Columbia River Project Water Use Plan

Lower Columbia River

Reference: CLBMON #28 (Year 12)

Lower Columbia River Adult White Sturgeon Monitoring Program: 2019 Investigations Data Report

Study Period: January 2019 - December 2019

BC Hydro and Power Authority

Prepared by:

BC Hydro
Water License Requirements
Castlegar, BC

July 29, 2020

Recommended Citation: BC Hydro. 2020. Lower Columbia River Adult White Sturgeon Monitoring Program (CLBMON-28). Year 12 Data Report. Report by BC Hydro, Castlegar, 75 pp.

EXECUTIVE SUMMARY

White Sturgeon (*Acipenser transmontanus*) in the Canadian section of the lower Columbia River (LCR), are one of four populations that were listed as endangered under the Species at Risk Act in 2006. The population was identified as a priority during the Water Use Planning (WUP) process because it is undergoing recruitment failure and considerable uncertainties exist related to recovery. However, given the high value of power generation mandated under the Columbia River Treaty, significant physical alterations on the system to address recruitment failure (e.g. flow augmentation) were not deemed feasible and, as such, the system was designated as a working river. As a result of this designation, management responses targeted on White Sturgeon were focused on the collection of biological information that could determine the possible mechanisms resulting in recruitment failure and address issues related to recovery. The general objectives of this monitoring program when first developed were to 1) collect data to describe abundance trends, population structure and reproductive status of adult White Sturgeon, 2) collect mature adult White Sturgeon to serve as broodstock for the annual Conservation Aquaculture Program as needed, 3) determine White Sturgeon spawning locations, habitat use, and movements using both direct (capture) and indirect (telemetry) methods, and 4) determine the timing and frequency of spawning events.

In 2013, a standardized population assessment was initiated to estimate survival rates and abundance of the entire transboundary White Sturgeon population which includes Canada and the US. While numbers of wild fish (~1,000) have remained relatively stable over the past decade due to an absence of recruitment and the species longevity, numbers of hatchery-origin fish in the population have increased significantly and currently represent >75% of White Sturgeon at large. Additionally, data from this program are being used to determine growth, fish condition, age class structuring, and sex ratios, with hatchery-origin fish starting to mature and contribute to wild spawning events. Movement data collected using acoustic telemetry indicated that wild adult sturgeon activity generally occurred during the summer months, likely for feeding or spawning activities. While an analysis of long-term movements is ongoing, adult White Sturgeon in the LCR are generally selecting deeper habitats of lower flow (e.g. eddies and deep runs), which do not appear to be limited under the current operational regime.

In 2019, spawning was estimated to have occurred from mid-June into late-July in the lower Columbia River. The timing and duration of spawning activity was similar to past years, with the majority of spawning days occurring on the descending limb of the hydrograph at water temperatures above 14ºC. Based on developmental stages of collected embryos and larvae, it was estimated that spawning in 2019 occurred June 12 through July 30 at Waneta; July 23 through July 24 at ALH; and June 24 through July 23 at Kinnaird.

In efforts to increase genetic diversity among stocked juvenile White Sturgeon, increase effective breeding number, and maintain genetic diversity within the population, wild-origin progeny are collected from spawning sites and reared temporarily at a Streamside Incubation Facility (SIF) constructed near the Waneta spawning location. This program was developed as a result of a 2011-2012 genetic study that determined the number of adults spawning annually in the LCR significantly higher than those that contributed as broodstock in the Conservation Aquaculture Program. Following incubation in the SIF, hatched larvae were transported to the conservation hatchery and reared for release in the following spring. While implemented in 2014 concurrently with the broodstock program (2001-2014), as of 2015, the SIF program was fully adopted with a total of 1095, 76, 800, and 607 wild-origin juvenile white sturgeon released in 2015 through 2018, respectively. Since 2018, release targets have been reduced to a maximum of 200 fish and these targets were met in both 2019 and 2020.

The state of knowledge pertaining to the various management questions associated with this monitoring project are summarized in Table ES1.

Table ES1. CLBMON-28 Status of Lower Columbia River Adult White Sturgeon Monitoring Program Objectives, Management Questions, and Hypotheses.

Management Question	Status
What are the abundance trends, population structure and reproductive status of adult White Sturgeon in the lower Columbia River?	- A systematic stock assessment encompassing the entire Transboundary Reach of the lower Columbia River in Canada and the US was initiated in 2013 and has been completed annually. The goals of the stock assessment were to estimate population abundance and survival that can be used to track recovery for this population. At the conclusion of 2018, twelve sessions have been completed in Canada and preliminary data analyses have estimated a wild population abundance of 1,042 (743-1,461) individuals. This is similar to the estimate of 1,100 developed by Irvine et al. (2007) prior to the Columbia WUP program being implemented. - The wild population remains dominated by adult age classes, with limited wild juveniles captured during sampling programs (<1%). Juveniles released from the Conservation Aquaculture Program are surviving and are represented in a large proportion of the adult captures. There are an estimated 5,083 (3,823-6,648) hatchery-origin individuals in Canada from analyses conducted using the stock assessment data. These juveniles have extended the estimated extirpation of this population by several decades and are now reaching a size and stage of maturity where they will start entering the adult population. - An aquaculture program that centers on using wild collected embryos and larvae was developed in 2014 based on results from previous year's genetic analyses. As of 2015, this is currently the sole source of offspring collected for stocking purposes in order to meet

Management Question	Status
	long term genetic goals for the population. It has resulted in suspending the traditional broodstock program going forward, which was an original objective of this monitoring program. - Using genetic methods, it was found that 121.5 ± 34.7 adults (mean ± SD) were spawning within the Canadian section of the lower Columbia River within each of two years (2011 and 2012). The sex ratio of the population has been stable at 1 female:1 male since monitoring began. Work to describe the reproductive structure is ongoing.
How much spawning occurs annually at known spawning locations, and are there other spawning locations unidentified in the lower Columbia River?	- Wild spawning has been detected annually at up to 3 locations in the Canadian section of the Columbia River, with the mean number of spawning events ranging from 1.42 at the Arrow Lakes Generating Station (ALH) site to 13.9 at the Waneta site from 2011-2019. Embryos survive to hatch at all locations. - Spawning occurs annually at the Waneta area, with the number of estimating spawning days varying by year. - Spawning has been identified through embryo and larval captures downstream of Hugh Keenleyside Dam and ALH. ALH represents the second known location of egg deposition in the Canadian section of the lower Columbia River and has been incorporated into annual monitoring programs to further describe spawning frequency and duration. - An additional spawning location is used annually (2007-2019) in the vicinity of Kinnaird but the exact location(s) of egg deposition remains unknown. - Additional spawning sites are used annually south of the international border (e.g., Northport WA).
What is the degree of interaction among sub-populations of White Sturgeon in the lower	- Though fidelity to specific habitats or locations has been identified as high, individuals have been identified to move throughout the river during the spring and summer months based on subsequent captures or telemetry tracking. We

Management Question	Status
Columbia River?	know through direct capture and telemetry methods that some individuals move between Canada and the United States, though this exchange is higher for hatchery-origin individuals soon after release. Analyses using the stock assessment data found that there was less than a 1% chance of movement between countries for wild adults captured more than once during the 5 year monitoring period. An analysis of long-term movements is ongoing to determine the interaction (i.e., spawning) of individuals from different sections of the transboundary reach.
How do existing river operations affect adult movements, habitat preference, spawning site selection, or spawning activity?	- Adults select deep, slow moving sections of the river, which are currently not limited by the existing operating regime of the river. Site fidelity is extremely high to very specific habitats and individuals spend >60% of their time at a single location and >90% of their time within a specific river reach (10 km of river habitat). When movements do occur, they tend to occur during periods of warmer water and increasing flows and are assumed to be for either feeding or spawning. - Spawning related movements have been identified for a select number of mature males and females. Individuals tend to move to spawning locations within the reach of river where they spend the majority of their time.

ACKNOWLEDGEMENTS

The 2019 study year of the Lower Columbia River Adult White Sturgeon Monitoring Program (CLBMON-28) was funded by BC Hydro Water Licence Requirements White Sturgeon Management Program in Castlegar, B.C. BC Hydro would like to thank the following partner organizations and individuals for their contributions to the program:

BC Hydro

Dean Den Biesen; James Crossman; Katy Jay

Columbia Power Corporation (Castlegar)

Wendy Horan

Colville Confederated Tribes

Jason McLellan

Freshwater Fisheries Society of BC

David Ek; Mike Keehn; Aaron Wolff

Golder Associates Ltd. (Golder)

Sima Usvyatsov (specifically sections 2.3.5 and 3.3.2)

Montana State University

Paige Maskill

Spokane Tribe of Indians

Andy Miller

Teck Metals Trail

Terraquatic Resource Management

Marco Marrello

US Fish and Wildlife Service

Molly Webb

University of Northern British Columbia

Caleb Jetter

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

White Sturgeon (*Acipenser transmontanus*) in the Canadian section of the lower Columbia River (LCR), are one of four populations that were listed as endangered under the Species at Risk Act in 2006. The population is undergoing recruitment failure (Hildebrand and Parsley 2013) and the current level of natural recruitment is considered to be insufficient for maintaining a self-sustaining population. The exact mechanisms resulting in recruitment failure are unknown and as a result White Sturgeon were identified during the Water Use Planning (WUP) process as a priority species for conservation in the Columbia River. As such, a monitoring program was developed to address recovery of the population. It was recognized that in order to make progress towards recovery, baseline data were lacking on the population such as spawning locations, spawning activity (i.e., timing and frequency), and population level metrics like habitat use, movements, growth, and age class distribution.

