, 2012). Flow data for the four river basins were downloaded from the Water Survey of Canada website (Environment Canada, accessed Aug 1, 2013). Data from the monitoring station at the SSR at Medicine Hat were used for analysis, as this location again represented the midpoint of the study area. Turbidity of the SSR at Medicine Hat was provided by the City of Medicine Water Treatment Plant, while turbidity data from the Oldman River at Lethbridge were provided by the City of Lethbridge Water Treatment Plant.

A coarse habitat assessment was conducted on the SSR from the Grand Forks to Lake Diefenbaker, the Bow River from the Bassano Dam to the Grand Forks, and 271 rkm of the Oldman River upstream of the Grand Forks. The Red Deer River was not included in the habitat survey because at the time of the survey no Lake Sturgeon had been detected in the river, and because the shallow depths of this river made it difficult to navigate with a boat. Similarly, only 271 rkm of the Oldman River were surveyed because no Lake Sturgeon had been detected further than 217 rkm upstream of the Grand Forks and access to the further upstream portion of the river by boat was limited.

Bathymetric mapping was conducted in a boat with a Suzuki™ 50 kHz echo sounder couple to Quester Tangent Corporation (QTC) View 5.5 acquisition hardware and software during June and July of 2012. The echo sounder sent a hydroacoustic signal via the transducer into the water which was then reflected back to the transducer from the bottom of the river. The sonar unit was connected via the QTC sounder interface module to a laptop running QTC VIEW 5.5 software, which recorded a bottom profile, depths, and information on roughness and size of bottom substrate. A differential Global Positioning System (Trimble, Sunnyvale CA) also logged continuously along with the acoustic data and depth. The ground speed of the boat was maintained at 10-15 km/h in order to keep the transducer properly positioned in the water. Emphasis was placed on obtaining coarse-scale data from a large area instead of fine-scale data from smaller reaches because of the large study area. Two passes of approximately 470 rkm of the SSR were surveyed, from upstream to downstream, with each pass one-third of the river width from either the left or right shore. Due to the shallower depths and smaller width of the Bow and Oldman rivers, only one survey was completed of these rivers, down the middle of the channel. In some areas where depths were extremely shallow, especially in the Oldman River, the equipment was removed from the water to avoid damage, leading to gaps in the survey. In addition, high water velocity reaches, such as at riffles, interfered with the equipment, decreasing the accuracy of the survey. Periodically throughout the survey, the water level at landmarks, such as bridge piles, was marked with spray paint. After the habitat survey was completed, these sites were revisited and the change in water elevation was measured to account for changes in depth caused by variable discharge.

After surveying, QTC IMPACT software was used to convert the acoustic data into habitat classes. Six different classes were initially identified within the study area. Ground truthing was carried out in August of 2012, in order to relate the classes to substrate composition. Substrates were classified by particle size using a modified Wentworth Scale (Wentworth 1922). Substrates were defined as the percent composition of silt (particle diameter less than 0.0625 mm), sand (0.0625 – 2 mm), gravel (2 – 64 mm), cobble (64 – 256 mm), boulder (256 – 1024 mm), and bedrock (greater than 1024 mm). Assessment of substrate type was done visually using snorkel surveys or, in areas where depth was too great, by using an aluminum pole to feel the bottom and estimate substrate composition. Ground truthing was performed at 92 locations distributed broadly across the survey area, accessible from seven road access sites.

Data Analysis

Data from the hydroacoustic receivers were imported into the database software provided by the receiver manufacturer (Vemco VUE). Data were selected by individual tag number and then exported from VUE into Microsoft Excel 2010 for processing. False detections are a detection of a transmitter code that is not actually present and may occur when there are multiple transmitters in the detection range and collisions result in a sequence being interpreted as valid by the receiver (Pincock 2012). Those detections were removed from the dataset prior to analysis. Typically, when a transmitter was detected at a receiver, multiple detections of the same individual in a short time period would occur. A macro was written in Visual Basic for Applications in Excel to highlight all single detections greater than 45 minutes from the previous or subsequent detections at a receiver. In addition, sequential detections at receivers further than 40 rkm apart were highlighted. The highlighted detections were then manually inspected, and suspect detections that were interpreted as false detections were removed from the dataset. The data analyzed in this thesis includes detections from August of 2010 to the end of September 2012.

All analyses treated individual fish as the experimental units (Rogers and White 2007). Rate of movement (rkm/day) was calculated as the distance between receivers with consecutive detections divided by the time between detections. Range was defined as the mid-channel distance between the furthest upstream and downstream receivers at which a tagged Lake Sturgeon was detected (Neufeld and Rust 2009; Barth et al. 2011). Rate of movement and range were calculated for all tagged fish combined and the juvenile and adult groupings. In order to get an idea of all movements made by Lake Sturgeon within their ranges, total movement was calculated as the sum of all distances moved upstream and downstream for the last 13 months of the study (September 1, 2011 to September 30, 2012), after all fish had been tagged. Six individuals were not detected during this time and were excluded from analyses. Total upstream and downstream movements made by all Lake Sturgeon were compared using paired t-tests. Residuals tended to be severely right-skewed and therefore data were square-root transformed before analysis to meet assumptions of normality and equal variances (Quinn and Keough 2002).

Since the size cut-off for determining maturity level of Lake Sturgeon was relatively arbitrary, fish were divided into five groups based on total length: 550-750, 751-950, 951-1150, 1151-1350, and greater than 1350 mm, and their ranges and rates of movement were compared using one-way ANOVAs with Tukey’s honestly significant difference (HSD) tests to see if any different patterns emerged when the fish were classified into smaller groups. Student's t-tests were used to compare the difference in mean rate of movements, range, and total movement between adults and juveniles during the entire study period, while two-way ANOVAs with Tukey's HSD post hoc tests were used to compare rates of movement and range across season and maturity level. One-way ANOVAs with Tukey's HSD post hoc were used to compare amount of upstream and downstream movement during each month.

Pearson's product moment correlation was used to compare the relationship between number of detections at acoustic receivers and river discharge. Only data from the ice-off period from both 2011 and 2012 were included in analysis, as it was suspected that ice interfered with the detection capability of receivers, based on post-hoc observations. In addition, since transmitters were being added to the study area throughout 2011, correlation analysis in that year only included the 34 Lake Sturgeon that had been tagged in 2010. The 2012 analysis included the entire sample, since tagging had been completed the previous year. Partial correlations were used to examine the relationship between mean weekly environmental conditions (water temperature, daily change in water temperature, turbidity, flow, and daily change in flow) and mean weekly rate of movement or range.

A two-way ANOVA was run to see if movement was independent of whether it was night or day or if movement differed by month. Arrivals and departures of sturgeon at receivers were used as representations of movement of the tagged fish, defined as the first or last detection of a transmitter at a receiver respectively, as the analysis would otherwise be influenced by a Lake Sturgeon remaining in the vicinity of a receiver for a long time. The amount of detections at receivers was standardized for day and night hours during each month. There were only enough detections to perform the tests on detection data from the months of April to October.

All statistical analyses were performed in SPSS (Version 19, IBM, Armonk NY) at the 0.05 significance level. All values reported are mean ± SE unless otherwise noted.

Results

Of the 123 Lake Sturgeon implanted with transmitters, 45 were classified as juveniles and 78 as adults. TL of tagged Lake Sturgeon ranged from 626 to 1601 mm (mean = 1112 ± 276 mm), with the most sturgeon tagged in the size range of 1150 to 1250 mm (Figure 2.2). Lake Sturgeon were detected an average of 151.4 ± 13.8 days during the time of the study (range: 5 -535 days of 778 days). Tagged fish had a mean range of 197.2 ± 15.1 rkm. Mean rate of movement for the whole study period was 1.0 ± 0.1 rkm/day. Mean total movement during the last 13 months of the study was 298.0 ± 26.6 rkm (n = 117), ranging from 3.1 – 1365.1 rkm. On average, tagged fish moved greater distances downstream (305.2 ± 21.9 rkm) than upstream (215.2 ± 20.4 rkm) ($t_{(122)} = 5.9$, $p < 0.001$).

The number of receivers in each river varied during the year (Figure 2.3), as receivers were removed from the water during the period from mid-October to late April/early May, including all receivers in the Red Deer River. Only one receiver was left in the Bow River, just upstream of the Grand Forks, during winter 2010-2011; however, this receiver was lost during winter 2011-2012. Similarly, only two (2011-2012) or three (2010-2011) receivers remained in the Oldman River during the winter: two near the

Grand Forks, and one at the furthest upstream deployment site, below the Oldman Dam. The study area in which Lake Sturgeon movement could be monitored was therefore reduced during those months. While a few receivers were removed from the SSR for the winter, most were deployed at sites with depths greater than two meters and could remain in the river. The distance between receivers ranged from 1 rkm to 156.9 rkm. The longest section of river not monitored was the stretch of the SSR from upstream of the Red Deer Forks to Lake Diefenbaker, as attempts to retrieve deployed receivers in this area were unsuccessful. The SSR downstream of the Red Deer Forks was characterized by sand substrate that formed large shifting sandbars which would frequently cover the locations where receivers had been deployed, making recovery impossible.

The total number of valid detections at receivers after filtering was 4 082 910. The mean number of detections per fish was 33 194 ± 3725, with a range of 41 – 206 235. All Lake Sturgeon implanted with transmitters were detected at some point during the study period.

Distribution

South Saskatchewan River

Of the 123 fish with acoustic transmitters, 122 were detected in the SSR. Sturgeon were detected throughout the 473 rkm of the SSR included in the study. Fifty-seven Lake Sturgeon (26 adults and 31 juveniles) were never detected moving out of the SSR during the study period, and the SSR was the only river where sturgeon were detected during the winter. Eighteen Lake Sturgeon (14 adults, 4 juveniles) were detected in Lake Diefenbaker during the study.

Oldman River

Fifty tagged Lake Sturgeon were detected in the Oldman River during the study. Twenty-four of these fish were tagged in or near the Oldman River (at Lethbridge or the Grand Forks) while the rest were tagged at least 50 rkm downstream in the SSR. In 2011, tagged Lake Sturgeon were detected in the Oldman River from May 4 to September 1, while in 2012 the detection dates ranged from May 1 to August 10. Fifteen Lake Sturgeon were detected upstream of the weir in Lethbridge (rkm 158) in 2011; twelve moved less than 7 rkm upstream of the weir, while three were detected 59 rkm upstream of the weir (at rkm 217). While two of the individuals detected 59 rkm upstream of the weir moved back downstream within 3 days, one was not detected downstream for a month. Due to loss of receivers deployed between rkm 217 and the Oldman Dam, it is possible that fish migrated further than 217 rkm up the Oldman; however, the timing of detections suggested that this was not the case, as fish were only detected at the rkm 217 receiver on one day. The Oldman River was the only river where tagged individuals were not detected moving to the furthest upstream location monitored, as none of the tagged Lake Sturgeon moved upstream to the Oldman Dam (rkm 322).

Bow River

Forty-eight Lake Sturgeon were detected in the Bow River between 2011 and 2012. Of these fish, 30 were tagged in Lethbridge or at the Grand Forks, while 18 moved into the Bow after being tagged downstream in the SSR. Lake Sturgeon were detected in the Bow between May 5 and October 5, 2011, and between May 1 and September 17, 2012. Tagged fish were detected in the entire reach of the Bow River being monitored, from the Grand Forks to the Bassano Dam, 173 rkm upstream. Only one fish was detected at Bassano in 2011, while three were detected below the dam in 2012, including the one that was detected there the previous year.

Red Deer River

Only one tagged Lake Sturgeon was detected in the Red Deer River during the study period. This adult fish (TL of 1260 mm) was detected at the furthest upstream receiver in this river on July 17, 2012 (135 rkm upstream from the Red Deer Forks). There were no detections in the Red Deer River before this date; therefore it is unknown exactly when this sturgeon entered the Red Deer. There were no receivers deployed in the Red Deer between mid-October 2011 and May 10, 2012, so it is likely that this individual swam upstream before there were any receivers in place to detect it. Since the furthest upstream receiver deployed in the Red Deer was not marked by a barrier to upstream movement, the sturgeon may have moved more than 135 rkm upstream.

