Sustaining the Recovery of Lake Sturgeon (*Acipenser fulvescens*) in the North Saskatchewan River of Alberta

by

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Abstract

Nearly all Lake Sturgeon (*Acipenser fulvescens*) populations across North America have experienced losses to historic abundances estimated to be > 99%. This species is especially vulnerable to overharvest, habitat degradation, river fragmentation from dams, and is slow to recover due to life history characteristics. In the Alberta section of the North Saskatchewan River, Canada, passive management strategies led to overharvest, and combined with poor water quality, contributed to the collapse of the Lake Sturgeon population circa 1940. However, improved water quality beginning in the 1960s, along with the implementation of a zero-harvest regulation in 1997 prompted a Lake Sturgeon population recovery. Lake Sturgeon population viability remained questionable with low population abundance with particularly few adult fish, complicated by industrial development, and an increasing human population. Furthermore, the North Saskatchewan River has a popular multi-species sport fishery, complicating Lake Sturgeon management and recovery. My objective is to determine whether the status of the Lake Sturgeon population in the North Saskatchewan River in Alberta is declining, improving or remaining the same. To address this objective I required knowledge of Lake Sturgeon life history and sources of mortality. More specifically, I investigated: 1) population metrics for a status assessment, 2) a resource selection function for identification of important habitat using inputs from telemetry and land classification data, 3) defining technological limitations of telemetry information and 4) an assessment of current rates of angling mortality and management options for Lake Sturgeon recovery. I found that both recruitment and adult abundance had increased in the most recent years (2008 to 2012), even though the total mortality rate was higher than the 7% threshold proposed by the Alberta Lake Sturgeon Recovery Team. However, a high rate of somatic growth implies that abundance in the North Saskatchewan River is still below carrying capacity.

Telemetry of 58 Lake Sturgeon over a 38-month period suggested that the population used the entire section of the North Saskatchewan River downstream from Drayton Valley, Alberta to the Alberta-Saskatchewan border. Additionally, some fish moved exceptional distances (> 925 rkm) between Alberta and Saskatchewan, illustrating the importance of river connectivity. Landscape classifications adjacent to the river were ineffective predictors of Lake Sturgeon congregations. There was a difference in habitat selection by males and females, with females found further downstream, but occupying similar slope gradients as the males. Small-scale details of habitat selection could not be investigated because of the technical limitations of existing telemetry technology. I found that radio telemetry detections from an aircraft were dependent upon transmitter type, water depth, receiver altitude, and scanning time. Larger transmitters were detected from a greater distance than smaller transmitters and the probability of detection was highest at a receiver altitude of 300 m when the two transmitter types were at a depth of 1 m. Furthermore, my relocations of the two transmitter types based upon maximum signal strength had a precision of ± 177 m distance for all depths and receiver altitudes from the actual transmitter location. I provide six probability of detection models for researchers to quantify their telemetry equipment. For investigating recovery management options, I used a theoretical objective of having a total population of 5,000 Lake Sturgeon, with an occasional fish surviving to 100-years. This requires total mortality to be approximately 5%, although my current estimate of total mortality is approximately 9.4%. To achieve my population objective, mortality must be significantly reduced. Estimates from catch and release fishing by three angler groups (non-specific anglers, anglers targeting sturgeon and research anglers) suggests that sport angling and its associated incidental mortality results in fewer than 18 dead Lake Sturgeon annually and further restrictions on sport angling are currently unnecessary. My only remaining management

option to improve Lake Sturgeon survival is through habitat protection. My telemetry data suggested 10 primary locations of Lake Sturgeon congregations. Existing provincial regulations (Class ‘A’ watercourse designations) currently protect approximately 30% of these congregation sites. To protect at least 75% of these areas, I propose 10 new Class ‘A’ extents that reduce the total area of current Class ‘A’ protection (from 64 to 58 river km), which provides an improved means for protecting Lake Sturgeon and habitat.

Acknowledgements

The completion of this study would not have been possible without the efforts of Dr. Stephen Spencer, Daryl "The Sturgeon General" Watters, the late Don "Donnie the Fish" Hildebrandt, Laura MacPherson, Matt Besko, Janet Boyd, Darrien Genereux, Ken Crutchfield, Jason Shpeley, Mike Hunka, and Kristen Wells for all their help and hard work in the field ...down by the river. Many thanks to my supervisor Dr. Lee Foote and my coworkers Drs. Stephen Spencer, Michael Sullivan, and Andrew Paul for their impromptu conversations, direction, support and advice which made the completion of this study much easier. This study would not have been possible without the funding and support of Alberta Environment and Sustainable Resource Development (ESRD; Fish and Wildlife Division). The majority of the funds were granted by the Creative Sentencing Program (ESRD) with thanks to The Honourable E.A. Johnson and Susan McRory of Alberta Justice, and Hanneke Brooymans of ESRD. Funding was also provided through the Federal Government's Habitat Stewardship Program for Species at Risk. Also, I would like to thank Evelyn Merrill and Stephen Hamilton (University of Alberta), Cindy Schmidt, Matt Ogrodnick, Ryan Jillard, and Shawn Keiser of ESRD for their help with ArcGIS. Many years of data were collected and provided through the volunteer program of the Northern Sturgeon Anglers Council. Last but not least, I wish to thank my friends and family, and a special thanks to my mother (I'm sure she'd smile) and my father for their support.

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Chapter 1 – General Introduction.

Due to declining Lake Sturgeon, *Acipenser fulvescens*, abundance and loss of historic range, the Committee on the Status of Endangered Wildlife (COSEWIC) in Canada met in November 2006 to recommend the Lake Sturgeon in Alberta (Designatable Unit 2) as Endangered (currently under federal review). In Alberta, the provincially mandated Endangered Species Conservation Committee listed Lake Sturgeon as a Threatened species under Alberta's Wildlife Act as a result of low adult density and population size (AESCC Scientific Sub-committee 2003). Late age-at-maturity and long periodicity between spawning events for female fish coupled with overharvest, low adult abundance (Berry 1996) and poor water quality, have contributed to the slow recovery of this species in Alberta.

Sturgeon appear unchanged over the last 200 million years with five rows of armour plating, a cartilaginous skeleton, a shark-like heterocercal tail, and an array of barbels to help locate sources of food (Scott and Crossman 1973). These are the largest fish in Alberta, and have the potential to grow more than 2.5 m, making them highly sought after as a sport fish species.

Lake Sturgeon are managed as two separate populations in Alberta: the North and South Saskatchewan River drainages (Scott and Crossman 1973, ALSRT 2011) isolated by the Gardiner Dam at Saskatoon, Saskatchewan. Although considerable work has been done on the South Saskatchewan River population (R.L.&L. 1991, R.L.&L. 1992, Clayton 2001, ALSRT 2011), the Lake Sturgeon population in the North Saskatchewan River has to date, received less attention. During the 1990s and early 2000s, this population appeared to be increasing and a popular sport fishery has developed (Earle 2002).

With Lake Sturgeon's low intrinsic rate of increase due to its life history, historic population collapse, continued low numbers with few adult fish threatened by a burgeoning human population and associated industrial developments, it is critical to determine the status and limitations to Lake Sturgeon in the North Saskatchewan River, Alberta. From this, recommendations for continued management can be developed. In this thesis, my overall goal has been to determine whether the population of Lake Sturgeon in the North Saskatchewan River, Alberta is decreasing, increasing or remaining unchanged. More specifically, my objectives of this study are to determine population life history, connectivity, distribution, and sources of mortality of the North Saskatchewan River population. With a reported longevity of > 150 years for Lake Sturgeon in Canada (Scott and Crossman 1973), my long-term objective is to have an occasional North Saskatchewan River Lake Sturgeon reach the age of 100 years-old.

To achieve these objectives, I analyzed biological and angling data collected from a long-term volunteer program to capture Lake Sturgeon, and investigated habitat selection and site fidelity information (derived from radio telemetry). In Chapter 2, I analyzed data from 1,156 Lake Sturgeon captures, compiled into 21 years of age-class distributions to evaluate abundance, growth, survival, recruitment and maturity. In Chapter 3, I present a resource selection function (RSF) model in which I relate Lake Sturgeon habitat use locations to landscape classifications. In Chapter 4, I assess detection probabilities and positional accuracy of radio transmitters. I used aerial surveys to track transmitter signals as influenced by transmitter type, depth of immersion, altitude of the receiver during the survey, and the effect of adding additional frequencies to the automatic scan of the receiver. I developed models to predict detection probabilities of two different sizes of radio transmitters at various depths, altitudes, and scanned frequencies. I also present the findings from detection distances, and locational errors. In Chapter 5, I assess fishing mortality on the population, and assess the current Class ‘A’ designated watercourses designed to protect congregations of Lake Sturgeon, and evaluate management options to achieve 100 year-old fish. Finally, based upon the key findings of this project, I provide management recommendations for continued Lake Sturgeon recovery in the North Saskatchewan River.

Chapter 2 - Conservation status of the North Saskatchewan River Lake Sturgeon (*Acipenser fulvescens*), based on quantitative life history.

Introduction. —Nearly all Lake Sturgeon populations across North America have experienced a reduction in historic abundance with losses estimated to be > 99% (Vélez-Espino and Koops 2008). This species is especially vulnerable due to overharvest, habitat degradation, habitat fragmentation from dams, and slow to recover following population overharvest or loss (McLeod et al. 1999, Thomas and Haas 2002). A slow recovery has been attributed to their low rates of intrinsic increase due to their late age-at-maturity (females > age-20; Priegel and Wirth 1971, Auer 1996) and long gaps between spawning events (i.e., 2 to 4 years for males, and 4 to 7 years for females; Auer 1999, Bruch et al. 2001).

Similarly, Alberta's Lake Sturgeon populations were reduced to near extirpation prior to the 1940s due to overexploitation (Berry 1996) and loss of habitat. A provincial closure to Lake Sturgeon harvest was in effect from 1940 to 1967 (Berry 1996, McLeod et al. 1999); however, by 1968 the North Saskatchewan River (hereafter NSR) sport fishery was re-opened for a limited harvest of two fish per year with no size-limit. Harvesting was halted again in 1997 under Catch and Release Only regulations for the Alberta section of the NSR and remains in force. However, the low population abundance continued. COSEWIC (2006) reported a greater than 50% drop in Lake Sturgeon abundance in Designatable Unit 2 within the previous 10 years. Despite very conservative regulations, there have been few fish sampled in the Alberta section of the NSR older than age-50 with the oldest having an estimated age of 62 years; while potentially, Lake Sturgeon can reach an age in excess of 150 years (Scott and Crossman 1973).

The NSR Lake Sturgeon population appears to have been affected not only by overharvest but by anthropogenically caused changes to its habitat. During the 1950s the City of Edmonton was the major contributor of wastewater to the NSR and nutrient levels reached the highest recorded levels (AENV 2011). Prior to the collection and treatment of the capital city's wastewater, low oxygen levels downstream of Edmonton caused many fish kills (AENV 2011). Although minimum oxygen thresholds have not been reported for Lake Sturgeon, Jenkins et al. (1993) suggest that < 2.5 ppm will cause death of Shortnose Sturgeon (*Acipenser brevirostrum*) at any life stage. Dissolved oxygen levels in the NSR during the winter months prior to Edmonton's wastewater treatment decreased exponentially with distance downstream of Edmonton with levels recorded below thresholds for fishes (CCME 2007, AENV 2011). Low winter flows likely contributed to the lethality of the low oxygen conditions during the winter. However, within the upper reaches of the NSR two hydroelectric dams currently regulate flow in the NSR and by 1972, winter flow rates increased threefold, thereby improving overwintering conditions. Lake Sturgeon likely re-colonized Alberta's NSR by the mid-1970s from downstream sources or alternatively, angler anecdotes suggest the possibility of a remnant population upstream of Edmonton. By 1990, reports of angler-captured Lake Sturgeon within the City of Edmonton were being received, suggesting increased abundance of Lake Sturgeon (Watters 1993a).

Despite evidence of improved water quality conditions and a population recovery likely underway, the NSR Lake Sturgeon population remained vulnerable. Angling increases the mortality rates through hooking and handling. In North America, rates of incidental mortality from hooking and handling are largely unknown (Watters 1993b, McLeod et al. 1999, ALSRT 2011). Earle (2002) indicates that catch-rate is also on the increase, possibly due to knowledge of effective angling methods and popular awareness of favored Lake Sturgeon congregation sites. Although incidental mortality is also somewhat uncertain for NSR Lake Sturgeon, Robichaud et al. (2006) reported an angling mortality rate for White Sturgeon (*Acipenser transmontanus*) at 2.6%. A high combination of incidental and natural mortality can inhibit current recovery efforts. Bruch (2009) estimated natural mortality for the Lake Winnebago Lake Sturgeon population at 5.4%. Although regulatory agencies cannot directly influence rates of natural mortality, incidental mortality rates can hopefully be managed through changes to conservation and management practices.

My overall objectives are to assess the sustainability of the Lake Sturgeon population in the Alberta section of the North Saskatchewan River: to describe the key factors contributing to the population status, and to provide management suggestions to ensure population recovery. To address these objectives, I used biological data provided by angling groups, and radio transmitter data. My objective is to allow the population to recover, defined as having an occasional fish reaching an age of 100 years. To achieve this objective, I examine total mortality and provide a minimum mortality rate and time frame.

Methods

Data Collection. —A tagging project (catch-and-release) to collect length and age-data, utilizing volunteer research anglers under the direction of Alberta Fish & Wildlife began in 1991. Additionally, Fish and Wildlife staff live-captured Lake Sturgeon by angling and in tangle nets (measuring 45.7 m in length with stretched multi-filament nylon mesh sizes of 203 mm or 254 mm). Captured Lake Sturgeon were measured (girth, total and fork length (mm)), examined for an external or an internal tag, and a 1 cm^2 section of the pectoral fin ray was excised for age determination. Having two types of tags provides a unique individual identifier (UID) to provide a history for each re-captured fish by year to estimate population parameters such as abundance. Abundance estimates were applied to age-class distributions to determine year-class proportions. Abundance estimates were provided by ALSRT (2011), and Hegerat and Paul (2013).

Fin Ray Preparation and Age Determination. —Prior to age determination, Lake Sturgeon pectoral fin-ray samples were dried for a minimum of one month in paper envelopes. Fin-rays were cut in 0.4 mm sections with an Isomet™ saw, and mounted in sequential order on a clear, acrylic slide. Cytoseal XYL™ was used as the mounting media. Mounted samples were dried within a fume hood for 24 hours. To determine age, fin-ray sections were viewed through a dissection microscope (≤ 40 X) against a black background with reflected light, to allow counting the combination of the opaque and hyaline zones, the two together constituting a completed year. The convention of January 1st was used as the calendar birthdate as described by Mackay et al. (1990).

Growth. —I used the Fishery Analysis and Modeling Simulator software ver. 1.0 (FAMS; Slipke and Maceina 2010) to describe Lake Sturgeon growth. The von Bertalanffy model (1938) was fitted to mean length-at-age for all age-classes for six, four-year intervals beginning in 1992, and plotted against Lake Sturgeon mean length-at-age for the 2009 South Saskatchewan River (SSR) population. The formula used was:

$$L(t) = L_{\infty}\,(1 - e^{-K(t+t_0)})$$

Where *L(t)* is fish length at time *t* (age in years, and fork length (mm)), L_∞ (length infinity) is the asymptotic length where growth is zero (theoretical maximum fork length (mm)), *e* is the base of the natural logarithm, *K* is the Brody growth coefficient (yr^{-1}) at which growth approaches the asymptote, and t_0 is the time at which length *L(t)* is equal to zero. Growth was assessed at t_0 for Lake Sturgeon, for every fourth year beginning in 1992 and continuing to 2012, including the 2009 data for the SSR where *K* and L_∞ were estimated from mean length-at-age in each given year.

As rates of growth can be high in more southern systems (Nowak and Jessop 1987), a wider comparison is investigated. Ages 23 to 27 have been reported as the range at which Lake Sturgeon achieve sexual maturity, and these adult year-classes are likely present in most fisheries (Fortin et al. 1996). Mean total lengths (mm) for ages 23 to 27 ($TL_{23\text{-}27}$) for the NSR were compared to the SSR $TL_{23\text{-}27}$, and ranked within a summary of 32 lake and river populations found throughout North America as reported by Fortin et al. (1996). Age determination and recorded lengths for both the NSR and SSR Lake Sturgeon were estimated separately for the NSR to provide mean lengths-at-age (mm). Where length (mm) was reported as total length (TL), a regression conversion for total length (TL) from fork length (FL) was estimated separately for both the NSR (n = 1,752; TL = 1.077(FL) + 27.747; $r^2 = 0.99$; $p < 0.01$), and SSR (n = 1,643; TL = 1.0826(FL) + 28.609; $r^2 = 0.99$; $p < 0.01$).

Fish Mortality. —With the use of the FAMS software program (Slipke and Maceina 2010), ages derived from fin-rays collected during the 2012 sampling period were used to estimate total mortality (*Z*) through catch curve analysis (Ricker 1975). Values of *Z* were plotted against the 2012 age data to illustrate the loss proportion of fish to age-100. The FAMS software and Lake Sturgeon ages were also used to calculate natural mortality rates (*M*) during the 1992 to 2012 sampling period; I used five different methods. These methods include; 1) Hoenig (1983), 2) Jensen (1996), 3) Pauly (1980), 4) Chen and Watanabe (1989) and 5) Quinn and Deriso (1999). Estimates were calculated for every fourth year beginning in 1992 to 2012 for each method. I derived angling mortality (*F*) from the coefficient of $Z = M + F$ (Ricker 1975). Additionally, I used a sequential analysis of cohorts to determine survivorship of the ages 5 to 9 distribution by determining the change in number at age *a* (1992) to age *x* (2012; age-30 to 34; Haddon 2001) to provide an additional mortality estimate. Cohort analysis of ages 5 to 9 was used to overcome variability in age determination, as Bruch et al. (2009) found that age determination using pectoral fin-ray cross sections can underestimate the actual age of fish greater than age-14, with a range of -4.96 to 4.57 years.

Population Range and Connectivity. —To determine Lake Sturgeon population range and connectivity, and areas of congregation, I used radio-telemetry to determine movements of Lake Sturgeon. I captured 58 Lake Sturgeon at three locations in the Edmonton region, and placed them in an anaesthetic tank for transmitter implantation. Using aseptic techniques, a 60 to 80 mm incision was made along the ventral surface of the fish adjacent to the mid-ventral line (*linea alba*). A needle was used to create a small hole just posterior to the incision. The transmitter was implanted into the abdominal cavity and the antenna was threaded through the needle. Incisions were closed with an absorbable, polyglyconate suture to prevent inflammation and wicking of water into the body cavity (Hurty et al. 2002). Gender and maturity status was determined when possible by a visual internal examination during radio transmitter implantation. I placed each Lake Sturgeon into a recovery hammock in a well-oxygenated backwater area of the river and monitored them continuously for recovery from the anesthesia. Once the Lake Sturgeon was able to right themselves and swim unaided, they were released.