Identification of spawning activity is an important component of recovery as it locates critical spawning habitat allowing for protection or enhancement of these areas as recovery moves forward. Prior to 2007, studies have identified White Sturgeon spawning sites at two primary locations in the mainstem LCR, including the confluence with the Pend d'Oreille River (Waneta, river kilometer (rkm) 56.0; UCWSRI 2012) and in the vicinity of Northport, Washington (Howell and McLellan 2006). From additional work, other sites have been located in the Canadian portion of the LCR based on embryo and larval captures and adult movements. Spawning has been identified at the area immediately downstream of Hugh Keenleyside Dam (HLK) and the Arrow Lakes Generating Station (ALH, rkm 0.1; BC Hydro 2013 2015a, 2016) and is known to occur in the vicinity of Kinnaird (rkm 13.0 to 19.0; Golder 2009a, 2009b; BC Hydro 2013, 2015a, 2015b, 2016, 2017, 2018, 2019), though the exact location(s) of egg deposition remains unknown. These results demonstrate that undocumented spawning locations remain in the LCR, and emphasize the importance of continued monitoring to describe adult reproductive ecology, determine mechanisms influencing spawning site selection, and understand underlying mechanisms resulting in recruitment failure.

In 2001, a broodstock acquisition program was developed to spawn captured mature adults and contribute supplemental offspring released in the LCR (BC Hydro 2009). The program (2001 – 2014) was successful in providing 175 individuals adults (78 females and 97 males) contributing 105,262 hatchery reared juvenile sturgeon released in the Canadian portion of the LCR. Based on a study by Jay et al. (2014), it was advised by the Upper Columbia White Sturgeon Recovery Initiative Technical Working Group (UCWSRI TWG) to design a Streamside Incubation Facility (SIF) to incorporate wild offspring into the stocking practices increasing representation of LCR spawning adults and levels of genetic diversity among stocked juvenile White Sturgeon. Alongside the broodstock acquisition program, a pilot SIF program was implemented in 2014 and was successful in releasing 1,095 wild progeny into the LCR the following spring. In 2015, the broodstock program was suspended and all juvenile White Sturgeon stocked as of the 2015 year class have been of wild origin collected through the SIF program. The release strategy for these wild origin fish is a minimum release weight of 200 grams to improve survival following release based on results of juvenile survival modeling (BC Hydro 2016b). A total of 76, 800, and 607 wild progeny were released for year classes 2015, 2016, and 2017. In 2018, release targets were reduced to a maximum of 200 fish and these targets were met in both brood years 2018 and 2019. Development of the SIF in Canada also aligned with the US portion of the LCR White Sturgeon population, as collections of wild origin larvae serve as the basis for hatchery releases in the US.

From 2013 to present, a systematic population assessment program was initiated to improve confidence in the abundance and survival rate estimates of the White Sturgeon population in the Transboundary Reach (TBR) of the LCR including both Canada and the US. While estimates have been made independently for both segments of the LCR population, it was deemed critical that confidence in the number of wild and hatchery origin at large was needed both to track progress towards recovery and to determining long-term population targets. This stock assessment program was developed to incorporate all habitats in Canada and the US and is being implemented concurrently by recovery initiative partners on both sides of the border. Data from this ongoing program will not only provide confidence in the number of wild adults remaining, but will be used to determine growth rates and sex ratios across mature adults and immature fish (<150 cm fork length), assess fish condition, age class structuring, and identify density dependent responses due to an increasing hatchery origin population.

Given that the collection of life history data is an important component of addressing the mechanisms resulting in recruitment failure and overall recovery of White Sturgeon, the general objectives of this program were to:

1. Collect naturally produced White Sturgeon embryos and larvae to contribute to the annual Conservation Aquaculture Program.
2. Determine White Sturgeon habitat use, movements and identify spawning locations through acoustic telemetry.
3. Describe White Sturgeon spawning locations, timing, and frequency through the deployment of egg mats and drift nets.
4. Implement the Canadian portion of the transboundary stock assessment to develop survival and abundance estimates for wild and hatchery origin White Sturgeon in the LCR population.

More specific objectives are provided in section 1.2.

1.1 Management Hypothesis

While impoundments and water management in the Columbia watershed have contributed to declines in White Sturgeon recruitment in the LCR, the precise mechanism(s) remain relatively unclear. Several recruitment failure hypotheses suggest that early life stages, including larval and early feeding phases, appear to be the most adversely affected life stage (Gregory and Long 2008). Additionally, other uncertainties regarding recruitment failure exist and could be influenced by spawning site selection, spawning timing, and possible adult behavioral responses related to water management decisions under the Columbia River Treaty.

This monitoring program was designed to provide long term information on adult White Sturgeon abundance, biological characteristics exhibited under current operation conditions, and reproductive status. In addition, it was designed to include continued baseline data collection on the remaining wild adults, which will be utilized as foundation to evaluate and explore other recovery measures. Specifically, it will provide data on current adult movements and spawning site selection to assess future management responses, and may also be used to refine current and future recruitment failure hypotheses.

It is intended that future monitoring of the LCR adult White Sturgeon population may provide key information to help resolve a number of the following outstanding issues identified by the WUP Fisheries Technical Committee (FTC).

1) As the annual average number of spawning days at Waneta appears small relative to the adult population size and the approximate female reproductive cycle, this adult monitoring program may identify additional spawning sites.

2) Changes in movement and spawning behaviour in response to management responses (relative to the baseline established through this monitoring program) may reveal that additional spawning sites (and sub populations) exist in the LCR.

3) Baseline information acquired through this monitoring program may verify that the abundance of adult White Sturgeon in the LCR will not be adversely affected by management response measures.

The overall approach of this monitoring program is intended to be descriptive rather than experimental in nature and, as such, is designed to provide baseline information that can be used in later years of the program to address the program's management questions.

1.2 Objectives and Scope

The monitoring program is intended to address a number of uncertainties related to the current status of the population in the LCR, but it will also provide: (i) input to and assist with the ongoing consideration of recruitment failure hypotheses and the evaluation of the effects of future management efforts on spawning success; and (ii) new information to guide adult broodstock acquisition, if deemed necessary, and assist with adjustments to stocking targets related to the Conservation Aquaculture Program.

The objectives for this program will have been met when:

1) Adult White Sturgeon life history characteristics including size, growth, age structure, and condition, and population characteristics including abundance and trajectory, survival rates, genetic status, and reproductive potential are quantified with sufficient consistency to describe annual trends.

2) Biological characteristics including spawn monitoring to assess annual timing and trends, and movements to assess seasonal habitat use and spawning site selection under the current range of operating conditions are adequately defined.

The specific objectives related to the various components of this adult monitoring program are summarized as follows.

1.2.1 *Spawn Monitoring*

1. Identify the timing and frequency of annual spawning days at the Waneta, ALH, and Kinnaird sites using egg mats and drift nets to collect White Sturgeon embryos and larvae.
2. Provide information on trends in the number of discrete spawning days as a measure of population demographics and reproductive potential.
3. Develop baseline data to assess the effectiveness of future management strategies.
4. Collect naturally produced embryos and larvae for streamside incubation and hatchery rearing for stocking purposes.

1.2.2 *Population Monitoring, Abundance, and Characteristics*

Biological, mark-recapture, and related age structure data accumulated through bi-annual stock assessment program will be used to:

1. Assess population size and age structure, reproductive structure, abundance, annual survival rates, and population trajectories.
2. Provide relative abundance and periodic updates to population estimates of the LCR White Sturgeon population.
3. Periodically compare new length frequency data to archived fin ray age analyses to correct for possible aging underestimates.
4. Collect blood samples from all captured fish of wild and hatchery origins to assess ploidy levels and determine proportion of population experiencing spontaneous autopolyploidy (12N).

Data from this program will be analyzed and evaluated on an ongoing basis to drive program decisions or to identify any emerging and imminent threats to the remaining population.

1.2.3 *Acoustic Tagging and Telemetry*

Monitor movements of acoustically tagged adult White Sturgeon using a passive remote receiver array established throughout the LCR to:

1. Provide new information on suspected staging areas, and other suspected spawning sites throughout the LCR that may be used during varying ranges of flows.
2. Provide information on seasonal and annual movements, macro-habitat use, and transboundary interactions.

1.3 Study Area

The study area for the 2019 monitoring program consisted of a 57 km stretch of the LCR between HLK and the Canada/U.S. Border (downstream of the Pend d'Oreille River confluence) with certain aspects (i.e., stock assessment) extending beyond the international border to Gifford, Washington (Figure 1). The study area also included a small section (~2.5 km) of the Kootenay River below Brilliant Dam extending to its confluence with the LCR. To identify distribution of White Sturgeon for certain components (e.g., population assessment, telemetry), the LCR study area was stratified into 5 equal zones (11.2 km in length; consecutively numbered 1 through 5 from HLK to Canada/Us Border). Specific areas of the LCR sampled under the various components of the program are described below.

