KEEYASK PROJECT

Generating Station

December 2012 Report # 11-02

Lake Sturgeon Population Estimates in the Keeyask Study Area: 1995 - 2011

Draft

ENVIRONMENTAL STUDIES PROGRAM

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Environmental Studies Program
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LAKE STURGEON POPULATION ESTIMATES IN THE KEEYASK STUDY AREA: 1995 - 2011

Draft Report Prepared for Manitoba Hydro

By

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OVERVIEW

In June 2012, the Keeyask Hydropower Limited Partnership (KHLP) filed an Environmental Impact Statement (EIS) in support of the Keeyask Generation Project, a 695 megawatt hydroelectric generating station (GS) that is proposed to be built at Gull Rapids on the Nelson River. An initial, intensive round of Keeyask environmental studies conducted between 1999 and 2006 provided the majority of the baseline information used in EIS descriptions of the existing environment and the predicted effects of the Project. Supplementary field studies were conducted starting in 2007 in order to: i) continue to collect long-term datasets on topics such as fish movements and mercury in fish flesh; and ii) address additional baseline information needs identified in the final phases of EIS preparation. Separate reports are being issued for each topic and for each year of updated long-term data.

This report presents methods used to develop, and results of, mark-recapture population studies on lake sturgeon in the Keeyask Study Area. Data on lake sturgeon populations in Gull Lake were first collected in 1995 by Manitoba Fisheries Branch in conjunction with the Split Lake Resource Management Board. From 2001 to 2011, lake sturgeon studies have been conducted annually in the Keeyask Study Area (Figure 1), which includes the Nelson River between the Kelsey GS and the Kettle GS, and the Burntwood River from First Rapids to Split Lake, including major tributaries in both river reaches. These sources of data were used to derive population estimates for two populations of lake sturgeon in the Keeyask Study Area. As part of these studies, individual lake sturgeon were marked with Floy-tags to facilitate the development of population estimates (mark-recapture) and a better understanding of lake sturgeon movements. The purpose of developing the population estimates is to monitor changes in lake sturgeon abundance prior to, during, and following construction and operation of the proposed Keeyask GS, and to assess the effectiveness of lake sturgeon mitigation measures.

TECHNICAL SUMMARY

In June 2012, the Keeyask Hydropower Limited Partnership (KHLP) filed an Environmental Impact Statement (EIS) in support of the Keeyask Generation Project (the Project), a 695 megawatt hydroelectric generating station (GS) that is proposed to be built at Gull Rapids on the Nelson River (Figure 1).

The Keeyask environmental studies program was designed to investigate and document interrelated components of the Burntwood, Nelson, Aiken, and Assean rivers as well as the associated lakes (Split, Stephens, Clark, Gull, and Assean). Investigations in support of the environmental assessment were undertaken from 1999 to 2006. Supplementary field studies were conducted starting in 2007 in order to: i) continue to collect long-term datasets on topics such as fish movements and mercury in fish flesh; and ii) address additional baseline information needs identified in the final phases of EIS preparation. Separate reports are being issued for each topic and for each year of updated long-term data.

The following report presents methods used to develop, and results of, population estimates derived for two populations of lake sturgeon (*Acipenser fulvescens*) in the Keeyask Study Area. Population estimates were developed for: 1) the Upper Split Lake Area population which includes lake sturgeon captured in the Burntwood River and tributaries between First Rapids and Split Lake, and the Nelson River and tributaries between the Kelsey GS and Split Lake; and 2) the lake sturgeon population existing in the Nelson River between Clark Lake and Gull Rapids. Population estimates were developed to monitor change in lake sturgeon abundance prior to, during, and following construction and operation of the Keeyask GS, and to assess the effectiveness of lake sturgeon mitigation measures.

Evidence from lake sturgeon movement and genetic studies conducted between 2001 and 2004 suggested that at least two populations of lake sturgeon exist in the Keeyask Study Area: (1) the Upper Split Lake Area lake sturgeon population; and (2) the Clark Lake to Gull Rapids population. Lake sturgeon from each population were captured in the spring over a five- to six-week sampling period during which they were marked with Floy-tags to facilitate the population estimates. Only lake sturgeon longer than 834 mm (fork length), and therefore reasoned to be adults, were included in the analysis. Local resource user tag returns were also included in the dataset to provide information on mortality and harvested lake sturgeon. Lake sturgeon that are marked contribute information to the estimation of recapture and survival parameters until they are removed from the population either by fishing mortality or resource harvest. A total of 480 individual lake sturgeon captured from 2001 - 2011 were used to estimate the Clark Lake to Gull Rapids population, while a total of 428 individuals were used to estimate the Upper Split Lake Area population. Lake sturgeon

marked during a study conducted in Gull Lake in 1995 by Manitoba Fisheries Branch and the Split Lake Resource Management Board (SLRMB) were also used to estimate the trajectory of the Clark Lake to Gull Rapids lake sturgeon population.

Mark-recapture data from both populations were analysed using Program MARK (White and Burnham 1999), an industry standard for the analysis of data from marked populations. To estimate population size, survival, and trajectory of Keeyask lake sturgeon populations, a hybrid model called Robust Design (Kendall 2001) was used which combines elements of closed and open population models. This model was selected because of the extended length of the time period involved (i.e., data collected over a 10+ year period), the variable spawning interval of lake sturgeon, and the potential for collection of additional long-term monitoring data that will be used to improve the precision of the estimate.

Mean local population estimates for lake sturgeon in the Clark Lake to Gull Rapids population were 141 for 2001, 119 for 2002, 190 for 2003, 166 for 2004, 440 for 2006, 222 for 2008, and 325 for 2010. Mean regional population estimates between 2001 and 2009 for the Clark Lake to Gull Rapids population ranged between 344 and 1,275. The model output indicated that survival was constant at 0.869, while immigration and emigration were random at 0.654, and probability of recapture varied between 0.087 and 0.469 among years. The results of the Burnham Lambda Jolly-Seber model for the Clark Lake to Gull Rapids population indicate similar values for survival at 0.919 for the 1995 tagging study and 0.851 for the present study (Table 8). The initial 1995 abundance estimate was 498 (95% CI: 280-936) lake sturgeon with a mean lambda (λ) of 1.01 (95% CI: 0.94-1.09).

Mean local abundance estimates for lake sturgeon on the spawning grounds for the Upper Split Lake population were 60 for 2001, 75 for 2002, 195 for 2005, 166 for 2006, 215 for 2007, 192 for 2009, and 259 for 2011. Mean regional population estimates for lake sturgeon in the Upper Split Lake population (2001 – 2009) ranged between 183 and 654. The model output indicated that survival was constant at 0.886, while immigration and emigration were random at 0.672, and recapture probability was variable among years (0.094 to 0.434). The results of the Burnham Lambda Jolly-Seber model for the Upper Split Lake population was 0.941, suggesting higher survival relative to the Clark Lake to Gull Rapids population. The initial 2001 abundance estimate was 306 (95% CI: 177-555) lake sturgeon with a mean λ of 1.1043 (95% CI: 1.02-1.19).

There were no clear trends (i.e., increasing or decreasing) in the population estimates for either the Clark Lake to Gull Rapids population or the Upper Split Lake population over time. However, the 95% confidence interval for the Lambda parameter (population growth) bound 1 for the Clark Lake to Gull Rapids population, and therefore, it is possible that lake sturgeon abundance in this area is in decline. The 95% confidence interval estimate for Lambda was slightly above 1 for the Upper Split Lake population.

Data used in this study reflect comparable effort over comparable time periods and across multiple years, and are typical of mark-recapture studies in fisheries science. The fluctuations in population estimates likely reflect a combination of annual variation in spring temperatures and discharges, the variable spawning intervals of lake sturgeon, and the variation in recapture probability of individual fish. The precision of these estimates tends to improve over time as more fish are added to the tagged population and as resource user tag returns become accounted for.

ACKNOWLEDGEMENTS

We would like to thank Manitoba Hydro for the opportunity and resources to conduct this study.

Chief and Council of Tataskweyak Cree Nation (TCN), York Factory First Nation (YFFN), and Fox Lake Cree Nation (FLCN) are gratefully acknowledged for their support of this program. We would also like to thank Ray Mayham of FLCN, Douglas Kitchekeesik and Clayton Flett of TCN, and Evelyn Beardy of YFFN for arranging logistic support and personnel needed to conduct the field work. Several members of TCN, YFFN, WLFN, and FLCN have worked on the project since 2001 and they are thanked for their local expertise and assistance in conducting the field work. Manitoba Conservation and Water Stewardship, Fisheries Branch, particularly Don MacDonald, are also thanked for logistical support.

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1.0 INTRODUCTION

In June 2012, the Keeyask Hydropower Limited Partnership (KHLP[1]) filed an Environmental Impact Statement (EIS) in support of the Keeyask Generation Project (the Project), a 695 megawatt hydroelectric generating station (GS) that is proposed to be built at Gull Rapids on the Nelson River (Figure 1).