Three types of three-stage, coded, enhanced range, radio transmitters (Advanced Telemetry Systems [ATS] Inc., Isanti, Minnesota) with whip antennae were used for implantation in this study. The details for each include:

- F1850B transmitters powered by a 3.5-V lithium AA cell battery (27 g) with a battery life of 1460 days transmitting on frequency 148.014 MHz,
- F1855B transmitters powered by a 3.5-V lithium C cell battery (87 g) with a battery life of 1460 days transmitting on frequency 148.185 MHz,
- F1860B transmitters powered by a 3.5-V lithium D cell battery (162 g) with a battery life of 3650 days transmitting on frequency 148.056 MHz.

Each radio transmitter transmits a coded signal in which individual fish are recognized by a receiver. All implanted transmitters were less than 2% of fish body weight (Winter 1983). Procedures and techniques affecting fish were conducted according to the Canadian Council for Animal Care through the University of Alberta (# 734-04-12). Lake Sturgeon were tracked by observers in a fix-wing aircraft or jet boat over a 38-month period. Telemetry surveys were conducted weekly during the spring, bi-weekly during the summer and winter months in which locations were recorded with a receiver.

Locations of tracked fish were inputted into ArcGIS for analysis, and explored for movement. I derived spatial distribution models of 2010-2013 Lake Sturgeon transmitter data by creating a geospatial centerline that overlaid a hydrologic layer in ArcMap 10.1 (Barth et al. 2011). Raster values (distance (m)) were created for each individual Lake Sturgeon (and subsequent locations), in which universal transect mercator (UTM) tracked points were snapped to the centerline. I exported raster values to determine longitudinal distance i.e., river kilometer, and 95% confidence intervals. In this example, raster values are analogous to river kilometers (rkm) as a measure of distance traced to a downstream location from Drayton Valley (0 rkm). Drayton Valley was selected as river kilometer zero (0 rkm), because this is the approximate upstream limit of Lake Sturgeon distribution in the North Saskatchewan River.

Results

Abundance Estimates. —Abundance estimates from 1992 to 2008 for the upper section of the NSR (Drayton Valley to Smoky Lake) did not indicate a population increase with a mean yearly density of approximately 820 Lake Sturgeon (ALSRT 2011). Abundance estimates in the lower section (south of the Town of Smoky Lake to the AB-SK border) are viewed as unreliable due to variations in tagging effort prior to 2008. However, in 2008, abundance for the lower section was estimated at 2,292 Lake Sturgeon (ALSRT 2011).

More recently, abundance estimates for the upper (upstream of Smoky Lake) and lower sections (downstream of Smoky Lake) indicate an increasing trend where, the upper section in 2011 ($\bar{x}$ = 1,886; 95% CI =1,272 – 2,828) increased by 70% in 2012 ($\bar{x}$ = 2,681; 95% CI = 1,956 – 3,711), and the lower section in 2011 ($\bar{x}$ = 2,756; 95% CI = 1,433 – 5,391) increased by 75% in 2012 ($\bar{x}$ = 3,673; 95% CI = 2,721 – 5,015; Hegerat and Paul 2013). Although a strong increase in abundance was apparent in the most recent years, this sudden variation in population size could be attributed to a number of factors, e.g., tag loss, and model convergence properties (ALSRT 2011, Hegerat and Paul 2013) or an overall increase in abundance, a strong pulse in

Lake Sturgeon recruitment, an increase in Lake Sturgeon immigration, or an increase in sampling effort.

Growth. —Growth rates for the NSR Lake Sturgeon population were explored to determine whether rates were very slow or very high and whether the population is approaching or at carrying capacity. North Saskatchewan River rates are compared to the SSR population, where productivity is higher. The von Bertalanffy growth functions (Fig. 2.1) were fitted to the mean fork length-at-age data, in which six growth curves were evaluated for the NSR from 1992 to 2012, and for the SSR for 2009. Aside for the 2012 age-class, all growth curves appear to follow a similar trajectory in both rivers, with rapid growth for the first 15 years of fish age, followed by a gradual decrease. Growth appeared slowest during 2012, potentially an effect of the increase in juvenile fish recruitment. The NSR exhibited the lowest K value for the 2012 growth curve (0.043) and highest for the 2004 growth curve (0.091; Fig. 2.2), K values for the NSR were continuously higher than the SSR (0.042) in 2009. Values for L_∞ among the sampled year-classes for the NSR was highest at 1,607 mm for the 2012 growth curve. Values for L_∞ for the SSR were consistently higher than the NSR, with an estimated maximum value for 2008 at 1,858 mm. Although the NSR is at a higher northern latitude, these two river systems appear to have similar growth rates and are comparable.

As another measure of growth, I examine growth of mature NSR Lake Sturgeon from ages 23 to 27, and ranked their physical length in comparison to the SSR and other North American Lake Sturgeon populations to determine if geographic latitude has an effect. I used the following procedures where assigned ages and recorded lengths of 57 Lake Sturgeon for the NSR (2012) provides a mean TL for ages 23 to 27 (mm; TL_{23-27}) of 1,270 mm. Assigned ages and recorded lengths of 26 fish from the SSR provided a mean TL_{23-27} of 1,390 mm. I found that the NSR ranked 27th, and the SSR ranked 32nd out of a possible 34 North American Lake Sturgeon populations when included into a summary conducted by Fortin et al. (1996). I concluded that overall growth rates have remained largely unchanged in Alberta, and are generally higher than growth rates reported elsewhere in North America. I concluded that geographic latitude is an irrelevant factor in positing growth rates in Lake Sturgeon in Alberta.

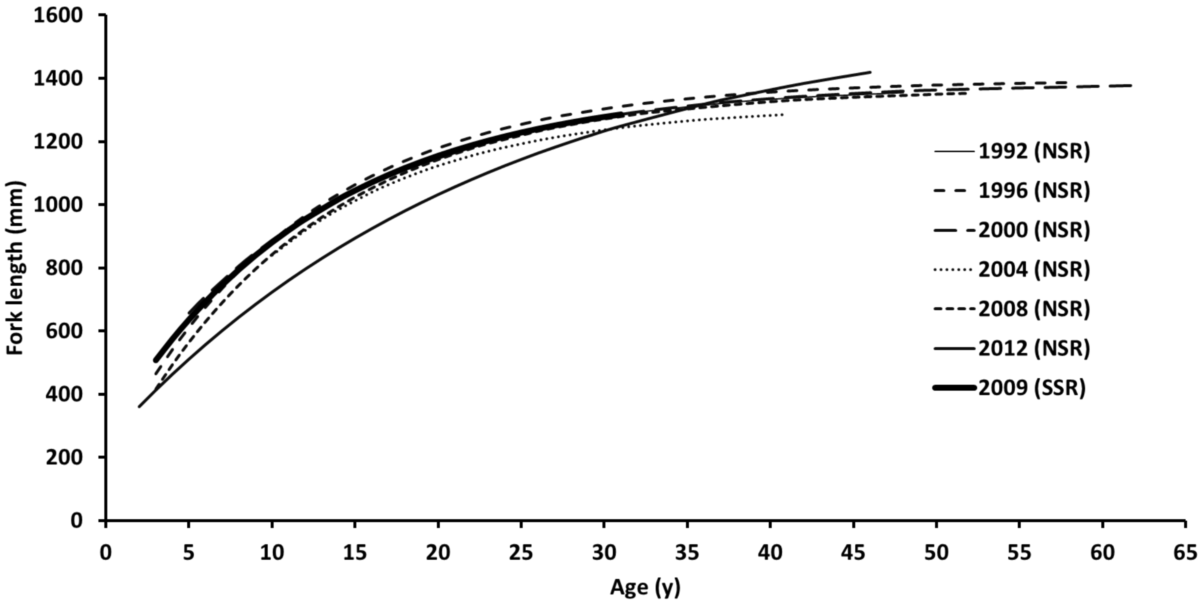

Figure 2.1. von Bertalanffy growth equations for Lake Sturgeon sampled from the North and South Saskatchewan Rivers, AB, covering the years 1992 to 2012.

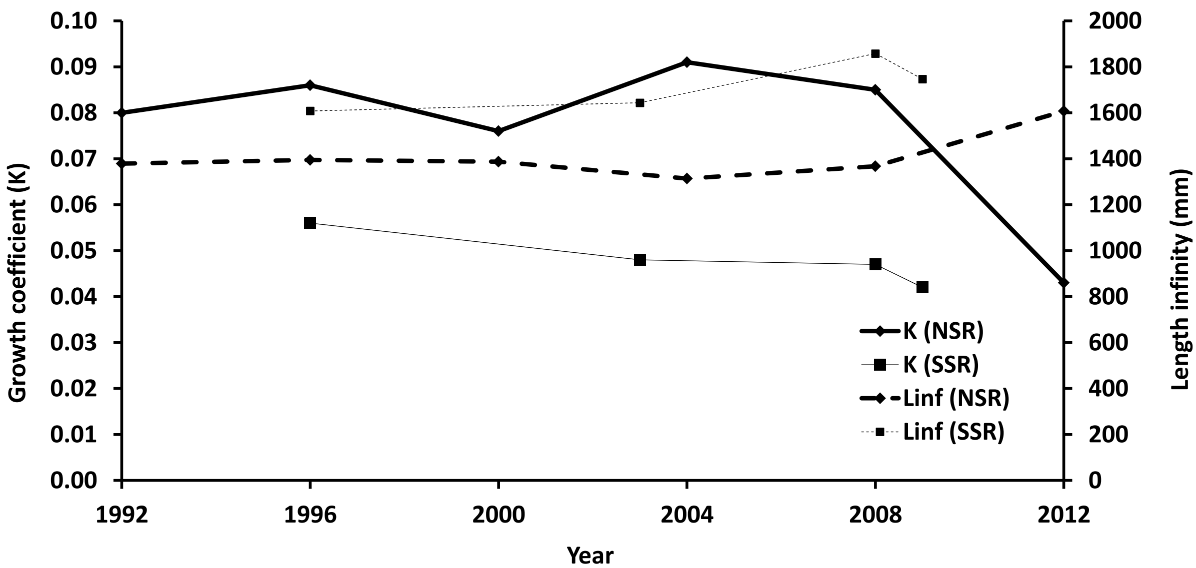

Figure 2.2. Lake Sturgeon growth (*K*) and length infinity (L_{∞}; mm) for the North and South Saskatchewan Rivers, AB, generated from the von Bertalanffy for six, 4 year periods (1992, 1996, 2000, 2004, 2008, and 2012).

Recruitment. —During the first three, 4 year sample periods (1992, 1996, and 2000 with both sexes pooled), there were very few adult Lake Sturgeon identified (> age-25) with the majority of the population consisting of juvenile Lake Sturgeon (< age-15). In 2008, ages 4 to 9 recruited to the population, and the recruitment of juveniles continued into 2012. Recruitment into the capture range for the combined netting and angling gear began at age-2 (year 2012), although Lake Sturgeon were primarily caught by angling, they are not fully susceptible to capture by the gear until age-4 (Watters 1993a; Fig. 2.3). Alternatively, they may be gathering in a very different part of the river than where the larger fish were captured. Based upon each annual population estimate, the proportion of mature Lake Sturgeon (≥ age-25) appeared to be increasing beginning in 2000 ($N = 46$), 2004 ($N = 145$), 2008 ($N = 227$), and 2012 ($N = 590$). The oldest Lake Sturgeon captured was age-62 (1938 year-class; year 2000). Given a population estimate of approximately 6,000 Lake Sturgeon, proportions from age-class data estimated 590 mature fish ≥ age-25. Assuming a male to female ratio of 1 to 1 (Fortin et al. 1993) and a spawning interval of 7 to 9 years for females, I estimate the number of spawning NSR females to be 32 to 42 per year (2012) which is a twofold increase from 2008 numbers.

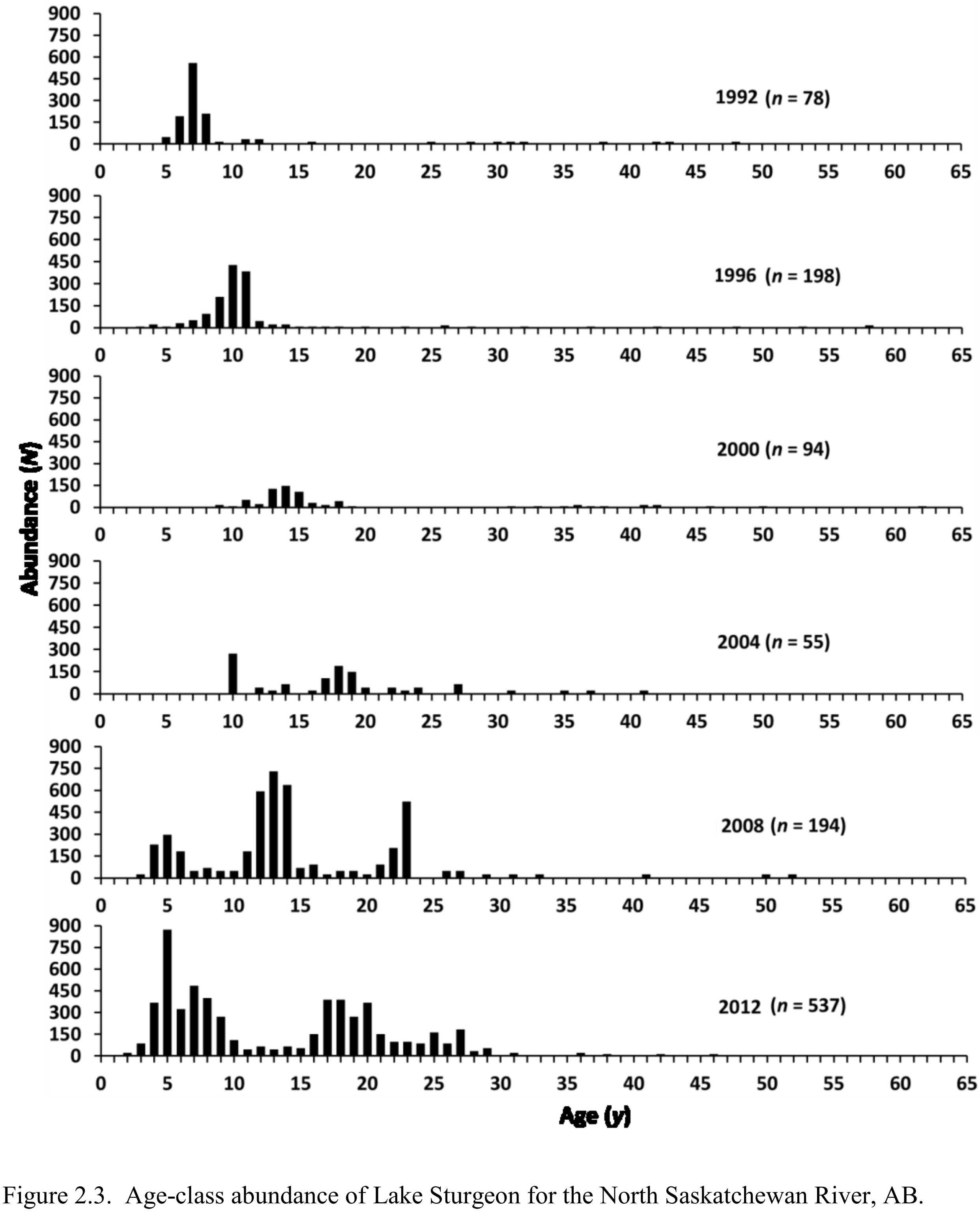

Figure 2.3. Age-class abundance of Lake Sturgeon for the North Saskatchewan River, AB. Abundance (*N*) estimates were derived through mark-recapture events from 1992 to 2012. A subsample of non-lethal age structures (*n*) was collected from each marking event.

Fish Survival and Mortality. —Catch-curve analysis of the 2012 age data (n = 537) was used to estimate total instantaneous mortality (Z = 9.4%), for ages 4 to 46 (Fig. 2.4). Recruitment was variable for different years with positive residuals coinciding with strong age-classes for ages-5 to 9, and ages-16 to 27, 29, 36, 38, 42, and 46.

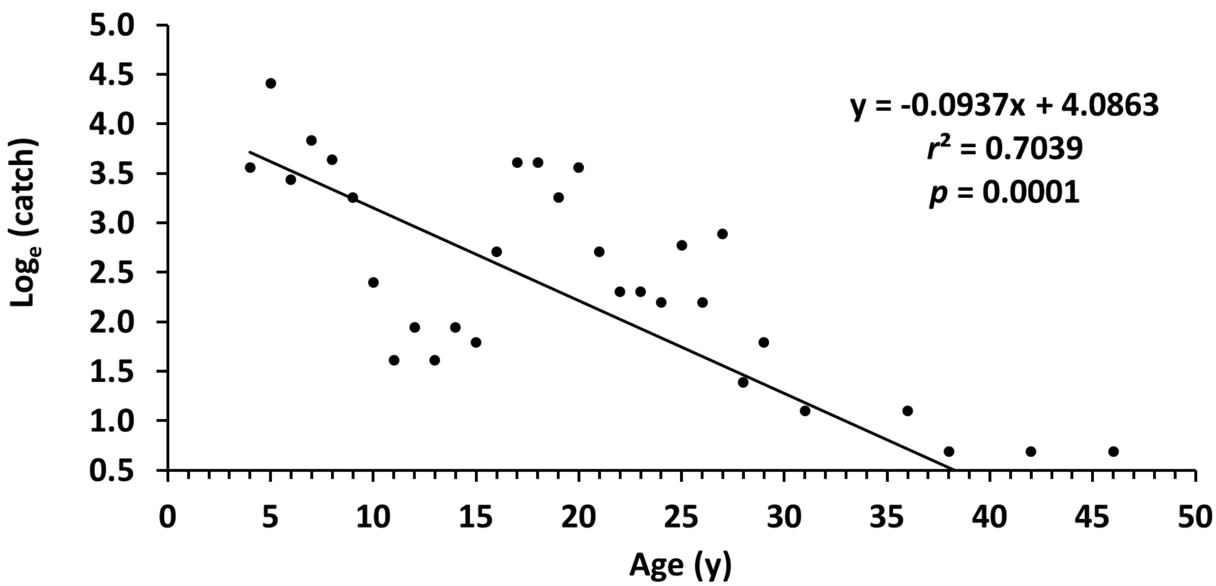

Figure 2.4. Catch curve analysis for Lake Sturgeon captured ($\log_e$) versus age in 2012 for the North Saskatchewan River, AB.