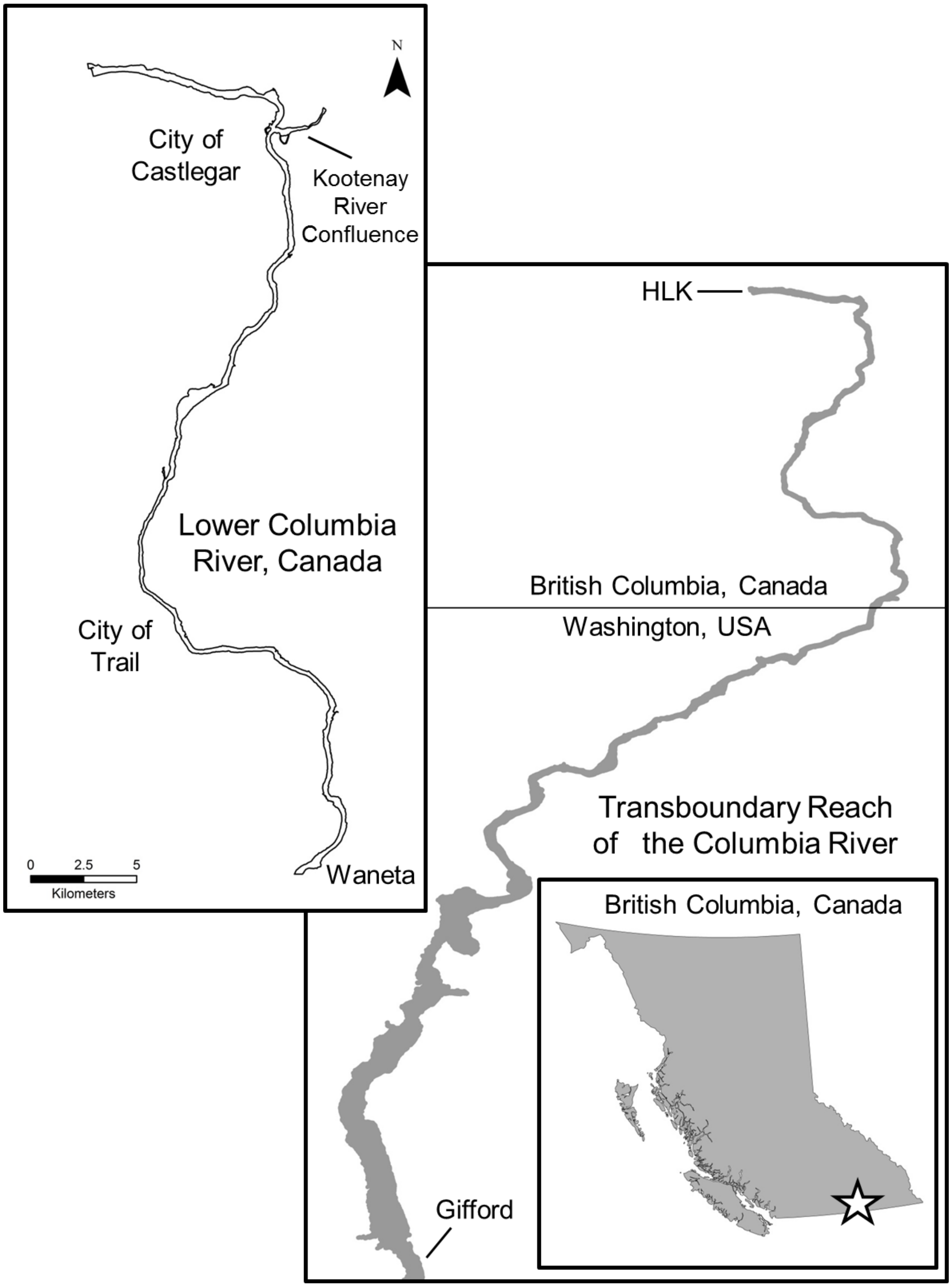


Figure 1. Overview of the study area in the lower Columbia River between Hugh L. Keenleyside Dam (HLK, rkm 0.1) and the Canada/US border (rkm 57.0) in relation to the Transboundary section of the Columbia River.

2.0 METHODOLGY

The monitoring study design follows the recommendations of the Upper Columbia White Sturgeon Recovery Initiative (UCWSRI) Technical Working Group (TWG) who provided an outline for what they viewed as the components of a LCR adult monitoring program (UCWSRI 2006) during the development of the Columbia WUP. Further, it incorporates the guidance of the WUP Fisheries Technical Committee (FTC). The program is divided into data collection during spawn monitoring, stock assessment, movement studies, and a suite of population characteristics including age structure and population size and survival estimation. These are described separately below.

2.1 Physical Parameters

2.1.1 *Discharge*

In 2019, discharge records for the LCR at Arrow Reservoir (combined HLK and ALH discharges from Arrow Lakes Reservoir; rkm 0.1), the Kootenay River (combined discharge from Brilliant Dam and the Brilliant Expansion facility; rkm 10.5), the LCR at Birchbank (combine discharge from Arrow Lakes Reservoir and Kootenay River; rkm 29), and the LCR at the Canada/United States border (combined discharge from Birchbank and the Pend d'Oreille River; rkm 57.0) were obtained from BC Hydro power records. Discharge data were recorded at one-minute intervals and averaged hourly in cubic meters per second (cms) and cubic feet per second (cfs) of passage flow.

Typically, the metric discharge measurement (cms) is used to discuss and present results of volumetric flow rates in technical reports and scientific publications. However, water planners and biologists readily use the non-metric discharge measurement (cfs) to discuss flows from hydroelectric facilities. As such, both units of measure (cms and cfs) are presented and referenced within the results section of this study report.

2.1.2 *Water Temperature*

For the 2019 study period, water temperatures were collected at several locations on the LCR including HLK (rkm 0.1), Kootenay River (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), and Waneta (rkm 56.0). Water temperatures were recorded hourly at each location using thermographs (Vemco Minilogs, accurate to ±0.1°C).

2.2 Spawn Monitoring

2.2.1 *Study Design*

Monitoring of White Sturgeon spawning was carried out at several sites for this program based on previous data collection where White Sturgeon have been confirmed or suspected to have spawned. LCR White Sturgeon cannot be observed congregating to spawn due to water depth and relatively high flow volume therefore spawning was documented through the collection of progeny.

Monitoring of spawning activity occurred at Waneta (rkm 56.0) located at the Pend d'Oreille River confluence immediately upstream of the Canada/US border (Figure 2). This site has been monitored for spawning activity since 1993 and is designated as the primary White Sturgeon spawning area within the Canadian portion of the LCR (Hildebrand et al. 1999; Irvine et al. 2007; Golder 2009a). Two secondary spawn monitoring sites were located in upstream sections of the LCR at ALH (rkm 0.1) and Kinnaird (rkm 13.4 to rkm 18.2). Spawning has been previously documented immediately downstream of ALH with geographical boundaries described by Terraquatic Resource Management (2011; Figure 2). The extent of sampling downstream of Kinnaird was based on past spawn monitoring surveys and White Sturgeon adult movement studies (BC Hydro 2013, 2015a, 2015b, 2016a, 2017, 2018, 2019; Figure 2).

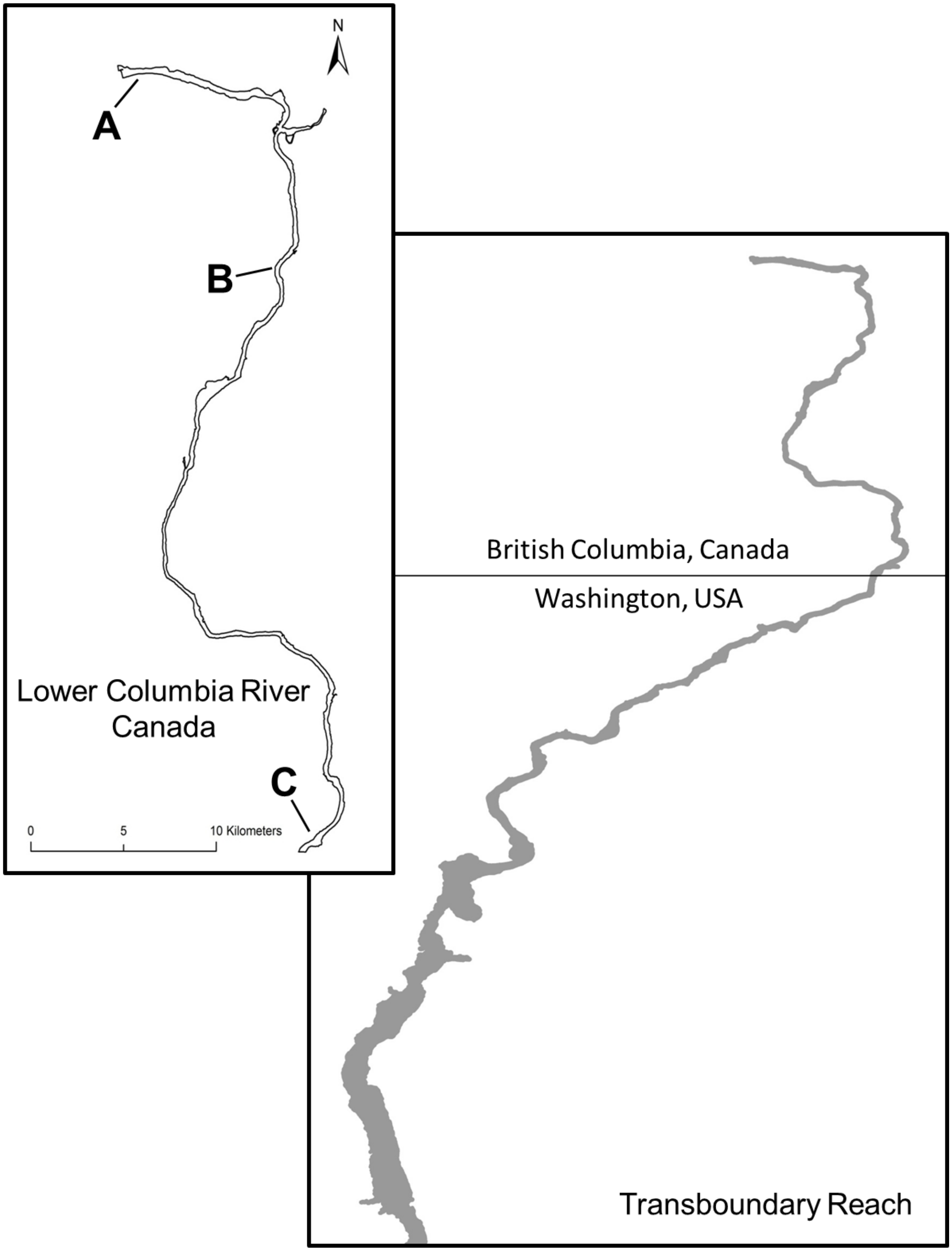


Figure 2. Egg mat and drift net deployment sites of ALH (rkm 0.1; A), Kinnaird (rkm 13.4 to rkm 18.2; B), and Waneta (rkm 56.0; C) in the lower Columbia River in 2016.

2.2.2 *Egg Collection Mats and Drift Net Sampling Methods*

White Sturgeon are broadcast spawners allowing for the collection of embryos and larvae using passive techniques such as egg collection mats and drift nets. Egg collection mats are a proven method of collecting White Sturgeon embryos (McCabe and Beckman 1990; McCabe and Tracey 1993) and have been effective in the LCR since 1993 (Golder 2002, 2010). Drift net sampling has been used successfully to capture both embryos and passively dispersing larvae for many sturgeon species including White Sturgeon (Golder 2009a), Lake Sturgeon (*Acipenser fulvescens*; Auer and Baker 2002), and Shortnose Sturgeon (*Acipenser brevirostrum*; Moser et al. 2000). Drift net sampling has been added as a component to the adult spawn monitoring program in recent years and has proven successful at documenting spawning activity through the collection of embryos and larvae (BC Hydro 2013, 2015a, 2015b, 2016a, 2017, 2018, 2019).