Collection of baseline information on the aquatic environment required for an environmental impact assessment was initiated at the Project site in 1999. Manitoba Hydro expanded the program in 2001, and again in 2002, in response to concerns raised by the Keeyask Cree Nations to include a broader geographic area to better characterize all aspects of the environment that may be affected by development at Gull Rapids. This included the reach of the Nelson River between, and including, Split Lake to Stephens Lake, the Burntwood, Aiken, and Assean rivers, as well as the associated lakes (Split, Stephens, Clark, Gull, and Assean). Biological investigations conducted during the initial round of Keeyask Environmental Studies from 1999-2006 included measurements of physical habitat, water quality, detritus, algae, aquatic macrophytes, aquatic invertebrates, and fish.

Supplementary field studies were conducted starting in 2007 in order to: i) continue to collect long-term datasets on topics such as fish movements and mercury in fish flesh; and ii) address additional baseline information needs identified in the final phases of EIS preparation. Separate reports are being issued for each topic and for each year of updated long-term data.

The following report describes methods used to derive, and results of, population estimates for lake sturgeon (*Acipenser fulvescens*) in the Keeyask Study Area using data from 1995 to 2011, and is one of the reports produced for the Keeyask Environmental Studies Program.

1.1 BACKGROUND INFORMATION

Lake sturgeon currently inhabit the section of the Nelson River that would be impounded by the Keeyask GS, as well as environments immediately upstream and downstream. First Nations have identified lake sturgeon as a culturally important species. The lake sturgeon has been designated a heritage species in Manitoba and recently, western Canada lake sturgeon populations (i.e., those in Manitoba, Saskatchewan, and Alberta) have been assessed as "endangered" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2006). Presently, the lake sturgeon is under

[1] *The Keeyask Hydropower Limited Partnership is comprised of four limited partners and one general partner. The limited partners are Manitoba Hydro, Cree Nation Partners Limited Partnership (CNP; controlled by TCN and WLFN), York Factory First Nation Limited Partnership (controlled by YFFN), and Fox Lake Cree Nation Keeyask Investments Inc. (controlled by FLCN). The four Cree Nations together are referred to as the Keeyask Cree Nations (KCNs). The general partner is 5900345 Manitoba Ltd., a corporation wholly owned by Manitoba Hydro.*

consideration for listing under Schedule 1 of Canada's Species at Risk Act (SARA). Due to their cultural importance and COSEWIC status, lake sturgeon was selected as a key species for the Keeyask environmental impact assessment.

The first lake sturgeon tagging study conducted in the Nelson River between Birthday and Gull rapids was carried out by the Split Lake Resource Management Board and Manitoba Fisheries Branch in 1995. It focused on providing information on the relative abundance, size, age and condition of adult lake sturgeon in this reach of the Nelson River. Subsequent lake sturgeon studies were initiated in 2001 as part of the Keeyask Environmental Studies Program. These studies were conducted in three general areas including: 1) the Upper Split Lake Area (includes: the Nelson River between the Kelsey GS and Split Lake; the Grass River from Witchai Lake Falls to its confluence with the Nelson River; the Burntwood River from First Rapids to Split Lake; and the Odei River from First Falls to its confluence with the Burntwood River); 2) the Nelson River between Birthday Rapids and Gull Rapids; and 3) Stephens Lake (Nelson River between Gull Rapids and the Kelsey GS); and, in addition to providing information similar to the 1995 study, were focused on identifying spawning areas, relative numbers of lake sturgeon at potential spawning sites, and adult habitat use. During each of these studies, lake sturgeon were marked with Floy-tags to describe movement patterns, spatially delineate populations, and establish a mark-recapture database to facilitate population estimation. Adult lake sturgeon were also tagged with acoustic transmitters in the reach of the Nelson River between Clark Lake and the Kettle GS from 2001 to 2004 to better understand lake sturgeon habitat use and movements.

Following an initial analysis of movement information from mark-recapture and acoustic telemetry studies conducted from 2001 to 2004, it was determined that: lake sturgeon movements between the Upper Split Lake Area and the Nelson River from Clark Lake to the Kettle GS were rare, and sturgeon in these areas likely constitute two distinct populations; that lake sturgeon move between Gull Lake and Stephens Lake both upstream and downstream; and that the relative abundance of lake sturgeon in Stephens Lake is low.

Beginning in 2005, mark-recapture data were collected on a bi-annual basis from the Upper Split Lake Area population during odd numbered years and the Clark Lake to Gull Rapids population during even numbered years (Barth and Ambrose 2006; Barth and MacDonald 2008; MacDonald 2008; MacDonald 2009; MacDonald and Barth 2011; Hrenchuk and McDougall 2012). The objectives of these studies were to: 1) develop a population estimate for adult lake sturgeon from each population; 2) to estimate the trajectory of the populations over time; and 3) to further delineate lake sturgeon movements in the study area. Spring gillnetting studies were also conducted in Stephens Lake in 2005, 2006, 2010 and 2011 (Barth and MacDonald 2008; MacDonald 2008, MacDonald and Barth 2011; Hrenchuk and McDougall 2012) to increase the number of marked sturgeon in the area, further understand the importance of movement through Gull Rapids, and describe the relative number of lake sturgeon spawning in the vicinity of Gull Rapids.

Population estimates were developed for the Upper Split Lake Area lake sturgeon population and the Clark Lake to Gull Rapids lake sturgeon population using data collected during baseline environmental studies conducted from 2001 through 2011 (Barth and Mochnacz 2004; Barth 2005; Barth and Murray 2005; Barth and Ambrose 2006; Barth and MacDonald 2008; MacDonald 2008; MacDonald 2009; MacDonald and Barth 2011; Hrenchuk and McDougall 2012). Mark-recapture data from lake sturgeon in Stephens Lake were not used in development of the population estimate for the Clark Lake to Gull Rapids population as it is unknown if lake sturgeon in Stephens Lake constitute a separate population (primarily due to low numbers of lake sturgeon captured). To estimate the trajectory (i.e., increasing, stable, or decreasing) of each population, data collected during the studies cited above were used for the Upper Split Lake population, and mark-recapture collected by Manitoba Fisheries Branch in 1995 were used in addition to the studies cited above for the Clark Lake to Gull Rapids population.

This report describes the methods and data used to derive population estimates and estimate survival rate and trajectory of two lake sturgeon populations in the Keeyask Study Area. Results for each population are presented.

2.0 THE KEEYASK STUDY SETTING

2.1 STUDY AREA

The Keeyask Study Area includes the reach of the Nelson River from Kelsey GS to Kettle GS, including Split, Clark, Gull, and Stephens lakes; the Burntwood River downstream of First Rapids; the Grass River downstream of Witchai Lake Falls; the Assean River watershed, including Assean Lake; and all other tributaries to the above stated reach of the Nelson River (Figure 1).

The entire Study Area lies within the High Boreal Land Region characterized by a mean annual temperature of –3.4°C and an annual precipitation range of 415 to 560 mm. Topography is bedrock controlled overlain with fine-grained glacio-lacustrine deposits of clays and gravels. Depressional areas have peat plateaus and patterned fens with permafrost present. Black spruce/moss/sedge associations are the dominant vegetation (Canada-Manitoba Soil Survey 1976).

Split Lake, which is immediately downstream of the Kelsey GS at the confluence of the Burntwood and Nelson rivers, is the second largest water body in the Study Area. Due to the large inflows from the Nelson and Burntwood rivers, the lake has detectable current in several locations. Split Lake has maximum and mean depths of 28.0 m and 3.9 m, respectively, at a water surface elevation of 167.0 m above sea level (ASL; Lawrence et al. 1999). The surface area of Split Lake was determined to be 26,100 ha (excluding islands), with a total shoreline length, including islands, of 940.0 km (Lawrence et al. 1999). The numerous islands in Split Lake represent 411.6 km of the total shoreline.

The reach of the Nelson River between Split Lake and Stephens Lake is characterized by: i) narrow sections with swiftly flowing water (including Long, Birthday, and Gull rapids); and ii) wider more lacustrine sections, including Clark and Gull lakes. Mean winter flow in the reach is 3,006 m^3/s and mean summer flow is 2,812 m^3/s (Manitoba Hydro 1996a).

The Assean River system is north of Split Lake and drains into Clark Lake (Figure 1). Except for the mouth of the Assean River, the hydrology of the watershed has not been affected by hydroelectric development.

Stephens Lake, the largest lake in the Study Area, is located downstream of Gull Rapids and was created through the development of the Kettle GS (est. 1974). Stephens Lake has a surface area of 29,930 ha (excluding islands) and a total shoreline length, including islands, of 740.8 km. The numerous islands encompass an area of 3,340 ha and 336.2 km of shoreline. There is no detectable current throughout most of this large lake, except for the old Nelson River channel.

Communities in the Study Area include the First Nations communities of Split Lake (TCN) and York Landing (YFFN), both located on Split Lake (Figure 1). Members of WLFN reside in Ilford south of the Nelson River while some members of FLCN reside in Gillam on the south shore of Stephens Lake. Gillam is the largest community in the Study Area and is the regional headquarters for Manitoba Hydro's northern operations.