Influence of Maturity Level

Lake Sturgeon were grouped into five size categories. There was a significant difference in range between the size classes (one-way ANOVA, $F_{(4,118)} = 11.695$, $p < 0.001$). A Tukey HSD post-hoc comparison revealed that the two smallest size classes did not differ significantly from each other but did have significantly lower ranges than the two largest size classes, which also did not differ significantly (Table 2.1). The middle size class, which included Lake Sturgeon with TLs of 951-1150 mm, did not differ significantly from any other group. These results were mirrored when the mean rate of movements of the size classes were compared (one-way ANOVA, $F_{(4,116)} = 13.919$, p <

0.001). Tukey HSD post-hoc tests on the results confirmed congruent results with TL (Table 2.1). Since the middle size class was not significantly different from larger or smaller fish, the size cut-off determined by previous work in the system was used to classify sturgeon as juveniles or adults.

Adult Lake Sturgeon had significantly greater ranges and moved significantly greater distances both upstream and downstream than did juveniles. Frequency distribution of movement ranges showed juveniles generally remaining in more restricted sections of the river (Figure 2.4). All juveniles, except one, had movement ranges of 308.9 rkm or less. The exception was a Lake Sturgeon with a total length of 1110 mm that had a movement range of 625.7 rkm. This individual was only 40 mm away from reaching the size cut-off to be classified as an adult, and may have been a mature fish. Adult fish tended to have more variation in their movement ranges (9.5 to 687.8 rkm). The highest number of adults moved between 251 – 350 rkm (Figure 2.4). Adults also had a significantly higher overall mean rate of movement and moved significantly greater total distanced than juveniles (Table 2.2).

A higher proportion of adult Lake Sturgeon was detected outside of the mainstem of the South Saskatchewan compared to juveniles. Only 14 juveniles were detected in the Bow and Oldman Rivers, representing 30% of the amount of juveniles tagged. No juveniles moved into the Red Deer River. In contrast, 60% of tagged adults (47 individuals) were detected outside of the SSR at some point in the study.

Seasonal Movement Patterns

When rates of movement were analyzed with a two-way ANOVA, the effect of both maturity level ($F_{(1, 348)} = 17.237$, $p < 0.001$) and season ($F_{(3, 348)} = 12.639$, $p < 0.001$)

were significant, however there was no significant interaction between the two variables ($p > 0.05$). Post-hoc analysis revealed that mean winter rate of movement was significantly lower than that of all other seasons but there were no other significant differences between seasons (Figure 2.5). Adults had significantly greater rates of movements than juveniles. When range was compared across season and maturity level, again both maturity ($F_{(1, 348)} = 23.286$, $p < 0.001$) and season ($F_{(3, 348)} = 42.219$, $p < 0.001$) were significant, however, there was also a significant interaction between the two variables ($p < 0.005$). Fall and winter ranges were not significantly different between maturity levels but adult ranges in spring and summer were significantly higher than those of juveniles. For both groups combined, winter and fall rates were not significantly different from each other but were significantly lower than spring and summer, which in turn were not significantly different (Figure 2.5).

No significant difference was found in the mean distance moved upstream or downstream within any season ($p > 0.1$ for all pairwise comparisons). When only upstream distances were examined, a significant difference between seasons was found ($F_{(3, 150)} = 18.075$, $p < 0.001$). Lake Sturgeon moved significantly smaller distances upstream in winter than during any other season and also moved significantly less downstream in fall than during spring and summer (Table 2.3). Similarly, when seasonal downstream distances were compared, there was a significant difference between seasons ($F_{(3, 150)} = 13.652$, $p < 0.001$) and when pairwise comparisons were made, the same seasonal differences were seen for downstream movement as for upstream movement.

Abiotic Factors

Month had a significant effect on number of detections ($F_{(6, 423)}$ =52.313, $p < 0.001$), as did time of day ($F_{(1, 423)}$ =590.661, $p < 0.001$). There was no significant interaction between the two variables ($p > 0.05$). Post-hoc analysis showed that there were significantly more detections during the night than during the day during all months, and there were significant differences in the number of night and day detections between months (Figure 2.6).

Rate of movement was significantly positively correlated with water temperature ($r = 0.709$, $p < 0.001$). There was no significant correlation between rate of movement and flow, turbidity, daily change in water temperature or daily change in flow ($p > 0.05$ for all comparisons). Range was also positively correlated with water temperature ($r = 0.552$, $p = 0.004$), as well as turbidity ($r = 0.488$, $p = 0.013$), and flow ($r = 0.721$, $p < 0.001$). Range was not significantly correlated to change in water temperature ($p = 0.785$) or change in flow ($p = 0.884$).

Maximum discharge of the SSR in both 2011 and 2012 occurred at the end of May (Figure 2.6). In 2011, the maximum flow of the SSR at Medicine Hat was 2160 m^3/sec on May 30 (Environment Canada 2013). In 2012, the peak flow was much lower, at 1340 m^3/sec on May 27. There was ice detected at the Water Survey of Canada monitoring station at Medicine Hat from November 16, 2010 to April 15, 2011 and from November 5, 2011 to March 14, 2012. In 2011, the maximum temperature of 23.8°C was on July 19, while in 2012 it was 24.3°C on July 11. Minimum water temperatures occurred between mid-November 2010 and early April 2011, and between early November 2011 and late March 2012.

Flow strongly affected the number of detections of transmitters during the ice-off period of both 2011 and 2012 (Figure 2.7). There were strong negative correlations between flow and number of detections in both 2011 ($r_{(189)} = -0.823$, $p < 0.001$) and 2012 ($r_{(193)} = -0.777$, $p < 0.001$).

Habitat Analysis

From the habitat data collected during the survey, the SSR had a mean depth of 3.23 m (SD = 1.14 m, maximum: 11.68 m), the Bow had a mean depth of 2.21 m (SD = 0.67 m, maximum: 6.22 m) and the Oldman had a mean depth of 1.90 m (SD = 0.64 m, maximum 5.63 m) during the time of the survey. Depths in the individual rivers were standardized using flow and elevation data from Water Survey of Canada gauges. It is not possible to compare the depths of the different rivers directly since they were completed at different discharges and there were not enough data collected to calculate a correction factor between rivers.

Ground truthing locations were chosen after analysis of the hydroacoustic data gathered during mapping, based on areas that had homogeneity of substrate class and were easy to access. Of the seven access sites, data from two had to be eliminated (South Saskatchewan downstream of the Red Deer Forks and Lake Diefenbaker) as there was great discrepancy between the hydroacoustic and ground truthing data. This discrepancy was most likely due to sedimentation that occurred between mapping and ground truthing, as there was a peak in discharge during this time. Flow in the SSR ranged from 600-1200 m^3/sec during mapping and was 150 m^3/sec during ground-truthing (Environment Canada 2013). From the hydroacoustic bottom data, six different substrate classes were identified in the mapped portion of the study area; however, two of the classes (3 and 5) were combined after ground truthing revealed them to be similar in composition, giving a total of 5 substrate types (Table 2.4).

The three rivers included in the habitat survey differed in their dominant substrate type (Table 2.4). The SSR was dominated by Class 1 (greater than 40% sand or finer substances), as well as Class 4 (gravel, cobble and boulder) substrates. It had a much higher proportion of sand-dominated substrates than the other two rivers. The Bow River also had a high proportion of Class 4 but had an even higher proportion of Class 5+3 (cobble and boulder). The Oldman River was overwhelmingly dominated by the Class 5+3 substrate.

Overwintering Locations

During the winter of 2010-2011, there were 34 Lake Sturgeon with transmitters in the study area, all of which had been tagged at Koomati, between rkm -184.7 and rkm -185.5 in the SSR (Figure 2.8). Of these fish, 26 were detected during the winter, all at Koomati. During winter of 2011-2012, a total of 59 out of 123 Lake Sturgeon were detected at three general areas: Koomati, Miners Flats and Rattlesnake (Figure 2.8). Twenty-one of the 26 Lake Sturgeon that overwintered at Koomati in 2010-2011 were detected there again during winter 2011-2012, while one was detected overwintering at Miners Flats, and four were not detected. Of the remaining 34 Lake Sturgeon detected throughout the winter of 2011-2012, eight were detected at Koomati, seven were detected at Miner’s Flats, and 22 were detected in the Rattlesnake area. The mean date of arrival at the sites was September 11, 2011 (1 SD of 72.7 days; range of May 3, 2011 to November 27 2011). Six individuals never left their overwintering sites before the end of the study period, including one individual that never left Koomati after it was tagged in 2010. Lake

Sturgeon moved away from overwintering areas significantly later in 2012 than in 2011, and the mean flows and temperatures were significantly greater on departure dates in 2012 (Table 2.5). It is important to note that there was a much higher sample size in 2012, and that there was only one overwintering location being monitored in 2011, compared to three in 2012. Lake Sturgeon were never detected in the Red Deer, Bow, or Oldman rivers during the winter.

The substrate of all overwintering locations varied, although all sites had substrate dominated by class 4 (mixture of gravel, cobble and bedrock) (Figure 2.9). All three locations also had large areas of sand substrate, with Miners Flats having the largest stretches of 100% sand substrate. Rattlesnake had the largest area of class 5 habitat (≥ 25% cobble and <20% boulder).

Discussion

Distribution

Lake Sturgeon moved large distances throughout the barrier-free portions of the South Saskatchewan River system, with adult fish typically moving farther than juveniles. The maximum detected range of Lake Sturgeon in this study, 687.8 rkm, is the second highest linear range ever recorded for Lake Sturgeon. The longest movement recorded for this species was an individual in the North Saskatchewan River that moved over 840 rkm from its tagging location (ALSRT 2011). The North Saskatchewan River is similar to the SSR in having several hundred rkm of unimpeded river, free of dams or weirs. The longest migration previously recorded in the present study area was 350 rkm, from mark-recapture data collected by the province of Alberta from 1985 to 2009

(ALSRT 2011). Lake Sturgeon in the SSR tracked in 1985 and 1986 using radio-telemetry had a maximum range of 210 rkm (R.L. & L. 1991), while another radio-tracking study conducted between December 1996 and July 1997 found a maximum movement range of 165 rkm (R.L. & L. 1998). Lake sturgeon moved very far distances within their ranges, with multiple individuals making total movements in excess of 1000 rkm in 13 months.

The range of Lake Sturgeon movement in the present study is significantly higher than maximum ranges reported from other systems (12 to 201 km; Auer 1996a; Knights et al. 2002; Boase et al. 2011; Shaw et al. 2013). The Saskatchewan River system is the only remaining river system in North America to have abundant Lake Sturgeon populations and barrier-free reaches in excess of 700 rkm. Although the results indicated that tagged fish moved greater distances downstream than upstream, this observation was influenced by the sampling locations. Many fish were tagged at the upstream extents of their ranges, such as at Lethbridge and the Grand Forks.

South Saskatchewan River

The South Saskatchewan River provides much of the critical habitat necessary for Lake Sturgeon. Almost half the fish implanted with acoustic transmitters were never detected outside of the SSR, indicating that Lake Sturgeon may not need to migrate into the tributaries to complete their lifecycle. However, the study period was not long enough to encompass all possible spawning events of tagged fish, since there may be up to five years between female spawning events (Bruch and Binkowski 2002), and if observed for a longer time period, more individuals may have left the SSR.

Eighteen Lake Sturgeon moved into Lake Diefenbaker during the study period, with some of these individuals likely overwintering in the lake. It is unknown whether there is a larger subpopulation of Lake Sturgeon that live mainly in Lake Diefenbaker and move upstream only to spawn, due to a lack of tagging in this area. In some areas where Lake Sturgeon ranges include lentic and lotic habitat, some individuals in the population may remain in rivers for most or all of the year (Rusak and Mosindy 1997; Boase et al. 2011; Borkholder et al. 2002), which is consistent with the observations made in this study. More commonly, however, Lake Sturgeon will move into lake habitats after spawning given the availability (Hay-Chmielewski 1987; Auer 1999; Holtgren & Auer 2004; Lallaman et al. 2008; Trested et al. 2011). Focusing on tagging Lake Sturgeon in Lake Diefenbaker and placing more acoustic receivers in the lake could give insight to how this reservoir is used by Lake Sturgeon.