Spawn-monitoring remained consistent with previously established locations of egg collection mat and drift net sampling (see Golder 2009b, 2010, 2012, 2013, 2014, and Terraquatic Resource Management 2011 for details). Egg collection mats and drift nets were deployed at Waneta, Kinnaird and ALH (Table 1). Sampling gear locations at Waneta, ALH, and Kinnaird (rkm 18.2) have been consistent sampling locations since 2007, 2010, and 2009, respectively.

Table 1. Number of egg mats and drift nets deployed at each spawn-monitoring site in 2019.

Site	rkm	Egg Mats	Drift Nets
Waneta	56.0	4	4
ALH	0.1	4	4
Kinnaird	14.5	1	4
Kinnaird	18.2	0	4

Egg Collection Mats – Equipment and procedures for deployment and retrieval were replicated from previous monitoring protocols (Golder 2009a; Terraquatic Resource Management 2011). Egg collection mats consisted of latex coated animal hair filter material fastened to a 0.76 m by 0.91 m steel frame. Two lead steel claw river anchors (30kg) attached by approximately 6 m of 3/8 galvanized chain were used to anchor each egg collection mat. One 30 m section of 0.95 cm diameter braided rope was extended between the upstream anchor and a buoy at the surface of the river providing means to remove the entire anchoring system. A second rope was attached between the downstream anchor and the front of the egg collection mat. A third 0.95 cm diameter braided rope was attached from the back of the egg collection mat to a surface buoy to facilitate deployment and retrieval without dislodging the anchor system. In areas of low flow, egg collection mats were deployed with a single 10 kg lead anchor fastened to a leading bridal. A rope from the back of the egg collection mat to a surface buoy was used to facilitate deployment and retrieval of the entire system.

Egg collection mats were deployed for one to three days. Egg collection mats rested flat on the river substrate and entrapped drifting or deposited embryos in the filter material. Upon retrieval, egg collection mats were brought to the surface by means of the buoy line. Once at the surface, egg collection mats were detached from the anchor system and brought into the boat for inspection. Both sides of the egg collection mats were inspected thoroughly by a minimum of 2 crew members before being redeployed. Embryos were enumerated by egg collection mat for each sampling location and occasion. Deployment and retrieval times, water temperatures (°C), and depths (m) at each sampling location were recorded.

Drift Net – Deployment and anchor system specifications were consistent among sampling locations in the LCR. Drift nets consisted of a 1.3 cm rolled stainless steel frame (D shape) with a 0.6 m x 0.8 m opening trailed by a 4 m tapered plankton net (0.16 cm delta mesh size) ending with a collection cup device. Rolled stainless steel bars (1.3 cm) welded vertically across the standard drift net frame at 15 cm intervals to prohibit adult and juvenile White Sturgeon from entering the drift net.

Two lead steel claw river anchors (30 kg) attached by approximately 6 m of 3/8 galvanized chain were used to anchor each drift net. One 30 m section of 0.95 cm diameter braided rope was extended between the upstream anchor and a buoy at the surface of the river providing a means to remove the entire anchor system. A second rope was attached between the downstream anchor and the front of the drift net. A third 0.95 cm diameter braided rope was attached from the top of the drift net frame to a surface buoy for deployment and retrieval without dislodging the anchor system.

Drift nets were deployed to stand perpendicular to the river bottom and collect drifting embryos and larvae in the tapered plankton net. Upon retrieval, drift nets were brought to the surface by means of the drift net buoy line. Once at the surface, drift nets were detached from the anchor system and brought into the boat for sample collection. Collection cups were removed from the plankton net, and contents were rinsed into a 19L bucket containing river water. Contents remaining in the drift nets were also rinsed into the same collection bucket. Collection cups were reattached and drift nets were redeployed. Collection contents were diluted with river water and small aliquots were transferred into white plastic inspection trays to improve contrast when searching for White Sturgeon embryos or larvae. Embryos and larvae were enumerated by net for each sampling location and occasion. Deployment and retrieval times, water temperatures (°C), and depths (m) at each sampling location were recorded.

2.2.3 *Embryo and Larval Sampling*

All live embryos and larvae were transported to the SIF (Section 2.2.5). No live samples were sacrificed and preserved as practiced in previous years (BC Hydro 2013, 2015a). Dead larval samples collected at all locations were preserved for possible future genetic analyses.

2.2.4 *Developmental Staging and Estimation of Fertilization Date*

Prior to transportation to the SIF, live embryos were examined in the field using a handheld magnifying glass and assigned a developmental stage. Larvae dead upon collection were preserved and assigned a developmental stage at a later date. Enumeration of stages corresponded to the classification by Dettlaff et al. (1993) including embryonic stages of 1 (fertilization) through 35 (pre-hatch) and larval stages of 36 (hatch) through 45 (exogenous feeding). No collected samples were developed beyond stage 45.

Fertilization date for collected embryos and larvae was estimated by back-calculation from the recorded date and time of capture/preservation based on developmental stage and mean incubation water temperature. The estimated age (hours; embryos, Parsley, U.S. Geological Survey, unpublished; larvae, Jay 2014) was subtracted from the preservation date and time to determine the estimated date and time of fertilization (i.e. spawning date). Calculated fertilization dates provided an estimation of spawning duration for each spawning site. However, the accuracy of embryo developmental staging as a method to delineate spawning days and estimate time of spawning can be affected by individual White Sturgeon spawning behaviour, embryo maturation rates, and more importantly, the fluctuation in daily thermal regimes (Parsley et al. 2010).

2.2.5 *Streamside Incubation Facility (SIF)*

Design of the LCR SIF was based on the culture techniques used in the hatchery program (FFSBC 2015). The facility was placed near the Waneta spawning location on the banks of the LCR, as this is the primary spawning location where it was envisioned most of the embryos would be collected from. Embryos collected from the LCR were transferred to the SIF for incubation in hatching jars (MacDonald Type; J30, Dynamic Aqua-Supply Ltd., Surrey, BC). Five jars were available for each collection location (i.e., upstream, downstream) and embryos of similar developmental stages were grouped together. Small neutrally buoyant plastic beads were added to jars with small numbers of eggs to ensure separation is maintained during incubation. Water was flow-through from the LCR and flows were maintained to ensure adequate embryo separation and oxygenation (~5 L/min). Upon hatch, larvae were flushed from the hatching jars directly into rearing troughs associated with each hatching jar and supplied with artificial substrate (1” diameter sinking Bio-Spheres; Dynamic Aqua-Supply Ltd. Surrey, BC) allowing larvae to burrow into interstitial spaces mimicking behaviour documented in the wild (McAdam 2011). To reduce sediment in the incubation jars and tanks, intake water was filtered (254 micron; Spin-Down Separator, Denton, TX) and tanks were cleaned twice a week by purging to remove sediment and waste. All larvae were transported to the conservation hatchery within 7 days of hatch in tanks of ambient river water provided with an oxygen source. Juveniles were reared at the conservation hatchery until approximately 9 months of age and a minimum size of 200 grams in weight. The release target for the LCR is a maximum of 200 individuals, with progeny for release distributed proportionally across spawning locations and spawning events within each spawning location (see FFSBC 2020 for details). Temperature loggers were stationed to record inside facility air, LCR water, and facility tank water temperatures.

2.3 Population Monitoring, Abundance, and Characteristics

White Sturgeon life history information, population characteristics, and mark-recapture related information have been accumulated through the annual broodstock collection program since it was initiated in 2001 and through adult sampling conducted under CLBMON 28 (BC Hydro 2013). Starting in 2013, a systematic stock assessment program to address uncertainties in the current adult abundance and survival estimates was developed between Canadian and US recovery partners. This study represents the first systematic population estimate for the entire TBR. The design of the stock assessment includes two annual surveys, one in the spring and one in the fall.

2.3.1 *Study Area and Design*

The study area for the stock assessment program started at HLK, Canada, and extended downstream to Gifford, Washington, USA (Figure 3). Sampling effort was consistent at 1.6 hooks per hectare of river throughout the entire study area and sampling sites were distributed randomly and spatially balanced using the Generalized Random-Tessellation Stratified Design (GRTS). This was conducted with the statistical package R (Program R, version 2.9.0) using the library packages spsurvey and sp, provided by the United States Environmental Protection Agency (US EPA). The library package spsurvey allows a user to input data/criteria needed for a GRTS sampling design. We developed shapefiles (i.e., geo-referenced maps) for each river zone using ArcMap (version 10.0, Environmental Systems Research Institute, Inc. (ESRI)). Each river zone shapefile was imported into spsurvey and sampling sites were randomly generated. The locations of each sampling site were output as coordinates in Universal Transverse Mercator (UTM) format for visual display on maps and for importing into handheld global positioning system (GPS) devices used for field application. Sites were sampled in ascending order until the required effort had been expended (further detail provided below).