Assuming recruitment and survival (S) of Lake Sturgeon to be constant in any given year and between years, an exponential decay curve representing Z (9.4%) for the 2012 year-class (beginning at the age-5 recruits), demonstrates a cumulative percent loss of age-25 fish to be 85% (15% survival; Fig. 2.5). Also suggesting that < 0.01% of fish will survive to age-100. An alternative method of estimating survivorship involves a sequential cohort analysis of survival (1 – mortality (M)) of the age-5 to 9 cohort from 1992 (N = 1019) to 2012, (age-30 to 34; N = 21). The analysis posits a higher survival rate of 17.6% where 0.01% of the fish will survive to age-65, with a significantly less survival rate to age-100. An overlay of the 2012, age-class distribution indicates that there were no fish captured ≥ age-46, the suggestion being that an estimated value of Z = 9.4% closely tracks the proportion of actual survival.

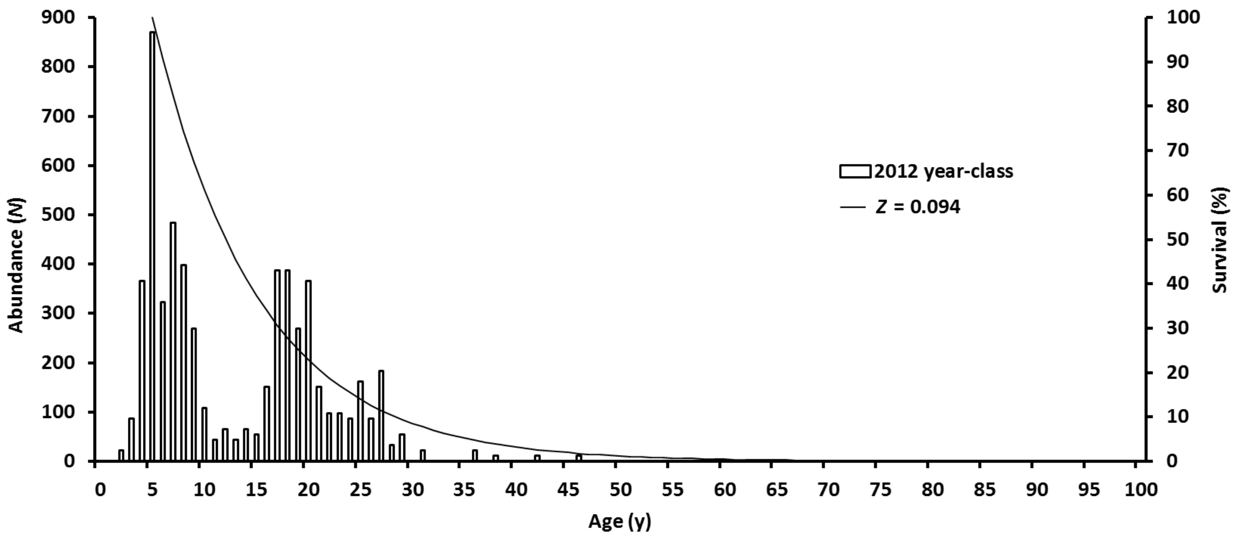

Figure 2.5. Estimated proportions of survival of 5 year-old Lake Sturgeon born prior to 2012, and subsequent year-classes for the North Saskatchewan River, AB.

The estimated natural mortality rate (*M*), for Lake Sturgeon for the NSR was found to range from 9.1% to 11.8% where $\bar{x}$ = 10.1% (Table 2.1). Angling mortality appears to be low (*F* = *Z* - *M*), ranging from 0.3% to an insignificant rate.

Table 2.1 —Rates of natural mortality (*M*), for Lake Sturgeon for the North Saskatchewan River, AB, and estimated mean rates of mortality by age-25. Estimates used were calculated for each fourth year (1992 to 2012).

Method	Year					
	1992	1996	2000	2004	2008	2012
	Natural mortality (*M*)					
Jensen (1996)	0.120	0.129	0.114	0.137	0.128	0.065
Pauly (1980)	0.109	0.114	0.106	0.121	0.114	0.070
Chen and Watanabe (1989)	0.108	0.113	0.096	0.133	0.119	0.074
Hoenig (1983)	0.086	0.071	0.067	0.101	0.080	0.090
Quinn and Deriso (1999)	0.091	0.079	0.073	0.098	0.101	0.136
	(mean (*M*))					
	0.103	0.101	0.091	0.118	0.108	0.087

Population Range and Connectivity. —During the period of 2010 and 2011, I surgically implanted a total of 58 Lake Sturgeon with radio transmitters at three locations along the NSR downstream of Drayton Valley (0 rkm; i.e., Lucky 4 (n = 41; 81 rkm), Smoky Lake (n = 5; 312 rkm), and Elk Point (n = 9; 432 rkm)). I detected locations of Lake Sturgeon from Drayton Valley, AB to the Alberta-Saskatchewan border (512 rkm: Fig. 2.6). In total, I identified Lake Sturgeon at 1,372 locations, clustered into 10 main congregations, i.e. zones of congregation (Fig. 2.6). These ten sites comprised 75% of all Lake Sturgeon locations which cover only 13% of the NSR. There appears to be seasonality to these locations where Lake Sturgeon congregate in fewer locations during the winter (Fig. 2.7).

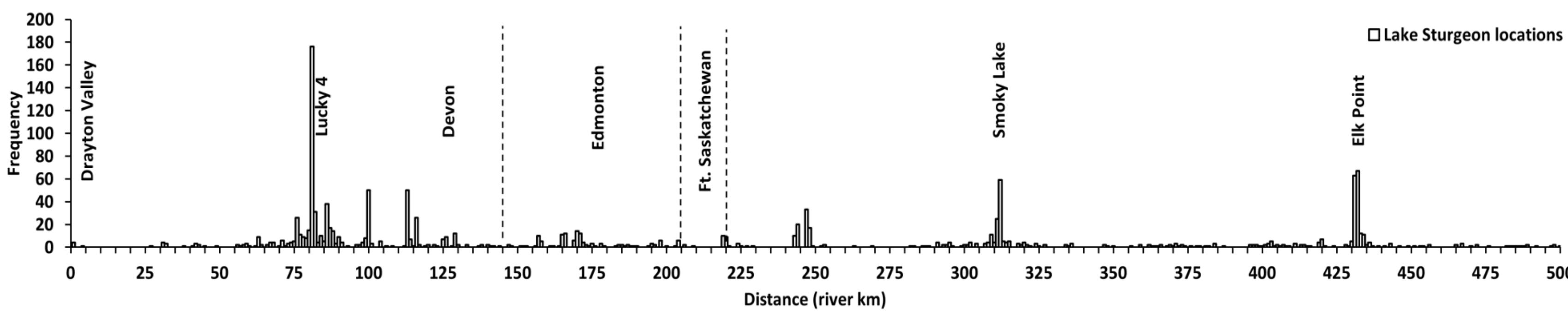

Figure 2.6. Sites of radio tracked Lake Sturgeon in the North Saskatchewan River, AB, for the period of 2010 to 2013. Vertical dotted lines mark approximate city limits.

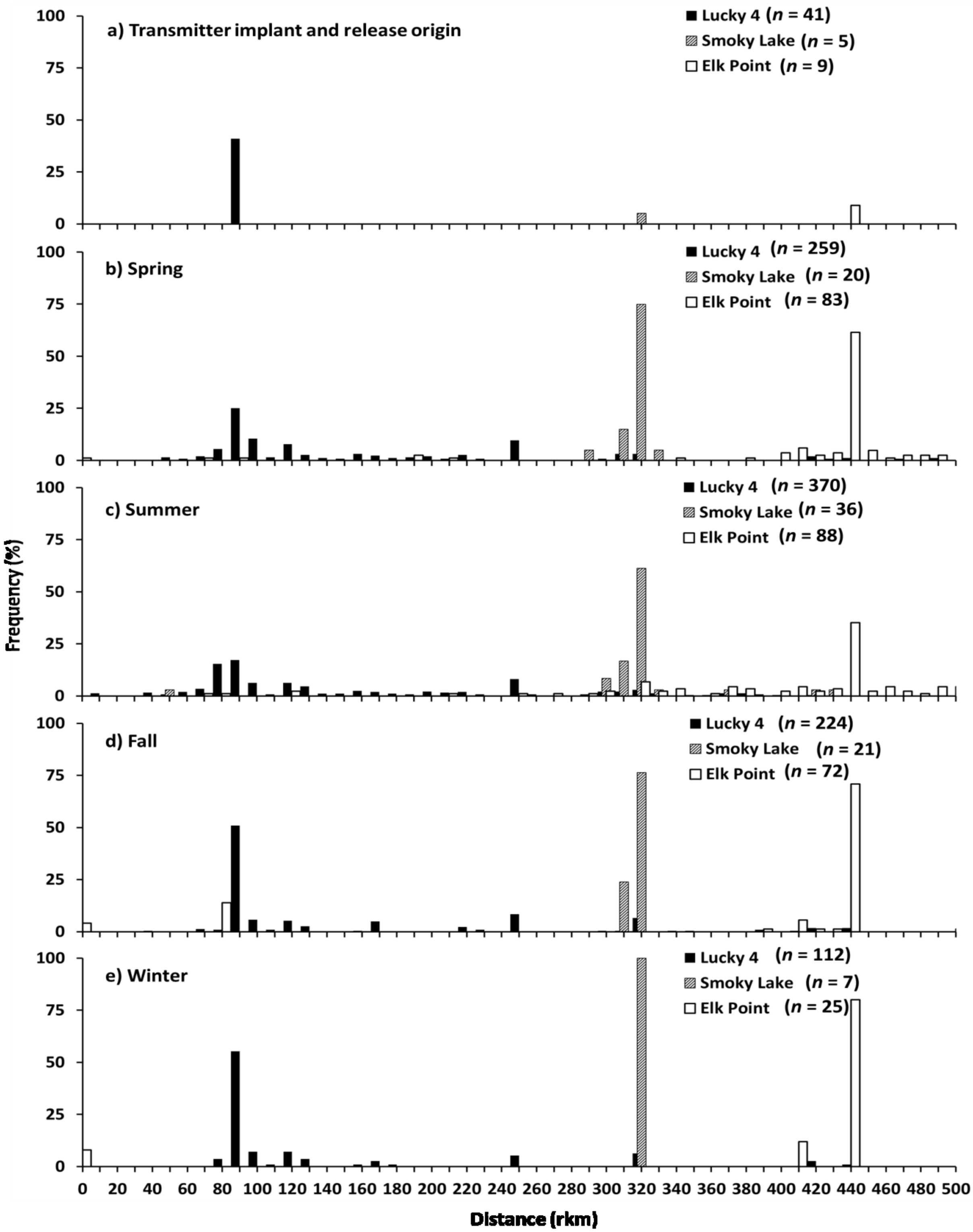

Figure 2.7. Percent frequency distributions of relocation sites of telemetered Lake Sturgeon from three implant locations; a) Lucky 4 (*n* = 41), Smoky Lake (*n* = 5), and Elk Point (*n* = 9) during the b) spring, c) summer, d) fall and, e) winter for the North Saskatchewan River, AB, from 2010 to 2013.

Discussion

My information suggests that Lake Sturgeon abundance in the NSR had increased in 2012 from the previous years. Although there were some problems with the mark and recapture abundance estimates due to low numbers of fish; abundance estimates indicated an increase in fish density with several year classes of recruiting fish. However, the Lake Sturgeon population was estimated at 9 sturgeon/rkm above Smoky Lake, and 18 sturgeon/rkm below and was comparatively low when compared to the Alberta section of the South Saskatchewan River at 25 sturgeon/rkm (Hegerat and Paul 2013), and to Wisconsin's Lake Sturgeon Management Plan that states objectives are to manage for densities of > age-2 Lake Sturgeon at 400 sturgeon/rkm in rivers (WDNR 2000). Overall, abundance estimates have indicated an increase over the last few years, but densities are substantially lower than in other jurisdictions.

Growth rates for the NSR Lake Sturgeon population were explored for inferences on density and evidence of approaching carrying capacity. Increases in growth rates within low density populations can indicate that a compensatory response exists (Rose et al. 2001). I compared the NSR population to the more southern SSR population since the SSR population is at a higher density, and likely in a more productive environment (i.e., higher growth rate). Annual growing degree days (GDD: annual sum of mean daily temperatures > 5°C) are higher at Lethbridge (GDD = 1,696) than those recorded at the NSR at Edmonton (GDD = 1,487) in 2011. Field measurements have shown a recent increase in growth rate for Lake Sturgeon in the NSR, and are comparable to the SSR population growth based upon the von Bertalanffy growth trajectories. Both the Brody growth coefficient (K) and the maximum attainable length (L_∞) suggest a very fast growth rate (0.043), and was similar to the SSR rate (0.042), implying that growth is comparable. Lake Sturgeon in the NSR are growing as fast as or faster than growth rates in other southern jurisdictions. The higher growth rate in the less productive NSR environment suggests that there is room for increased fish density here.

Up to 2012 recruitment has been irregular in the NSR, but is expected to improve in future years. The irregularities in recruitment in earlier years could be attributed to the narrow range of sampling (spatial and/or effort) or inconsistencies in their fish life history. The 2012 catch-curve analysis reveals much more consistent recruitment of fish aged 4 to 9 years. This improvement in recruitment should continue as the ages of 16 to 29 year old Lake Sturgeon increase, enabling them to become active spawners. This may be the first known generation of locally recruited Lake Sturgeon species engendered following the improvement in water quality since the 1960s. The major improvements allowing the recovery of Lake Sturgeon may follow from decreases in nutrients from municipal sewage, and regulated winter water flow. However, the annual number of spawning females in any given year remains quite low (likely fewer than 50 individual fish). This expectation is far below the Alberta Endangered Species Conservation Committee (ESCC) sub-committee criterion of 2,500 mature fish (Endangered).

Critical to increasing the numbers of mature fish is low fish mortality. I found that estimates of natural mortality (*M*) for the NSR Lake Sturgeon population ranged from 9.1% to 11.8% (1992 to 2012), and beyond the 7.0% total mortality threshold as recommended by the ALSRT (2011). Despite a high rate of mortality, recruitment and overall abundance have increased during the 1992 to 2012 study period. Due to contradictory evidence and potential error surrounding the population estimates, I believe my estimated mortality rates could be reduced.

Encouragingly, Lake Sturgeon subpopulations in the NSR remain well-connected throughout the province, and downstream into Saskatchewan. Lake Sturgeon exhibited complex migration and movement patterns with movements at their highest during the spring and fall months. Seasonally, Lake Sturgeon tended to stay within the same home range near areas of capture. This propensity indicates that most Alberta Lake Sturgeon are resident with no discernible migration occurring outside of the fall season and during the spawning season. Maximum movements observed during the spring season appear to be associated with spawning activity in which transboundary movements into Saskatchewan occurred. These transboundary movements were observed on two occasions; a radio-telemetry surveillance flight into Saskatchewan tracked two fish, one at Frenchman's Butte in 2013, and one at North Battleford in 2013. At Lucky 4, I recaptured a Lake Sturgeon that was originally tagged 45 rkm downstream of Prince Albert, SK, an upstream migration into Alberta of 925 rkm. Such movements reduce the sub-population's risk of extirpation. They further lower the risk of genetic issues that might appear in other low-density fisheries.

I found that there were 10 important areas where Lake Sturgeon tend to congregate. The fact that Lake Sturgeon tend to relocate from place to place suggests that Lake Sturgeon have preferred areas of congregation, to which they exhibit site fidelity. Identification of these areas suggests conservation options. The observed number of over-wintering locations indicates that suitable winter habitat locations may either be limited or because transmitters were implanted in only three locations. On the other hand, the fact that only three locations were selected for the implantation of radio transmitters into fish may bias the number of transmittered Lake Sturgeon recorded at any specific location. Despite this choice of implantation limitations, observed locations have indicated areas of congregation, and Lake Sturgeon recorded in my study frequented the entire range of the Alberta study area.

Conclusion

My telemetry data identified excellent connectivity of Lake Sturgeon between implant sites and into Saskatchewan, an event that reduces various population concerns. Mortality estimates of Lake Sturgeon are high, but I detailed increased recruitment and overall comparative abundance. At these overwhelming mortality rates, 100 year-old fish will not be achieved. However, as the recruitment of both young and mature fish appears to be on the increase along with overall population abundance and high growth rates, this would suggest that the population of Lake Sturgeon in the NSR is recovering and sustainable. Although the reported numbers constitute a mixed outcome for the sustainability assessment, conservation options need to be quantitatively assessed. In particular, future assessments must ensure that recruitment is maintained and mortality rates remain low.

Chapter 3 - A model to predict Lake Sturgeon (*Acipenser fulvescens*) habitat selection in the North Saskatchewan River, Alberta.

Introduction. —The immediate terrestrial landscape surrounding lotic ecosystems serves as a buffer to various landscape-level disturbances, which can influence food chains and other components of the aquatic ecosystems (Schlosser 1995, Amezaga et al. 2002). Landscape-level disturbances have contributed to the extirpation and reduction of some fish species across North America (Miller et al. 1989, Fairchild et al. 1998). Gravel extraction, urbanization, and agriculture over the last century in North America have all increased sedimentation rates, affecting nutrient inputs, changing channel morphology, and increasing erosion, thereby negatively altering hydrologic and thermal regimes of aquatic systems (Fleischner 1994, Hughes et al. 1994, Gammon et al. 2003).

In Alberta, fish assemblages are both directly and indirectly affected by the type and intensity of land use, where agricultural activities such as water erosion of soil have negatively affected lotic ecosystems (Wichert and Rapport 1998, Yoder and Smith 1999). Timoney and Lee (2001) reported that up to 98% of Alberta's prairie-parkland ecozone has been transformed into farm land. Similarly, human immigration has encouraged further growth and expansion among provincial towns and cities. Alberta is not immune from such developments. If we are to protect current fish populations, we must know their distribution and understand the relationship between landscape position and fish occurrence (Smith and Kraft 2005) to maintain and protect fish populations (Creque et al. 2005). This state of affairs would especially apply to species such as Lake Sturgeon (*Acipenser fulvescens*), as they currently exist in low numbers, and are sensitive to the water quality and channel morphology changes caused by agriculture (McPhail and Carveth 1992).