The names assigned to some of the features described in Section 2.3 and illustrated in Figure 1 may be inconsistent with local names, topographic maps, and/or the Gazetteer of Canada. When field programs were initiated in spring, 2001, names of several features within the Study Area were unknown to North/South Consultants Inc. (NSC) biologists and First Nation assistants. Therefore, some features for which no name was known were assigned names by field personnel. Chief and council of TCN, YFFN, WLFN, and FLCN or the Canadian Permanent Committee on Geographical Names have not approved names of features described within this document.

2.2 PREVIOUS HYDROELECTRIC DEVELOPMENT

The Study Area is bounded by two Manitoba Hydro hydroelectric generating stations on the Nelson River: the Kelsey GS just upstream of Split Lake and Kettle GS downstream of Stephens Lake. The Kelsey GS came into service in 1961 and is operated as a run-of-river plant with very little storage or re-regulation of flows (Manitoba Hydro 1996a).

The Kettle GS was completed in 1970 and raised the water level at the structure by 30.0 m and created a backwater effect upstream to Gull Rapids. Approximately 22,055 ha of land were flooded in creating Stephens Lake (Manitoba Hydro 1996a). Kettle GS is operated as a peaking-type plant, cycling its **forebay**[2] on a daily, weekly, and seasonal basis. The forebay is operated within an annual water level range of 141.1 m to 139.5 m ASL (Manitoba Hydro 1996a).

Since 1976, two water management projects, the Churchill River Diversion (CRD) and Lake Winnipeg Regulation (LWR), have influenced water levels and flows within the Study Area. These two projects augment and alter flows to generating stations on the lower Nelson River by diverting additional water into the drainage from the Churchill River (CRD) (Manitoba Hydro 1996b) and managing outflow from Lake Winnipeg (LWR). The CRD and LWR projects reversed the Nelson River pre-Project seasonal water level and flow patterns in the Keeyask Study Area by increasing water levels and flow during periods of ice cover and reducing flows during the open-water period. Overall, there has been a net increase of 246 m^3/s in average annual flow at Gull Rapids since CRD and LWR (Manitoba Hydro 1996a). The historic and current flow regimes are described in "History and First Order Effects, Split Lake Cree Post-Project Environmental Review", Volume Two (Manitoba Hydro 1996a).

[2] *Definitions for words appearing in bold are provided in the glossary (see Section 5.0).*

2.3 REPORT-SPECIFIC STUDY AREA

2.3.1 Kelsey GS Area

The Kelsey GS is located on the upper Nelson River in northern Manitoba, approximately 137 km upstream of the Kettle GS. Kelsey GS was completed in 1961 and was the first hydroelectric station built on the Nelson River. The Kelsey GS powerhouse and spillway are located on the west and east shores, respectively, of the Nelson River and are separated by an island. Downstream of the GS there is an approximately 5 km long reach of the Nelson River, characterized by predominantly fast moving water, with rocky shoreline and substrate, after which the Nelson River splits into two channels around a large island. Each channel contains a set of rapids: the Anipitapiskow Rapids (~ 7.0 km north of the GS on the north channel) and Sakitowak Rapids (~ 10.0 km north east of the GS on the south channel). Both channels empty into Split Lake at the base of the rapids.

2.3.2 Burntwood River

The Burntwood River flows swiftly in a north-easterly direction from First Rapids (Unetoianumayo Rapids) for approximately 35 km prior to emptying into the western arm of Split Lake. Under high flow conditions, these rapids appear to be a natural barrier to upstream fish passage. Shorelines in this stretch are dominated by moderately sloping bedrock, which is often overlaid by fine sediments near First Rapids and becomes increasingly exposed towards Split Lake. Hard substrates predominate in the main channel, while loose fine sediments and associated macrophyte growth occur in many off-current areas. The hydrology of the Burntwood River has been affected by the Churchill River Diversion (CRD). Outflow from the Burntwood River to Split Lake prior to CRD was estimated at 90.0 m^3/s at First Rapids, and increased nearly 10-fold following diversion to 849.0 m^3/s.

2.3.3 Split Lake to Birthday Rapids

Split Lake is located along the Nelson River approximately 7 km downstream of Kelsey GS. The Aiken (Landing) River enters Split Lake in the southern-most portion of the lake adjacent to the community of York Landing. The Ripple and Mistuska rivers enter Split Lake along the southern shore west of Aiken River.

Split Lake is situated in a landscape with poor drainage, dominated by black spruce forest in upland areas and black spruce bogs, peatlands, and fens in lowland areas. The shoreline is stable and largely bedrock-controlled interspersed with bog and marsh areas. **Riparian** vegetation includes willow, alder, black spruce, and trembling aspen. Riparian vegetation extends to the water line along portions of the shoreline. Mineral and organic soils occur adjacent to Split Lake, with sporadically distributed permafrost (Agriculture and Agri-Food Canada 2003). Lake substrates are primarily composed of fine mineral sediments (clay and silt) with small amounts of organic material. Ice typically forms on the lake during November and break-up occurs in April. Following break-up, the surface of the lake warms to 20°C by mid-July.

As discussed in Section 2.2, Split Lake hydrology has been affected by both LWR and CRD. Split Lake receives its largest inflow from the Nelson River, with an annual average discharge at Kelsey GS of 2,150 m^3/s, about 68% of the total inflow for Split Lake. Inflow from the Burntwood River prior to CRD was historically estimated at 90m^3/s at First Rapids, and following CRD increased nearly 10-fold to 849.0 m^3/s or about 29% of inflow to Split Lake (Manitoba Hydro 1996b). This large increase in river discharge resulted in extensive erosion of clay and silt sediments along the existing shoreline at First Rapids, as well as increased the surface area of Split Lake by approximately 100 ha (Environment Canada and Department of Fisheries and Oceans 1992; Manitoba Hydro 1996b). The Grass River watershed, which is not affected by hydroelectric development, has an average annual discharge of 66.5 m^3/s at Standing Stone Falls (approximately 40 km upstream of Witchai Lake Falls). The remainder of the inflow to Split Lake is from the Aiken (Landing) River and other small tributaries such as the Ripple and Mistuska rivers.

The land adjacent to Clark Lake and the Nelson River downstream to Birthday Rapids is well drained and dominated by black spruce forest, with stands of trembling aspen sporadically distributed. Mineral soils are predominant in the area with permafrost distributed sporadically and bedrock outcrops near Birthday Rapids (Agriculture and Agri-Food Canada 2003).

Clark Lake is located immediately downstream of Split Lake, and approximately 42 km upstream of Gull Rapids on the Nelson River. Current is restricted to the main section of the lake, with off-current bays outside the main channel. Lake substrates are composed of fine mineral sediments and areas of bedrock. The shoreline is stable and largely bedrock with areas of mineral and organic sediments. Riparian vegetation includes willow, alder, and black spruce. Aquatic vegetation is restricted to, and abundant in, shallow off-current bays. The Assean River is the only major tributary to Clark Lake, flowing into the north side of the lake. Two small **ephemeral** creeks also flow into the north shore of Clark Lake.

Downstream from the outlet of Clark Lake, the Nelson River narrows and water velocity increases significantly for a 3 km stretch, with numerous rapids (Long Rapids) that are largely confined within bedrock shorelines. The substrate and shoreline features of this section of the river are largely bedrock and boulder/cobble. For the next 7 km the river widens, velocity decreases, and fine sediments become predominant. Five small ephemeral creeks drain into the Nelson River between Clark Lake and Birthday Rapids.

2.3.4 Birthday Rapids to Gull Lake

The majority of the reach of the Nelson River between Birthday Rapids and Gull Lake lies within a landscape of well-drained mineral soils, dominated by black spruce forest. Immediately upstream of Gull Lake, the land adjacent to the south shore of the Nelson River is generally poorly drained, and is dominated by organic soils, and black spruce bogs, peatlands, and fens. Trembling aspen occurs occasionally along the shores of the Nelson River in areas that are well-drained. Exposed bedrock occurs along the north shore and upstream portions of the south shore of the Nelson River, particularly within the first 2 km downstream of Birthday Rapids. Permafrost is discontinuous to sporadic in this section of the river (Agriculture and Agri-Food Canada 2003).

Birthday Rapids is located approximately 10 km downstream of Clark Lake and 30 km upstream of Gull Rapids on the Nelson River. The drop in elevation from the upstream to downstream side of Birthday Rapids is approximately 5 m. The 14 km reach of the Nelson River between Birthday Rapids and Gull Lake is characterized as a large, somewhat uniform channel with medium to high water velocity. A series of exposed shoals and boulders are located within the first 7 km downstream of Birthday Rapids, after which run habitat dominates the river. There are a few large bays with reduced water velocity and a number of small tributaries that drain into the Nelson River between Birthday Rapids and Gull Lake. River bottom substrates are typically bedrock, boulder, cobble, and sand, with some fine sediment in areas with reduced current. The shoreline in this section of the river contains large sections of bedrock and some areas of fine sediments. Riparian vegetation includes willow, alder, black spruce, tamarack, and trembling aspen. Aquatic vegetation is restricted to bays that are removed from the major river current.

2.3.5 Gull Lake to Gull Rapids

Gull Lake is situated within a landscape of well-drained mineral soils, dominated by black spruce forest. Trembling aspen occurs sporadically along the shores of Gull Lake and in areas that are well drained. Permafrost is sporadically distributed along this section of the river (Agriculture and Agri-Food Canada 2003).