Oldman River

The Oldman River was occupied by Lake Sturgeon mainly in the spring and summer. The weir in Lethbridge was a barrier to fish in 2012, but upstream movement was observed in 2011. High flows in 2011 backwatered the weir, eliminating the drop and decreasing velocities on the sides of the structure. Lake Sturgeon in other areas have been recorded moving upstream over natural rapids (Welsh and McLeod 2010), as well as over a breached weir (Trested et al. 2011). Members of this species are relatively poor swimmers, however, especially compared to salmonid species (Peake 1997), and so may avoid moving past the weir unless there is easy passage around it. There is another weir on the Oldman River 289.4 rkm upstream of the Grand Forks. It is unknown to what extent Lake Sturgeon are able to pass upstream of this structure, as no tagged fish was ever detected upstream of it. There is photographic evidence of anglers capturing Lake Sturgeon upstream of the second weir, right below the Oldman Dam (Saunders 2006), which likely occurred in a year of very high flow. Barring failure of the receivers to detect the tagged fish, it is unlikely that any of the sturgeon tagged during this study were travelling great distances upstream of Lethbridge, as the individuals that were detected 59 rkm upstream of Lethbridge were only detected there on one day. If fish had migrated a significant distance upstream of this receiver, detections at two separate times would be expected: one when the sturgeon was moving upstream and the second when it came back downstream. The results of this two-year study suggest that Lake Sturgeon do not occupy the upstream reaches of the Oldman River.

Bow River

Much like the Oldman River, the Bow River was inhabited by Lake Sturgeon on a seasonal basis. Only three individuals migrated up to the furthest point accessible on the Bow River, the Bassano Dam. The area below the dam could possibly provide spawning habitat, as it has the characteristic high velocities and appropriate substrate size; however, Lake Sturgeon were only detected there in mid-to-late July in both years, after the suspected spawning time. It is therefore more likely that fish were migrating upstream in search of food.

Red Deer River

Only one Lake Sturgeon was detected in the Red Deer River during the study period, suggesting that habitat may not be ideal in this river. There are angler reports of Lake Sturgeon being caught in the Red Deer River near Drumheller, Alberta, 150 rkm upstream of the area monitored during this study (Saunders 2006). In addition, a spring 2004 survey of fish populations in the lower 470 rkm of the Red Deer River caught one Lake Sturgeon and observed two others (Blackburn & Cooper 2006). There is no barrier to movement above the study's furthest upstream receiver, so it is uncertain how far upstream the one sturgeon detected in this river moved. The results of this study indicate that the tagged Lake Sturgeon did not use the Red Deer River; however, most fish were tagged some distance from this river, and the tagged fish may not be representative of fish occupying the lower reaches of the SSR. Further tagging efforts in the lower SSR and Lake Diefenbaker may reveal more Lake Sturgeon utilizing the Red Deer River.

Influence of Maturity

In general, adult Lake Sturgeon moved greater distances and had higher rates of movement than juvenile fish. It naturally followed that adults moved farther upstream and downstream in the system. This trend has been seen in other systems as well (Trested et al. 2011). Although adults did move more than juveniles, movement was variable even among individuals of the same size.

The overall mean rate of movement for adults of 1.3 ± 0.7 rkm/day (range: 0.2 – 3.8 km/day) in this study was higher than has been observed in other systems such as Rainy Lake, Ontario (0.17 - 0.80 km/day; Adams et al. 2006), Grasse River, New York (0.05 - 0.93 km/day; Trested et al. 2011), and Rainy River/Lake of the Woods, Ontario (0.080 - 0.955 km/day; Rusak and Mosindy 1997). There was a lot of variation in the ranges of adults, from less than 10 km of river used to over 680 km used, a pattern that has been observed in other studies (Rusak and Mosindy 1997; Knights et al. 2002; McDougall 2011). Some of the variation may be attributed to the reproductive status of the individuals tagged, as spawning females have been observed to move significantly higher distances than non-reproductive females (Shaw et al. 2013).

The mean rate of movement of 0.5 ± 0.1 rkm/day (range: 0.04 - 1.8 rkm) observed for juvenile Lake Sturgeon during the entire study period falls within the range of 0.3 to 1.6 km/day observed for juveniles in the Sturgeon River/Portage Lake System, Michigan (Holtgren and Auer 2004). Juveniles moved at a lower rate in the Grasse River, New York (0.1 - 0.2 km/day; Trested et al. 2011). Juveniles larger than 90 cm in Black Lake, Michigan moved 1.43 km/day, although that study included movement only from July to October (Smith and King 2005). Although juveniles tended to remain in more restricted ranges of the river than adults, many juveniles still moved 100 rkm or more during the study period. Even the smallest size class of Lake Sturgeon tagged in the study had a mean range of over 80 rkm, much higher than ranges found in other studies (e.g. Holtgren and Auer 2004, Barth et al. 2011, McDougall 2011, Trested et al. 2011), although the unrestricted habitat available to Lake Sturgeon was much less in those systems.

Seasonal Patterns

Lake Sturgeon moved less during the winter than the rest of the year. When water temperatures are low, Lake Sturgeon may remain in areas where there is sufficient food for their lowered metabolic rates, hence the decreased movement during this time (Hay-Chmielewski 1987). Some studies have also found Lake Sturgeon to be less active in the summer than during the spring or fall (Rusak and Mosindy 1997; McKinley et al. 1998; Trested et al. 2011). However, the results of the current study suggest that Lake Sturgeon are active throughout the system during spring, summer, and fall. Fish likely migrate to and from feeding and spawning areas in the spring and summer, but in the fall remain in a smaller reach of river actively feeding. Lake Sturgeon may move back to overwintering areas sooner in the SSR than in other systems, which explains the restricted range in the fall compared to spring and summer. Adults had significantly higher rates of movement and ranges than juveniles during spring and summer. The higher mobility of adults during the spring can be attributed to spawning migrations in the spring and the subsequent return to other areas of the river in the summer.

Diel Movement Patterns

Lake Sturgeon moved significantly more at night than during the day. Juvenile Lake Sturgeon have shown diel movement patterns in other areas, being more active at night and therefore more likely to be captured in a gillnet (Chiasson et al. 1997), and also moving into deeper water during the night (Holtgren and Auer 2004). Age-0 Lake Sturgeon also show increased activity after dark (Benson et al. 2005). Chiasson et al. (1997) suggested that diel patterns are linked to food availability, as aquatic invertebrates are often more active at night. However, diel movement patterns are not universally observed in lake sturgeon populations (Hay-Chmielewski 1987; Altenritter et al. 2013).

Other sturgeon species seem to be influenced by diel period as well, although studies are often conflicting. Two studies found Green Sturgeon (*A. medirostris*) to exhibit no diel movement patterns in the wild (Kelly et al. 2007; Moser and Lindley 2007); however, in the lab, larval and juvenile fish of this species were more active at night (Kynard et al. 2005). White sturgeon (*A. transmontanus*) in the lower Columbia River displayed greater activity at night than during the day and moved into deeper water when it was light (Parsley et al. 2008). Pallid sturgeon (*Scaphirhynchus albus*) have been found to be unaffected by time of day (Jordan et al. 2006), more active during the day

(Bramblett and White 2001), and more active at night (Wanner et al. 2007). Therefore, although there is evidence for diel movement patterns for sturgeon, it is conflicting and there does not seem to be a universal pattern, even within the same species. Further study on sturgeon movements in different systems may provide more information on the effect of diel period on behaviour.

Effect of Abiotic Factors

Flow was negatively correlated with detection, indicating that detection capability of receivers may be compromised during times of high discharge, and, therefore, movements of Lake Sturgeon may be underestimated during these times. Lake Sturgeon rates of movement and ranges were positively correlated with water temperature. Range was also significantly positively correlated with turbidity and flow. Discharge, and not temperature, was found to be correlated with mean monthly movement of Lake Sturgeon in the Mississippi River (Snellen 2008). Similarly, Borkholder et al. (2002) found that river discharge was correlated with Lake Sturgeon movement, as fish would move upstream when discharge increased and back downstream when discharge decreased. Movement of this species has also been found to be influenced by a combination of discharge and temperature (Lallaman et al. 2008).

Overwintering Locations / Core Habitat Areas

From the habitat survey, it was possible to identify some common features found in all three sites where sturgeon were detected during the winter. All three overwintering areas occurred at areas with slower velocities and greater depths than the surrounding areas. Each area had at least one location with a depth of 5 m or greater at the time of the habitat survey (Figure 2.9). Lake Sturgeon tracked in the Saskatchewan River, downstream of the confluence of the North and South Saskatchewan rivers, have been observed overwintering at sites with depths of 3-7 m (Saskatchewan Watershed Authority (SWA) 2011). Lake Sturgeon in Black Lake, Michigan, overwintered at mean depths of 7.1 m (Hay-Chmielewski 1987), while in Lake of the Woods and Rainy River, occupied areas with depths of 6-11.5 m during the winter (Rusak and Mosindy 1997). Lake Sturgeon may move into deep holes during the winter in in order to be protected from environmental changes at the surface (Altenritter et al. 2013). Protection from ice may be a key factor in selecting these depths, since large ice-jams can form on the South Saskatchewan River.

The three overwintering sites in the South Saskatchewan River also appear to be important core areas of use for Lake Sturgeon in all seasons. After the sample was implanted with transmitters, Lake Sturgeon were constantly detected at Koomati, Miner's Flats and Rattlesnake. Some individuals that were tagged at Koomati and Rattlesnake were never detected anywhere else during the study period. In addition, individuals that did move away from these areas tended to return to them, as was evident in the high number of fish returning to overwinter at Koomati in 2011-2012. The use of core areas by Lake Sturgeon has been documented in other systems as well (Fortin et al. 1993; Borkholder et al. 2002; Knights et al. 2002; McDougall 2011).

The high percentage of sand at these sites may play a role in selection by sturgeon. Sand substrates have been reported as ideal Lake Sturgeon habitat in many areas. Haugen (1969) sampled 223 Lake Sturgeon in the South Saskatchewan River and found that 82% of the Lake Sturgeon were captured in areas that had some percentage of sand-silt substrate. Lake Sturgeon in the Saskatchewan River, just downstream of the confluence of the North and South Saskatchewan rivers, were found to prefer silt/sand and silt/mud over other available substrates in the river (SWA 2011). Lake Sturgeon have also been documented in other systems to show a preference for sand (Chiasson et. al 1997; Rusak & Mosindy 1997; Peake 1999; Benson et al. 2005; Smith & King 2005). The preference of Lake Sturgeon for small substrate size is linked to suitable habitat for benthic invertebrate prey species, which have been found to be more abundant in this substrate type (Hay-Chmielewski 1987; Chiasson et al. 1997). Ample food may be the reason Lake Sturgeon remain in areas with sand substrate. Sand is also found in depositional areas in the river, where current is low, and may indicate an area of low flow preferred by lake sturgeon in order to minimize energy expenditure, since the fish are relatively weak swimmers (Peake et al. 1997).

Although not all of the Lake Sturgeon with acoustic transmitters were detected during the winter, the common features identified in the three overwintering locations may allow for discovery of more potential sites used for both core habitat use and overwintering. Deployment of receivers at sites that have appropriate depths and substrate would help determine if the features identified in this study are, in fact, determinants for overwinter and core habitat.

Spawning Locations

Temperature loggers in the Oldman, South Saskatchewan and Bow rivers indicated that conditions were conducive to spawning between early May and late June in both years, as temperatures at that time were in the 9-18 °C range in all rivers. This timing is supported by previous radio-telemetry tracking in the system, which suggested that Lake Sturgeon were spawning between mid-May and early June of 1986-1987 in the SSR (R.L. & L. 1990). Movements and locations of Lake Sturgeon during the present study allowed the identification of some possible spawning sites.