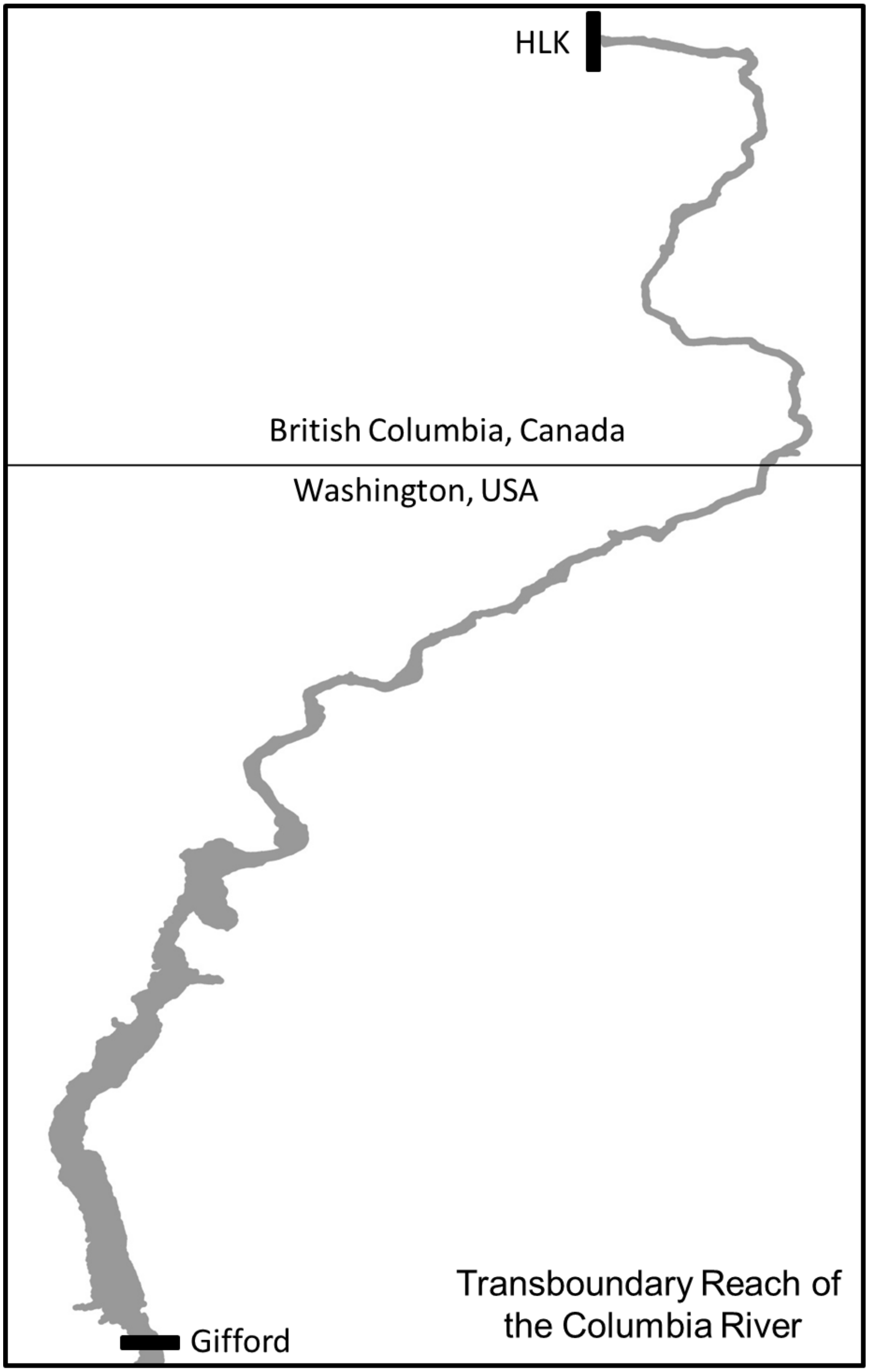


Figure 3. Study area for White Sturgeon stock assessment survey occurring from 2013-2019 in the transboundary reach of the Columbia River. Upstream extent of the study area is Hugh Keenleyside Dam in British Columbia, Canada, and the downstream extent of the study area ends at Gifford, Washington, USA.

2.3.2 *Fish Capture*

The requirement for a consistent, well-documented approach to adult White Sturgeon collection activities is a necessary component of the Upper Columbia River White Sturgeon Recovery Plan (UCSWRI 2012). The document, entitled "Upper Columbia River Adult White Sturgeon Capture, Transportation, and Handling Manual" provides a very detailed and standardized methodology for the capture and handling of adult White Sturgeon (Golder 2006). Set lines were the only method used to capture White Sturgeon during the stock assessment and have been successfully used in the LCR for the past few decades (Irvine et al. 2007).

A medium line configuration was the standard used for set lines, similar to that used by the Oregon Department of Fish and Wildlife (ODFW) and the Washington Department of Fish and Wildlife (WDFW) to capture White Sturgeon in the United States portion of the Columbia River (Nigro et al. 1988). Medium lines measured 84.0 m in length and consisted of a 0.95 cm diameter nylon mainline with 12 circle halibut hooks attached at 6.0 m intervals. Hooks were attached to the mainline using a 0.95 cm swivel snap and a 0.7 m long ganglion line tied between the swivel and the hook. Four different Halibut hook sizes were used to select for different size classes of White Sturgeon. Hook sizes included 14/0, 16.0, 18/0, and 20/0 that a known to select for both adult and juvenile White Sturgeon. Hooks were systematically attached to the mainline in 3 sets of each hook size in descending order of size. The barbs on all hooks were removed to reduce the severity of hook-related injuries and to facilitate fish recovery and release. All set line hooks were baited with pickled squid obtained from Gilmore Fish Smokehouse, Dallesport, WA USA.

Set lines were deployed from a boat at preselected sampling locations and set configuration was based on the physical parameters (i.e., depths and water flow) of the site. Set line configuration consisted of either deploying the line parallel to the shore in faster flowing water or perpendicular to the shore in slower moving water. This was conducted to ensure that fish were able to orientate themselves into the current and rest on the bottom of the river, minimizing stress. Prior to each set, water depth (m) was measured by an echo sounder, and this information was used to select a float line of appropriate length. Anchors were attached to each end of the mainline and a float line was attached to the back anchor of the mainline. The set line was secured to shore with a shore line of suitable length to ensure that the set line was deployed in water depths greater than 2 m. Set lines were deployed and remained in overnight at each selected site.

The set line retrieval procedure involved lifting the back anchor using the float line until the mainline was retrieved. The boat was then propelled along the mainline and each hook line was removed. If a fish was captured on a hook, the boat was stopped while the fish was removed. White Sturgeon removed from the set line were tethered between two anchor points to the port or starboard side of the boat. While tethered, the entire body of the fish was submerged. Once all fish were removed from the set line, the boat was idled into shore or anchored within a nearby back eddy and White Sturgeon were individually brought aboard for biological processing (described in Section 2.3.3). Catch per unit effort (CPUE) was calculated as the total number of fish captured per set line hour.

2.3.3 *Fish Handling and Release*

Captured White Sturgeon were individually guided into a 2.5 m by 1.0 m stretcher that was raised into the boat using a winch and davit assembly. The stretcher was secured on the boat and fresh river water was continuously pumped over the gills during the processing period. A hood on one end of the stretcher protected the head of the White Sturgeon from exposure to direct sunlight and also retained a sufficient amount of water allowing the fish to respire during processing.

All individuals were checked for the presence of a Passive Integrated Transponder (PIT) tag (400 kHz PIT tags or 134.2 kHz ISO PIT tag; Biosonics Inc.) indicating previous capture. Untagged fish were considered to be new captures (i.e., not previously handled by researchers) and had PIT tags injected subdermally in the tissue layer between the ventral edge of the dorsal fin and the right mid-dorsal line. Prior to insertion, both the tag and tagging syringe were immersed in an antiseptic solution (Germaphene). Care was taken to angle the syringe needle so the tag was deposited in the subcutaneous layer and not the muscle tissue. The 2^{nd} left lateral scute was removed from new captures (or recaptured White Sturgeon if present) using a sterilized scalpel in a manner consistent with the marking strategy employed by WDFW and ODFW.

White Sturgeon were measured for fork length to the nearest 0.5 cm. Weight was determined by suspending the fish in the stretcher from the winch and davit assembly using a 250 kg capacity spring scale accurate to ± 2.2 kg. All life history data were recorded in the field on standardized data forms and later entered into an electronic database. Tissues samples were taken from every wild fish captured for future genetic analysis. A small piece of tissue (approximately 1.5 cm by 1.5 cm) from the tip of the dorsal fin was removed using surgical scissors, split into two sub samples, and archived in labelled scale envelopes.

Blood samples were collected from all fish via the caudal vasculature, taken midline just posterior of anal fin. A hypodermic needle (25 gauge) was inserted slowly into the musculature perpendicular to the ventral surface until blood enters the syringe. Approximately 1 ml of blood was extracted. Blood was immediately centrifuged, and plasma collected and frozen for steroid analysis. Plasma T and E2 will be extracted from plasma for analysis by radioimmunoassay (RIA) at the Bozeman Fish Technology Center, Bozeman, MT, USA. This work is expected to help assign reproductive status to wild and hatchery-origin White Sturgeon in the lower Columbia River less invasively.

The ploidy of White Sturgeon has been previously determined to be 8N (Hedrick et al. 1991). However, spontaneous autopolyploid (12N) females that successfully mated with normal (8N) males producing viable offspring of intermediate ploidy (putative 10N; Drauch Schreier et al. 2011) using artificial spawning techniques has recently been detected in the wild brood within the

Kootenai River White Sturgeon Conservation Aquaculture Program (Schreier et al. 2013). This has raised concerns within the LCR White Sturgeon Conservation Aquaculture Program, as the hatchery reared offspring reproductive success and effects on the wild population are unknown. Due to these recent discoveries, blood samples (smears) were collected from all captured fish in 2014 through 2016 (BC Hydro 2015a, 2016a, 2017), to determine the incidence of 12N fish in the wild as well as hatchery-reared fish stocked in earlier years when ploidy levels were unknown. It was identified that the blood smear method underestimated true rates of autopolyploidy (Andrea Schreier, U.C. Davis, personal communication) and blood samples were not collected in 2017 as new methods were being developed. A subset of fish captured during the fall stock assessment session were sampled in certain years (e.g. 2018) to test ploidy levels using a coulter counter. This will be repeated in future years.

Once all biological data was collected, White Sturgeon were returned to the water following processing and remained in the stretcher until they swam away under their own volition.

2.3.4 *Length, weight and year class characteristics*

Wild and hatchery-origin White Sturgeon biological data analyzed in this report include sex ratios, fork length frequencies and means, mean weight, and mean relative weight (W_r). Relative weight (W_r) is a measure of fish plumpness allowing comparison between fish of different lengths, inherent changes in body forms, and populations (Wege and Anderson 1978). W_r is calculated with the following formula:

$$W_r = (W/W_S) * 100$$

where W is the actual fish weight (kg), and W_S is a standard weight for fish of the same length (Wege and Anderson 1978). W_S was calculated according to the White Sturgeon standard weight-length equation developed by Beamesderfer (1993):

$$W_S = 2.735E^{-6} * L^{3.232}$$

where L is fork length (FL; cm).

Length frequency plots of hatchery reared and wild by year and season of sampling were produced using the ggplot2 package (Wickham 2016) in R v. 3.5.3 (R Core Team 2019), Length distribution of hatchery reared year classes within each season's catch was also plotted.