Gull Lake is a section of the Nelson River where the river widens and is lacustrine in nature with moderate to low water velocity featuring numerous bays. Gull Lake is herein defined as the reach of the Nelson River beginning approximately 17 km upstream of Gull Rapids and 14 km downstream of Birthday Rapids, where the river widens to the north into a bay around a large point of land, and extending downstream to the downstream end of Caribou Island, approximately 3 km upstream of Gull Rapids. Gull Lake has three distinct basins, the first extending from the upstream end of the lake downstream approximately 6 km to a large island; the second extending from the large island to Morris Point (a constriction in the river immediately upstream of Caribou Island); and the third extending from Morris Point to the downstream end of Caribou Island. Water velocity in the third basin is somewhat faster than in the first two, particularly under low flow scenarios, as the river channel flows around Caribou Island. Gull Lake has numerous small tributaries, with the majority being ephemeral. Lake substrates are predominantly silt and sand with some cobble and boulder in the first two basins where current is slow, and predominantly cobble, boulder, and bedrock in the third basin, with soft substrates in off-current areas. Riparian vegetation includes willow, alder, black spruce, tamarack, and trembling aspen. Aquatic vegetation is restricted to bays that are removed from the major river channel.

The landscape between Gull Lake and Gull Rapids consists of well-drained mineral soils, with bedrock outcrops. Black spruce is the dominant forest cover, with trembling aspen occurring sporadically along the shore. Permafrost is sporadically distributed adjacent to this section of the river (Agriculture and Agri-Food Canada 2003).

This 3 km reach of the Nelson River is characterized by a steep gradient with high water velocity. The river channel is separated into two by a large island at the upstream end of Gull Rapids. The substrate is bedrock, boulder, and cobble with small amounts of clay and silt in off current bays. Aquatic vegetation is restricted to a bay on the south shore.

2.3.6 Gull Rapids

Gull Rapids is located approximately 3 km downstream of Caribou Island on the Nelson River (Figure 1). Two large islands and several small islands occur within the rapids, prior to the river narrowing. The rapids are approximately 2 km in length, and the river elevation drops approximately 19 m from the downstream end of Gull Lake to the downstream end of Gull Rapids. The substrate and shoreline of Gull Rapids are composed of bedrock and boulders. One small tributary flows into the south side of Gull Rapids, approximately 1 km downstream from the upstream end of Gull Rapids.

2.3.7 Stephens Lake

The land bordering Stephens Lake includes areas of poor, moderate, and well-drained soils, dominated by black spruce forest in upland areas and black spruce bogs, peatlands, and fens in lowland areas. Trembling aspen occurs sporadically along the shoreline of Stephens Lake in areas that are well-drained. Soils are predominantly organic along the north shore, but include a section of mineral soil surrounding the north arm, and both mineral and organic soils along the south shore. Permafrost is discontinuous and sporadic, and exposed bedrock occurs at the west end of the lake (Agriculture and Agri-Food Canada 2003).

As discussed in Section 2.2, construction of the Kettle GS resulted in extensive flooding immediately upstream of the GS. Moose Nose Lake (north arm) and several other small lakes that previously drained into the Nelson River became continuous with the Nelson River to form Stephens Lake. Flooded terrestrial habitats compose a large portion of the existing lake substrates, and include organic sediments as well as areas of clay and silt. Woody debris is abundant due to the extensive flooding of treed areas. Outside the flooded terrestrial areas, substrates are dominated by fine clay and silt. Sand, gravel, and cobble, and areas of organic material dominate the shoreline, with much of the shoreline being prone to erosion. Riparian vegetation includes willow, alder, black spruce, tamarack, and scattered stands of trembling aspen.

Major tributaries of Stephens Lake include the North and South Moswakot rivers that enter the north arm of the lake. The only other major tributary of Stephens Lake was the Butnau River. However, during construction of the Kettle GS, an earth dyke was constructed at the inlet of the Butnau River at Stephens Lake, and a channel developed to divert the Butnau River through Cache Lake into the Kettle River (Manitoba Hydro 1996a). Looking Back Creek is a second order ephemeral stream that drains into the north arm of Stephens Lake.

3.0 METHODS

3.1 POPULATION DELINIATION

Populations of lake sturgeon in the Keeyask Study Area were delineated using a combination of results from movement studies conducted in the Keeyask Study Area between 2001 and 2011 and genetics analyses presented in Côté et al. (2011). Evidence from lake sturgeon movement studies suggested that at least two populations of lake sturgeon exist in the Keeyask Study Area: (1) the Upper Split Lake Area lake sturgeon population; and (2) the Clark Lake to Gull Rapids population. Data suggested that lake sturgeon rarely moved between the Upper Split Lake Area and the Nelson River downstream of Clark Lake. Questions remained, however, whether lake sturgeon in Stephens Lake could be considered a third population. Data indicated that a proportion of lake sturgeon in the area moved both upstream and downstream through Gull Rapids. However, ultimately, the number of lake sturgeon captured in gillnets in Stephens Lake was too low to provide enough information to make this determination.

Further evidence to support the notion that the Upper Split Lake Area lake sturgeon population is distinct from the Clark Lake to Gull Rapids population was provided in Côté et al. (2011). In this study, tissue samples were collected from seven spawning sites on the Nelson River and one spawning site on each of the Churchill and Hayes rivers. Results suggested the existence of five genetically distinct management units including: Sipiwesk Lake; the Upper Split Lake Area; Clark Lake to Kettle GS; the Lower Nelson River/Hayes River; and the Churchill River. Specifically, results indicated that there is genetic differentiation between the Upper Split Lake Area sturgeon population and the Clark Lake to Gull Rapids sturgeon population.

Based on the lack of lake sturgeon movement between the Upper Split Lake Area and the Clark Lake to Gull Rapids reach of the Nelson River, and genetic differences between lake sturgeon living in these areas (Côté et al. 2011), it was determined that the lake sturgeon in these reaches exist as behaviourally isolated populations and therefore population estimates should be derived for each. Between 2001 and 2011, 110 lake sturgeon were captured during spring gillnetting conducted in Stephens Lake. However, as of 2011, it remains unknown whether lake sturgeon in Stephens Lake can be considered a distinct population from sturgeon living between Clark Lake and Gull Rapids, and as such, mark-recapture information from lake sturgeon captured in Stephens Lake was not included in development of the population estimates. Further, the number of lake sturgeon captured in Stephens Lake is too low to provide an accurate abundance estimate, if indeed the Stephens Lake population was to be considered distinct.

3.2 DESCRIPTION OF MARK-RECAPTURE DATASET

As previously discussed, mark-recapture data collected during baseline environmental studies conducted from 2001 through 2011 (Barth and Mochnacz 2004; Barth 2005; Barth and Murray 2005; Barth and Ambrose 2006; Barth and MacDonald 2008; MacDonald 2008; MacDonald 2009; MacDonald and Barth 2011; Hrenchuk et al. 2012) were used to develop a population estimate for the Upper Split Lake Area sturgeon population and the Clark Lake to Gull Rapids sturgeon population.

A total of 480 individual lake sturgeon captured from 2001 - 2011 were used to estimate the Clark Lake to Gull Rapids population, while a total of 428 individuals were used to estimate the Upper Split Lake Area population (Figure 1). Only lake sturgeon larger than 834 mm (fork length), and therefore reasoned to be adults, were included in the analysis. This length was selected as it was the length of the smallest mature lake sturgeon captured in the Keeyask Study Area from 2001 – 2011. All of the lake sturgeon included in the analyses were captured in the spring over a five- to six-week sampling period. Local resource user tag returns were also included in the dataset to provide information on mortality and harvested lake sturgeon. Harvested lake sturgeon contribute to the estimation of recapture and survival parameters until they are removed from the population. In total, 29 tags were returned from lake sturgeon harvested in the Clark Lake to Gull Rapids reach, representing about 6.0% of the 480 tags applied across all years, while 10 tags were received from the Split Lake reach, representing 2.3% of the 428 tags applied across all years.

Lake sturgeon marked during the study conducted in Gull Lake in 1995 by Manitoba Fisheries Branch and the Split Lake Resource Management Board (SLRMB) were only used to estimate the trajectory of the Clark Lake to Gull Rapids lake sturgeon population. These data were included in the estimate of the population trajectory because they provide a long-term survival estimate. However, because lake sturgeon captured in 1995 were tagged with a different type of tag, and because a different time frame exists between sampling (mark-recapture) periods, they were not included in the data used to derive population estimates for the Clark Lake to Gull Rapids population.

3.3 POPULATION ESTIMATION OF ADULT-SIZED LAKE STURGEON

Mark-recapture data were collected over a five- to six-week sampling period during the spring of each study year. Each year of study was divided into spawning (1) and post-spawning (2) intervals. Generally, the spawning and post-spawning intervals were defined based on water temperature data. For example, a river mainstem water temperature of 14°C was used to define the end of the spawning interval. In order to analyze the mark-recapture dataset, an encounter history was constructed for each tagged fish based on spawning (1) and post-spawning (2) intervals for each year of study.