Since mature Lake Sturgeon were caught below the Lethbridge weir, it is likely a spawning location. Lake Sturgeon will often make use of the fast-moving areas below dams to spawn (Auer 1996b; Dumont et al. 2011; North/South Consultants Inc. 2011; Thiem et al. 2013). Fifteen adult Lake Sturgeon were implanted with transmitters below the weir in 2011, and four additional adults were detected at receivers at this site. During transmitter implantation, two females were determined to be in spawning condition, with loose eggs in the body cavity. In 2012, three adult Lake Sturgeon were detected below the weir in Lethbridge. All Lake Sturgeon detected in Lethbridge in both 2011 and 2012 moved upstream to the site in May and downstream by mid-July. Upstream movement during spawning period followed by downstream movement after spawning times is characteristic of this species (Scott and Crossman 1973). Lake Sturgeon may move downstream after spawning to avoid being stranded in shallow areas of the river (Auer 1999). Detailed habitat mapping of this area was not possible due to the proximity to the weir; however, the stretch of river just downstream of the weir was composed of cobble and boulder substrate, which is the preferred spawning substrate of this species (Bruch and Binkowski 2002).

Another location where Lake Sturgeon were suspected to be spawning was the Grand Forks area. This area has long been reported as a possible spawning area (R.L. & L. 1991), although no conclusive evidence of spawning has been collected. Fourteen adult Lake Sturgeon were caught in the vicinity of the Grand Forks during the spawning period of 2011. The captures included a mature male expelling milt. In addition, four adult Lake Sturgeon that were tagged downstream were detected moving upstream to the Grand Forks in that year. In 2012, eighteen adult Lake Sturgeon were detected just upstream of the Grand Forks when the river was at spawning temperature. There is a series of riffles in the Oldman River upstream of the Grand Forks, but receivers were not placed near each one, and it was unclear exactly where Lake Sturgeon were spending time during spawning temperatures. The substrate in the section of the Oldman River in the vicinity of the first two riffles upstream of the Grand Forks was composed mainly of class 5 (cobble and boulder), with two areas of class 6 (boulder and sand) interspersed. Unlike the Lethbridge site, not all Lake Sturgeon moved away from the Grand Forks area after the assumed spawning time, with some individuals remaining until summer and fall. Fish may spawn upstream in the Oldman River and then remain in the slower water at the confluence of the Bow and Oldman rivers to forage until they return downstream to their overwintering sites.

Although Lethbridge and the Grand Forks were the only locations where spawning adults were observed, there are likely many other spawning sites in the system. R.L. & L. (1991) described a radio-tagged Lake Sturgeon moving upstream to Miner’s Flats during the spawning period of 1986, which they classified as a suspected spawning event due to appropriate habitat and behaviour of the fish. Lake Sturgeon did move to the Miner’s Flats area when water temperatures were optimal for spawning, but it was impossible to determine the reason for the migration. One indication that spawning occurs upstream was the abundance of juvenile fish captured in this area. Of the 58 Lake Sturgeon captured while angling at this site, all were juveniles and 32 had TLs less than

600 mm. The smallest sturgeon captured during the study (TL = 326 mm) was caught at this location. The high numbers of juveniles captured suggest that Miner's Flats may be a nursery area for juveniles. All the juvenile Lake Sturgeon were caught in the deepest hole in the area, which was 7 - 8 m at the time of the habitat survey. Juveniles have been documented to prefer deep water habitats from 5.4 - 20m (Smith and King 2005; Lord 2007; Barth et al. 2009; Haxton 2011). The SSR is a much shallower system than the ones examined in these studies and habitat 6 - 7 m deep is approaching the maximum for this system. Further study in this area, perhaps to see if larval sturgeon can be captured, and to determine where spawning is occurring upstream, could provide more information about this potential nursery area.

Previous studies have identified other possible spawning locations throughout the South Saskatchewan River (R. L. & L. 1991). Adult Lake Sturgeon in this study were detected migrating upstream and downstream throughout the river during the spring, and it is probable that some of these movements were spawning-related. Many fish moved into the Bow River during the spring, and thus may be spawning in that river. Many movements were also detected in the spring that were most likely unrelated to spawning; for example, adults moving into Lake Diefenbaker. Juvenile Lake Sturgeon also moved upstream and downstream during this period, so it is likely that adults were moving for other reasons as well, such as to find foraging habitat. A finer scale study to identify more spawning locations as well as to confirm the suspected locations identified in this study would be a valuable continuation of this project. In addition, a more specific examination of Lake Sturgeon spawning at the Grand Forks and Lethbridge should be conducted, such as using spawning mats to collect eggs or drift traps to collect larval sturgeon.

Summary

This study provided substantial insight into large scale movement patterns of Lake Sturgeon in the South Saskatchewan River system. Lake sturgeon moved extremely long distances in the system, with the second-highest range of this species being recorded. Adults moved more than juveniles, although both groups had large ranges. Lake sturgeon movement was impacted by time of day. Three overwintering sites and two possible spawning sites were identified, drawing attention to areas of the river where future study can be focused.

While demonstrating a broad-scale picture of the extent of movements and general habitat use of this species, the results of this study also emphasize data gaps for the population of Lake Sturgeon in this area, such as precise spawning locations and location of all overwintering sites. However, this study provided information that will make it easier to fill in these data gaps. Given the lifespan of the transmitters used in this study, it will be possible to track the movement of fish for an additional 2.5 years, with the potential for more distinct patterns of Lake Sturgeon behaviour to emerge.

Tables and Figures

Table 2.1 Descriptive statistics of Lake Sturgeon with transmitter grouped into total length size classes. Size classes with the same superscript letter (a or b) do not have significantly different rate of movements. Size classes with the same superscript symbol (* or +) do not have significantly different mean home ranges. (Tukey HSD post-hoc test, $\alpha < 0.05$ for all comparisons).

	Rate of movement (rkm/day)			Range of River Used (rkm)		
Size Class (mm)	**n**	**Mean ± SE**	**Range**	**n**	**Mean ± SE**	**Range**
550-750^{a*}	23	0.5 ± 0.1	0.05 - 1.3	23	80.3 ± 16.9	2.2 - 285.3
751-950^{a*}	17	0.5 ± 0.1	0.04 - 1.6	18	87.1 ± 23.4	0.0 - 308.9
951-1150^{ab*+}	4	1.0 ± 0.3	0.5 - 1.8	4	215.3 ± 141.2	24.9 - 625.7
1151-1350^{b+}	52	1.3 ± 0.1	0.2 - 3.8	53	264.5 ± 23.7	9.5 - 687.8
1351-1550^{b+}	25	1.3 ± 0.1	0.2 - 2.4	25	246.0 ± 30.6	33.1 - 687.8

Table 2.2 Descriptive statistics for mean rate of movement, range, total distance (13 months), upstream distance and downstream distance moved by adult and juvenile Lake Sturgeon with transmitters during the entire study period, as well as result of 2-sample t-test tested at the 0.05 significance level. All t-tests were run on data square-root transformed in order to meet assumptions of normality and equal variances; however, untransformed data are presented for the descriptive statistics.

	Adults			**Juveniles**				
Variable	**Mean ± SE**	**Range**	**n**	**Mean ± SE**	**Range**	**n**	**t**	**p**
Rate of movement (km/day)	1.3 ± 0.1	0.2 - 3.8	78	0.5 ± 0.1	0.04 - 1.8	45	7.095	< 0.001
Range (rkm)	258.6 ± 18.8	9.5 - 687.8	78	95.0 ± 17.6	0.0 - 625.7	45	6.659	< 0.001
Total Distance (rkm)	371.7 ± 36.1	3.1 – 1365.1	76	161.5 ± 24.5	8.2- 551.0	41	4.090	<0.001
Upstream Distance (rkm)	285.8 ± 28.3	0.0 - 1179.4	78	92.8 ± 13.7	0.0 - 380.5	45	5.911	< 0.001
Downstream Distance (rkm)	413.8 ± 25.6	18.4 - 1061.7	78	116.9 ± 19.4	0.0 - 628.3	45	9.141	< 0.001

Table 2.3 Descriptive statistics for seasonal upstream and downstream distances moved by Lake Sturgeon from Fall 2011 to Summer 2012. Seasons with the same superscript letter do not have significantly different mean upstream or downstream distances moved. There were no significant differences in mean upstream and downstream distances moved within any season. Tests performed at the 0.05 significance level

	Upstream Distance (rkm)		**Downstream Distance (rkm)**	
Season	**Mean ± SE**	**Range**	**Mean ± SE**	**Range**
Fall[a]	13.1 ± 2.4	0.0 - 55.9	12.0 ± 2.0	0.0 - 46.1
Winter[b]	5.7 ± 1.1	0.0 - 27.3	5.6 ± 1.0	0.0 - 27.3
Spring[c]	96.1 ± 16.0	0.0 - 425.8	79.7 ± 16.6	0.0 - 450.7
Summer[c]	43.8 ± 11.2	0.0 - 361.0	65.8 ± 11.8	0.0 - 297.7

Table 2.4 Substrate classes identified during habitat mapping of study area and percent of survey sites in each river composed of each substrate type. Class 5 and 3 were combined into a single class after data analysis.

Substrate Class Number	% Composition of Substrate Types	% in SSR	% in Bow	% in Oldman
1	≥ 40% Sand or finer substance	37.8	6.6	3.7
2	100% Sand	2.1	< 0.1	0.2
4	≥ 25% Gravel, < 25% Cobble and any % Bedrock	46.2	36.5	16.7
5 + 3	≥ 25% Cobble and < 20% Boulder	11.9	55.9	78.0
6	≥ 20 % Boulder and < 40% Sand	2.1	1.0	1.5

Table 2.5 Descriptive statistics for date of departure from overwintering grounds, as well as temperature and flow on these days. Results of two sample t-test at the 0.05 significance level also presented.

	2011			2012				
Variable	**Mean ± SE**	**Range**	**N**	**Mean ± SE**	**Range**	**N**	**t**	**p**
Date of Departure	4/4/2011 ± 1.7 days	4/1/2011 - 5/8/2011	25	4/23/2012 ± 3.6 days	3/21/2012 - 7/17/2012	52	3.7	< 0.001
Flow on Date of Departure (m^3/sec)	172.8 ± 7.5	153 - 291	25	284.1 ± 22.7	64.7 - 885	52	3.345	0.001
Water temperature on Date of Departure (°C)	1.105 ± 0.615	-0.004 - 11.224	25	9.929 ± 4.939	(- 0.031) – (21.795)	52	8.238	< 0.001