Lake Sturgeon are endemic to North America and have been found in rivers and lakes throughout central and eastern Canada (Williamson 2003, Barth et al. 2011). The western populations of Lake Sturgeon have been recommended as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; COSEWIC 2006) and are classified as Threatened under Alberta's Wildlife Act. In Alberta, they are located at the edge of their northern and western range in the North Saskatchewan River (hereafter NSR; Scott and Crossman 1973). Any understanding of habitat selection by Lake Sturgeon is essential for long term local monitoring which can aid in the conservation of this species through federal and provincial conservation objectives such as the identification of locations for species protection, area closures and harvest limitations.

My telemetry surveys identified many congregations of Lake Sturgeon throughout the NSR. I attempted to determine whether there were any landscape features associated with habitat suitability. To this end I used a resource selection function (RSF) to understand Lake Sturgeon habitat selection in the NSR. This logistic regression technique uses statistical relationships to describe the distribution and probability of use in relation to a resource unit within a defined scale (Boyce et al. 2002). Logistic regression has been used to predict the extent of fish occurrence using Geographic Information System (GIS) and multiple landscape classes (Fransen et al. 2006). Lake Sturgeon encounters a resource, and decides to use the resource or not to use the resource, a binomial decision, hence my use of logistic regression. My objectives are (1) to create a logistic regression model (i.e., resource selection function) of Lake Sturgeon habitat selection using landscape classes at the scale of Lake Sturgeon home range in the NSR, (2) to test whether life history parameters differ in importance between male and female Lake Sturgeon habitat selection and (3) to conduct a validation of the Lake Sturgeon RSF model through correlation of location data collected independently of model formulation.

Methods

Study Site. —The NSR is located within the aspen parkland ecoregion of north-central Alberta (53°36’7”W, 110°0’23”N) and spans approximately 830 km from its headwaters in Banff National Park, Alberta to the Alberta-Saskatchewan border (Mitchell and Prepas 1990). The river is a major tributary of the Saskatchewan-Nelson River system. Within Alberta, the top four land type activities, by land area percentage of the NSR basin, include crops (26.8%), sand and gravel quarries (0.2%), natural vegetation (trees, shrubs and grasses; 45.8%), and pasture/tame grasslands (12.2%; NSWA 2009). For my 2010 to 2013 study, 58 Lake Sturgeon were radio-tracked in a 512 km section of the NSR spanning from Drayton Valley, Alberta to the Alberta-Saskatchewan border (Fig. 3.1). Historically, very few Lake Sturgeon have been recorded upstream of this section (possibly a result of thermal limitations, high water velocity, or water conductivity).

Figure 3.1. Map of the North Saskatchewan River in north-central Alberta. Telemetry survey efforts targeting Lake Sturgeon were focused from Drayton Valley, Alberta to the Alberta-Saskatchewan border. Bolded area denotes the North Saskatchewan River drainage within the province of Alberta.

Fish Locations. —Radio telemetry was used to track the locations of Lake Sturgeon in this study. Lake Sturgeon were captured using angling and tangle nets in the NSR. Angling use consisted of still-fishing with heavy action spinning rods, high-tensile strength line, and bait. Angling was actively monitored (i.e., set-lines were not used). Tangle nets measuring 45.7 m consisted of multi-filament nylon mesh (203 mm or 254 mm), deployed in back-eddy areas with low water velocity where visual sightings of Lake Sturgeon had occurred previously. Nets were checked every 20 minutes to minimize harm to captured Lake Sturgeon.

Prior to surgical implantation of coded, radio transmitters, Lake Sturgeon were placed individually into an anaesthetic tank with a concentration of 400 mg/L of buffered tricane methane sulfonate (MS-222). A buffering agent ($NaHCO_3$) was used at an equal concentration of 400 mg/L to maintain neutral pH. Lake Sturgeon were monitored closely, and were considered fully induced into anesthesia at the point when gill movement ceased. Manual current-flow over gills was initiated to maintain blood-oxygen saturation during surgery. In total, 58 Lake Sturgeon were implanted with radio transmitters; 25 males, 13 females, and 20 of unknown sex. Mean total length of transmittered fish was 1,165 mm (s.d. = 152; 875 mm – 1630 mm).

Telemetry. —I conducted or supervised telemetry surveys over a 38-month period (May, 2010 to July, 2013), using either a jet boat or fixed-wing aircraft (Cessna 185E Skywagon). Weekly surveys were done during the putative spring spawning migration, and bi-weekly during the summer and winter months. Fish locations were recorded with an Advanced Telemetry Systems ([ATS] Inc., Isanti, Minnesota) R4520C System II Coded Receiver containing a global positioning system (GPS) with an external antenna.

Model Formulation. —Based on 2010 and 2011 Lake Sturgeon telemetry locations and random points within home ranges, I created a resource selection function (RSF) to predict habitat selection by Lake Sturgeon with model inputs derived through ArcMap 10.1 (Barth et al. 2011). As a measure of habitat availability, random points were generated within the 95% minimum convex polygons (contained between the banks of the river) of each fish home range at a sampling intensity ratio of 3:1 (0.0001 pts/m^2). My analysis assumed that all fish had access to all resources, and all areas within its home range. Distances from used and available locations were determined to five landscape classes; crops, grassland, gravel, sand, and vegetation (i.e., trees and shrubs). Crops was defined as the "PFRA Agricultural Land Cover Alberta CLASS, Cropland" layer. Grassland was defined as the "PFRA Agricultural Land Cover Alberta CLASS, Grassland" layer. Gravel was defined as the "SAND_GRAVEL MATERIAL" layer, which includes 17 different classes of gravel and other materials. Sand was defined as the "SAND_GRAVEL_PY" layer, which includes 9 different classes of sand and other materials. Vegetation was defined as the "PFRA Agricultural Land Cover Alberta CLASS, Trees and Shrubs" layer. Distances to each class were measured up to a 500 m maximum. Distances to each type of resource within a 500 m transect for both used and available points were calculated to generate candidate models. Landscape variables were calculated from a 30 m digital elevation model (DEM) to identify gradient (slope %), elevation, gravel, sand, grassland, and vegetation. All landscape data was obtained from the Alberta Ministry of Environment and Sustainable Resource Development. I assumed that landscape classes situated along the NSR (e.g., sand and gravel) were also situated across the river's substrate. Lake Sturgeon are bottom feeders, and adapted to feed in such areas (Scott and Crossman 1973). I also assumed that the other landscape classes can influence areas of water quality, e.g., dissolved oxygen concentration, water temperature, and overall productivity.

A null model with no predictor variables served as a beginning reference point in which there is no effect on land classification, slope or elevation. Competing models were composed of a random intercept representing individual fish (use~1 + (1|individual fish (unique identification number))). In contrast, all 10 models were used to examine the relationship between used and available locations within the NSR which had been influenced by varying levels and combinations of land use. Akaike's Information Criteria (AIC) was used to for select the most appropriate model (Burnham and Anderson 2002). My best model was considered to have the lowest AIC value.

I used lmer4 in software package in R (version 2.14.2) for mixed-effects logistic models to estimate the beta coefficients (β) of the following exponential RSF to model the variation between individual Lake Sturgeon (i.e., males and females; Table 3.1). The logistic regression model was represented by:

$$RSF(x) = w(x) = \exp(\beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n)$$

Where:

β = selection coefficient

X = predictor variable

Beta coefficients and predictor variables were entered into a raster calculator in ArcMap 10.1 to create a spatial RSF map. To standardize, and scale the RSF values between 0 – 1, I used the following expression:

$$(RSF - RSF\ minimum\ value) / (RSF\ maximum\ value - RSF\ minimum\ value)$$

Prior to testing candidate models in AIC, and to avoid biased estimates, I examined predictor variables and generated a Pearson r correlation matrix to determine if $r > 0.6$. Problems in co-linearity can lead to inflated standard errors. If correlation values were > 0.6, I excluded one of the collinear variables (McCleary and Hassan 2008).

To generate a distribution of possible values for male and female Lake Sturgeon reach location (i.e., elevation (m) and slope %); I resampled the range of locations 250 times utilizing a bootstrapping technique (Haddon 2001). I generated maximum likelihood estimates (MLE) and ninety-five percent confidence intervals (CI) for both sexes. I calculated the final values (i.e., standardized) to range between 0 and 1 (Paul et al. 2003). Finally, I used a two-tailed t-test assuming unequal variance to determine significance ($p < 0.05$) between male and female Lake Sturgeon for both elevation and gradient.

I evaluated the predictive capability of the RSF model, whereby I regressed the number of Lake Sturgeon telemetry locations per river kilometer (collected during 2012 and 2013) with mean RSF values per river kilometer to determine a coefficient of determination (r^2).

Results

A Pearson's r correlation matrix revealed co-linearity between two predictor variables; grassland and vegetation (Table 3.1.). Although the two predictor variables were moderately correlated $r = 0.46$, I took a conservative approach and randomly eliminated the grassland variable from model evaluation.

Table 3.1. —Pearson's r correlation matrix of independent variables for sites where Lake Sturgeon were present. Shading indicates a moderately correlated variable ($r = 0.46$).

	Crops	Elevation	Grassland	Gravel	Sand	Slope	Vegetation
Crops	1.00	-0.15	-0.20	0.08	0.04	-0.16	-0.16
Elevation		1.00	-0.39	-0.04	0.09	0.07	-0.27
Grassland			1.00	-0.04	-0.09	0.17	0.46
Gravel				1.00	0.03	-0.03	-0.12
Sand					1.00	-0.08	0.06
Slope						1.00	0.13
Vegetation							1.00

Model 1, consisting of 7 variables; distance to gravel, sand, crops, and vegetation, which included slope and elevation and a mixed-effect (i.e., males and females) was the best RSF model (Table 3.2). The RSF output was generated based upon these model variables and beta coefficients (Table 3.3) in which values were stratified between 0 and 1, where a value of 1 indicates the highest probability of use (Fig. 3.2).

Table 3.2. —Summary of the independent variables used to evaluate the logistic relationship between the occurrence of Lake Sturgeon and environmental variables, as a function of elevation (ELEV), slope (SLOPE), vegetation (VEG), gravel (GRAVEL), sand (SAND), GENDER, and interactions.

Model	Model Description	*K*	DEV	LL	AIC	ΔAIC	w
1	ELEV+SLOPE+VEG+GRAVEL+SAND+ELEV*GENDER	7	1119	-559.5	1135	0	0.99
2	ELEV+SLOPE+VEG+GRAVEL+SAND+GENDER	7	1131	-565.5	1145	10	0.01
3	ELEV+SLOPE+VEG+GRAVEL+SAND+SLOPE*GENDER	7	1131	-565.5	1147	12	0.00
4	ELEV+SLOPE+VEG+GRAVEL+SAND+MATURITY	7	1138	-569	1152	17	0.00
5	ELEV+SLOPE+VEG+GRAVEL+SAND	6	1624	-812	1636	501	0.00
6	ELEV+SLOPE	3	1683	-841.5	1689	554	0.00
7	ELEV+SLOPE+CROP+ROAD	5	1679	-839.5	1689	554	0.00
8	VEG+GRAVEL+SAND	4	1822	-911	1830	695	0.00
9	CROP+ROAD	3	1864	-932	1870	735	0.00
NULL	USE~1+(1|c_UID)	2	1867	-933.5	1871	736	0.00

I did not find a significant difference between male and female Lake Sturgeon for distance (m) to gravel ($t = 1.14$, $df = 672$, $p > 0.05$), sand ($t = 1.38$, $df = 641$, $p > 0.05$) and crops ($t = -0.873$, $df = 709$, $p > 0.05$). Distance (m) to vegetation ($t = -2.33$, $df = 811$, $p < 0.05$) for both sexes was significantly different.

Table 3.3. —Summary statistics for the independent variables used for a general linear mixed model of Lake Sturgeon telemetry detections in the North Saskatchewan River, Alberta, as a function of elevation, slope, vegetation, gravel, sand, sex, and an interaction between elevation and sex. Model parameters include standard error, *z*, probabilities (*P*) of a Type I error, Bayesian information criteria (BIC), and log-likelihood (logLik).

Fixed Effects	Estimate	Std. Error	z-value	Pr(>|z|)
Intercept	1.10E+00	3.16E+00	0.348	0.727691
Elevation	-4.61E-03	4.78E-03	-0.965	0.334400
Slope	-4.95E-01	5.94E-02	-8.335	< 2E-16 ***
Vegetation	2.25E-03	5.71E-04	3.933	8.39E-05 ***
Gravel	-2.04E-03	5.41E-04	-3.766	0.000166 ***
Sand	3.23E-03	1.49E-03	2.174	0.029728 *
Gender	-1.91E+01	5.07E+00	-3.764	0.000167 ***
Elevation:Gender	2.75E-02	8.01E-03	3.434	0.000595 ***
		BIC	logLik	deviance
		1192	-559.5	119
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'				

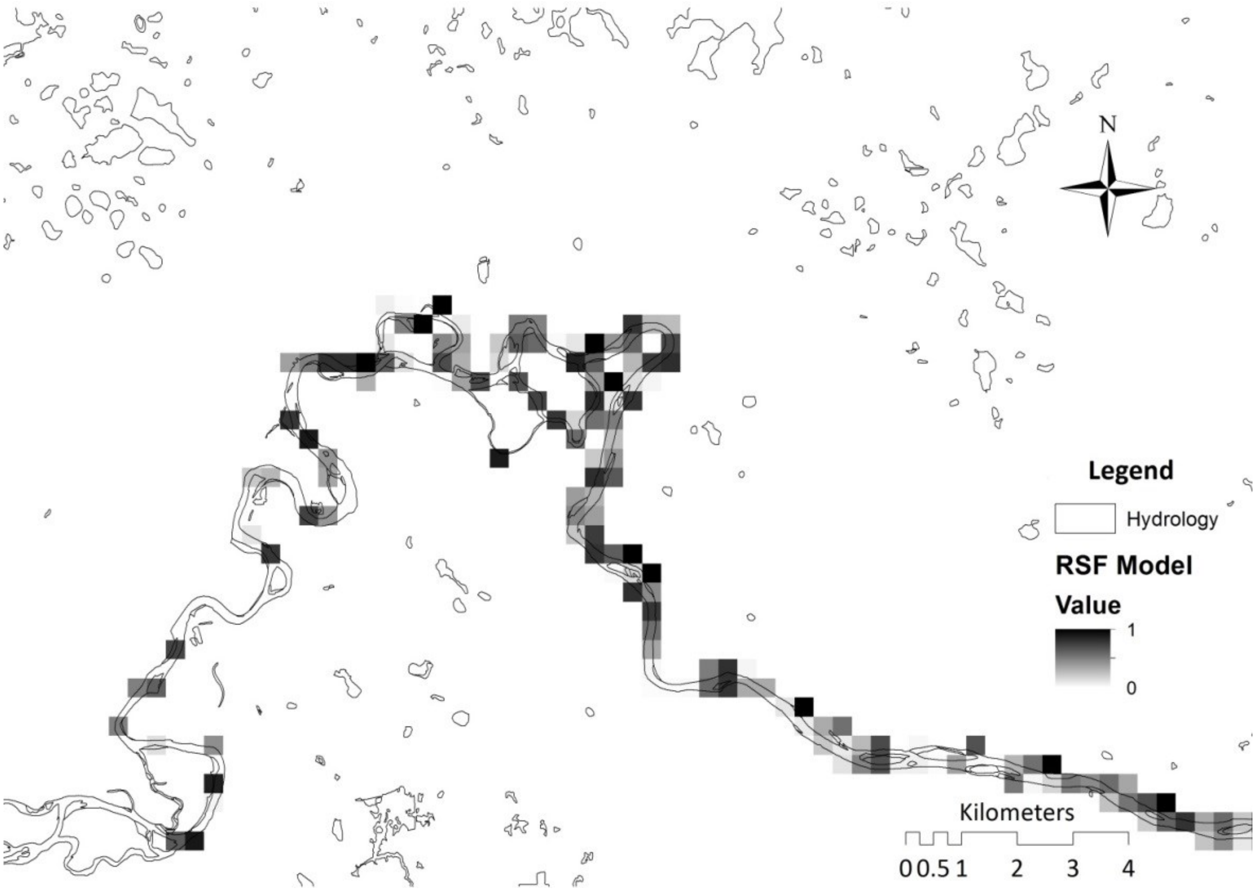

Figure 3.2. The probability of occurrence of Lake Sturgeon based on a resource selection function using land cover classification, slope and elevation in a 30 km section of the North Saskatchewan River, 70 km west of Edmonton, Alberta. The darkest shade indicates the highest probability of occurrence.

In the two-tailed t-test for unequal variance, a significant difference indicated male and female Lake Sturgeon are occupying different elevations ($t = 4.46$, $df = 539$, $p < 0.05$). The maximum likelihood for occurrence for males was 619 m (95% CI = 613 - 621), and 603 m (95% CI = 596 - 608) for females (Fig. 3.3), meaning that male sturgeon were, on average, found further upstream than female sturgeon. Notably, there was no significant difference in selection of river gradient, with male and female Lake Sturgeon occupying the same slope (%) at 5.7 and 5.9 respectively ($t = -0.409$, $df = 860$, $p > 0.05$; Fig. 3.4).

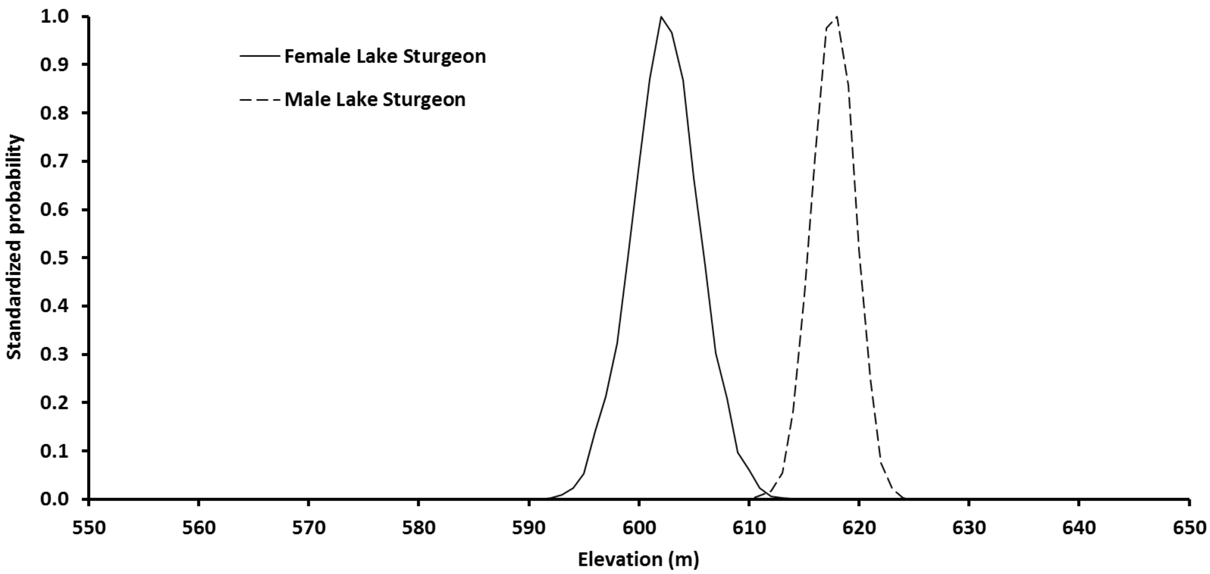

Figure 3.3. Probability of Lake Sturgeon location by elevation, North Saskatchewan River, AB. A standardized probability function of elevation (m) between male (MLE = 619; 95% CI = 613 - 621) and female (MLE = 603; 95% CI = 596-608).