2.3.5 *Mark-recapture analyses*

The analysis of the coordinated stock assessment program has been ongoing, with the full analysis provided in Appendix 1 of this report. We thank Sima Usvyatsov of Golder Associates for her work to continually refine the analysis and incorporate new data when available. We provide a brief summary of the approach in this section, with the full methods outlined in Appendix 1.

The 2013-2018 White Sturgeon mark and recapture dataset in the Transboundary Recovery Area of the Columbia River was used to generate survival, cross-boundary movement probabilities, and population abundance estimates using the programs R v. 3.5.3 (R Core Team 2019), ggplot2 package (Wickham 2016) and MARK (White and Burnham 1999) through the package ‘RMark’ (Laake 2013). For this program, we are reporting aspects of the mark-recapture analysis that inform the wild population. The full analysis is included within BC Hydro (2020).

Mark-recapture data were collected by three agencies (BC Hydro, Colville Confederated Tribes [CCT], and Spokane Tribe of Indians [STOI]) in spring and fall periods from 2013 through 2018 (“2013-2018”). The data were compiled into a single dataset that included information on effort (e.g., date/time and GPS coordinates of sampling) and biological data on sturgeon (e.g., fork length and weight and PIT tag). The unique PIT tag numbers were used to identify sturgeon capture and recapture events. The unique PIT tag numbers were also used to retrieve release data for hatchery fish, including weight and fork length, year class, and country of release.

Multiple mark-recapture models were constructed to estimate survival, recapture probabilities, and population abundance for wild and hatchery fish in the US and Canada. Survival, recapture, and population abundance estimates were produced separately for wild and hatchery-reared fish, as well as by sampling area (Canada / US / combined transboundary area). Fish that were removed from the population (either via culling that began in 2015 or by relocation from the river) were coded as mortalities upon sampling, to account for the change in number of tags at large.

The full dataset was split into two separate files, by country of sampling. This was done due to three reasons:

1. Since no sampling was undertaken in spring 2018 in the US, it was not possible to analyze the combined US/Canada dataset using a single model without omitting the spring 2018 data collected in Canada.
2. In spring 2016 and 2017, the spatial distribution of samples taken in the US was limited, with no sampling performed in zone 6 in spring 2017 and no sampling performed in zones 6 and 7 in spring 2018. Due to the skewed spatial distribution, these spring samples also had to be removed from analysis. If the US/Canada data were analyzed together, the data collected in Canada during these sampling sessions would also have to be removed.
3. Lastly, the sturgeon harvest fishery, which took place in the US in summer 2017 and summer 2018, was likely to affect survival in the US, but not in Canada, due to the low rate of movement between the two countries.

Therefore, the overall dataset was analyzed using four separate sets of models – a set of Cormack-Jolly-Seber (CJS) and POPAN (a parameterization of the Jolly-Seber model) for data collected in the Canadian portion of the transboundary area and a set of CJS and POPAN models for data collected in the US. In the CJS formulation of an open population, only two parameters are modeled – the survival probability and the recapture probability of fish. The POPAN model parameterization is more complex, with four parameters – probability of survival, probability of recapture, probability of entering the population, and a super-population value. The probabilities of survival and recapture are similar to the CJS parameterization. The super-population is a purely mathematical construct, and can be thought of as a reservoir of animals that may enter the population during the course of the study. The probability of entry is the probability of a new animal from the super-population entering the population (via birth or immigration).

To account for differences in survival rates of hatchery fish from different brood years, year class was included as a predictor in the models. This variable used the actual year class information available for each fish in the dataset, with two exceptions:

1. year class was coded as “Wild” for wild fish, and
2. in the US, fish of year classes 2009-2013 were binned together into a year class of ≥2009, since the rare captures of each of these year classes led to model convergence difficulties if these years were included as separate year classes. In Canada, where fewer fish from late year classes were observed, fish of year classes 2007 and later were binned together.

Multiple Cormack-Jolly-Seber (CJS) and POPAN models were constructed to assess the effects of year class, age, and time on survival and recapture. Output models were tested for goodness-of-fit and compared using quasi-Akaike information criterion (QAIC). Non-converged models were removed from analysis, and the remainder were used to produce model-averaged estimates of survival, recapture, and population abundance. Note that CJS-based abundance estimates are expected to be less precise than the POPAN estimates and should only be used for comparison purposes. All data analyses were performed in R v. 3.5.3 (R Core Team 2019) and MARK (White and Burnham 1999) through the package ‘RMark’ (Laake 2013). Full model descriptions are available in BC Hydro (2019).

2.4 Acoustic Tagging and Telemetry

Acoustically tagging White Sturgeon within the LCR is required to monitor movement trends such as seasonal habitat use, and spawning site selection, timing, and duration. Additionally, unknown spawning habitat locations within the LCR have been identified through spawn related movements (BC Hydro 2013). Spawn related movements are defined as rapid movements from one area of long-term residency to an area of short-term residency during the spawning season (June/July/August), and returned movements to the original area of long-term residency. In 2017, movements of multiple fish were examined to provide additional support when identifying a possible spawning location.

Vemco model V16 acoustic tags (operational life of 10 years) were allocated to adult White Sturgeon predicted to spawn within the following 1-3 years (based on sex maturity examinations) in 2009, 2011, and 2013 (BC Hydro 2011, 2013). In 2007 through 2012, all adults collected for broodstock were implanted with an acoustic tag prior to their post spawning release (BC Hydro 2013). In 2013, only one female that was collected for broodstock and did not successfully spawn was implanted with an acoustic tag prior to release in order to monitor post release movements related to spawning. No fish were acoustically tagged in 2014. In June 2015, 4 females expected to spawn in that year were acoustically tagged. In May 2016, 1 male that was expected to spawn was acoustically tagged. One female was tagged in May 2017. No tags were deployed in 2018 or 2019. Total number of White Sturgeon acoustically tagged is provided in Table 2.

Table 2. Acoustic tags implanted by year for female and male adult White Sturgeon in the lower Columbia River (LCR). Tags were either implanted in wild adults captured and released back into the LCR or in those selected as broodstock that were transported to the conservation hatchery for spawning and then returned to the LCR.

Year	Wild		Broodstock		Total
	Female	Male	Female	Male	
2007	0	0	5	6	11
2008	0	0	8	7	15
2009	11	8	10	12	41
2010	0	0	9	10	19
2011	4	1	10	11	26
2012	0	0	8	10	18
2013	1	1	1	0	3
2014	0	0	0	0	0
2015	4	0	0	0	4
2016	0	1	0	0	1
2017	1	0	0	0	1
2018	0	0	0	0	0
2019	0	0	0	0	0
Total	21	11	51	56	139

2.4.1 *Acoustic Receiver Array*

We used an array of fixed station remote receivers (Vemco, model VR2 and VR2W) already deployed within the LCR to detect spatial and temporal movements of acoustically tagged White Sturgeon. Since being initially deployed in 2003, the spatial extent of the array encompassing the LCR from HLK (rkm 0.1) southward to the Canada/U.S. International Border (rkm 57.0) remained constant until 2009. In early May of 2010, the array was repositioned to 3 km intervals starting at HLK and moving downstream to the international border. This was done to improve spatial coverage throughout the study range (as indicated through increased detectability of individual fish exhibiting site fidelity). We also increased the spatial coverage of the array by adding receivers in areas that were previously not covered, improving our ability to detect movements on a finer spatial scale.

Each station consisted of a weighted mainline of either 0.95 cm diameter nylon rope or 0.64 cm stainless steel cable extended between a large pyramid reinforced concrete anchor (55-80 kg) and a highly buoyant low drag float (Model LD-2 or LD-3). Materials used for each station was dependent on location and water flow. A receiver was secured with cable ties approximately 3 m below the water surface on the weighted mainline with the hydrophone orientated towards the river bottom. Data downloading and equipment maintenance (e.g., replace or repair cable ties, rope, float, mainline, and batteries) for all stations was conducted quarter annually. Raw data were downloaded using Vemco User Environment (VUE) software (version 2.2.2) and all raw data were exported at the end of each calendar year into a Microsoft Access database.

2.4.2 *Telemetry Data Analysis*

Although the acoustic array was originally intended to track the movements of White Sturgeon, multiple research projects involving other fish species are ongoing in the LCR and, as such, user agreements with other agencies and researchers have been developed for the utilization of the telemetry array. For all projects combined, we often record more than 4 million detections annually. Over a period of the last several years, this has resulted in a larger amount of data than anticipated and issues regarding tag collisions increasing the total number of “false” detections occurring in the database. False detections are echoes generated by the system’s environment (e.g., bathymetric profile, substrate, narrow river) or pings of multiple tags colliding resulting in detections that were not linked to an active transmitter, or does not align with movement data for an active transmitter. Finally, our ability to upload, store, and analyze raw data collected from the multitude of acoustic receivers has become more labour intensive with the large numbers of active acoustic transmitters at large (>400) in the LCR between HLK in Canada and Grand Coulee Dam in WA, USA.

We developed a telemetry database using a Client-Server model in Microsoft Access to help address data requirements related to examining White Sturgeon movements, assist with identifying “false” detections, and filter out unwanted/unnecessary tag data (e.g., non-sturgeon species). The database was designed as a filtering tool that allows the organization and summary of data in a manner that results in outputs suitable for analyses. Queries were generated for each individual tag containing the total number of times each tag was detected by day at a particular station or river kilometer. Data were binned in 24-hour periods, as site fidelity is known to be high in this system and hourly observations of movement proved to be too fine scale for this species. The detection record was examined for each individual, and observed false detections were removed. In 2018-2019, a relational database has been developed to manage not only acoustic white sturgeon data but multiple data types including life history information (e.g. capture and biological information), environmental covariates (e.g. flows or habitat), animal movements (e.g. telemetry), and other important program components (e.g. hatchery programs). This database will directly support more advanced analyses of habitat use and movements.

Detection data from 2009-2017 were summarized and proportional habitat use throughout the LCR was examined as a function of individual fish and sex. We calculated the proportional spawning site use as a function of individual fish and sex based on suspected spawn related movements (defined in Section 2.4). Additionally, we examined migration trends from site of residency to suspected spawning site including total distance travelled (rkm), travel time (days), and time spent at a spawning location (days). In 2018, a large analysis of all sturgeon detections since 2008 was initiated through the development of a relational database and more complex models. While still ongoing, this analysis will measure residence time in specific habitats within a 57 km section of the upper Columbia River and estimate the probability of movement and distance migrated as a function of habitat selection and environmental conditions (discharge and temperatures). Results will help determine the effect of environmental factors and river regulation on habitat use and movements of white sturgeons.