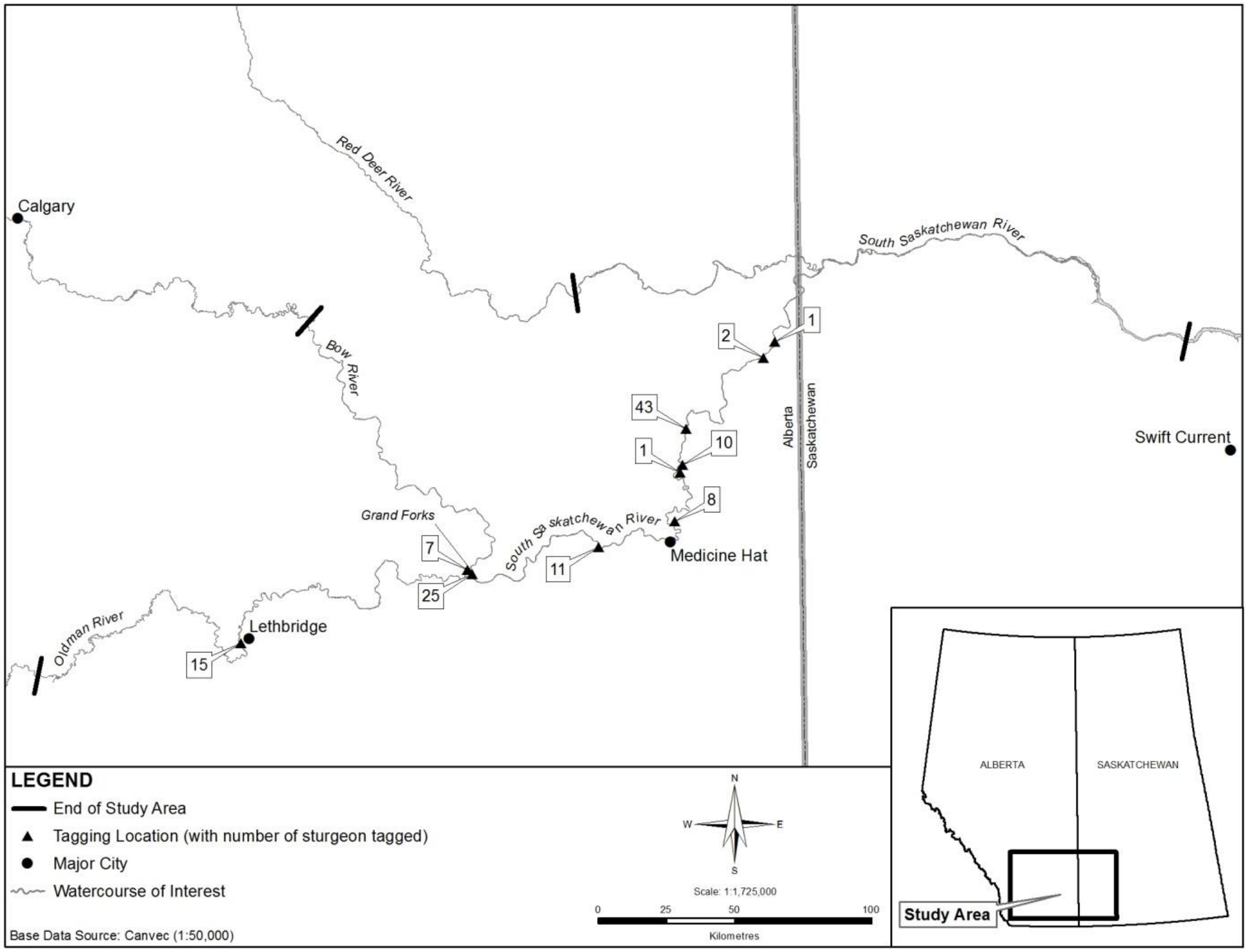


Figure 2.1 Map of study area with tagging locations marked. Black bars represent the extent of the study area. Numbers of Lake Sturgeon implanted with transmitters at each site are labeled.

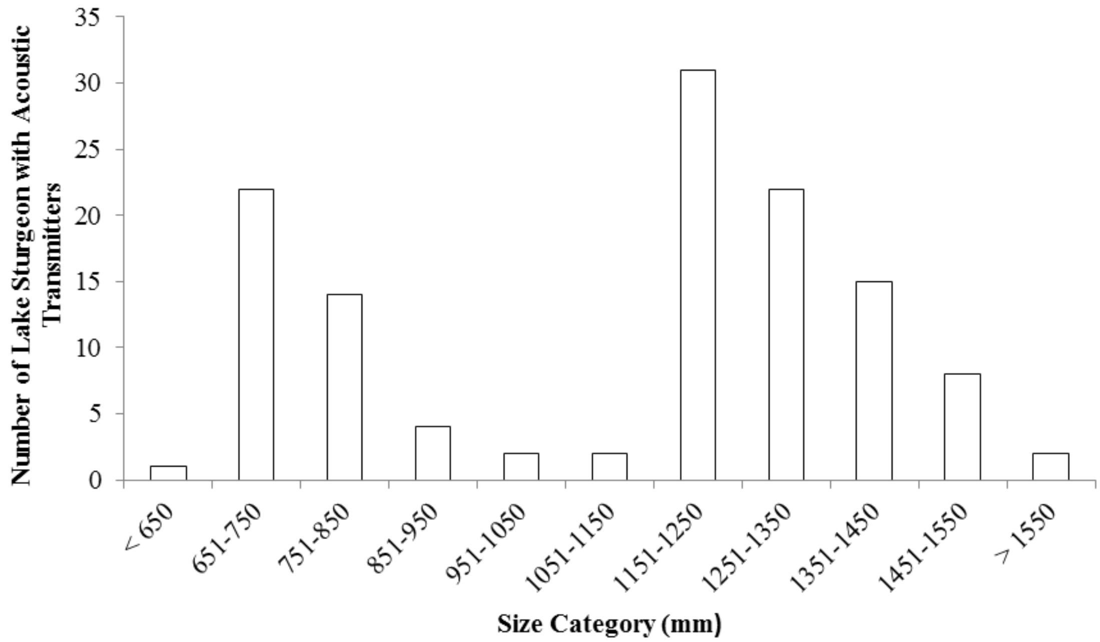


Figure 2.2 Frequency distribution of Lake Sturgeon in different size classes implanted with transmitters (n = 123). Size categories represent total length of the fish.

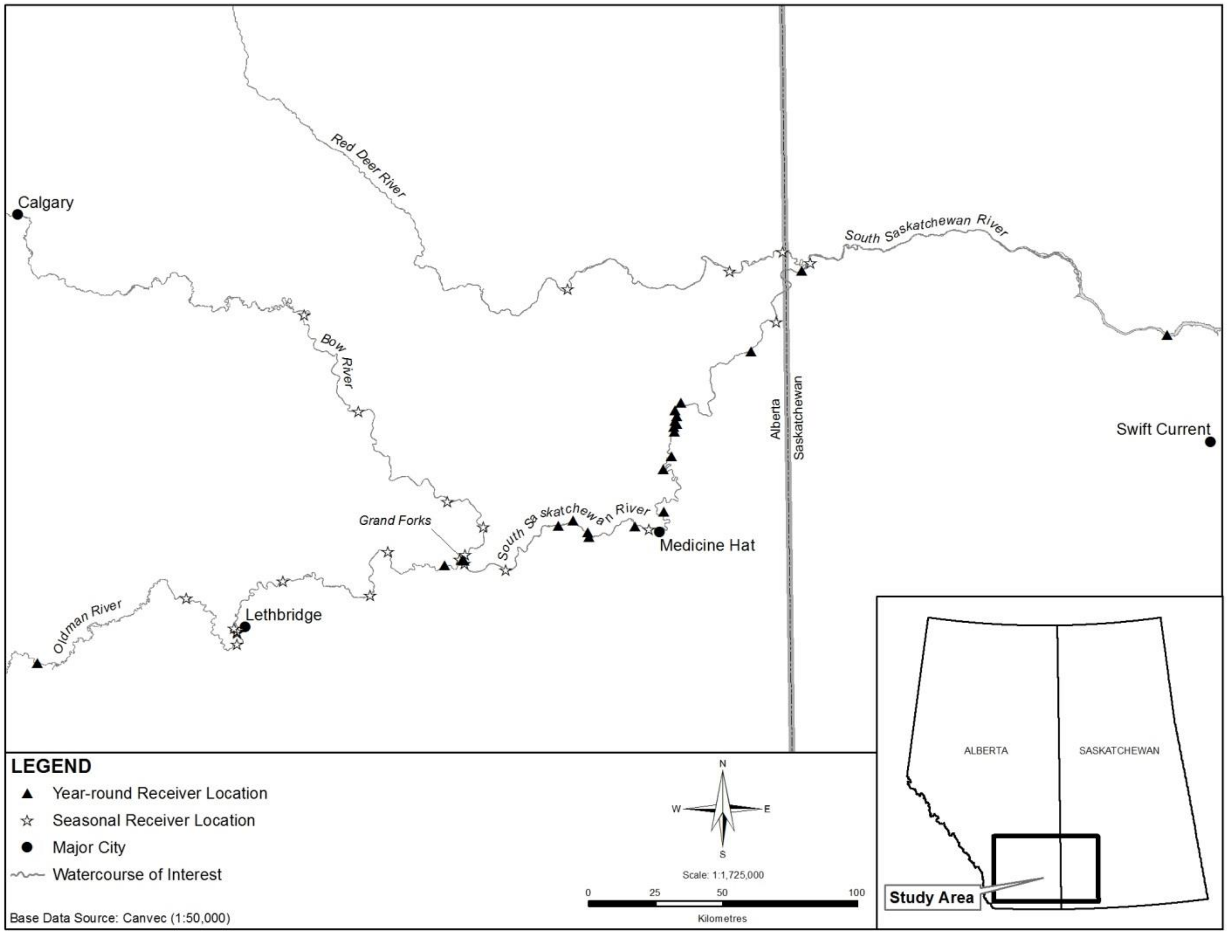


Figure 2.3 Receiver locations in the study area. Triangles represent receivers that remained in the river year-round, while stars represent receivers that were removed in the fall and redeployed after ice-off

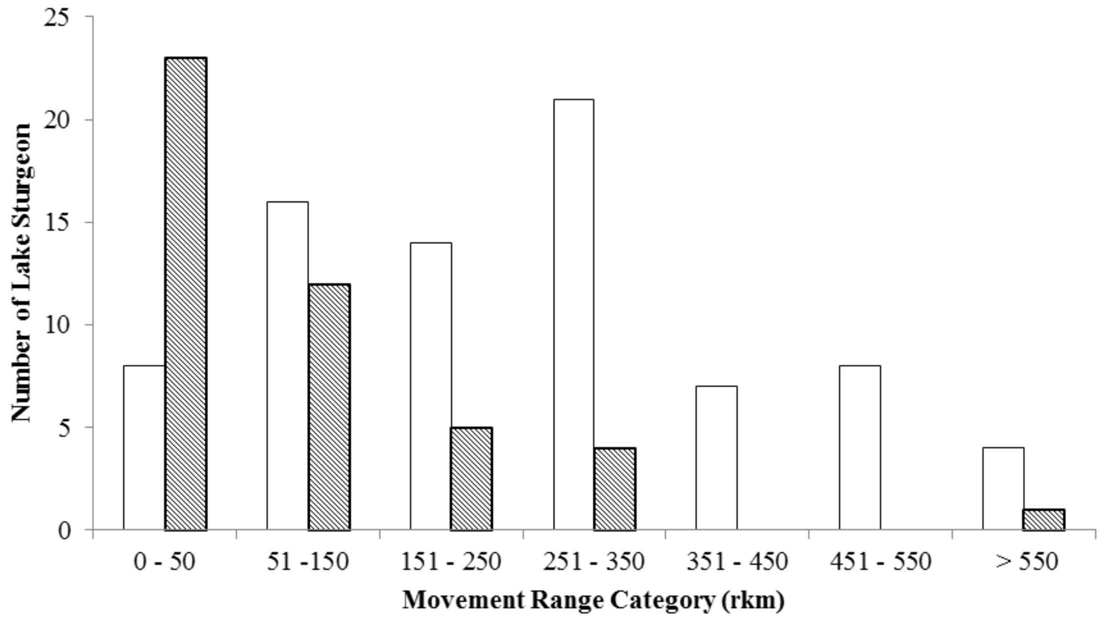
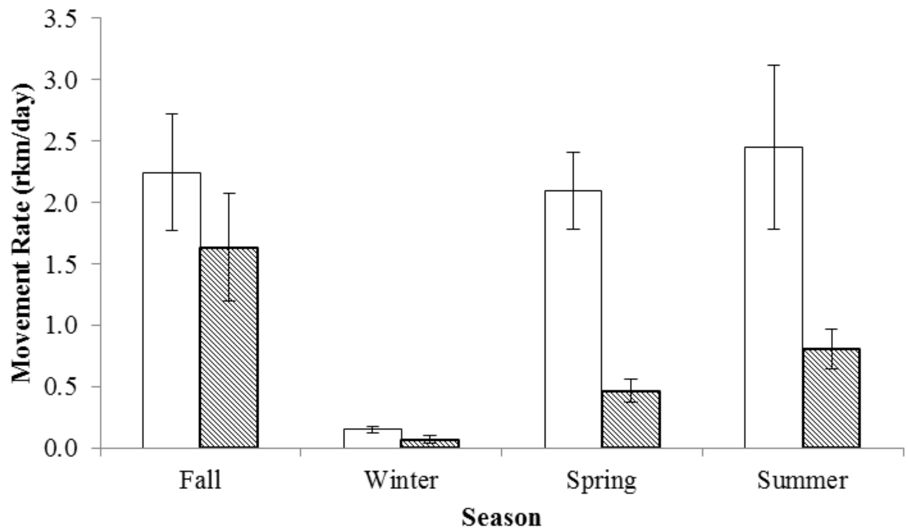


Figure 2.4 Frequency distribution of movement ranges of adult (open bars; n = 78) and juvenile (shaded bars; n = 45) Lake Sturgeon during the study period.