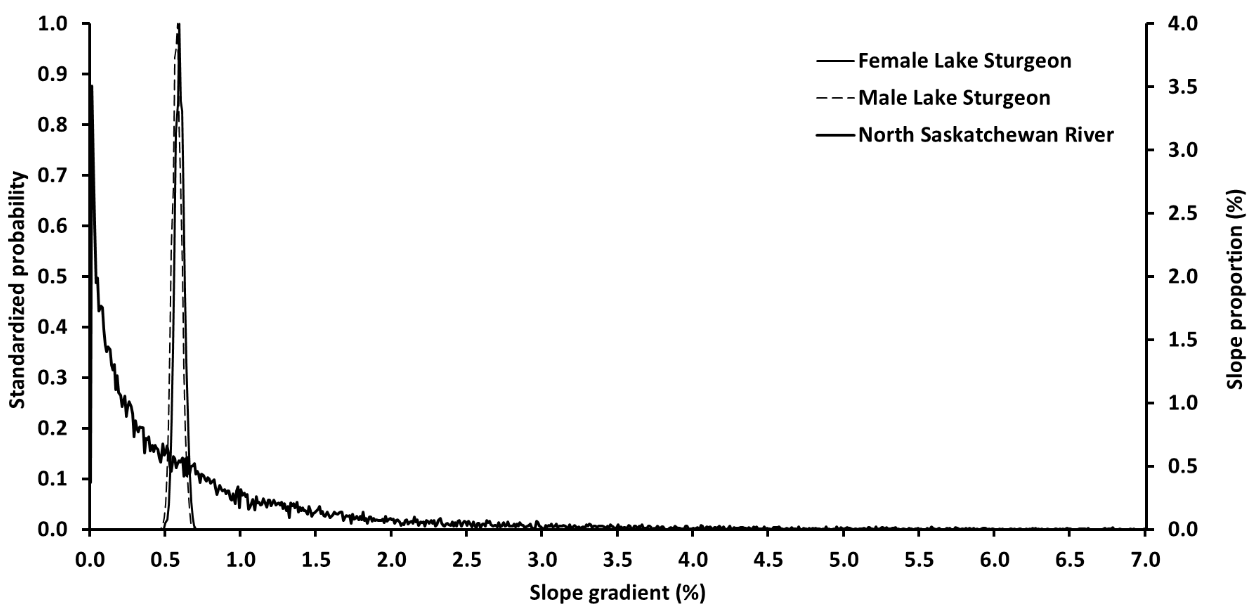

Figure 3.4. Probability of Lake Sturgeon location by river gradient (slope %), North Saskatchewan River, AB. A standardized probability function of slope gradient between male (MLE = 0.057; 95% CI = 0.051-0.064) and female (MLE = 0.059; 95% CI = 0.053-0.0065), calculated from a 30 m digital elevation model.

To determine the usefulness of the RSF model in predicting Lake Sturgeon locations, I regressed the number of Lake Sturgeon telemetry locations with the mean RSF values on the scale of river kilometer. This relationship was not significant ($df = 152$, $r^2 = 0.014$, $p = 0.14$; Fig. 3.5).

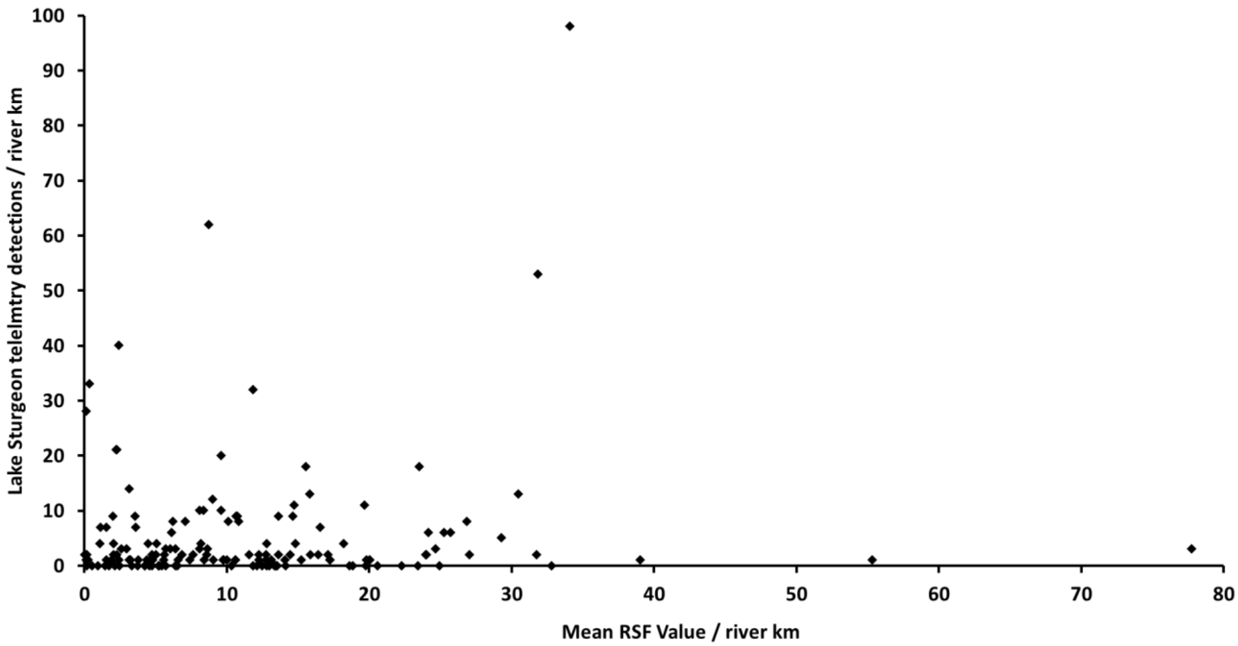

Figure 3.5. Mean resource selection function values per river kilometer and number of Lake Sturgeon telemetry locations per river kilometer for a 512 km section from Drayton Valley, Alberta to the Alberta-Saskatchewan border.

Discussion

Even though Lake Sturgeon congregated in many locations within the river, I found that Lake Sturgeon distribution within the NSR was not associated with all investigated landscape variables. However, there were two important landscape attributes that emerged from the generated RSF model; slope gradient and elevation. Male and female Lake Sturgeon selected locations with reaches of similar slope gradients of less than 1%. Slope gradients less than 1% are indicative of a pool/run habitat (low velocity) where slope gradients greater than 1% are indicative of run/riffle habitat (Jowett 1993). Lake Sturgeon populations in the NSR congregate in deeper pools of the river, particularly at outside bends (> 5 m; Watters 1993a). My measures show 76% of the NSR study area is occupied by these low velocity habitats. Although male and female Lake Sturgeon preferred similar slope gradients, they preferred different elevations, an average difference where females were generally found further downstream. Landscape variables are associated with elevation differences; Rahel and Hubert (1991) determined that elevation is an important environmental variable affecting fish assemblages between cool and cold water species.

Upon evaluation of the RSF model's capability in predicting Lake Sturgeon locations, I found the correlation between Lake Sturgeon telemetry locations and mean RSF values by river kilometer to be unvaryingly low. A relatively low Lake Sturgeon population may indicate that not all suitable locations (habitats) are being utilized at these population levels. This behavioral model could be described as a "hotel concept", in which there might be many appropriate rooms, but not enough patrons to fill the hotel. An alternate model would hold that there are very few suitable sites and they are all filled, and as resources become less available, fewer rooms would become more attractive. Yet a third hypothesis could be that habitat within the NSR had changed in relation to timing of the original dataset that was used to create the model to the time a subsequent dataset was used to explore the variation. In 2011, the NSR experienced a flooding event which changed the river's morphometry. This event had created and changed areas of the river which may have altered the detectability of suitable Lake Sturgeon habitat. I had located telemetered Lake Sturgeon in areas previously inaccessible to them (i.e., breached gravel mines and intermittent oxbows). These areas were neither part of, nor identified within a hydrologic GIS layer at the time of model creation and their use may have added unquantified variability to the RSF-telemetry test data comparison, thereby weakening congruence.

The RSF model graphically depicts that there are high probability locations (high RSF values) of Lake Sturgeon "use". There are four absolute locations on the NSR that coincide with high RSF values where I have captured Lake Sturgeon by net or fishing. Although this species is generally sedentary (i.e., in certain seasons), yet having the capacity for long movements such as the > 925 km recorded in the NSR (Watkins *unpubl. data*), it is probable that there are many other suitable locations throughout the NSR as indicated by the distances these fish migrate, and the relative values of the RSF model. Auer (1996) summarized that Lake Sturgeon exhibit strong multi-year fidelity to particular sites. In the previous chapter, telemetry surveys indicated repeat and new locations frequented by transmitter-equipped Lake Sturgeon. Considering site fidelity and limited capture locations, a skewed picture of how fish distribute themselves could be expected.

A conceptual model such as this is a very valuable tool for integrating the many simultaneous influences of landscape, river morphology, and the selection of seasonal habitats by fish; however, there are many sources of data variation or sources of error when using radio telemetry to develop these models (Chapter 4). When researchers design telemetry studies, location error and signal attenuation of radio transmitters should be considered. Equipment should be tested to determine how the role of detection affects scale, thereby influencing the understanding of habitat suitability.

Conclusion

Significant patterns of gender-selected habitats and significant land uses have emerged from this study despite logistics suggesting signal attenuation of radio transmitters. Conceptual models describing the influence of landscape variables on fish distributions need to integrate a broader range of landscape variables, and different seasonal timings. Landscape variables that were originally used to build the model may be inappropriate for predicting habitat suitability within the NSR. Ideally, a continuous dataset of *in situ* river variables (e.g., flow, temperature, dissolved oxygen, conductivity, substrate composition, and food sources) could be best utilized to create a Lake Sturgeon RSF model. Sampling the entire NSR would be logistically impossible given the aforementioned river variables. This was the case with this initial effort. The next generation of models will also benefit from accounting for seasonality in fish movement and the various influences affecting different Lake Sturgeon life history stages.

Chapter 4 - Limitations of high-frequency radio transmitters for tracking fish in a large river.

Introduction. —Researchers commonly use radio telemetry with aerial surveys to assess the survival, movement, behavior, and habitat use of fishes (Pollock et al. 2004, Braithwaite and Perera 2006, Trested et al. 2011). Such devices perform on the assumption of unimpaired detectability, or at least non-systematic bias in signal recovery. The influence of signal attenuation through water, however, can significantly reduce radio transmitter detectability and influence results. In telemetry studies of fish, transmitter depth, signal distance, and receiver altitude are key attributes affecting the detectability of radio transmitter signals (Peters et al. 2008, Shroyer and Logsdon 2009). Additionally, the probability of detecting radio transmitters while scanning multiple frequencies can impose a secondary issue of systematically missed signals during surveys. The use of aircraft-based receivers is an effective method of quickly locating fish tagged with radio transmitters in large lotic ecosystems. They eliminate the need to access the study area over private land, or over remote areas (Roberts and Rahel 2005). Winter (1983) found that line-of-sight detection distances from an aircraft were two to three times greater than distances measured on the ground. It is essential, consequently, to understand the limits of the telemetry equipment.

One must also consider the spatial scope, or more precisely the scale, in relation to location error of radio transmitter detectability when determining habitat selection of fishes. Location error can affect the scale at which reliable conclusions can be drawn (Brenden et al. 2004). Roberts and Rahel (2005) suggested that accuracy can be problematic when researchers define small-scale habitat features needed for delineating stream-use by fishes. Missed signals may be more problematic for fishes that aggregate in schools or share spawning areas (e.g., Lake Sturgeon) than for fishes that are well spaced or sedentary. Associated spatial errors or the failure of radio transmitter detectability may fall outside the scope or scale of the research question. Roberts and Rahel (2005) report a mean location error of 189 m during their independent study, but they stated that 4 of 17 aquatic telemetry studies provided them with a mean location error of 158 m associated with aerial surveys when compared with known locations of transmitters.

Direction of flight may be chosen to adjust to prevailing wind direction. Such manoeuvers may affect time to detect transmitters due to geomorphology and air speed. To increase the probability of detection in an aerial survey, Hockersmith and Peterson (1997) flew in their own geographic area in both upstream and downstream directions to maximize detection, but they failed to report any detection differences.

Limitations in detection include the effect of signal attenuation of high-frequency transmitters (i.e., bandwidth > 100 MHz) in aquatic environments where conductivity approaches or exceeds 400 μS/cm (Gingerich et al. 2012). Freund and Hartman (2002) suggested that signal attenuation can affect the results of telemetry surveys through false negatives. In some cases attenuation has been disregarded in respect to quantifying and reporting this effect of attenuation on the outcome of studies. Stasko and Pincock (1977) described relationships between signal attenuation as a function of radio frequency in freshwater, and report that radiotelemetry is "useful" at depths in excess of 50 m assuming that water conductivity decreases with water depth. More recently, factors such as transmitter frequency, transmitter size, and measurement errors affecting the accuracy of detection of telemetry transmitters have been documented (Brenden et al. 2004, Roberts and Rahel 2005, Peters et al. 2008). Brenden et al. (2004) and Roberts and Rahel (2005) suggest that biologists quantify location error when considering a telemetry survey to understand habitat use and movement studies of fishes. Freund and Hartman (2002) suggested that detection error can under-represent fishes utilizing deeper depths.

Detection can fail when researches scan one frequency within a bank of frequencies. Typically during an aerial survey, the telemetry receiver sequentially monitors preprogrammed frequencies for a set length of time. When a signal is detected, the receiver is manually held on the detected frequency until the maximum signal strength has been logged to record the transmitter's location. Under these conditions a transmitter can be missed: 1) while different frequencies are scanned, 2) while the receiver is held on another transmitter's frequency while its location is determined, or 3) although the receiver passes over or nearby a transmitter, the signal is too weak to be detected. Of the three causes, the second (the receiver has missed a transmitter while the location of another transmitter is located) is easily corrected by the pilot returning the aircraft to the location to where the receiver was placed in the hold position and then the researcher continues the survey. Causes one and three, on the other hand, are inherent to the described protocol. In addition to signal detection, the accuracy and precision of estimated locations are also important.

This study was part of a project to monitor survival and habitat use of Lake Sturgeon in a 512 km section of the North Saskatchewan River, Alberta, Canada. My objectives were to assess detection probabilities and positional accuracy of radio transmitters tracked through the use of aerial surveys as influenced by: 1) different transmitter types (AA versus D batteries), 2) transmitter depth in the water column, 3) altitude of the receiver during the aerial survey, and 4) effect of adding additional frequencies to the automatic scan of the receiver.

Methods

Study Site. —On May 17, 2013 I tested transmitters at a single site located west of Edmonton, Alberta in the North Saskatchewan River (53°23'N, 114°23'W). The study site had a maximum depth of 7 m, a wetted width less than 110 m, discharge of 157 to 227 m^3/s (the river is subject to daily hydropeaking from two upstream reservoirs), and water conductivities that ranged from 317 to 358 μS/cm throughout the duration of the experiment.

Transmitters. —I compared two types of three-stage, coded, enhanced range, radio transmitters (Advanced Telemetry Systems [ATS] Inc., Isanti, Minnesota) with whip antennae, and a pulse rate on-time of 20 ms, and off-time of 1,100 ms. I followed a block-study design that incorporated five transmitters each of two types; two Model F1850B transmitters powered by a 3.5-V lithium small cell battery (hereafter small transmitter) that weighed 27 g, and three Model F1860B transmitters powered by a 3.5-V lithium large cell battery (hereafter large transmitter) that weighed 162 g. Both transmitter types operated on separate 148-MHz frequencies and transmit a unique identification number (coded). Transmitters were individually tested before and after deployment and activation occurred immediately prior to field trials. For this experiment, single transmitters were wrapped in a nylon tape sheath with antennae projecting externally, attached to a 5 kg non-metallic anchor and secured but separated by a 1 m nylon cord. An 8 m nylon cord connected the anchor to a surface float which identified the unique transmitter number and radio frequency. I used two, two-element radio Yagi antennae forward-mounted on the fixed wing struts of a Cessna U206G for detection of the two transmitter frequencies. Transmitter detections were logged by frequency, location, time of day, and identification number using two separate ATS R4520C System II Coded Receivers connected individually to a single Yagi antennae using RG58 coaxial cable through a left/right/both switchbox. Receivers were randomly assigned to either transmitter type (i.e., frequency) prior to flight overpass. Receivers were equipped with a separate internal Global Positioning System (GPS), and an external GPS antenna mounted to the dash of the cockpit to determine the plane's location.

Prior to the first flight overpass, each receiver was placed in the hold position for the duration of the flight (i.e., a single frequency was being monitored by each receiver). One receiver was randomly held on either 148.056 MHz (large transmitters) or 148.104 MHz (small transmitters) and the other receiver was held on the other frequency. Receivers logged transmitter identification, location, time of day, and signal strength whenever a transmitter was detected. All relevant protocols followed the methods used in the larger study of Lake Sturgeon movements and habitat selection.

Field Experiment. —Due to the river morphology i.e., location of deep water, I positioned columns of transmitters approximately 25 m from the east bank (85 m from the west bank) at 1 m depth intervals from the surface to 7 m and with a 5 m central radius between transmitter types. I recorded the center of the two columns of transmitters on the ground with a handheld GPS (Garmin 60CSX). At a mean airspeed of 167 km/h, each flight passed directly over the study area at one of three altitudes; 300 m, 450 m, and 600 m above ground level (AGL). To determine the range and probability of transmitter detectability, the aircraft's starting position began out of detectable range and then flew a consistent linear path (northeast to southwest or vice-versa) over the transmitters until the signal was no longer detected (i.e., beyond detectable range). I recorded flight time and altitude, synchronized with the receiver's internal clock and subsequent time of recorded detection data.