Several example encounter histories are provided in Table 1. Lake sturgeon with tag #47106 was first captured during the spawning period in 2001, recaptured during the spawning period in 2006, and not seen since but is presumed to be alive, as denoted by the 1 in the record column. Lake sturgeon with tag #47107 was first tagged during the spawning period in 2001, recaptured during the spawning period in 2003, and harvested during the post-spawning period of 2003, as denoted by the -1 in the record column (Table 1). Encounter histories were then analysed using Program MARK (White and Burnham 1999), which is an industry standard for the analysis of data from marked populations. Program MARK uses the cumulative pattern of 0's and 1's to generate a probability distribution of tag recaptures which form the basis for population estimation, while values of -1 allow the fish capture history up to the known date of death to be included.

Several different population model variants exist, but most can be classified as either closed or open models. Closed models assume there are no births, deaths, immigration, or emigration between sample periods, while open models assume that these processes occur. To estimate population size, survival, and trajectory of Keeyask lake sturgeon populations, a hybrid model called Robust Design (Kendall 2001) was used which combines elements of closed and open population models. This model was selected because of the extended length of the time period involved (i.e., data collected over a 10+ year period), the variable spawning interval of lake sturgeon, and the potential for collection of additional long-term monitoring data that will be used to improve the precision of the estimate. The key difference between the Robust Design and a classic open model (e.g., Jolly-Seber model) is that there may be multiple secondary samples (i.e., capture occasions) within each primary sample (i.e., each year of sampling) (Figure 2). The population is assumed closed (i.e., no births, death, immigration, or emigration occurs) between secondary sampling events within a given year because they are spaced so closely in time, while the population is assumed open between primary sampling events. The closed part of the model allows both an estimate of mean local abundance (*N;* population estimate) and the probability that an animal is captured (*p*) at least once during the secondary samples, termed the probability of recapture. The mean local abundance estimate reflects the number of adult-sized lake sturgeon in the sample area during the study period.

The open part of the model is the time between primary sample occasions (or spawn occasions in this study). This period is long enough that gains (births and immigration) and losses (deaths and emigration) to the population do occur, and therefore the primary samples are used to estimate survival, emigration, and immigration parameters similar to a classic open model. The immigration and emigration parameters measure the degree of movement and detection among years, and provide an estimate of the proportion of lake sturgeon temporarily available for capture. Immigration and emigration (gamma' and gamma") are modeled as either **random** or **markovian** (see Figure 3).

Under the Robust Design model, the population is assumed to be closed between secondary sample occasions and open between primary sample occasions (Figure 2). Because population estimates may be subject to violations of the closure assumption between the primary and secondary sampling periods, the closure assumption was tested using the CloseTest application (Stanley and Burnham 1999). The CloseTest application is a statistical software package (Stanley and Burnham 1999) that uses the Chi-squared statistic to test the Jolly-Seber model against no mortality (NM) and no recruitment (NR), both of which indicate a violation of the closure assumption. Therefore, two separate Chi-squared tests were used to test the closure assumption, one testing for additions to the population between time j and time j+1, and one testing for losses from the population between time j-1 to time j. However, mark-recapture estimates for lake sturgeon may be confounded by variables such as spawning periodicity (not completely understood for these populations), inter-annual variation in river flows (which may affect catch efficiency in gillnets), and levels of resource harvest during the spring (the typical period during which lake sturgeon are harvested). For this reason, tests for statistical significance were considered at alpha 0.01.

3.4 LAKE STURGEON POPULATION TRAJECTORY

To assess the long-term trend in abundance, a Burnham Lambda variant of the Jolly-Seber model was run to estimate both abundance and population growth. This particular variant of the Jolly-Seber estimates new individuals added to the population indirectly by modeling the rate of population growth (lambda; λ) between time intervals. The Lambda parameter provides a measure of population growth since the first year, with values <1 indicating population decline, a value of 1 indicating equilibrium, and values >1 indicating population growth. Formulations to assess λ were developed by Burnham (1991) and Pradel (1996). The difference between the two variants is that the Pradel-λ method is conditional upon individuals being seen, while the Burnham method is not. The Burnham Jolly-Seber method thus includes an estimate for population size at first time period. Therefore, as previously discussed, the mean local population estimates reflect the number of adult-sized lake sturgeon in the sample area during the study period, however, the mean regional population estimate for any single time period is the mean local abundance estimate divided by 1-gamma (immigration/emigration). Thus, the smaller gamma, the closer the local abundance estimate reflects the regional population size. Akaike's information criterion is a standard model selection tool that weights models based on their fit with the average model and selects the best model based on information theory. This tool was used to select the model that described the best fit with the data from each population.

As previously discussed, the 1995 Split Lake Resource Management Board (SLRMB) tags were included in the analyses for the Clark Lake to Gull Rapids population to assess survival and population growth.

4.0 RESULTS

4.1 TESTING MODEL ASSUMPTIONS

Prior to derivation of population estimates, the Robust Design model was tested to determine if the closure assumption (the assumption that the population remains closed between secondary sampling periods) was violated. Two CloseTest application statistical tests (one testing for additions to the population, the other testing for losses from the population), using data from both populations, were used to test for violations of the closure assumption.

4.1.1 Clark Lake to Gull Rapids Population

For the Clark Lake to Gull Rapids population, subcomponent statistics from the CloseTest application for additions to the population indicated that with the exception of 2006, post-spawn occasions have lower *p*-values than spawn occasions for all years (Table 2). This indicates that there was a greater probability that lake sturgeon were added to the local population between years as opposed to within the same sampling year. Further, subcomponent statistics from the CloseTest application for losses from the population indicated that with the exception of 2002, spawn occasions generally have lower *p*-values than post-spawn occasions (Table 3), indicating that there was a greater probability that sturgeon were lost from the population between years, as opposed to within the same sampling year. These patterns are expected under the Robust Design model.

It should be noted that between post-spawn occasion 2004 and spawn occasion 2006, there were losses from the population that are considered significant while the population model was considered open (p=0.0000) (Table 3). This was due to a relatively large number of tagged fish being harvested from the population, resulting in significant losses to the population during this time period.

4.1.2 Upper Split Lake Population

For the Upper Split Lake population, subcomponent statistics from the CloseTest model for additions to the population indicated that post-spawn occasions for which sufficient data existed had a lower *p*-value than spawn occasions in 2006 only (Table 4). This suggests that lake sturgeon were added to the population between sampling events, thus violating the closure assumption for two of the three years in which sufficient data existed to test this assumption. Between spawn occasion 2009 and post-spawn occasion 2009, there were additions to the population that are considered significant (p = 0.0000), while the population was assumed closed under Robust Design. Subcomponent statistics from the CloseTest model for losses from the population indicated that spawn occasions often had lower *p*-values than post-spawn occasions, with the exception of 2005 (Table 5), suggesting that the closure assumption was violated in one of five tests. A single test was considered significant at alpha = 0.01 and indicated there were losses from the population between post-spawn 2007 and spawn 2009 (Table 5). Similar to the Clark Lake to Gull Rapids population, a relatively high number of tags were returned from local resource harvesters during this time period.

4.2 POPULATION ESTIMATION OF ADULT-SIZED LAKE STURGEON

4.2.1 Clark Lake to Gull Rapids Population

Mean local population estimates for lake sturgeon in the Clark Lake to Gull Rapids population were 141 for 2001, 119 for 2002, 190 for 2003, 166 for 2004, 440 for 2006, 222 for 2008, and 325 for 2010 (Table 6). Mean regional population estimates between 2001 and 2009 in the Clark Lake to Gull Rapids population ranged between 344 and 1,275 (Table 6). Based on Akaike's Information Criteria, the model output indicated that survival was constant at 0.869, while immigration and emigration were random at 0.654, and probability of first capture varied between 0.087 to 0.469 among years (Table 6).

4.2.2 Upper Split Lake Population

Mean local abundance estimates for lake sturgeon on the spawning grounds for the Upper Split Lake population were 60 for 2001, 75 for 2002, 195 for 2005, 166 for 2006, 215 for 2007, 192 for 2009, and 259 for 2011 (Table 7). Mean regional population estimates for lake sturgeon in the Upper Split Lake population ranged between 183 and 654 (Table 7). The model output indicated that survival was constant at 0.886, while immigration and emigration were random at 0.672, and probability of first capture was variable between 0.094 to 0.434 among years (Table 7).

4.3 LAKE STURGEON POPULATION TRAJECTORY

4.3.1 Clark Lake to Gull Rapids Population

The results of the Burnham Lambda Jolly-Seber models for the Clark Lake to Gull Rapids population indicate values for survival at 0.919 for the 1995 tagging study and 0.851 for the present study (Table 8). The initial 1995 abundance estimate was 498 (95% CI: 280-936) lake sturgeon with a mean λ of 1.01 (95% CI: 0.94-1.09), indicating this population could be stable or in a decline, or at minimum it has experienced variable or inconsistent recruitment since 1995.