(a)



(b)

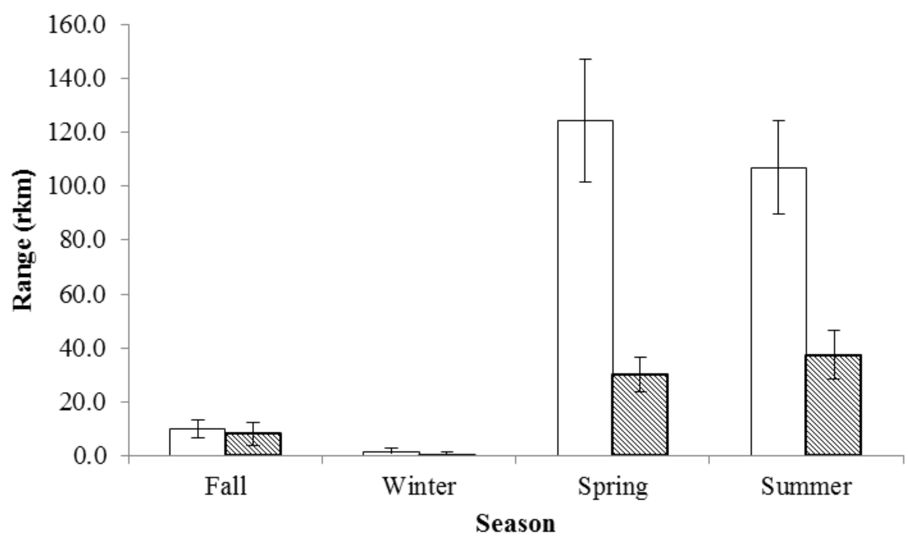


Figure 2.5 Comparison of mean seasonal rate of movements (a) and mean seasonal ranges (b) for adult (open bars) and juvenile (shaded bars) Lake Sturgeon implanted with transmitters from Fall 2011 to Summer 2012. Error bars represent ± 1 SE. There was no significant interaction between maturity level and season for rate of movement (a). Adults had significantly higher movement rates than juveniles. Rate of movement was significantly lower in the winter but there were no other significant differences. There was a significant interaction between season and maturity for range (b). Adults and juveniles did not have significantly different ranges during the fall or winter but adults had higher ranges in the spring and summer. All tests performed at the 0.05 significance level.

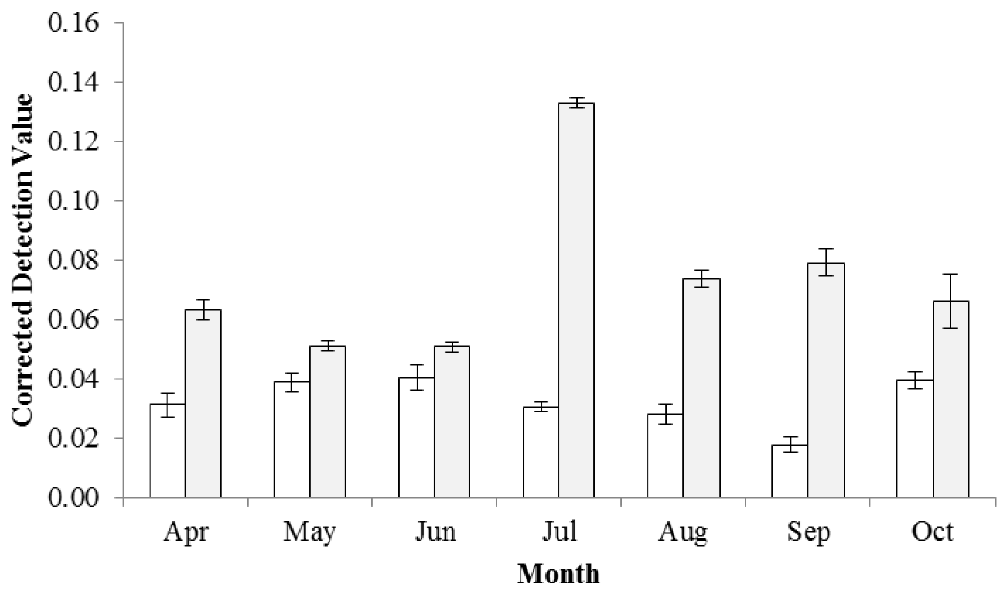
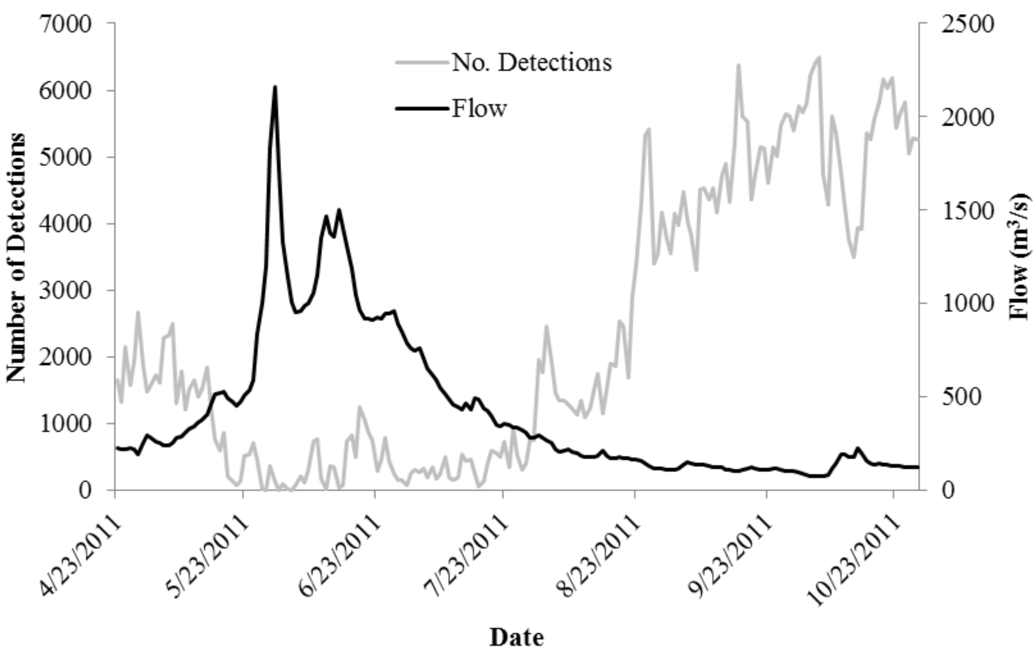


Figure 2.6 Comparison of corrected monthly detections at receivers during the day (open bars) and night (shaded bars). Detections were corrected to compare for the varying day and night hours during individual months. Detections were significantly higher at night for every month. Error bars represent ± 1 SE; tests performed at the 0.05 significance level.

(a)



(b)

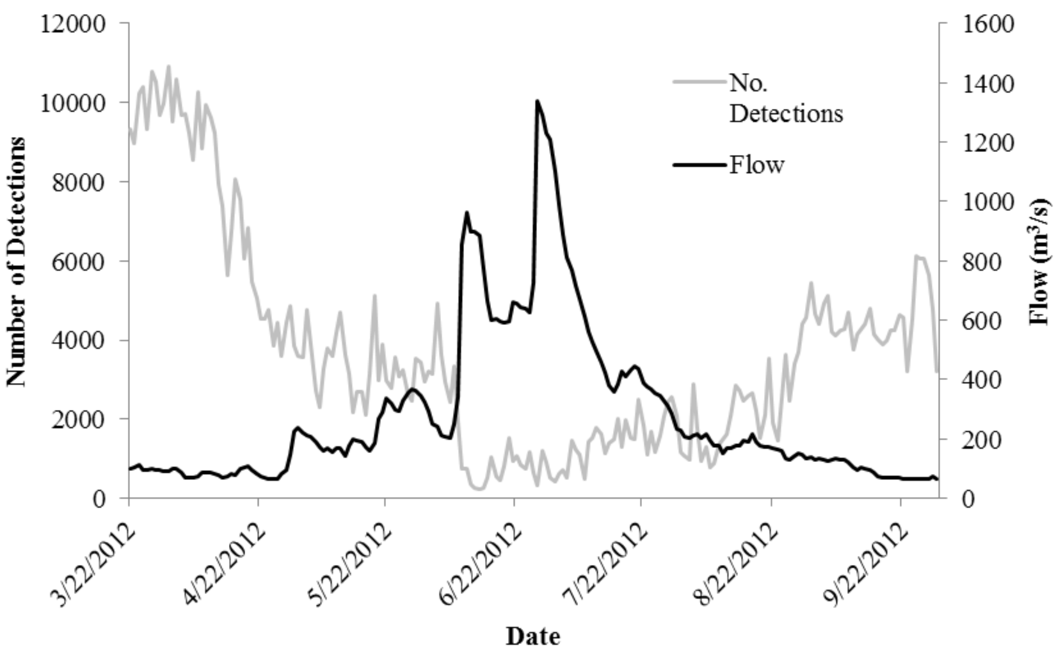


Figure 2.7 Flow and number of detections at receivers for Lake Sturgeon during ice-off conditions in (a) 2011 (b) 2012. Only detections from transmitters in the study area before 2011 (n = 34) are included in chart (a), detections from all transmitters detected during 2012 (n = 121) are included in chart (b). Flow data obtained from the Water Survey of Canada monitoring station on the South Saskatchewan River at Medicine Hat.