Data Analysis. —I plotted the data files of both receivers as a series of X/Y spatial coordinates in decimal degrees into ArcMap 10.1. Shapefiles were created for each transmitter type (i.e., separately for each small and large transmitter by depth and altitude). I visually inspected each plotted shapefile to assess anomalous X/Y coordinates. To determine maximum detection distance (m), shapefiles were converted into two-dimensional grid coordinates (Universal Transverse Mercator) using XTools Pro, and exported into R for analyses (R Development Core Team 2013). Maximum detection distance was estimated as the Euclidean distance between the first and last detection for each transmitter for a given flight altitude and transmitter depth. Mean airspeed over transmitters (km/h) was estimated by dividing maximum detection distance by total elapsed time. Maximum signal strength was used to determine the most likely transmitter location and location error is defined by the distance between the indicated and the actual transmitter location.

To evaluate effects of transmitter type, water depth and receiver altitude on maximum detection distance, I developed log-linear models to describe the response variable (maximum detection distance) as a function of transmitter depth (m) and receiver altitude (m) for each transmitter type. A coefficient of determination (r^2) was calculated to determine variance in maximum detection distance that could be explained by depth or altitude.

Logistic regression was used to evaluate the relationship between detection probability (P_{det}) and transmitter type, transmitter depth, receiver altitude and first-order interactions. Akaike Information Criteria (AIC) were used to select the model best supported from my data (Burnham and Anderson 2002). All analyses were completed using R (R Development Core Team 2013).

To estimate the effect of scanning multiple frequencies on the resulting detection probability (P_{det}), I developed the following model:

$$P_{det} = 1 - (1 - P_{max})^{\frac{1}{f}}$$

Where P_{max} is the maximum detection probability when searching a single frequency (determined from the previous logistic regression analyses) and f is the number of frequencies being scanned (see Appendix A for derivation of the equation).

Results

Transmitter Detection. —Maximum detection distance was inversely related to depth for both transmitter types. Detection of small transmitters declined with altitude, but detection of large transmitters increased with altitude (Fig. 4.1). For the small transmitters, maximum detection distance was 5,614 m (at 1 m transmitter depth and 300 m receiver altitude; Fig. 4.1a). Detection time interval for this distance was 128 s (Table 4.1). Detection distance decreased dramatically with altitude for the small transmitters, failing at 600 m. Large transmitters were detected much more readily than the smaller ones (Fig. 4.1b). The detection distance for large transmitters was at a maximum distance of 14,508 m (at a depth of 1 m, but at the highest receiver altitude of 600 m). Detection time for this distance was 313 s, almost three-fold greater than the small transmitters (Table 4.1).

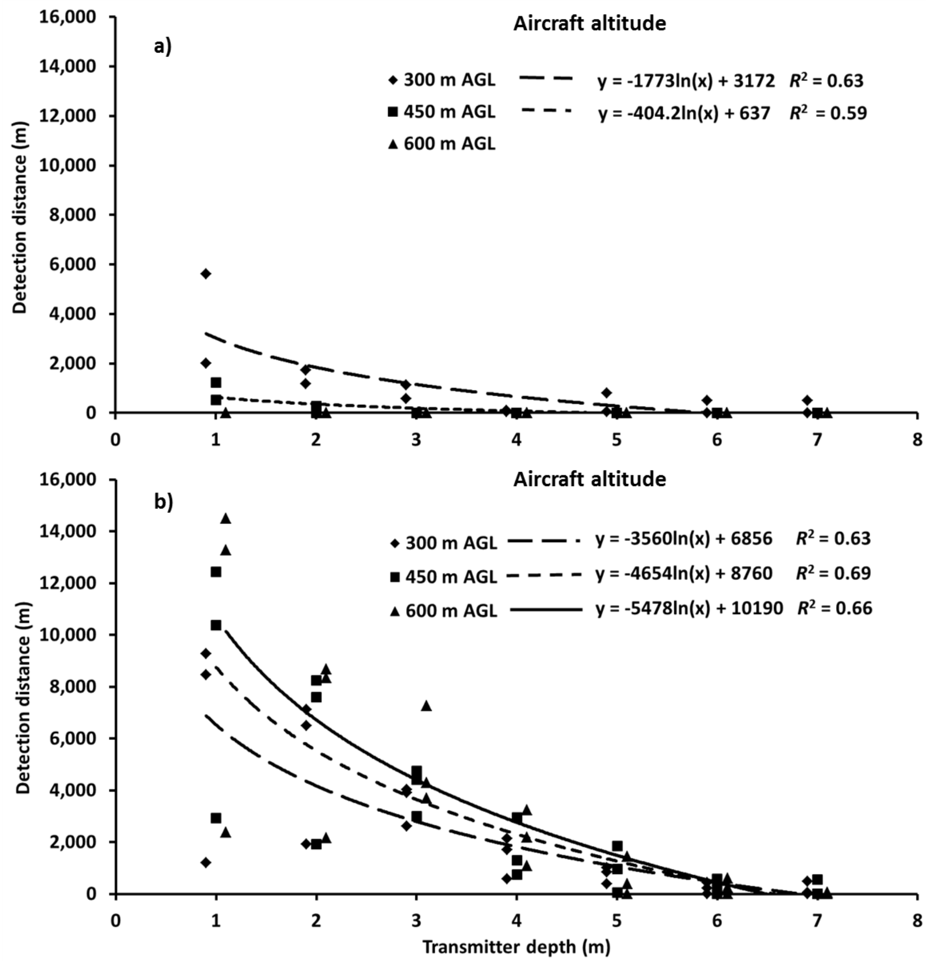

Figure 4.1. Detection distance at different depths and receiver altitudes for small type (a) and large type (b) radio transmitters in the North Saskatchewan River, Alberta.

Table 4.1. —Minimum and maximum detection times of the two transmitter types at given transmitter depths and receiver altitudes in the North Saskatchewan River, Alberta.

Transmitter	Depth (m)	Altitude (m)	Detection Time (s) Minimum	Detection Time (s) Maximum	Altitude (m)	Detection Time (s) Minimum	Detection Time (s) Maximum	Altitude (m)	Detection Time (s) Minimum	Detection Time (s) Maximum
small	1	300	44	128	450	12	26	600	0	0
small	2	300	23	35	450	0	8	600	0	0
small	3	300	14	26	450	0	0	600	0	0
small	4	300	2	25	450	0	0	600	0	0
small	5	300	1	18	450	0	0	600	0	0
small	6	300	0	11	450	0	0	600	0	0
small	7	300	0	10	450	0	0	600	0	0
large	1	300	28	210	450	62	249	600	52	313
large	2	300	39	150	450	45	193	600	43	176
large	3	300	61	93	450	64	101	600	83	163
large	4	300	13	47	450	18	70	600	25	68
large	5	300	10	23	450	1	36	600	0	33
large	6	300	0	9	450	0	15	600	0	12
large	7	300	0	10	450	0	11	600	0	1

Location error (combined for transmitter types, transmitter depths, receiver altitudes) ranged from 8 to 842 m, with a mean of 177 m (*SE* = 15.2; 95% confidence interval = 149 – 209 m; Fig. 4.2). Flight direction influenced location error, with estimated locations mistakenly placed further along the flight path than actual locations; i.e., 86% of locations recorded in a northeast flight path were found to the north of the actual location; 79% of locations recorded in a southeast flight path were to the south of the actual location (Fig. 4.3).

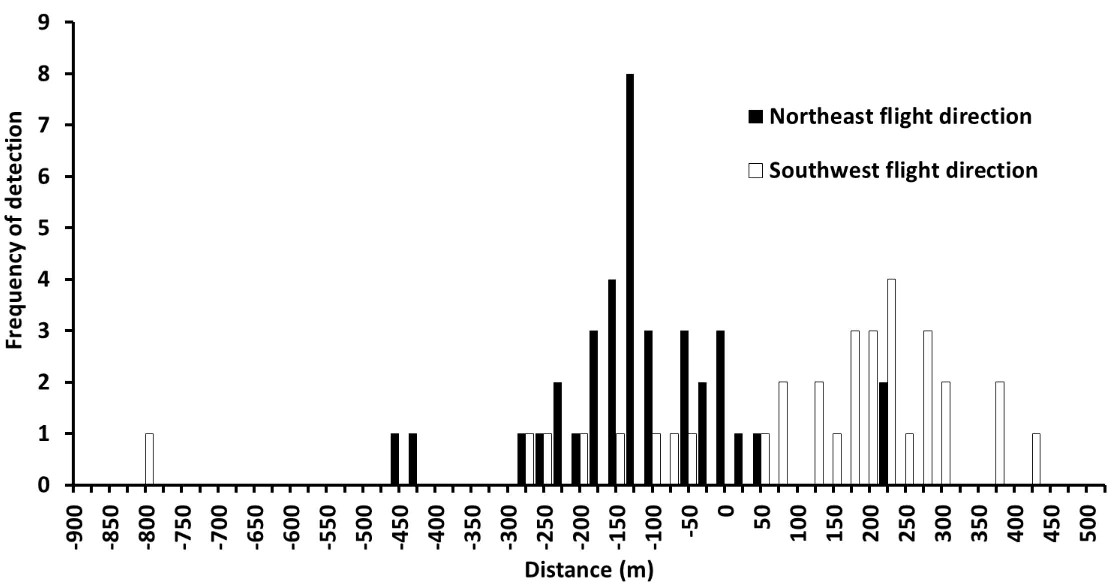

Figure 4.2. Estimated positional location of two transmitter types, depths and receiver altitudes for aerial surveys flown in either a northeast or southwest direction in the North Saskatchewan River, Alberta. Negative values represent estimated locations that are to the northeast of the actual location and positive values are estimated locations to the southwest.

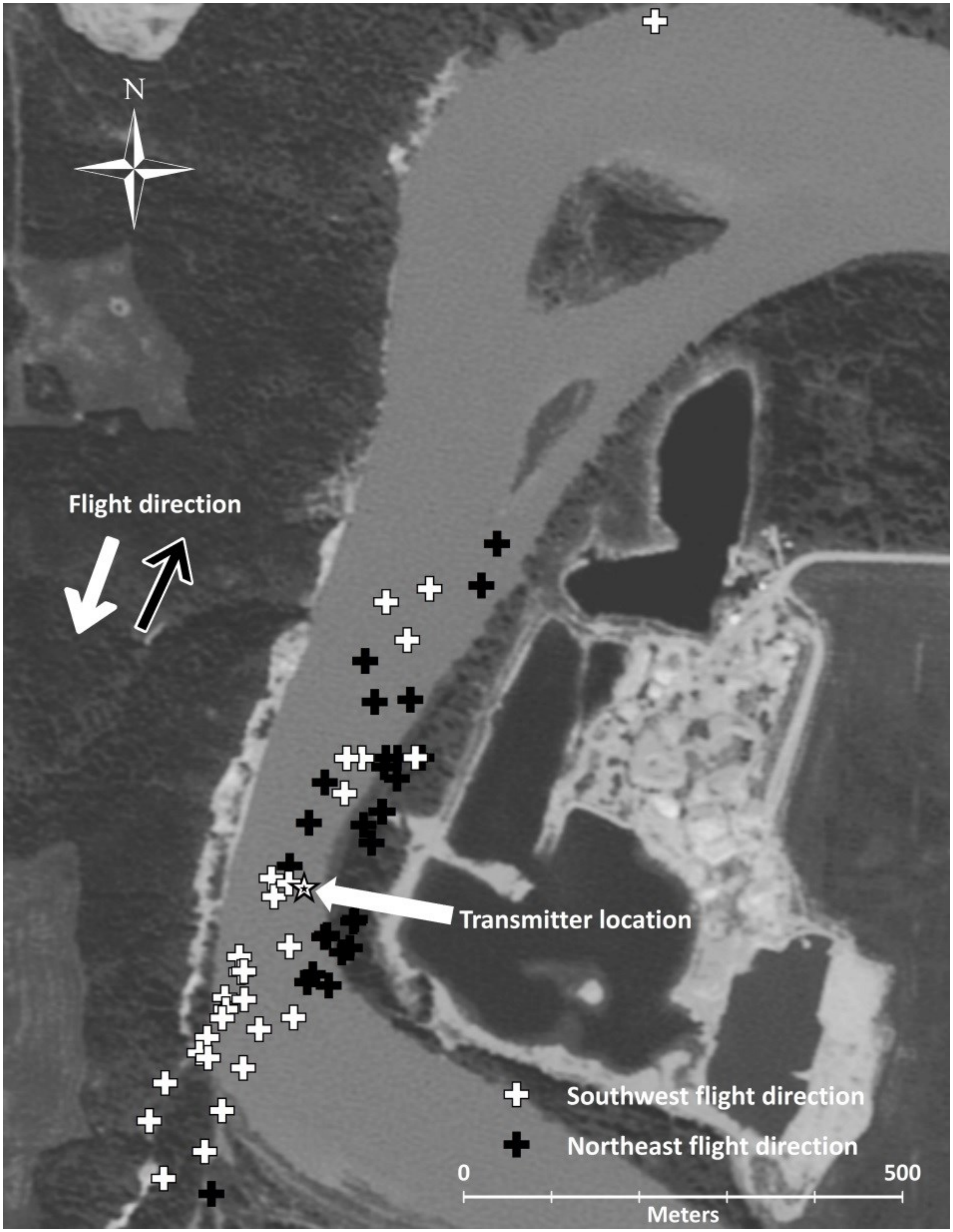

Figure 4.3. Locations of recorded telemetry transmitters ($N = 70$, of which 25 were recorded on shore) for all flights combined, based on maximum signal strength in the North Saskatchewan River, Alberta. Not all points are visible due to overlap.

Detection Model. —Probability of detection (*Pdet*), in the best supported logistic-regression model, was predicted by transmitter type, transmitter depth, receiver altitude with an interaction between receiver altitude and transmitter type (Table 4.2). A tabulation of summary statistics in the best supported logistic-regression model had probabilities in which $P \leq 0.01$ for each of the independent variables (Table 4.3).

Table 4.2. —Summary of *a priori* models relating transmitter detection to transmitter type (type), receiver altitude (alt), transmitter depth (dep) and the first-order interaction terms. Parameter number (*K*), residual deviance (DEV), log likelihood (LL), Akaike Information Criteria score (AIC), difference between AIC and the lowest AIC (ΔAIC), and model weight (w) are included for each of the candidate models.

Independent variables	*K*	DEV	LL	AIC	ΔAIC	w
detect~type,alt,dep,alt*type	5	42.69	-21.346	52.69	0.00	0.62
detect~type,alt,dep,alt*type,dep*type	6	41.66	-20.831	53.66	0.97	0.38
detect~type,alt,dep,dep*type	5	60.62	-30.309	70.62	17.93	0.00
detect~type,alt,dep,alt*dep	5	60.86	-30.428	70.86	18.16	0.00
detect~type,alt,dep	4	64.88	-32.439	72.88	20.19	0.00

Table 4.3. —Coefficients and their summary statistics for the best supported detection probability model (Table 4.2). Summary statistics include 95% confidence intervals, standard error, z-values and *probabilities (P) of a Type I error*.

Result	Coefficient	2.5%	97.5%	SE	z-value	*P*
Intercept	23.84	13.09	40.43	6.871	3.470	<0.001
type D	-12.80	-24.29	-4.39	4.990	-2.565	0.01
alt	-0.0467	-0.0808	-0.0246	0.014	-3.292	<0.001
dep	-1.47	-2.48	-0.79	0.424	-3.474	<0.001
type D*alt	0.0445	0.0213	0.0779	0.014	3.076	0.002

The interaction between receiver altitude and detection probability was diametric for the two transmitter types. Detection probability decreased with increasing number of scanned frequencies (Fig. 4.4). The reduction was most pronounced with small transmitters when the detection probability is additionally reduced with increased depth of transmitters or increased altitude of the receiver in the flight overpass. This degree of reduction did not occur with large transmitters (Fig. 4.4). At 300 m altitude, both the large and small transmitters have high detection probabilities at depths < 5 m when scanning one frequency ($P_{det} > 0.9$).

For large transmitters at their optimal altitude (300 m), *Pdet* fell below 80% at transmitter depths greater than 1 m with more than five frequencies scanned. For small transmitters at their optimal altitude (300 m), *Pdet* fell below 80% at transmitter depths greater than 2 m with more than five frequencies scanned. At their respective optimal altitudes, both sizes of transmitters had *Pdet* less than 50% at depths greater 3 m and at more than 10 frequencies scanned.

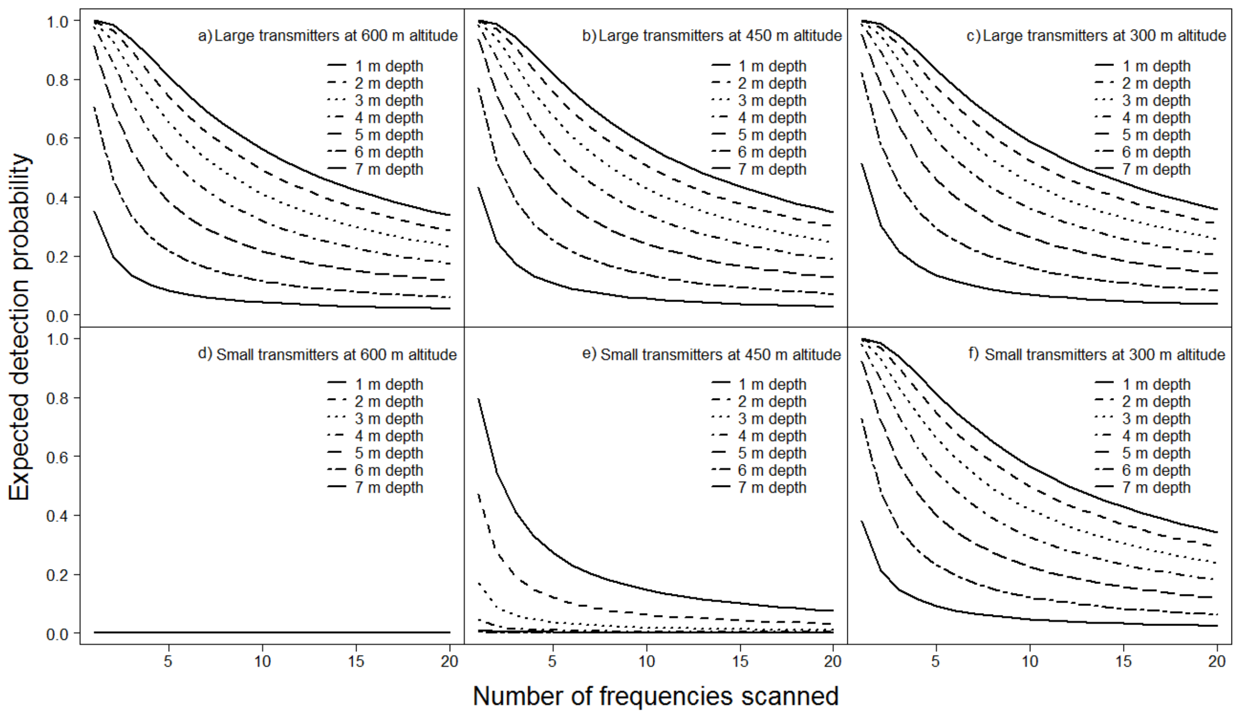

Figure 4.4. Expected detection probability versus number of frequencies scanned for the two transmitter types at different depths and receiver altitudes in the North Saskatchewan River, Alberta.