4.3.2 Upper Split Lake Population

The results of the Burnham Lambda Jolly-Seber model for the Upper Split Lake population (0.941) indicate higher survival relative to the Clark Lake to Gull Rapids population (Table 9). The initial 2001 abundance estimate was 306 (95% CI: 177-555) lake sturgeon with a mean λ of 1.1043 (95% CI: 1.02 -1.19), indicating this population has been growing and/or recruiting since 2001.

4.4 INTERPRETATION OF ESTIMATES

There were no clear trends in the population estimates for either the Clark Lake to Gull Rapids population or the Upper Split Lake population over time (i.e., increasing or decreasing). The Lambda parameter provides a measure of population growth since the first year, with values <1 indicating population decline, a value of 1 indicating equilibrium, and values >1 indicating population growth. Because the 95% confidence interval for the Lambda estimate bound 1 for the Clark Lake to Gull Rapids population, it is possible that lake sturgeon abundance in this area is in decline; however, results are confounded by the time lag between 1995 and 2001 and the fact that different tags were used in 1995, both of which may contribute to increased variability in abundance among years.

Data used in this study reflect comparable effort over comparable time periods across multiple years and are typical of mark-recapture studies in fisheries science. The fluctuations in population estimates likely reflect a combination of annual variation in spring temperatures and discharges, the variable spawning intervals of lake sturgeon, and the variation in recapture probability of individual fish. The precision of these estimates tends to improve over time as more fish are added to the tagged population and as resource user tag returns become accounted for.

4.5 FUTURE RESEARCH

The following comments are provided in support of continuing these bi-annual lake sturgeon population studies in the Keeyask Study Area:

- A decision on whether the Nelson River lake sturgeon populations will be listed as endangered under the Federal Species at Risk Act is pending;
- Any longer-term hiatus in sampling and tag application requires additional effort to gain the same level of precision in the future;
- Both of the populations discussed in this report are currently harvested by local resource users for sustenance, so it is certainly possible the survival and or recruitment in these populations are being impacted. If, in retrospect, the Keeyask Study Area populations are in decline, data are required during the decline to document it properly;
- Manitoba Hydro has a long-term lake sturgeon stewardship plan that includes enhancement initiatives towards recovery. Data from long-term monitoring studies such as this are of paramount importance;
- The current fish movements and tag recapture data are inference tools only but can be supported by population genetic tools being developed to determine the historical level of effective dispersal; and

- Studies such as these also allow juvenile cohorts to be analysed and in conjunction with population genetics tools being developed can determine whether recruitment and/or probability of capture result in successful spawning years of a few or many lake sturgeon.

5.0 GLOSSARY

Ephemeral − a stream that flows only in direct response to precipitation, and thus ceases flowing during dry seasons.

Forebay – the portion of a reservoir immediately upstream of a hydroelectric facility.

Markovian – relating to or generated by a **Markov process**.

Markov process – "a random process in which the probabilities of states in a series depend only on the properties of the immediately preceding state or the next proceeding state, independent of the path by which the preceding state was reached" (http://www.thefreedictionary.com/Markov+process). Markov process can be continuous as well as discrete.

Random – Having no specific pattern, objective or purpose.

Riparian – along the banks of rivers and streams**.**

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TABLES AND FIGURES

Table 1. Example of an encounter history using six fish from the Gull Lake dataset, showing tag number, year, sample period (1 = spawn, 2 = post-spawn), captured (1), not captured (0), and record (1 = alive and -1 = dead).

Tag Number	2001		2002		2003		2004		2006		2008		Record
	1	2	1	2	1	2	1	2	1	2	1	2	
47106	1	0	0	0	0	0	0	0	1	0	0	0	1
47107	1	0	0	0	1	1	0	0	0	0	0	0	-1
47108	1	0	1	0	0	1	0	0	0	0	0	1	1
47109	1	0	0	1	0	0	0	0	0	0	0	0	-1
47110	1	0	0	0	0	0	0	0	0	0	0	0	1
47111	1	0	0	0	0	0	0	1	0	0	0	0	-1

Notes: Fish that were recovered dead are given a 1 in the closest previous sample period to indicate it was known to be alive. For mortalities, grey shaded boxes represent the last known alive period, and a -1 in the record column denotes that the fish is known to be dead.

Table 2. Subcomponent statistics of the No Recruitment versus Jolly-Seber Test for the Clark Lake to Gull Rapids population. Low *p*-values (<0.05 or 0.01) on the j^{th} occasion indicate there were additions to the population between post-spawn occasion *j* and subsequent spawn occasion *j*+1.

Occasion	Chi-square	Degrees of freedom	*p*-value
Post-Spawn 2001	4.2238	1	0.0399
Spawn 2002	7.3001	1	0.0069†
Post-Spawn 2002	7.7447	1	0.0054†
Spawn 2003	0.8683	1	0.3514
Post-Spawn 2003	5.3527	1	0.0207†
Spawn 2004	3.1966	1	0.0738
Post-Spawn 2004	6.1121	1	0.0134†
Spawn 2006	4.7170	1	0.0299†
Post-Spawn 2006	0.4887	1	0.0441†
Spawn 2008	3.0459	1	0.0809
Post-Spawn 2008	4.0537	1	0.0441†
Spawn 2010	0.4394	1	0.5074

† Significant at $\alpha = 0.05$, but not at $\alpha = 0.01$

Notes: Significance at spawn occasions violates the closure assumption of the Robust Design model (i.e., that the population is closed between secondary sampling periods), while significance at post-spawn occasions indicates the population was open between primary samples (i.e., years). Gray shading indicates occasions where population is expected to be considered open (i.e., Robust Design).

Table 3. Subcomponent Statistics of the No Mortality versus Jolly-Seber Test for the Clark Lake to Gull Rapids population. Low *p*-values on the j^{th} spawn occasion indicate there were losses from the population between the previous post-spawn occasion *j*-1 and current spawn occasion *j*.

Occasion	Chi-square	Degrees of freedom	*p*-value
Post-Spawn 2001	0.1242	1	0.7245
Spawn 2002	0.4631	1	0.4962
Post-Spawn 2002	4.7648	1	0.0291†
Spawn 2003	0.2673	1	0.6052
Post-Spawn 2003	0.2071	1	0.6491
Spawn 2004	2.2635	1	0.1325
Post-Spawn 2004	1.7539	1	0.1854
Spawn 2006	26.0406	1	0.0000‡
Post-Spawn 2006	0.1622	1	0.6871
Spawn 2008		Insufficient data for test	
Post-Spawn 2008		Insufficient data for test	
Spawn 2010		Insufficient data for test	

† Significant at $\alpha = 0.05$, but not at $\alpha = 0.01$

‡ Significant at $\alpha = 0.01$

Note: Significance at spawn occasions indicates population was open between primary samples, while significance at post-spawn occasions violates closure. Gray shading indicates occasions where population is expected to be open in Robust Design.

Table 4. Subcomponent Statistics of the No Recruitment versus Jolly-Seber Test for the Upper Split Lake population. Low *p*-values on the j^{th} occasion indicates there were additions to the population between post-spawn occasion *j* and subsequent spawn occasion *j*+1.

Occasion	Chi-square	Degrees of freedom	*p*-value
Post-Spawn 2001		Insufficient data for test	
Spawn 2002		Insufficient data for test	
Post-Spawn 2002		Insufficient data for test	
Spawn 2005		Insufficient data for test	
Post-Spawn 2005		Insufficient data for test	
Spawn 2006	5.2992	1	0.02134
Post-Spawn 2006	7.8181	1	0.0052
Spawn 2007	3.4089	1	0.0648
Post-Spawn 2007	0.0423	1	0.8370
Spawn 2009	27.7057	1	0.0000‡
Post-Spawn 2009	4.5268	1	0.0334†
Spawn 2011	0.9335	1	0.3339

† Significant at $\alpha = 0.05$, but not at $\alpha = 0.01$

‡ Significant at $\alpha = 0.01$

Notes: Significance at post-spawn occasions violates closure, while significance at spawn occasions indicates population was open between primary samples. Gray shading indicates occasions where population is expected to be open in Robust Design.

Table 5. Subcomponent Statistics of the No Mortality versus Jolly-Seber Test for the Upper Split Lake population. Low *p*-values on the j^{th} spawn occasion indicate there were losses from the population between the previous post-spawn occasion *j*-1 and current spawn occasion *j*.

Occasion	Chi-square	Degrees of freedom	*p*-value
Post-Spawn 2001	0.0662	1	0.7970
Spawn 2002	1.7424	1	0.1868
Post-Spawn 2002	1.3530	1	0.2448
Spawn 2005	0.4702	1	0.4929
Post-Spawn 2005	1.0477	1	0.3060
Spawn 2006	0.8545	1	0.3553
Post-Spawn 2006	0.0531	1	0.8178
Spawn 2007	3.7583	1	0.0526
Post-Spawn 2007	0.0234	1	0.8785
Spawn 2009	29.8775	1	0.0000‡
Post-Spawn 2009	0.9138	1	0.3391
Spawn 2011	0.4309	1	0.5116

‡ Significant at $\alpha = 0.01$

Notes: Significance at spawn occasions indicates population was open between primary samples, while significance at post-spawn occasions violates closure. Gray shading indicates occasions where population is expected to be open in Robust Design.