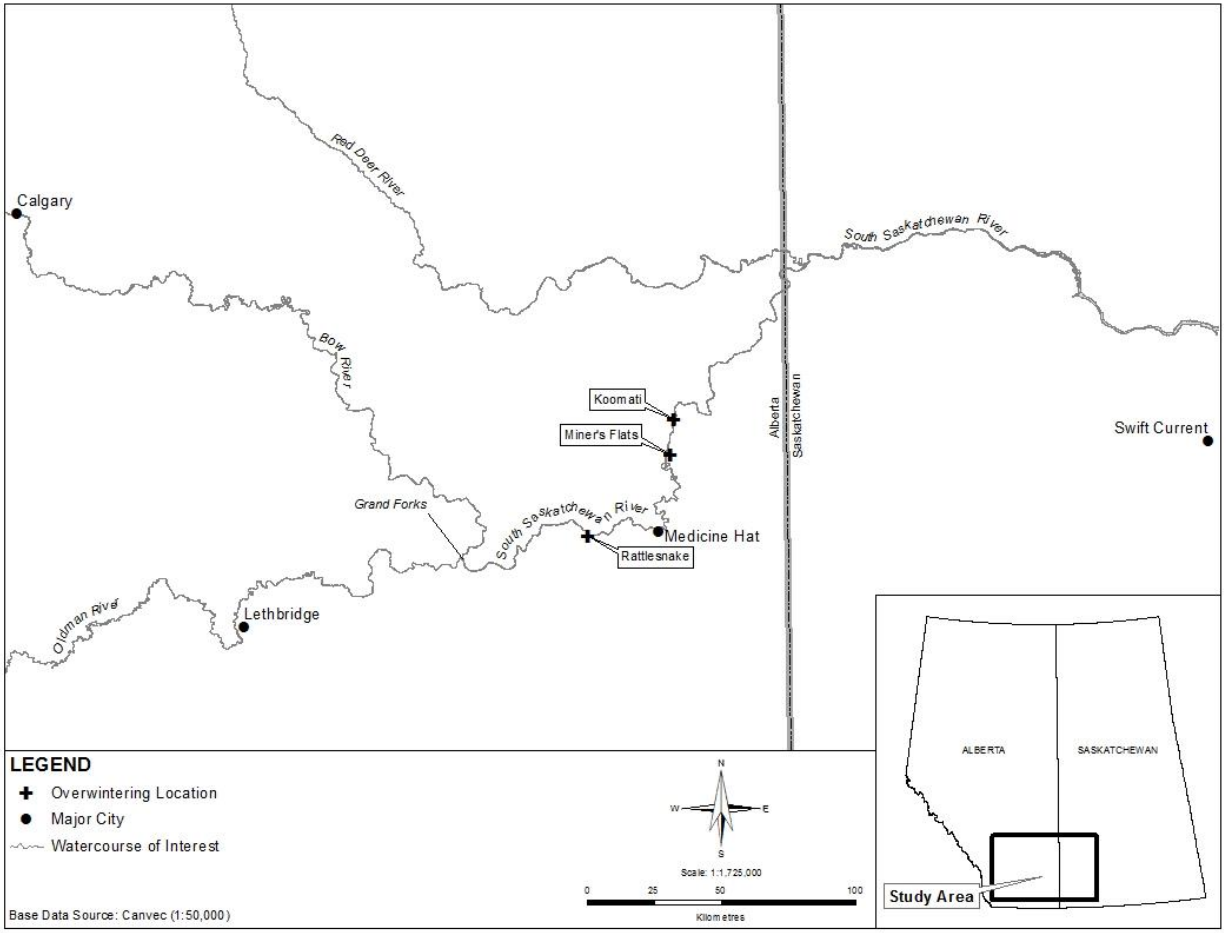


Figure 2.8 Overwintering sites in the South Saskatchewan River. Lake Sturgeon were only detected at Koomati during the winter of 2010-2011 and at all three sites during the winter of 2011-2012.

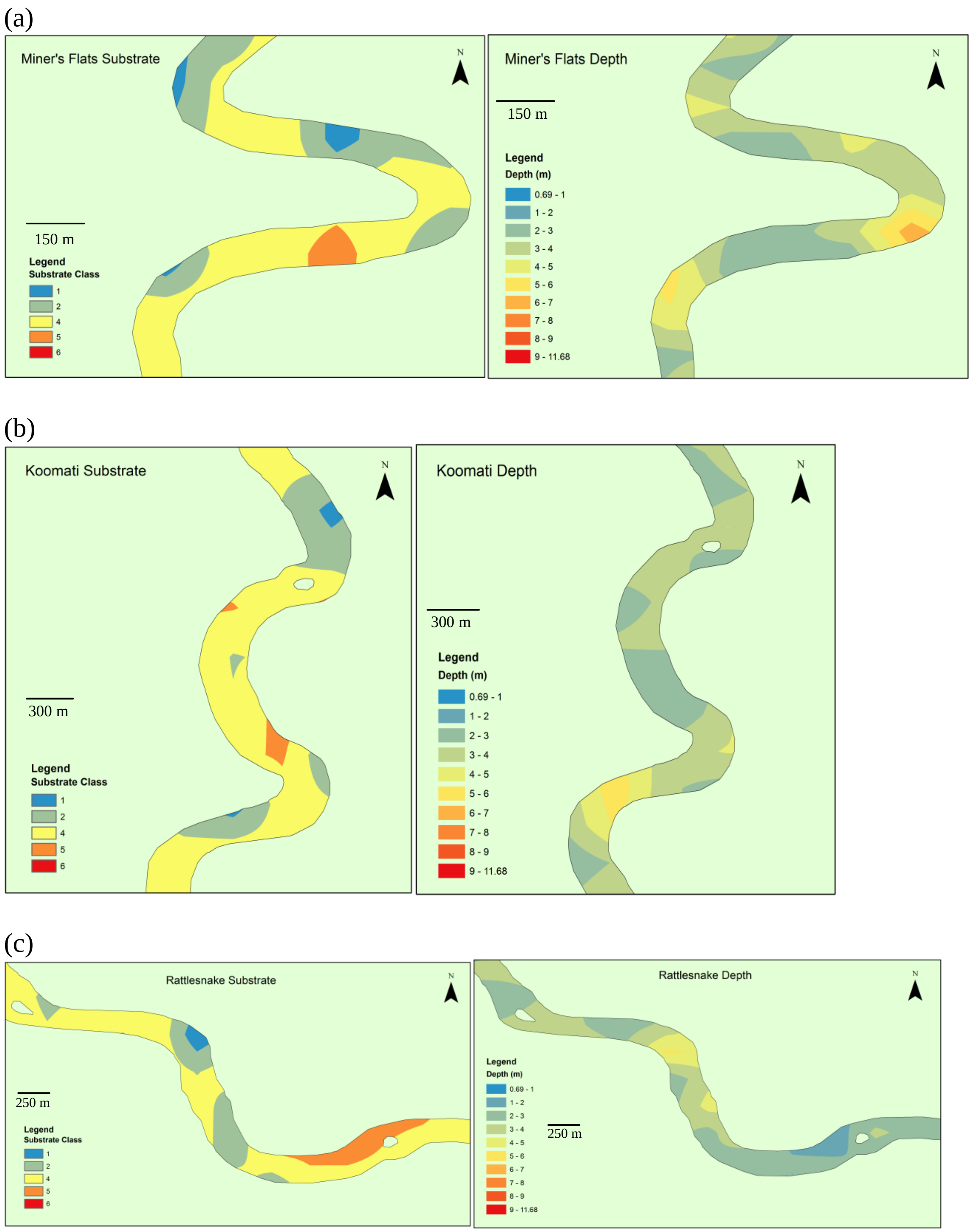


Figure 2.9 Substrate composition and depths of overwintering locations in the South Saskatchewan River: a) Miners Flats, b) Koomati, and c) Rattlesnake. Locations of overwintering sites can be seen in Figure 2.8, while descriptions of habitat classes are in Table 2.4.

CHAPTER 3: SUMMARY AND MANAGEMENT IMPLICATIONS

Although the movement information collected by this study was quite coarse, a large-scale picture of the migration patterns of Lake Sturgeon in the South Saskatchewan River system was obtained. Collection of continuous, coarse-scale data is necessary to determine fish habitat use and dispersal patterns in rivers, as critical habitats for fish in various life stages may be scattered over a large spatial scale in these environments (Fausch et al. 2002). Without covering such a large expanse of river, wide-ranging movement patterns of Lake Sturgeon would not have been identified, such as migration to Lethbridge for spawning, or number of fish that entered Lake Diefenbaker. The migration of Lake Sturgeon between Saskatchewan and Alberta highlights the necessity for interprovincial cooperation to protect this at-risk species.

Telemetry was a valuable tool in tracking the movement of Lake Sturgeon. Continuous monitoring from stationary receivers collected an amount of data that would not have been attainable through mark-recapture methods, or even active tracking of tagged individuals. Telemetry is being widely used as a method in conservation biology, with endangered species in a variety of terrestrial and aquatic habitats being tracked in this way (Cooke 2008). When studying fish populations, it is important to note variability in movement of individuals, and not just the commonalities in the whole population; studying this variability can help with conservation efforts (Cooke 2008). By monitoring Lake Sturgeon movement in a large area, greater ranges of fish movement than had ever been recorded in this area were observed. Restriction of study area size is a common problem when determining home ranges of stream fishes, especially when mark-recapture techniques are used. Fish that move long distances away from tagging areas are rarely captured, and home ranges are then underestimated (Fausch et al. 2002).

The long migrations made by Lake Sturgeon in the study area emphasize the need to keep the rivers as barrier-free as possible. Even low-head dams seem to impact the movement of this species, as Lake Sturgeon were only detected moving over the weir in Lethbridge when flows were high and the sides of the weir were inundated. In the past, there has been interest in building a new dam on the SSR, approximately 5 km upstream of the Saskatchewan border, in order to create a reservoir for irrigation. Southern Alberta has a semiarid climate (Alberta Agriculture and Rural Development 2003). Accordingly, there is significant interest in creating more irrigated land to stimulate economic development in the area. The construction of the dam was rejected after a study calculated that the cost of construction would far outweigh economic benefits (Golder 2002). However, if circumstances change and the dam becomes economically feasible, construction of a dam would negatively impact Lake Sturgeon populations. Lake Sturgeon located upstream of the dam may be less affected as all the overwintering and spawning sites that have been identified are upstream of the proposed dam location. Fish trapped below the dam, however, would not be able to access any of the upstream sites and, although there may be appropriate feeding and overwintering locations downstream of the dam, it is unknown whether there is any appropriate spawning habitat. Even if a dam incorporates a fish-passage structure specifically designed to allow upstream movement, there is very limited information on the success of these structures for sturgeon. One study on Lake Sturgeon (Thiem et al. 2011) and another on White Sturgeon (Parsley et al. 2007) found that number of fish that successfully moved upstream was low compared to the number that entered the fishway. Building a dam also brings into consideration all of the documented negative effects such as habitat destruction, anoxic conditions, siltation, and susceptibility to inbreeding (Beamesderfer and Farr 1997; Hay-Chmielewski and Whelan 1997; Jager et al. 2001).

The identification of core areas of use by Lake Sturgeon, as well overwintering sites and potential spawning locations, highlight locations where it is especially important not to disturb habitat. These locations include the two possible spawning locations at Lethbridge and the Grand Forks, as well as the three overwintering sites in the South Saskatchewan River. When considering development on the river, such as construction of pipelines for oil and gas, these sites must be protected for the health of the species.

The risks and declines faced by Lake Sturgeon are not unique to this species. The Order Acipenseriformes is one of the most endangered aquatic groups on earth (Pikitch et al. 2005). Harvest for caviar has decimated populations, yet large commercial fisheries are still in operation, especially for species in the Caspian Sea (Pikitch et al. 2005). Range restriction is also a global problem for members of this order. Between the 1930s and the 1980s, a boom in major dam construction led to fragmentation of almost all large river systems in the Northern Hemisphere (Sulak and Randall 2002). The decline of sturgeon indicates a larger problem arising from interference with large river habitats. These environments, due to fragmentation, have almost ceased to be the large, continuous ecosystems they once were (Beamesderfer and Farr 1997).

Future Research

One of the limitations of this study was its short duration. Lake Sturgeon movement was monitored for only two years, which is not enough time to encompass all possible spawning events. Haugen (1969) sampled 198 Lake Sturgeon from the SSR in 1968 and found that only 10 individuals were in spawning condition during that year. It also took a significant amount of time to capture and implant acoustic transmitters in 123 Lake Sturgeon, and as a result, the time when the entire sample size could be observed was limited. Due to all these factors, further research would be valuable.

The capture of mature fish in two locations, Lethbridge and the Grand Forks, indicated that these are two possible important spawning areas for this species. In Lethbridge, mature females were captured immediately downstream of a weir, which is the most likely location for spawning. The mature male captured at the Grand Forks was not in the immediate vicinity of an area of cobble and boulder substrate with high velocities and so it is necessary to do a much finer-scale spawning study, with many acoustic receivers deployed around suspected spawning habitat, combined with egg-traps to confirm spawning. Drift traps to determine the extent of larval drift after spawning would also provide more information on the life history of Lake Sturgeon in this system, and may also point to the locations of juvenile nursery areas in the river, important sites to protect.

The degree to which Lake Sturgeon use the lower reaches of the SSR and Lake Diefenbaker is still mostly unknown. At least two of the tagged Lake Sturgeon entered the lake and never went back into the river during the study period. By tracking Lake

Sturgeon further downstream in Lake Diefenbaker and tagging fish in the lake, it may be found that some fish spend most of their time in the reservoir. In addition, more attempts to track Lake Sturgeon downstream of Gardiner Dam would be useful to see if the fish move downstream over the dam.