3.0 MONITORING RESULTS

It is intended that the long term results of all White Sturgeon monitoring programs will be used to characterize movements and redistribution patterns, spawning behavior and frequency, relative abundance, habitat preferences, growth rates, and survival. Additionally, results will provide information on potential new hypotheses and physical works options, and provide baseline information necessary to evaluate physical works experiments and effects of opportunistic flows.

3.1 Physical Parameters

3.1.1 *Discharge*

Mean daily discharge (cms; cfs) on the lower Columbia River was measured from Arrow Reservoir, Kootenay River, Birchbank, and Canada/U.S. International Border for the 2019 study period and is presented in Figure 4a. Discharge measurements closest to the Waneta site and those closest to the ALH and Kinnaird spawning sites are presented in Figure 4b and 4c, respectively. Mean daily discharge (cms) and estimated spawning period at spawning locations within the lower and middle Columbia River is summarized in Figure 4d. Minimum and maximum discharge (cms; cfs) for each location and year is given in Table 3.

White Sturgeon spawning in the LCR typically occurs when water temperatures exceed 14.0°C and flows are on a descending pattern (Hildebrand et al. 1999; BC Hydro 2013; BC Hydro 2016a). The timing and duration of White Sturgeon spawning period is annually estimated to occur between June 1 and August 15 based on embryo and larval collections over the past decade. At the Canada US border, peak freshet flows were relatively low, with 3,873.7 (cms) reached on May 18th, 2019, well ahead of with the estimated initial spawning date (Figure 4 a through c).

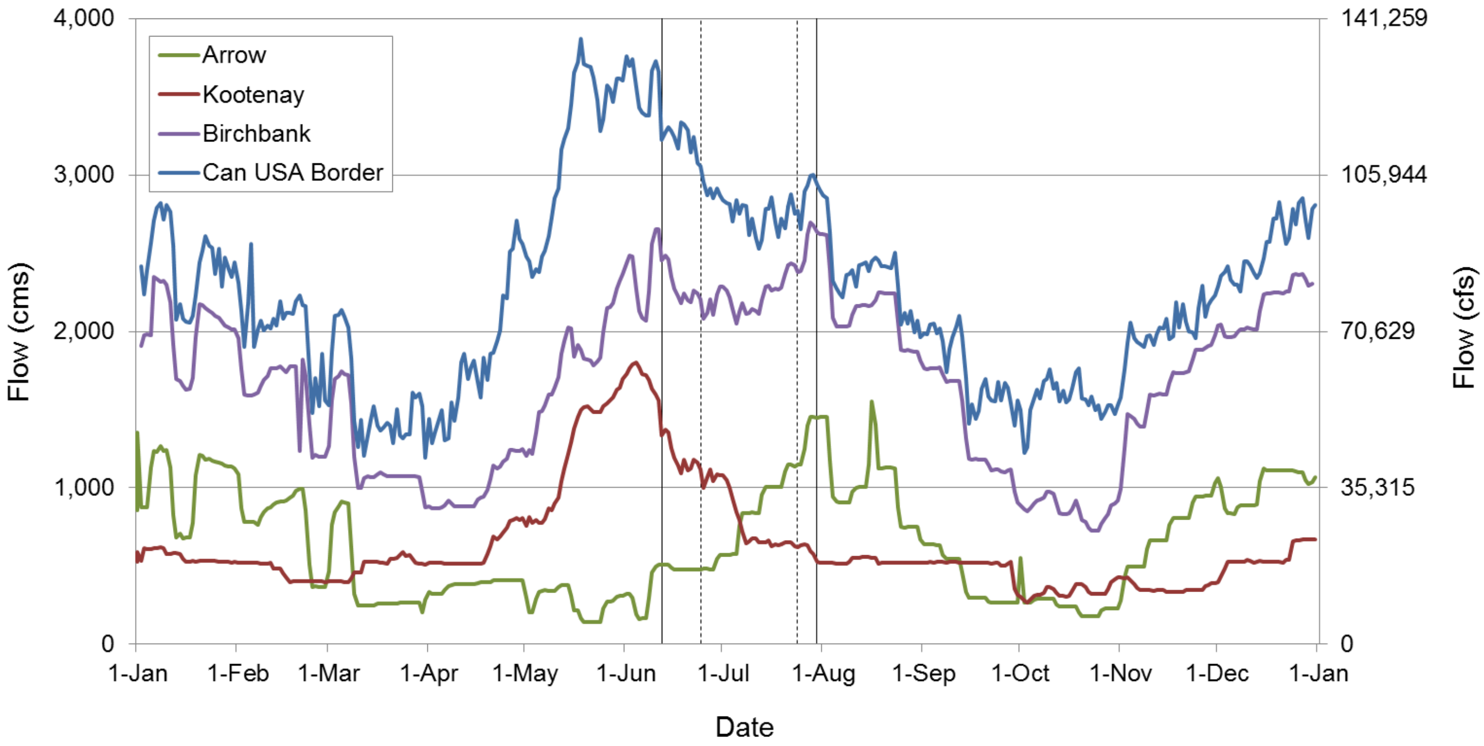


Figure 4a. Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada/U.S. International Border on the lower Columbia River from January 01, 2019 – December 31, 2019. The solid vertical bars represent the first and last estimated spawning date at the Waneta site in 2019. The dashed vertical bars represent the first and last estimated spawning dates at ALH and Kinnaird combined. Estimated spawning dates were based on the developmental stage of collected embryos and/or larvae.

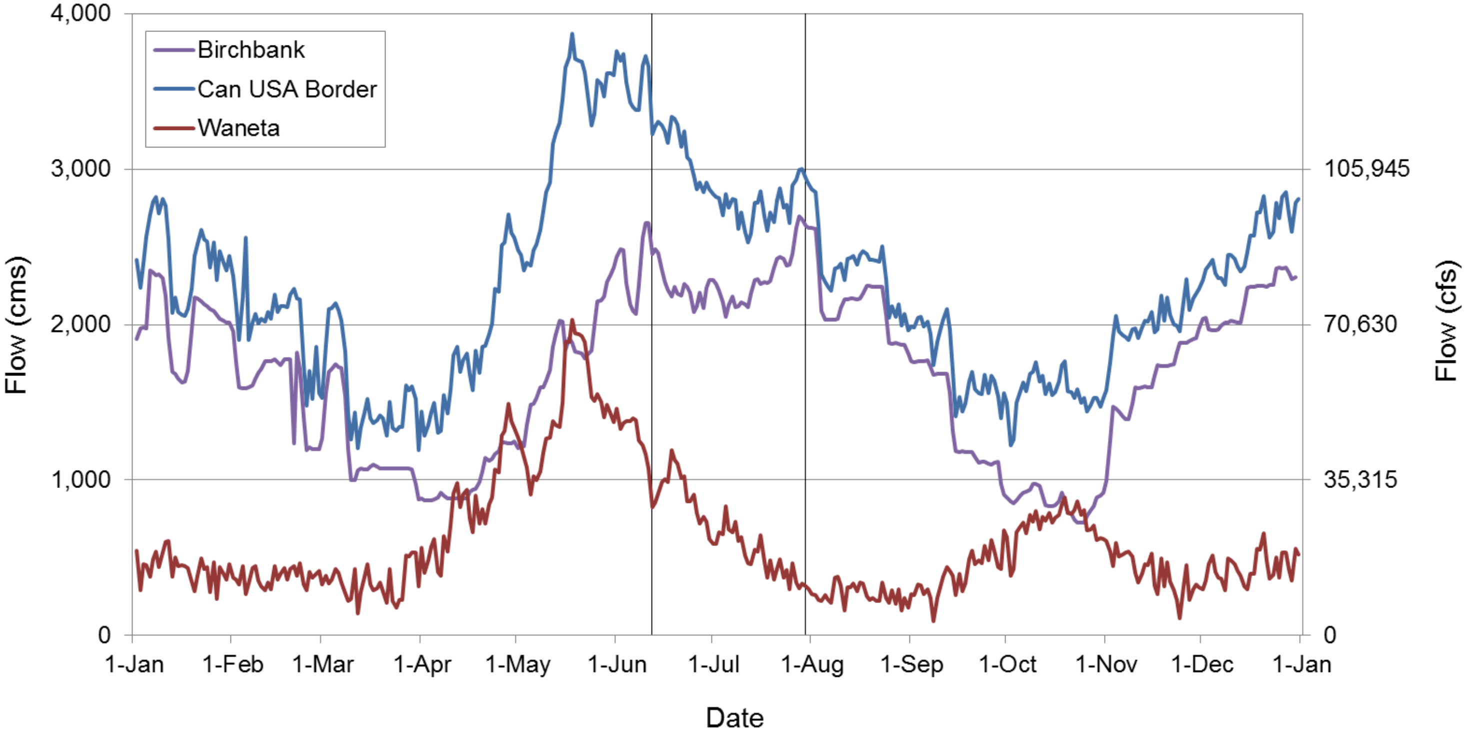


Figure 4b. Mean daily discharge near the Waneta spawning site in 2019. Discharge was measured at Birchbank, Waneta Dam and the Canada/U.S. International Border on the lower Columbia River from January 01, 2019 – December 31, 2019. The solid vertical bars represent the first and last estimated spawning date at the Waneta site in 2019.