Table 6. Best model output for Clark Lake to Gull Rapids population estimation. Best model is indicated based on standard Akaike's Information Criterion. Regional population estimates are derived by dividing the local estimate by 1-Immigration/emigration.

Parameter	Year	Mean	Standard Error	Local 95% Confidence Interval		Mean Regional	Regional 95% Confidence Interval	
				Lower	Upper		Lower	Upper
Survival	Constant	0.8692	0.0394	0.7710	0.9292	-	-	-
Immigration/Emigration	Constant	0.6547	0.0767	0.4938	0.7866	-	-	-
Probability of 1st Capture	2001	0.4698	0.1109	0.2702	0.6795	-	-	-
Probability of 1st Capture	2002	0.3584	0.1200	0.1672	0.6085	-	-	-
Probability of 1st Capture	2003	0.4015	0.0940	0.2376	0.5908	-	-	-
Probability of 1st Capture	2004	0.2309	0.0688	0.1232	0.3909	-	-	-
Probability of 1st Capture	2006	0.2092	0.0523	0.1245	0.3296	-	-	-
Probability of 1st Capture	2008	0.1145	0.0329	0.0640	0.1963	-	-	-
Probability of 1st Capture	2010	0.0870	0.0328	0.0407	0.1763	-	-	-
Probability of 2nd Capture	Constant	0.1105	0.0165	0.0821	0.1472	-	-	-
Abundance	2001	140.0017	24.1517	113.7679	220.1372	405.4333	329.4624	637.4990
Abundance	2002	118.4673	32.4540	84.7016	229.7836	343.0715	245.2889	665.4340
Abundance	2003	189.5963	34.8723	148.0871	297.1544	549.0552	428.8478	860.5343
Abundance	2004	165.9477	45.8418	108.9413	302.3295	480.5706	315.4848	875.5211
Abundance	2006	440.0000	101.0441	301.9038	717.3951	1274.2033	874.2883	2077.5163
Abundance	2008	221.8832	66.4444	132.3350	406.5152	642.5552	383.2310	1177.2340
Abundance	2010	324.0361	123.5482	168.9003	688.6332	n/a[†]	n/a	n/a

[†] Survival and gamma are confounded in last time interval and therefore parameter cannot be estimated.

Table 7. Best model output for the Upper Split Lake population estimation. Best model is indicated based on standard Akaike's Information Criterion. Regional population estimates are derived by dividing the local estimate by 1-Immigration/emigration.

Parameter	Year	Mean	Standard Error	Local 95% Confidence Interval		Mean Regional	Regional 95% Confidence Interval	
				Lower	Upper		Lower	Upper
Survival	Constant	0.8859	0.0534	0.7339	0.9563			
Immigration/Emigration	Constant	0.6717	0.0631	0.5386	0.7819			
Probability of 1st Capture	2001	0.3640	0.2176	0.0831	0.7832			
Probability of 1st Capture	2002	0.1588	0.0968	0.0437	0.4385			
Probability of 1st Capture	2005	0.0944	0.0561	0.0280	0.2738			
Probability of 1st Capture	2006	0.2235	0.0700	0.1155	0.3881			
Probability of 1st Capture	2007	0.4337	0.0921	0.2686	0.6150			
Probability of 1st Capture	2009	0.4262	0.0771	0.2860	0.5794			
Probability of 1st Capture	2011	0.2491	0.0716	0.1354	0.4126			
Probability of 2nd Capture	Constant	0.1211	0.0182	0.0898	0.1615			
Abundance	2001	59.9515	28.8260	39.7484	189.0473	182.6171	121.0766	575.8528
Abundance	2002	74.7282	44.0057	34.6817	241.2331	227.6278	105.6433	734.8149
Abundance	2005	194.0369	113.7811	80.1067	595.7319	591.0517	244.0112	1814.6458
Abundance	2006	165.7566	48.2042	106.6442	310.8411	504.9074	324.8466	946.8463
Abundance	2007	214.4183	34.4997	172.9164	319.9115	653.1349	526.7167	974.4755
Abundance	2009	191.8105	27.1481	156.9096	270.3549	584.2697	477.9588	823.5222
Abundance	2011	258.6234	66.4860	175.0644	454.6805	n/a†		

† Survival and gamma are confounded in last time interval and therefore parameter cannot be estimated.

Table 8. Results of the Burnham Lambda Jolly-Seber model for the Clark Lake to Gull Rapids population.

Parameter	Year	Mean	Standard Error	95% Confidence Interval for Local Estimate	
				Lower	Upper
Survival	Constant	0.9191	0.0309	0.8341	0.9625
Survival	Constant	0.8508	0.0373	0.7623	0.9103
Probability of Capture	1995	0.1242	0.0400	0.0645	0.2257
Probability of Capture	2001	0.1931	0.0287	0.1430	0.2555
Probability of Capture	2002	0.1394	0.0202	0.1043	0.1838
Probability of Capture	2003	0.2355	0.0299	0.1820	0.2989
Probability of Capture	2004	0.1252	0.0185	0.0932	0.1661
Probability of Capture	2006	0.3120	0.0506	0.2223	0.4186
Probability of Capture	2008	0.0832	0.0204	0.0510	0.1329
Probability of Capture	2010	0.1181	0.0365	0.0631	0.2102
Lambda	Constant	1.0127	0.0378	0.9413	1.0896
Abundance	1995	497.3669	159.6711	279.0035	935.4620

Population was not closed based on Chi-Square statistic 58.62 with degrees of freedom = 12 and p = 0.000

Table 9. Results of the Burnham Lambda Jolly-Seber model for the Upper Split Lake population.

Parameter	Year	Mean	Standard Error	95% Confidence Interval for Local Estimate	
				Lower	Upper
Survival	Constant	0.9406	0.0351	0.8222	0.9819
Probability of Capture	2001	0.1176	0.0388	0.0602	0.2171
Probability of Capture	2002	0.0636	0.0186	0.0355	0.1112
Probability of Capture	2005	0.0761	0.0166	0.0493	0.1158
Probability of Capture	2006	0.1276	0.0226	0.0895	0.1788
Probability of Capture	2007	0.2659	0.0400	0.1950	0.3512
Probability of Capture	2009	0.1873	0.0303	0.1349	0.2540
Probability of Capture	2011	0.1262	0.0276	0.0813	0.1908
Lambda	Constant	1.1043	0.0444	1.0206	1.1949
Abundance	2001	305.4807	92.5986	176.0089	554.6803

Population was not closed based on Chi-Square statistic 19.71 with degrees of freedom = 9 and p = 0.0198.

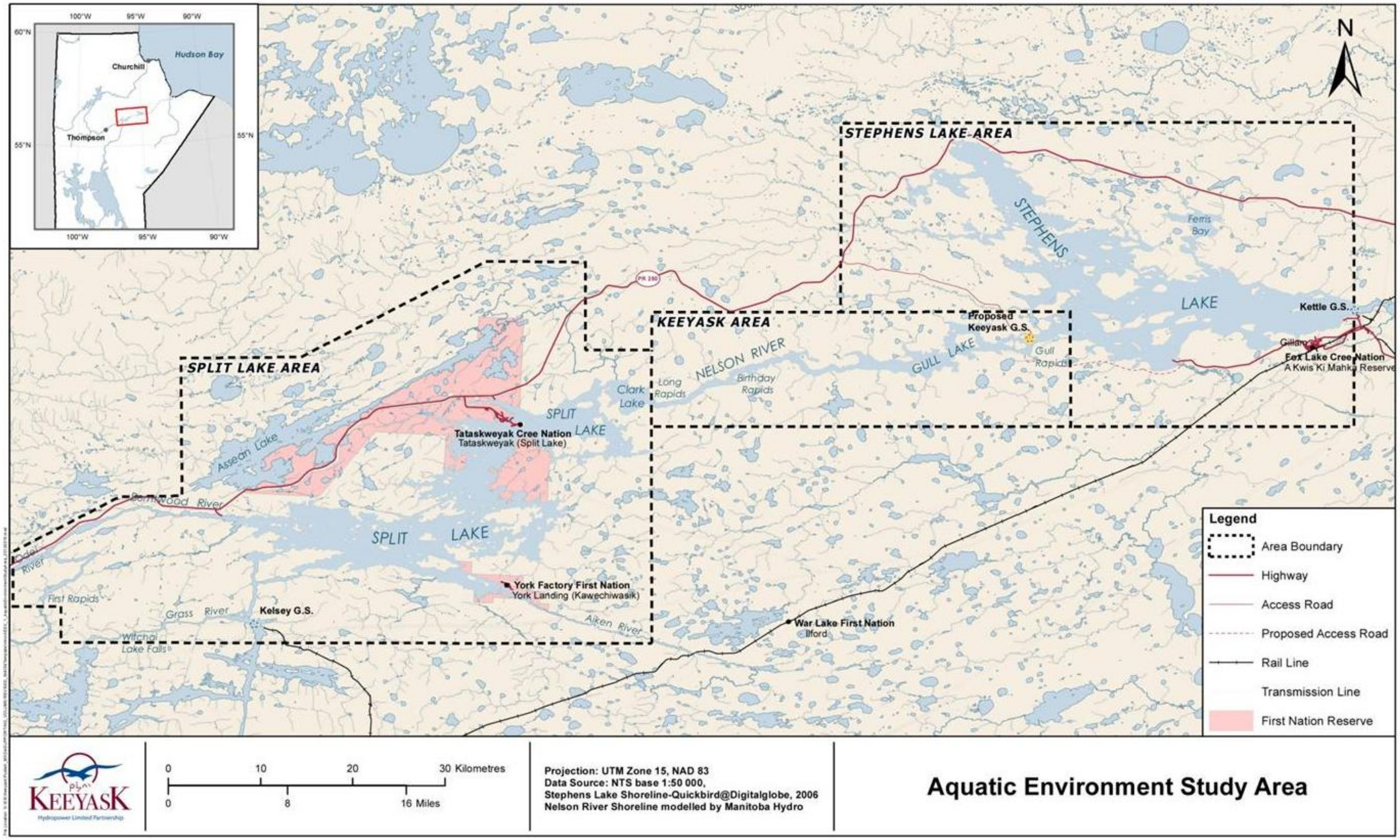

Figure 1. Overview of the Keeyask Study Area indicating three study reaches.