The data gathered during this project provided information that can be directly used to protect this species, as well as provided a foundation for future research on Lake Sturgeon in the area. The apparent health of Lake Sturgeon populations in this area is likely due, at least in part, to the relatively unrestricted stretch of river available to this species. The continued monitoring of Lake Sturgeon using acoustic telemetry will provide more information to assist with conservation efforts.

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APPENDIX

Table A1 Tagging information and detection data for lake sturgeon implanted with acoustic tags during the study.

Transmitter	Location Tagged (12 U)	Total Length (mm)	Date of Capture	Date of First Detection	Date of Last Detection	Total Detections
286	527591, 5570383	739	6/13/2011	6/28/2011	9/23/2012	41
287	527591, 5570383	755	6/14/2011	6/22/2011	10/16/2012	88937
288	527591, 5570383	747	6/14/2011	7/21/2011	9/7/2012	1802
289	450789, 5530472	1320	5/26/2011	6/2/2011	10/11/2012	9871
290	366053, 5505335	1152	6/9/2011	6/21/2011	7/4/2011	260
291	527591, 5570383	731	6/13/2011	6/28/2011	9/5/2012	1291
292	366053, 5505335	1174	6/1/2011	6/8/2011	7/4/2012	6292
293	366053, 5505335	1201	6/1/2011	6/6/2011	7/27/2012	331
294	366053, 5505335	1272	5/31/2011	6/2/2011	10/11/2012	31242
295	366053, 5505335	1341	5/30/2011	6/6/2011	10/11/2012	19557
296	366053, 5505335	1365	5/30/2011	6/2/2011	8/17/2012	4942
297	366053, 5505335	1245	5/30/2011	6/3/2011	9/22/2012	1413
298	366053, 5505335	1542	5/30/2011	6/22/2011	9/15/2012	4929
299	366053, 5505335	1278	5/30/2011	6/24/2011	6/19/2012	1194
300	366053, 5505335	1270	5/30/2011	6/19/2011	9/20/2012	2404
301	366053, 5505335	1597	5/28/2011	6/4/2011	9/17/2012	9783
302	366053, 5505335	1292	5/30/2011	6/7/2011	10/11/2012	60376
303	366053, 5505335	1223	5/30/2011	6/21/2011	9/17/2012	7209
304	450789, 5530472	810	6/22/2011	4/30/2012	9/12/2012	1816
305	450789, 5530472	801	6/22/2011	6/28/2011	10/11/2012	16584
306	557154, 5609388	1213	7/25/2011	7/25/2011	10/4/2012	15438
307	450789, 5530472	1484	6/21/2011	6/22/2011	6/30/2012	357
308	450789, 5530472	626	6/21/2011	6/22/2011	8/14/2012	1796
309	450789, 5530472	802	6/21/2011	6/25/2011	9/12/2012	452
310	450789, 5530472	1382	6/21/2011	7/1/2011	6/18/2012	248
311	450789, 5530472	1200	6/21/2011	6/29/2011	8/19/2012	15732
312	450789, 5530472	1217	6/21/2011	6/25/2011	9/8/2012	11456
313	527591, 5570383	720	6/16/2011	11/27/2011	5/12/2012	1850
314	450789, 5530472	723	6/20/2011	7/1/2011	7/16/2011	917
315	450789, 5530472	1172	6/22/2011	6/22/2011	7/19/2012	7116
316	526857, 5567534	1489	6/15/2011	7/10/2011	10/14/2012	47130
317	527591, 5570383	742	6/16/2011	6/30/2011	5/28/2012	14525
318	527591, 5570383	891	6/16/2011	6/28/2011	10/15/2012	1399
319	527591, 5570383	695	6/14/2011	7/4/2011	7/26/2012	1256
320	448888, 5531978	752	5/18/2011	5/26/2011	8/20/2012	2195
321	527591, 5570383	721	6/14/2011	7/14/2011	4/10/2012	3107
323	528918, 5583492	1525	9/30/2010	9/30/2010	8/17/2012	747
324	528918, 5583492	1342	9/30/2010	9/30/2010	10/14/2012	77681
325	366053, 5505335	1160	5/31/2011	7/16/2011	8/16/2012	633
326	528918, 5583492	1322	10/1/2010	10/1/2010	7/15/2012	71299

Table A1 Continued.

Transmitter	Location Tagged (12 U)	Total Length (mm)	Date of Capture	Date First Detected	Date Last Detected	Total Detections
328	448888, 5531978	1540	5/19/2011	5/21/2011	9/16/2012	11313
329	448888, 5531978	1160	5/18/2011	5/20/2011	7/16/2012	29989
330	450789, 5530472	1197	5/4/2011	5/4/2011	6/10/2012	1269
331	366053, 5505335	1405	5/20/2011	6/22/2011	9/27/2012	3000
332	524839, 5549744	711	5/25/2011	7/10/2011	10/11/2012	34738
333	524839, 5549744	741	5/24/2011	7/1/2011	7/16/2012	752
334	448888, 5531978	1167	5/16/2011	5/17/2011	8/8/2012	1107
335	527591, 5570383	707	6/14/2011	4/25/2012	7/7/2012	73
336	448888, 5531978	738	5/13/2011	5/20/2011	8/28/2012	1207
337	450789, 5530472	1194	5/6/2011	5/6/2011	10/11/2012	19322
338	450789, 5530472	1110	5/5/2011	5/5/2011	7/14/2012	4028
339	524839, 5549744	765	5/25/2011	7/14/2011	9/21/2012	46806
340	448888, 5531978	1255	5/16/2011	5/21/2011	8/19/2012	2789
341	524839, 5549744	1181	5/25/2011	7/26/2011	10/11/2012	62436
342	528918, 5583492	1368	9/22/2010	9/22/2010	9/23/2012	89245
344	528918, 5583492	1028	9/22/2010	9/22/2010	10/16/2012	206235
345	528918, 5583492	1305	9/22/2010	9/22/2010	8/20/2012	34026
346	528918, 5583492	1386	9/22/2010	9/22/2010	8/28/2012	141259
347	528918, 5583492	1180	9/22/2010	9/22/2010	6/30/2012	38434
348	528918, 5583492	1228	9/22/2010	9/22/2010	10/11/2012	86733
349	448888, 5531978	1167	5/18/2011	5/22/2011	6/11/2012	460
350	528918, 5583492	1275	8/15/2010	8/15/2010	6/26/2011	1877
45582	528918, 5583492	1157	8/15/2010	8/15/2010	9/13/2012	88419
48562	528918, 5583492	1357	8/18/2010	8/18/2010	9/14/2012	130208
48563	528918, 5583492	1312	9/15/2010	9/15/2010	9/2/2012	14062
48564	528918, 5583492	1545	8/17/2010	8/17/2010	10/6/2012	93759
48565	528918, 5583492	1601	8/19/2010	8/19/2010	9/24/2012	137262
48566	528918, 5583492	1402	9/15/2010	9/15/2010	9/13/2012	94909
48567	528918, 5583492	1244	8/18/2010	8/18/2010	10/11/2012	104949
48568	528918, 5583492	1407	9/15/2010	9/15/2010	9/13/2012	56972
48569	528918, 5583492	1313	9/15/2010	9/15/2010	9/17/2012	57370
48570	528918, 5583492	1202	8/18/2010	8/18/2010	5/24/2012	47167
48571	528918, 5583492	1060	9/15/2010	9/15/2010	9/28/2012	78875
48572	528918, 5583492	1267	9/22/2010	9/22/2010	9/6/2012	72317
48573	528918, 5583492	1432	8/17/2010	8/17/2010	10/16/2012	68248
48574	528918, 5583492	1185	9/15/2010	9/15/2010	8/22/2012	30483
48575	528918, 5583492	1397	9/15/2010	9/15/2010	9/29/2012	63982
48576	528918, 5583492	888	8/23/2011	8/23/2011	9/25/2012	16573
48577	528918, 5583492	886	8/23/2011	8/23/2011	7/18/2012	2495
48578	528918, 5583492	857	8/23/2011	8/23/2011	9/16/2012	17118
48579	528918, 5583492	741	8/17/2011	8/20/2011	8/17/2012	11903
48580	497022, 5540281	765	8/22/2011	8/22/2011	9/20/2012	16347
48581	528918, 5583492	704	8/22/2011	8/22/2011	7/5/2012	7197
48583	497022, 5540281	803	8/17/2011	8/24/2011	10/11/2012	61516
48584	497022, 5540281	791	8/17/2011	8/17/2011	9/1/2012	1009

Table A1 Continued.

Transmitter	Location Tagged (12 U)	Total Length (mm)	Date of Capture	Date First Detected	Date Last Detected	Total Detections
48585	524839, 5549744	1285	5/24/2011	6/2/2011	10/5/2012	30100
48586	497022, 5540281	776	8/17/2011	8/17/2011	10/11/2012	65215
48587	497022, 5540281	1256	8/17/2011	8/17/2011	6/22/2012	8378
48588	497022, 5540281	1316	8/17/2011	8/17/2011	9/27/2012	38622
48589	497022, 5540281	1180	8/16/2011	8/20/2011	9/27/2012	3727
48590	497022, 5540281	834	8/16/2011	8/16/2011	10/11/2012	136388
48591	497022, 5540281	1260	8/16/2011	8/16/2011	8/22/2012	4614
48592	528918, 5583492	1311	9/29/2010	9/29/2010	9/28/2012	94113
48593	528918, 5583492	1535	9/29/2010	9/29/2010	9/5/2012	1896
48594	497022, 5540281	684	8/16/2011	8/19/2011	6/3/2012	37857
48595	557154, 5609388	1430	8/10/2011	8/10/2011	10/12/2012	576
48596	524839, 5549744	671	8/11/2011	8/11/2011	9/10/2012	1296
48597	497022, 5540281	796	8/16/2011	8/28/2011	9/27/2012	28420
48598	450789, 5530472	1230	7/29/2011	7/29/2011	10/11/2012	41747
48599	557154, 5609388	1208	8/10/2011	8/10/2011	9/2/2012	4026
48600	561296, 5615205	740	8/10/2011	8/10/2011	8/1/2012	20894
48601	450789, 5530472	732	7/28/2011	7/28/2011	10/1/2012	781
48602	450789, 5530472	816	7/28/2011	7/28/2011	8/10/2012	4969
48603	450789, 5530472	1433	7/28/2011	7/28/2011	8/28/2012	6601
48604	450789, 5530472	1182	7/28/2011	7/28/2011	10/16/2011	5043
48605	450789, 5530472	1176	7/28/2011	7/28/2011	10/11/2012	38965
48606	450789, 5530472	695	7/28/2011	7/28/2011	9/26/2012	12327
48607	450789, 5530472	1318	7/28/2011	7/28/2011	10/10/2012	4536
48608	524839, 5549744	692	5/24/2011	7/13/2011	9/27/2012	7360
48609	524839, 5549744	708	5/24/2011	7/3/2011	10/11/2012	15068
48610	450789, 5530472	1292	6/21/2011	6/22/2011	10/11/2012	77888
48611	450789, 5530472	1230	7/27/2011	7/27/2011	9/19/2012	4306
48612	450789, 5530472	1395	5/3/2011	5/3/2011	8/21/2012	1505
48613	528918, 5583492	1364	9/29/2010	9/29/2010	10/14/2012	123544
48614	528918, 5583492	1470	9/29/2010	9/29/2010	9/13/2012	122937
48615	528918, 5583492	1402	9/29/2010	9/29/2010	10/14/2012	86693
48616	528918, 5583492	1166	9/29/2010	9/29/2010	10/3/2012	58779
48617	528918, 5583492	1296	9/29/2010	9/29/2010	9/3/2012	82237
48618	528918, 5583492	1152	9/29/2010	9/29/2010	8/31/2012	95002
48619	528918, 5583492	1152	9/29/2010	9/29/2010	10/2/2012	115370
63334	528918, 5583492	957	8/24/2011	8/24/2011	9/2/2012	34537
63335	528918, 5583492	822	8/24/2011	8/24/2011	8/19/2012	2656
63336	528918, 5583492	717	8/24/2011	8/24/2011	9/5/2012	28091