Discussion

The use of radio telemetry for tracking lotic fishes using aerial surveys cannot assume positional accuracy or capture probabilities of 100%; as with other fishery methods (e.g., mark-recapture), these nuisance parameters should be considered within the overall study design, data interpretation and conclusions. The potential for poor detection and the inaccuracy of estimated locations as I found in this study must be considered when interpreting fish telemetry data, as well in planning future studies. With multiple frequencies, typical aircraft altitudes, and fish in moderately deep water, the likelihood of finding transmittered fish is surprisingly low. The inaccuracy of estimated locations can easily result in inappropriate conclusions regarding finescale movements and habitat selection studies. In my study, 25 out of 70 estimated transmitter locations were found to be on land and not in the NSR. For the coarse-scale objectives of my Lake Sturgeon study, however, these low levels of detection and inaccurate locations were acceptable.

Care must also be used when using different types of transmitters, as there are competing and interactive effects on detection. In essence, transmitters passively compete for receiver time with stronger transmitters being detected earlier; thereby occupying the receiver channel while the plane flies over and the receiver misses detection of the weaker transmitters before the channel is free to detect them again. Therefore, as the number of large transmitters transmitting on separate frequencies increase, the likelihood of detecting the smaller powered small transmitters can decrease.

My probability of detection model is useful for assessing different scenarios of telemetry studies. For example, it can be used to determine if radio transmitters or acoustic transmitters are more appropriate when detection probabilities may be too low because of transmitter depth or receiver altitude (e.g., aviation flight rules over a developed area). Implications for detecting transmitters within shallow, braided streams where the depth component may be less critical as opposed to deeply incised, deep water rivers in which small transmitters which may hit their limits for detection. Likewise, implications may be less critical where low altitude surveys are a possibility (e.g., prairie streams with abundant flat emergency landing spots available). Also, I found that detection is maximized if one frequency is used. Alternatively, a separate receiver should be used to monitor each additional frequency. The absolute number of transmitters means channel congestion, frequency competition and an increase in artificial absences are implied. Multiple passes per flight per frequency or circling back when each cycle has completed would increase detection probability but is inefficient. If large fish in similar water conductivities typically inhabit depths > 5 m, or if flights must be substantially > 300 m elevation, the highest-power sized transmitters should be used if percentage of transmitter weight to body weight of the fish is appropriate, or a different method for detecting individuals such as acoustic transmitters. Based on my models, I recommend that all transmitters should be on a single frequency, and if different powered transmitters are utilized, a flight altitude of 300 m should be maintained.

Chapter 5 - Management Considerations for Lake Sturgeon in the North Saskatchewan River, Alberta.

In the past, the sustainability of Lake Sturgeon (*Acipenser fulvescens*) in the North Saskatchewan River (hereafter NSR) was threatened by high mortality from poor water quality and overharvest. Furthermore, a burgeoning human population has resulted in the development and alteration of the bed and shore of the NSR, potentially altering Lake Sturgeon habitat. Although I demonstrate that the Lake Sturgeon population has shown recent increases in abundance, the number of fish (especially adults) remains low. Current and potential sources of mortality need to be evaluated and mitigated to ensure the ongoing recovery of this important species.

Long-lived species like Lake Sturgeon are vulnerable to injury and illegal harvest from angling, a cumulative risk throughout their lifetime (Boreman 1997). As Lake Sturgeon have the potential to be long-lived (> age-100) in Canada, any fishing may impede population recovery. The collapse of Alberta's walleye (*Sander vitreus*) populations was due to increases in angling on Alberta's sport fisheries, which lead to excessive harvest of these slow-growing and late-maturing fish (Sullivan 2003). Similarly, Alberta's Lake Sturgeon population has experienced high exploitation rates.

Angling for Lake Sturgeon in the NSR appears to have greatly increased in popularity during the past few years. Considerable information about local Lake Sturgeon angling is now available through social media, web boards, fishing apps, and internet videos. Some of this information explains to anglers how Lake Sturgeon congregate in specific areas, especially during periods of spawning and low flows. High congregations of both Lake Sturgeon and anglers leads to increased catches, and the probability of a single fish being subject to multiple recapture events resulting in increased mortality through injury and capture myopathy. I have documented histories for individually tagged Lake Sturgeon with multiple captures during a single year and many recaptures over several years.

Additionally, Alberta's human population growth has resulted in increased development affecting Lake Sturgeon habitat. These developments include bridges, pipeline crossings, gravel pits, boat launches, erosion protection structures, stream channelization, and water intakes.

Currently, several specific locations in the NSR have received provincial legislative protection from development in the form of designated Class ‘A’ fish habitats. These designations have been largely based on local knowledge by fisheries biologists rather than a quantitative assessment of data. Protecting areas of Lake Sturgeon congregations is, at the least, a responsible and precautionary approach to habitat protection.

My objective is to provide the fisheries management branch with recommendations that will assist in the long-term recovery of the NSR Lake Sturgeon population. This objective involves: 1) Developing quantitative population objectives that represent a recovered or low-risk Lake Sturgeon population, 2) Review the information concerning the NSR sport fishery and determine the magnitude of any potential threats posed by fishing, and explore management options to mitigate these threats, and 3) Identify areas of known Lake Sturgeon congregations for enhanced habitat protection.

Current Status and Population Goals

For the past 22 years (1991 to 2012), volunteer anglers have provided mark-recapture information on Lake Sturgeon in the NSR. It has not proved possible, however, to derive precise estimates of the numbers of Lake Sturgeon, mainly because of low sample size, low capture probability, and movements of fish in and out of the study area (AESRD 2015 *unpubl.*). However, for the purposes of quantifying threats, a reasonable estimate is that approximately 5,000 Lake Sturgeon currently use the Alberta portion of the NSR. Recent data describing the structure of this population revealed the oldest Lake Sturgeon was age-62, with most of the population represented by fish < age-30, and 51% of the population ≤ age-10.

My aspirational goal (i.e., in 60 to 70 years’ time) for the NSR would be to have 100-year old Lake Sturgeon in the population. Although this age is below the maximum reported age (age-154; Scott and Crossman 1973) for the species in Canada, a goal of a 100-year old fish in the NSR would allow for numerous spawning events by an individual fish. Lake Sturgeon females are intermittent spawners (every 5-7 years after maturity at age-25; Scott and Crossman 1973), and a maximum age of 100 with a population of 5,000 would allow for 148 females to spawn per year.

Currently in Alberta, research angling catches approximately 550 Lake Sturgeon per year (n = 6 years; min = 213; max = 1,526). If a 100 year-old Lake Sturgeon was captured every year (out of 550 fish), it could be described as a common occurrence. A more reasonable quantitative goal might be to capture such a very old fish once every 5 years. For example, across the various fish sampling projects in Alberta targeting the recovered walleye fisheries, a very old walleye of ≥ age-25 is captured approximately once every 5 years (FWMIS data, Alberta Fish and Wildlife Division file), and biologists describe this occurrence as noteworthy, but not extremely rare. A similar and reasonable quantitative goal to describe a recovered Lake Sturgeon population is the capture of at least one 100-year old fish captured out of ˜2,500 fish sampled (i.e., every five years). To achieve a goal of one centenarian fish identified in a sample of ˜2,500 fish (therefore two, 100 year-old fish in the population of 5,000 fish), rates of mortality can be calculated. Assuming constant mortality and recruitment rates across ages, I used a deterministic model to achieve my goal, as represented by:

$$N_{t+1} = N_t\,(1 - Z)$$

beginning with $N_{(age\text{-}5)}$ when Lake Sturgeon are vulnerable to fishing, and where Z = total mortality rate. The population is the sum of the number of fish in each age class, and is adjusted to N = 5,000 by varying the initial number (at age-5) and Z.

When Z = 5%, N = 5,000 and $N_{(age\text{-}5)}$ = 252 fish allows for the goal of two, 100 year-old fish within the population. To ensure this objective, total mortality should not be accepted significantly beyond 5% and cannot exceed more than 250 dead fish per year. Considering my empirical estimates of natural mortality (Z = 9.4; Chapter 2) are greater than this number, therefore, mortality must be reduced from current levels.

Management Considerations for the Fishery

Estimating Annual Lake Sturgeon Deaths from Fishing. —While conducting field work on the NSR during the past several years, I've encountered different types of anglers. I will categorize these anglers into groups: 1) Non-specific Anglers that do not target Lake Sturgeon, 2) Sturgeon Anglers that target Lake Sturgeon, and 3) Research Anglers that target Lake Sturgeon for our population monitoring. I assume that all three groups of anglers have the potential of capturing

Lake Sturgeon. My question is: how many Lake Sturgeon might the three groups of anglers be catching, and how many fish are dying from catch and release fishing (i.e., hooking and handling)?

Only one angler survey for the NSR fishery has been conducted recently (Patterson and Sullivan 1998), but was confined to the reach of river near the City of Edmonton and did not include most of the popular Lake Sturgeon angling locations. Patterson and Sullivan (1998) did not record any anglers catching a Lake Sturgeon during this survey; however, 24,979 (± 4.2%) angling hours were estimated. I categorized these anglers as Non-specific Anglers. Furthermore, Lake Sturgeon abundance has increased since Patterson and Sullivan's (1998) survey and interest in angling for this species has also increased. During my study, I conducted a small-scale angling survey (AENV 2011 *unpubl.*) from Drayton Valley downstream to the provincial border and found that a small percentage of anglers (i.e., 18% of angling effort) were found outside of the Edmonton City limits. Therefore, I extrapolated Patterson's estimate to my larger study area and estimated angling effort at 1.18 x 24,979 hours = 29,475 (Table 5.1). With a catch rate of 0.004 Lake Sturgeon per hour for Non-specific Anglers (AENV 2011 *unpubl.*), this results in an angler catch of approximately 118 Lake Sturgeon per year, with a potential mortality of three fish. Because of the large sample size of the previous estimates, I was able to calculate the likelihood distributions around these estimates (Figure 5.1). This suggests that there were likely fewer than five Lake Sturgeon killed by non-specific anglers, and almost certainly fewer than 20 fish killed.

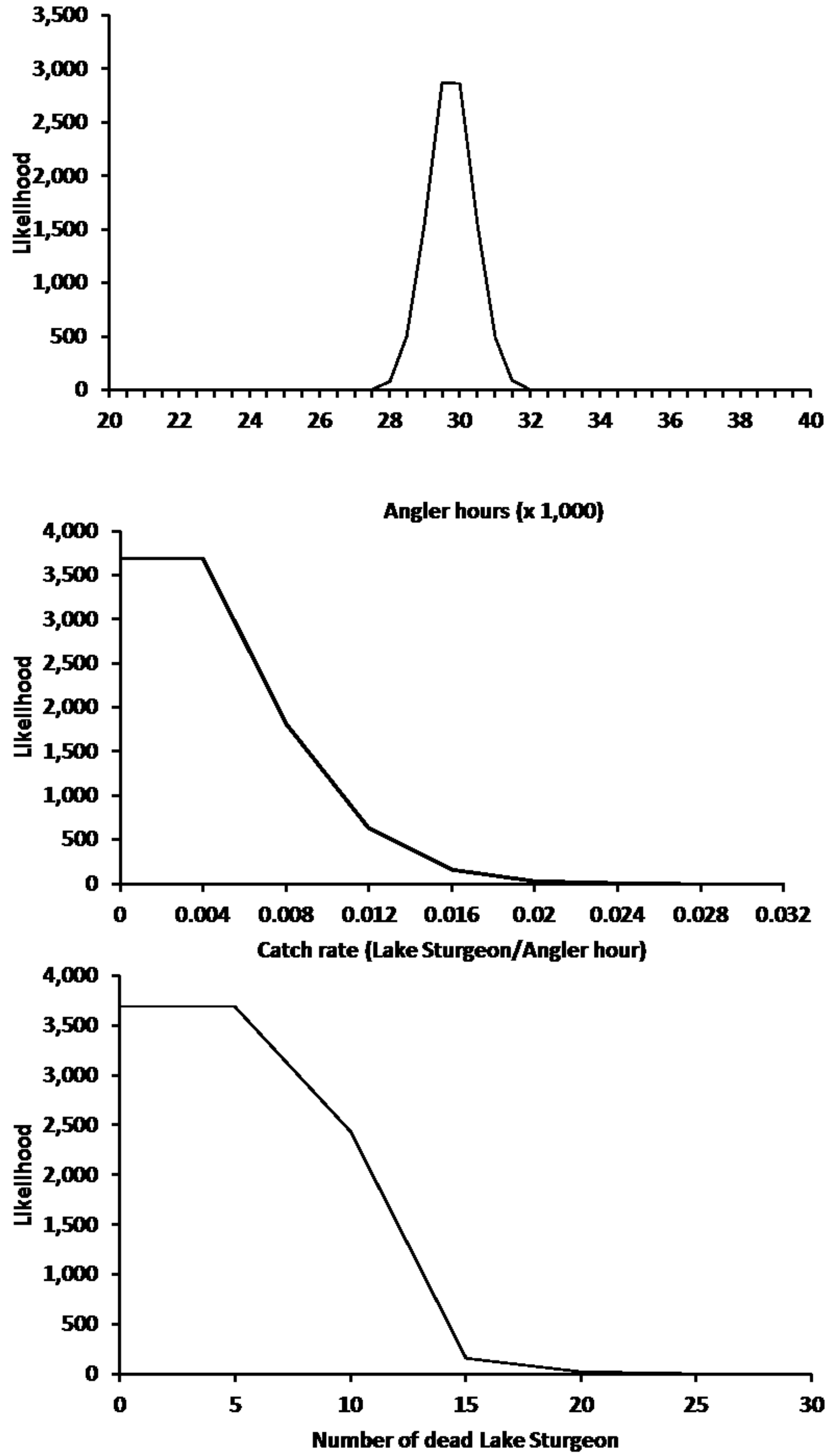

Figure 5.1. Likelihood distributions around (a) estimates of non-specific angler hours, (b) angler catch rate of Lake Sturgeon, and (c) numbers of Lake Sturgeon killed by non-specific anglers. All likelihoods based upon 10,000 simulations.

The second group of anglers, Sturgeon Anglers targeting Lake Sturgeon, partially reports their catches to district Fish & Wildlife offices in response to requests in various media to report tagged Lake Sturgeon. In 2012, Lake Sturgeon Anglers reported 19 Lake Sturgeon captured. Green (1983) reported a mean non-reporting rate of 71% (29% reporting rate) for seven groups of sport fishes tagged by biologists and reported by anglers. Applying this tagged fish reporting rate of 29% provides an estimated catch of 66 Lake Sturgeon per year by this group.

The third group of anglers, Research Anglers, is comprised of provincial biological staff, and a volunteer group of anglers that target Lake Sturgeon in the NSR in Alberta. On average, this group catches 550 Lake Sturgeon per year (n = 6 years; min = 213; max = 1,526).

The combined catch for the three groups of anglers is estimated to be 734 Lake Sturgeon per year. I estimated angling mortality for Lake Sturgeon using the White Sturgeon angling mortality rate of 2.6 % (Robichaud et al. 2006) for a total of 19 Lake Sturgeon dying yearly from hooking and handling mortality. I conclude that the estimated number of Lake Sturgeon deaths due to fishing is insignificant when compared to my estimates of natural mortality (M = 9.1 to 11.8 % or 455 to 590 dead Lake Sturgeon per year). However, to achieve 100 year-old fish, the goal is to reduce total mortality to 250 dead fish per year (i.e., 205 to 340 fewer dead fish per year). Consequently, reducing mortality through angling restrictions will not overly contribute to achieving the goal. Real recovery requires a significant reduction in mortality from other sources.

Data collection by the research anglers remains the largest component (75%) in the catch of Lake Sturgeon (Table 5.1). Therefore, research angling potentially has the largest effect on fishing mortality rates than the other angling groups. The current annual level of collection is intensive (catching ~550 fish per year). Monitoring of the Lake Sturgeon population every 5 years would likely be adequate to understand the progress of the recovery. If research angling ceases, the risk of hooking mortality on Lake Sturgeon would be reduced and would buffer for predicted increases in human population and angling. I recommend that the research angling program be reduced in intensity and become focused to an intensive single study season, once every five years.

Table 5.1. —Capture and mortality estimates of Lake Sturgeon by three angling groups in the North Saskatchewan River, AB. City estimate from Patterson and Sullivan (1998).

	Angler groups			Total deaths
	Non-specific	Targeted	Research Angling	(year)
City estimate (angling hours)	24,979			
Angling ratio (hours; river wide to city)	1.18			
Study area estimate (angling hours)	29,475			
Lake Sturgeon (Catch per unit effort)	0.004			
Lake Sturgeon (Reported catch)		19		
Rate (Reported catch)		0.29		
Lake Sturgeon (Captured)	118	66	550	
Anging mortality rate (F)	0.026	0.026	0.026	
Angling mortality (no. of deaths/year)	3.07	1.70	14.30	19

I did not include estimates of illegal harvest due to the low number of Lake Sturgeon caught, and the catch and release regulation. Sullivan (2002), studied illegal harvest of Walleyes in Alberta and found that 0.2 to 68.9% of the fish caught were not released. However, at the lakes with a catch and release regulation, Sullivan estimated illegal harvest was only 0.4%. Furthermore, the majority of Lake Sturgeon being captured is by volunteer anglers and government staff so I assume that the illegal harvest rate would be even lower. Other sources of human caused mortality were not quantified. These could include poaching by non-anglers (e.g., illegal spearing and netting), boat collisions (e.g., propeller strikes), industrial accidents (e.g., impingement on water intakes), and localized spills of deleterious substances (e.g., hydrochloric acid spill in Edmonton creek, Blais 2015).