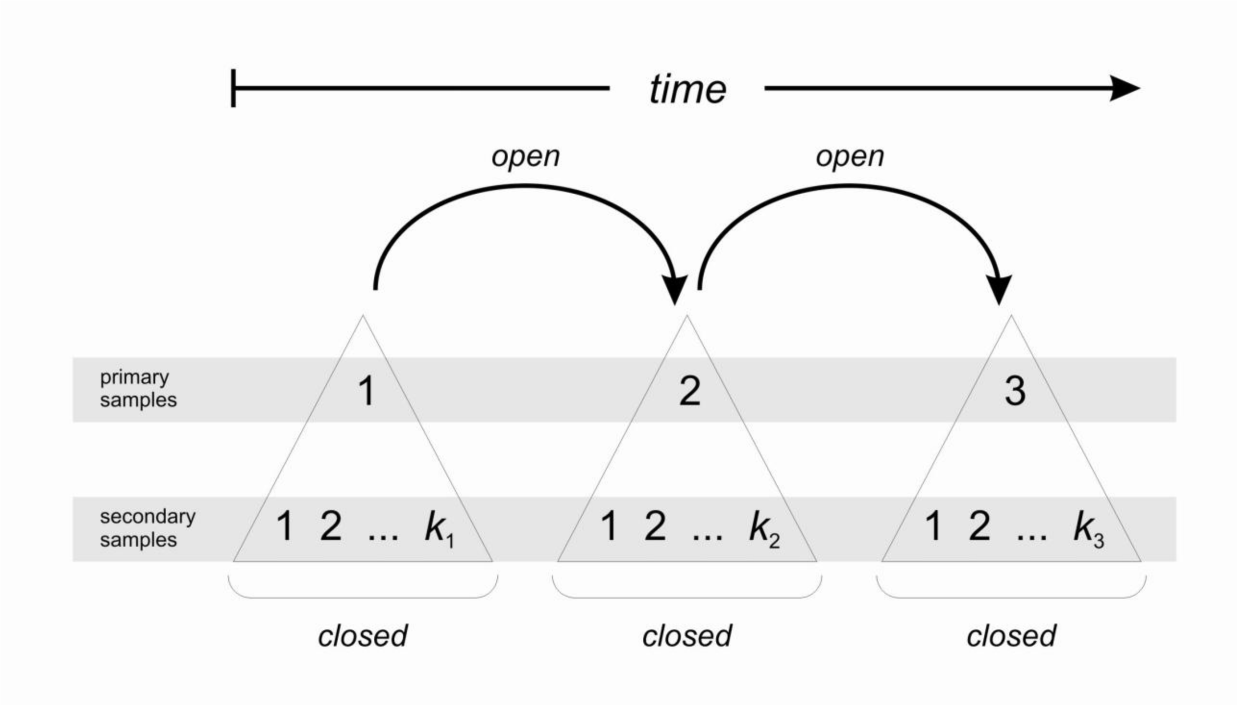

Figure 2. The basic model structure of a typical Robust Design model. For the Keeyask data, primary samples represent inter-annual periods and secondary samples are spawning and post-spawning periods within each primary sample. The population is assumed to be open between primary samples and closed between secondary samples. Figure adapted from Program MARK 'A Gentle Introduction' user manual.

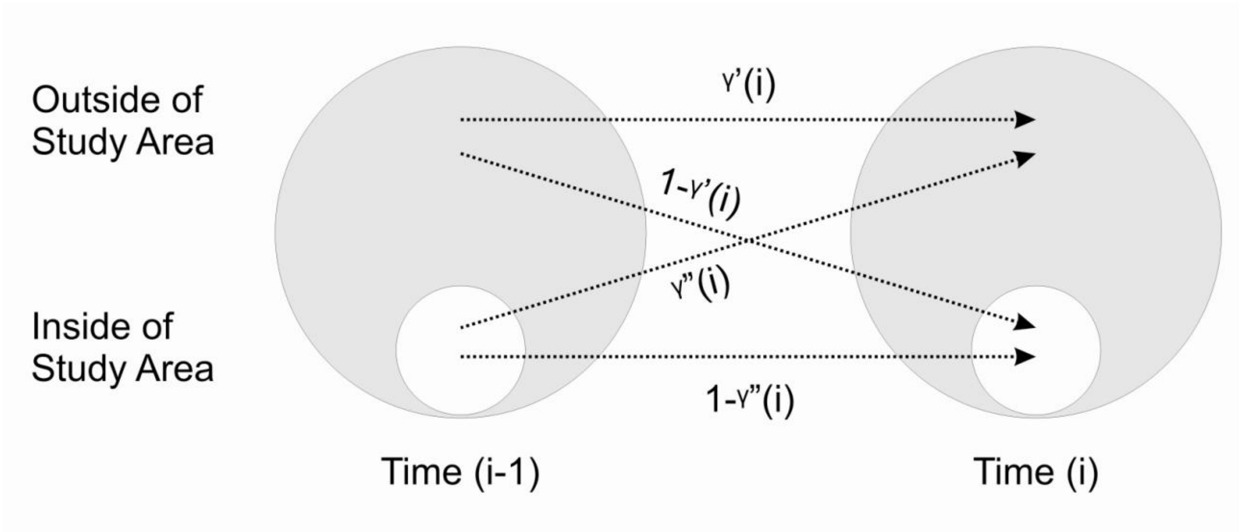

Figure 3. Diagram indicating the relationship between gamma parameters in Robust Design. Two basic types of movement are (a) random and (b) Markovian. Random movement has no assumptions of conditional dependence between time (*i*-1) and time (*i*), while Markovian movement assumes that movements are conditional at time (*i*) based on time (*i*-1). Figure adapted from Program MARK 'A Gentle Introduction' user manual.

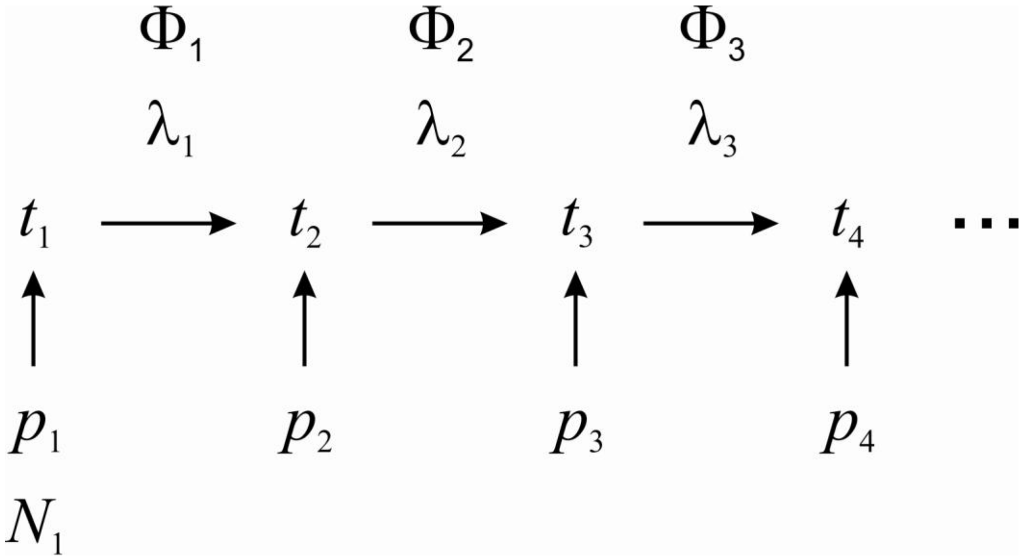

Figure 4. Process model for Burnham and Pradel-λ parameterizations of Jolly-Seber Model. Where p_i is the probability of capture at time *i*; Φ_i is the probability of survival between times period *i* and *i+1*, λ_i represents the rate of population change, and N_1 is the population size at time *i*. Figure adapted from Program MARK 'A Gentle Introduction' user manual.