Angling management regulations applied to non-research anglers such as gear restrictions, zone closures, and bait bans would reduce the current total death by few fish, these options appear relatively insignificant in comparison to other sources of mortality. Non-research anglers might cause the mortality of 4 or 5 Lake Sturgeon annually. Imposing gear or handling restrictions might reduce mortality to 2 or 3 dead fish annually, saving only 1 to 3 fish. For future concerns, I estimate that angling or Lake Sturgeon catch, would have to climb an order of magnitude before additional angling restrictions are required. As angling restrictions will not overly protect Lake Sturgeon (currently catching < 750 fish per year or less than 15% of the population), an alternative option is habitat protection.

Habitat Protection. —Although not well documented, I believe that degradation or improvement to fish habitat can effectively change mortality rates. A loss of habitat important to

Lake Sturgeon may occur due to physical alterations to the river, e.g., water intakes and pipeline crossings. ALSRT (2012) states “water withdrawals that reduce river depth and draw from deep pools can impact sturgeon”, and Watters (1993a) found that Lake Sturgeon congregate in deep pools of the NSR (> 5 m). Auer (1996) also indicates that a change to river flow limits Lake Sturgeon populations. Therefore, if industrial, municipal, agricultural or commercial influences cause changes to the river flow pattern in which the pool is no longer a pool, those fish will not remain there anymore. If less than ideal habitat remains, Lake Sturgeon will be forced into suboptimal habitats.

Environmental conditions such as water turbulence, water temperature, and total dissolved solids are factors that can reduce dissolved oxygen (DO) levels. Jenkins et al. (1993) found that acute exposure to DO levels < 2.5 ppm for Shortnose Sturgeon can cause death, and chronic exposure to DO levels < 5.3 ppm can cause a reduction in growth of White Sturgeon. Exposure to low dissolved oxygen levels can also result in stress for fishes (Small 2004). Responses to stress for White Sturgeon have led to viral infections such as herpesvirus and iridovirus (LaPatra et al. 1996, Manitoba Conservation and Water Stewardship 2012) and death. Lake Sturgeon residing in suboptimal habitat can also be affected by a variety of factors that can cause mortality. When forced to reside or move through a section of river where there are no pools (e.g., Sturgeon River), the instances of depredation on Lake Sturgeon by terrestrial predators such as Ospreys (*Pandion haliaetus*), Bald Eagles (*Haliaeetus leucocephalus*) and Coyotes (*Canis latrans*) is increased. Predators such as these may not always be successful in harvesting fish, but can cause injury leading to death. I have observed several Lake Sturgeon that have exhibited signs of injury and stress (lesions and underweight for their size). In circumstances like this, these fish may be a proportion of the population experiencing poor habitat quality. By maintaining prime habitat, mortality and emigration of fish will not increase.

To lose prime Lake Sturgeon habitat increases the probability of emigration. Emigration (i.e., to Saskatchewan) is equivalent to a decrease in population size, which from a population standpoint, is equal to mortality. A better designed Class ‘A’ system based upon a quantitative assessment of occupied locations by Lake Sturgeon will provide for management the options for providing protection thereby reducing the mechanisms that cause mortality and emigration.

My telemetry survey over a recent 38-month period revealed many congregations of Lake Sturgeon in the NSR that are not protected by the Class 'A' classification. I defined congregations by 1km sections of the NSR (from Drayton Valley to the Alberta-Saskatchewan border) where 381 sections (75%) of 512 km of river had 8 or more telemetry detections. Class 'A' watercourses are intended to reduce the potential risks to Lake Sturgeon and their habitat by specifying certain approved activities and timings to avoid sensitive periods (e.g., spawning) as regulated by relevant Codes of Practice (e.g., Watercourse Crossings, Pipelines and Telecommunication Lines Crossing a Water Body; AENV 2001). The 10 current Class 'A' watercourses are protecting only 38 % (˜64 rkm) of Lake Sturgeon congregations. I consequently propose 10 new protective reaches to protect 75% (˜58 rkm) of Lake Sturgeon congregations (Fig. 5.1) which are strategically less of the river. To be precautionary, based upon the resolution of my telemetry data and the broad movements of these fish, the scale of these protective reaches are best measured in kilometers rather than meters (Table 5.2). As the NSR is currently regulated by upstream dams, the river exhibits strong channel fidelity and stability. My proposed protective reaches will provide improved protection for Lake Sturgeon. If large flooding events or near-stream construction occur (e.g., extensive gravel pits or channelization) and cause the river to realign, these new protective reaches will need to be reassessed.

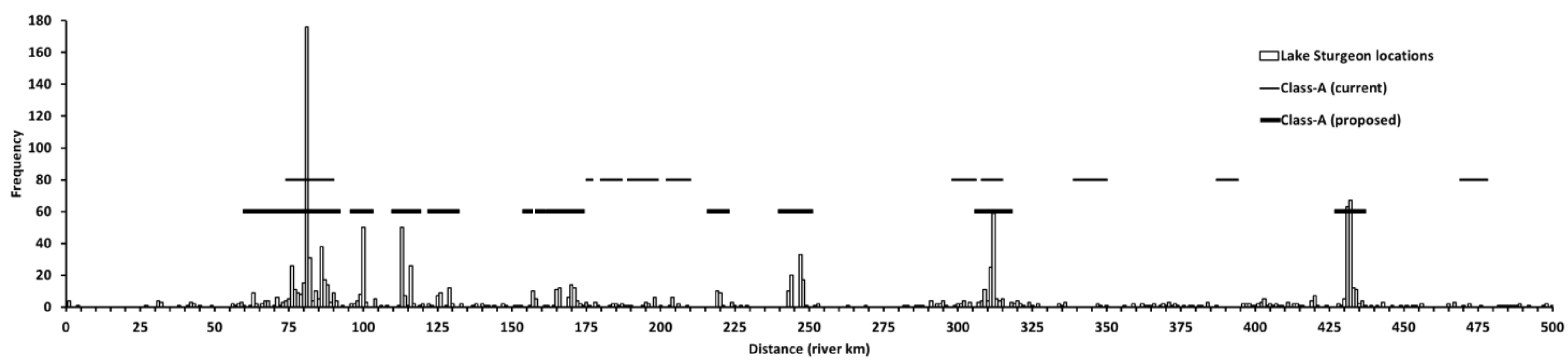

Figure 5.2. Denoted areas of protection of present and proposed Lake Sturgeon Class ‘A’ watercourses (horizontal lines) with telemetry locations of Lake Sturgeon (vertical bars). Measurement of distance begins at Drayton Valley, AB and ends at the Alberta-Saskatchewan border.

Table 5.2. —Proposed locations and lengths of Lake Sturgeon Class ‘A’ watercourses for protecting Lake Sturgeon habitat within the North Saskatchewan River, AB.

Proposed protective area	Length (km)	Location	Latitude (DD)	Longitude (DD)	Distance from Drayton Valley (rkm)
1	27	upstream	53.3805	-114.4064	63
		downstream	53.3711	-114.2503	90
2	1	upstream	53.3474	-114.1288	99
		downstream	53.3484	-114.1151	100
3	3	upstream	53.3417	-113.9703	113
		downstream	53.3372	-113.9196	116
4	4	upstream	53.3574	-113.8062	125
		downstream	53.3580	-113.7655	129
5	1	upstream	53.4891	-113.6181	157
		downstream	53.4844	-113.6054	158
6	6	upstream	53.5136	-113.5424	165
		downstream	53.5308	-113.5157	171
7	1	upstream	53.7582	-113.1683	219
		downstream	53.7674	-113.1691	220
8	5	upstream	53.8984	-112.9431	243
		downstream	53.9282	-112.8866	248
9	6	upstream	54.0597	-112.2261	309
		downstream	54.0221	-112.1789	315
10	4	upstream	53.8605	-110.9174	430
		downstream	53.8462	-110.8722	434

Conclusion

Under provincial angling regulations, all Lake Sturgeon captured in Alberta must be released, which is the primary tool for reducing harvest mortality. Therefore, I investigated the catch and release angling regulation to determine if the level of incidental mortality is inhibiting population recovery. I had found that mortality due to angling is negligible, only preventing the loss of a few fish per year and natural mortality is much higher. I believe that the current regulation of catch-release is adequate when the total catch of Lake Sturgeon remains relatively low. If research angling was eliminated, the catch by non-research angling would be < 4% of the Lake Sturgeon population, and preventing the death of a few fish. Therefore, to include bait bans and gear restrictions to the current regulation effecting non-research anglers will not overly contribute to the reduction of incidental mortality with little effect on Lake Sturgeon population dynamics. These types of restrictions are purely an ethics or public relations regulation, and will not overly contribute to achieving the goal of 100 year-old fish. However, if catch rates and subsequent mortality increases by an order of magnitude, fisheries management will have to consider alternate angling restrictions.

There is a reasonable expectation that protecting prime habitat would reduce natural mortality by preventing losses of fish due to stress and emigration from prime habitat into suboptimal habitat. I have identified 10 locations of prime Lake Sturgeon habitat through the use of telemetry surveys, and efforts to protect these locations against degradation and loss is in order to support Lake Sturgeon and inherent to the recovery goal. Therefore, I strongly support adjusting the current Class 'A' locations to protect high density Lake Sturgeon congregations and their habitat. Prime Lake Sturgeon congregations could come under siege due to development. If these locations are being developed, this would create stress on the Lake Sturgeon population. For example, if 5 out of 10 prime locations were lost to development, Lake Sturgeon would emigrate from those locations. Emigration equals mortality if individuals leave the province or are forced to reside in areas of less than optimal habitat causing death in response to increased stress. If there is an overall loss of individuals or long-term recruitment failures caused by degradation to spawning areas or to essential habitat can inhibit or prolong Lake Sturgeon recovery. The fact that Lake Sturgeon tend to relocate from place to place suggests that Lake Sturgeon have preferred areas of congregation, to which they exhibit site fidelity. My newly proposed locations of protection will provide a greater coverage of Lake Sturgeon habitat and act as source areas for fish production (e.g., potential spawning and foraging areas) thereby maintaining recruitment and reducing loss.

Thesis Summary

After improvements in water quality and two decades of harvest protection, it appears the North Saskatchewan River Lake Sturgeon population is now recovering in numbers; however, few adult fish support the population. I found that abundance and recruitment of young and mature fish has recently increased, although there is an underrepresentation of fish ≥ age-30 which suggests that the legacy of poor water quality and over harvest is still evident. I also found that growth rates in the NSR are comparable to the more productive South Saskatchewan River, and high in comparison to North American populations elsewhere, suggesting that abundance in the NSR remains below carrying capacity.

Although there have been previous studies of the Lake Sturgeon population in the Alberta section of the North Saskatchewan River (NSR), none have detailed the population's range, dispersal, and investigated twenty-one years of data. These details are necessary to assess the sustainability of the population through an examination of abundance, growth, recruitment, and mortality through age-class and abundance data. Lake Sturgeon population viability was believed to be questionable due to low population abundance, few adult fish, and seemingly low recruitment along with an ever increasing human population in Alberta.

Prior to prescribing management options for recovery, I believe that it is important to define population goals. I describe a recovered Lake Sturgeon population in the NSR as having 5,000 fish with an occasional fish achieving 100 years of age. One hundred years of age is approximately two thirds of the maximum reported age of Lake Sturgeon in Canada. Achieving this age will allow for multiple years of spawning and thus, population resilience. I developed a deterministic model to achieve this goal, and determined that total mortality could not exceed 5 %, yet my empirical data indicated that current levels of mortality are greater than 9%. I then evaluated sources of mortality to determine if angling is a significant contributor. I found that fishing mortality is low, and to further reduce mortality through restrictive options such as bait bans and gear restrictions would result in negligible benefit, and would therefore be unnecessary. Therefore, the only option left to aid in the continued recovery of Lake Sturgeon is to reduce natural mortality. I believe it to be reasonable that population recovery can be achieved through the protection of essential Lake Sturgeon habitat thereby reducing natural mortality.

Understanding Lake Sturgeon range, distribution and habitat use is an important consideration for fisheries conservation and management. Movement studies such as the present one improve knowledge of habitat use, movement timing, population mixing and dynamics, and finally provide opportunities to mitigate potential threats (Parsley et al. 2008, Van Wishingrad et al. 2014). Potential threats to NSR Lake Sturgeon are many, including chemical spills, breached surface mines, and nutrient releases that can cause incremental changes to habitat that could reduce survival. To help mitigate the future impacts of land use on Lake Sturgeon recovery, this study has identified the population extent of this species, including the seasonality of movements, and specific summer and overwintering locations.

Predicting important Lake Sturgeon habitat will also provide significant conservation and management opportunities for mitigation as considerable development is proposed e.g., bridge construction, outfalls, and intake facilities. My resource selection function model findings indicated that surrounding land classifications were not significant where Lake Sturgeon are not randomly distributed, but instead aggregate in several key areas. Although resource selection function values were not predictive of Lake Sturgeon occurrence, I would recommend using land-use classifications at a higher resolution, hydrological variables, and precise telemetry data which may improve these predictive models.

Aerial radio telemetry has identified significant areas of Lake Sturgeon congregations to and from summer and over-wintering locations. There appears to be various movement strategies for individual fish (from near-sedentary to highly mobile or migratory) into distinct summer and winter ranges. Lake Sturgeon also appear to use these through areas differentially, some sites are travel corridors while others may be continuously occupied for weeks or months. I also found that Lake Sturgeon exhibited high site fidelity throughout the seasons returning to the three areas from which they were originally identified. Maintaining the integrity of high use areas as identified through telemetry will protect a majority of high density Lake Sturgeon congregations and their habitat, thereby contributing to the recovery of Lake Sturgeon in the NSR.

I determined that only some of the areas frequented by Lake Sturgeon were protected by the Alberta Government's Class 'A' designations designed for the protection of Lake Sturgeon and their habitats. After reviewing Lake Sturgeon congregations during this study, I propose a more effective Class 'A' structure that encompasses less area overall. Effective habitat protection can reduce mortality rates by reducing emigration, disease, starvation, and predation. If prime habitat areas are inundated by development (e.g., water intake) and force the Lake Sturgeon out of these locations, Lake Sturgeon in a suboptimal environment would be vulnerable to the effects listed above. Although the links between habitat protection and mortality are complicated and difficult to quantify, these proposed areas of protection, if effective should reduce mortality rates.

I found that transmitter type, receiver altitude, flight direction, signal distance and transmitter depth affected either the detectability of transmitters or their estimated locations. Aerial telemetry has been regarded as an important tool to assess the survival, movement, behavior, and habitat use of fishes. However, the influence of signal attenuation through water can reduce radio transmitter detectability thereby affecting the interpretation of results of telemetry studies; transmitter depth, signal distance, and receiver altitude are only a few of the factors contributing to the efficiency of radio transmitter signals. For example, transmitters in deeper water were difficult to detect, leading to a conclusion that fish have little use for deep water. As the role of detection and estimated locations influenced my project, I found it necessary that my proposed areas of habitat protection be best measured in kilometer sections rather than meters. It is imperative for researchers to test the limits of their telemetry equipment prior to field surveys to determine how the role of detection will influence the outcome of their projects. I provide models for this purpose.

I found that the NSR Lake Sturgeon are capable of long-distance movements > 925 rkm. These movement are likely very important for colonization and genetic exchange. The subpopulation of the SSR and lower mainstem Saskatchewan fish are now isolated from their historic range due to impassable dams at Saskatoon, Nipawin, and Tobin Lake, Saskatchewan. A catastrophic event, such as a chemical spill from a pipeline, causing a loss of fish in the Alberta section of the NSR would similarly affect the population in the Saskatchewan section of the NSR. Recolonization through immigration from the larger lower mainstem populations downstream of the Saskatchewan Gardiner Dam will not be possible. Based on the large migrations recorded in my telemetry and tagging programs for the Lake Sturgeon in the NSR, it is critical that no further fragmentation of the population through dam construction should occur.

Critical to the conservation of a species is to understand its status, habitat use and sources of mortality. Gaining insight into the life history of this fish population can provide resource managers with options to recover Lake Sturgeon. It appears that current catch and release regulations have enabled the NSR population to respond in abundance, but further recovery is required with ongoing monitoring. Other management options such as bait bans and gear restrictions won't overly reduce angling mortality, due to the low number of Lake Sturgeon being caught. Certainly, the areas identified in my study for habitat protection will be more effective than the current Class 'A' areas at protecting congregations of Lake Sturgeon. According to Taylor et al. (2005: p. 362) "Species with critical habitat for two or more years appeared to be more likely to be improving and less likely to be declining than species without." Basic habitat requirements for most fishes is relatively unknown (Hutchings and Reynolds 2004), however, protecting areas of fish congregations is, at the least, a responsible and a precautionary approach to habitat protection.

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Appendix A: Derivation of detection probability when scanning multiple frequencies.

Let P_s be the probability of detecting a single 'beep' emitted by a radio transmitter and will depend on numerous factors including transmitter type (small versus large), transmitter depth, water conductivity, receiver distance and receiver altitude. If I keep these factors constant, the probability of detecting at least one 'beep' (i.e., probability of detection, P_{det}) is

$$P_{det} = 1 - P_{miss} \qquad (1)$$

where P_{miss} is the probability of missing all 'beeps' such that

$$P_{miss} = (1 - P_S)^S \qquad (2)$$

and S is the number of 'beeps' emitted while the receiver is within range (i.e., $P_S > 0$). Substituting equation (2) into (1) gives

$$P_{det} = 1 - (1 - P_S)^S. \qquad (3)$$

The variable S will depend on time (t) that the receiver is within range and the period (λ) between 'beeps'

$$S = \frac{t}{\lambda}. \qquad (4)$$

Time will depend on distance of the detection range (d) and velocity (v) of the receiver so equation (4) can be recast

$$S = \frac{d}{\lambda \cdot v}. \qquad (5)$$

If multiple frequencies are being scanned, S will be inversely proportional to the number of scanned frequencies (f)

$$S = \frac{d}{\lambda \cdot v \cdot f} \qquad (6)$$

assuming equal time is spent scanning each frequency. The maximum detection probability (P_{max}) will occur when $f = 1$ and can be written as

$$P_{max} = 1 - (1 - P_S)^{S_{max}} \qquad (7)$$

where $S_{max} = d/(\lambda v)$. I solved equation (7) for P_S to get

$$P_S = 1 - \sqrt[S_{max}]{1 - P_{max}} \qquad (8)$$

when substituted back into equation (3) gives

$$P_{det} = 1 - (1 - P_{max})^{\frac{1}{f}}\ . \qquad (9)$$