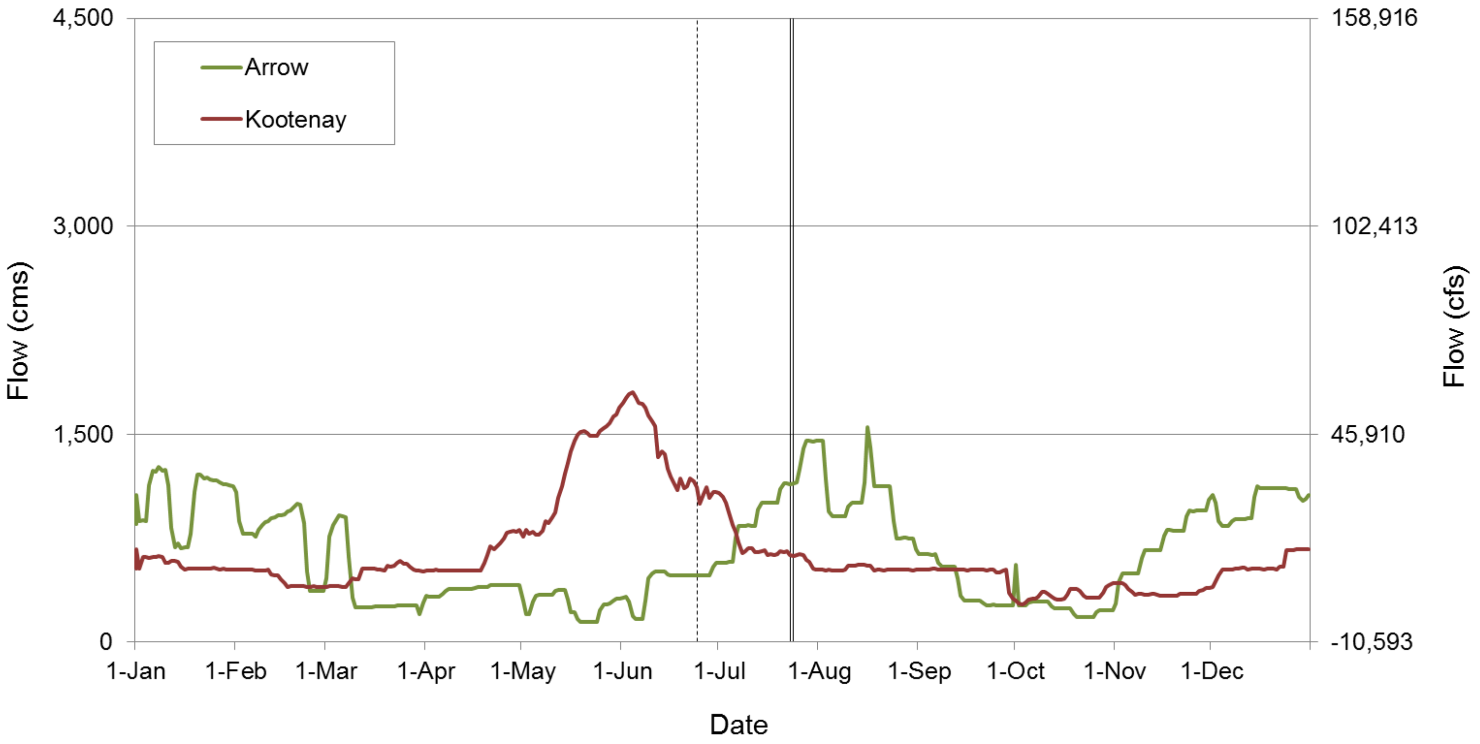


Figure 4c. Mean daily discharge near the ALH and Kinnaird spawning sites in 2019. Discharge was measured from Arrow Reservoir (HLK and ALH dams) and the Kootenay River (Brilliant and Brilliant Expansion dams) from January 01, 2019 – December 31, 2019. The solid and dashed vertical bars represent the first and last estimated spawning date at the ALH and Kinnaird sites in 2019, respectively.

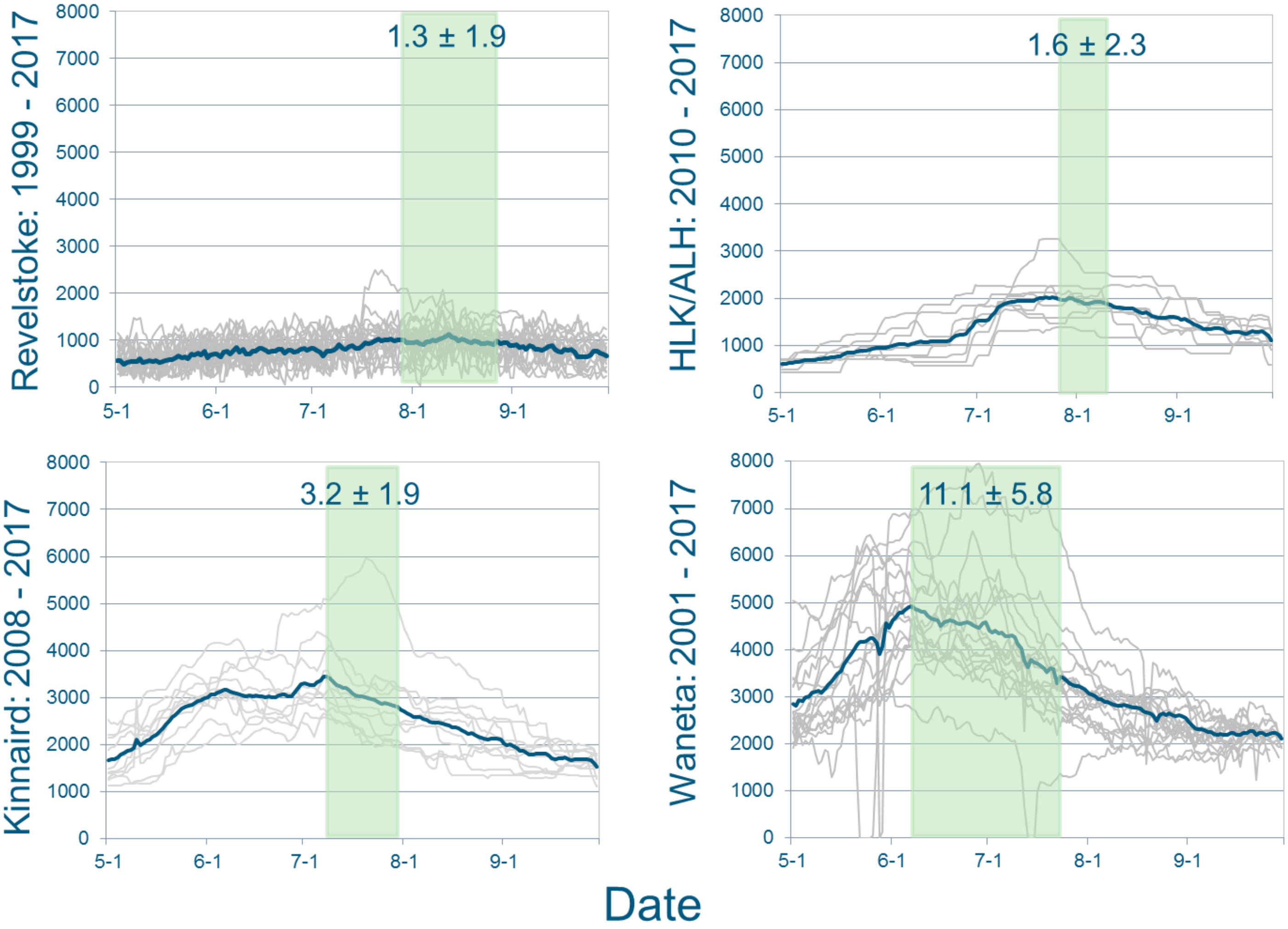


Figure 4d. Mean daily discharge for up to 18 years at the Revelstoke (Middle Columbia River), ALH, Kinnaird and Waneta spawning areas. Blue line indicates mean discharge over the duration of observations. Green blocks and associated values indicate estimated spawning period and number of spawning events (mean +/- SD) over the duration of observations, respectively.

Table 3. Minimum and maximum discharge (cubic meters per second, cms; cubic feet per second, cfs) at four locations on the lower Columbia River in 2019.

Location	Discharge			
	Minimum (cms)	Maximum (cms)	Minimum (cfs)	Maximum (cfs)
Arrow Reservoir	144.8	1,551.4	5,112	54,788
Kootenay River	268.8	1,803.0	9,491	63,673
Birchbank	727.9	2,695.6	25,706	95,195
Border	1,195.0	3,873.7	42,200	136,799

3.1.2 *Water Temperature*

LCR mean daily water temperatures (°C) during 2019 are illustrated in Figure 5a. Mean daily water temperature (°C) and estimated spawning period for the lower and middle Columbia River is summarized in Figure 5b. Annual mean (± SD), minimum, and maximum water temperatures (°C) at locations HLK (rkm 0.1), Kootenay Eddy (rkm 10.5), Kinnaird (rkm 13.4), Genelle Eddy (rkm 26.0), and Waneta Eddy (rkm 56.0) are summarized in Table 4. The date of occurrence of spawning temperature threshold (14°C) at each location is provided in Table 4. Variations in water temperatures experienced during the study period can be attributed to warm/cold water influences caused in the Arrow Reservoir system (i.e., combined HLK and ALH discharges from Arrow Lakes Reservoir), and other cold-water tributary influences.

Table 4. Daily mean (± SD), minimum, and maximum water temperatures (^{o}C) recorded within the lower Columbia River during 2019. Data was recorded at locations of Hugh L. Keenleyside dam (HLK; rkm 0.1), Kootenay Eddy (rkm 10.5), Kinnaird (rkm 13.4), Genelle Eddy (rkm 26.0), Rivervale (rkm 35.8), and Waneta Eddy (rkm 56.0). Additional temperature loggers were installed at the upper and lower ends of the Waneta spawning area on June 12, 2019.

		Temperature			Date of Suspected Spawning Threshold (14°C)
Location	RKM	Mean ± SD	Min	Max	
HLK	0.1	9.2 ± 5.2	2.1	17.8	04-Jun
Kootenay	10.5	9.7 ± 5.9	1.6	19.6	13-Jun
Kinnaird	13.4	10.0 ± 5.5	1.9	18.9	15-Jun
Genelle	26.0	10.0 ± 5.4	2.0	18.6	13-Jun
Rivervale	35.8	10.0 ± 6.0	2.1	18.7	13-Jun
Waneta	56.0	10.4 ± 6.0	1.5	20.0	13-Jun
Waneta - *lower**	56.0	16.0 ± 4.4	6.8	20.7	n/a
Waneta - *upper**	56.0	15.9 ± 4.4	6.8	20.5	n/a

*Temperature loggers installed on June 12

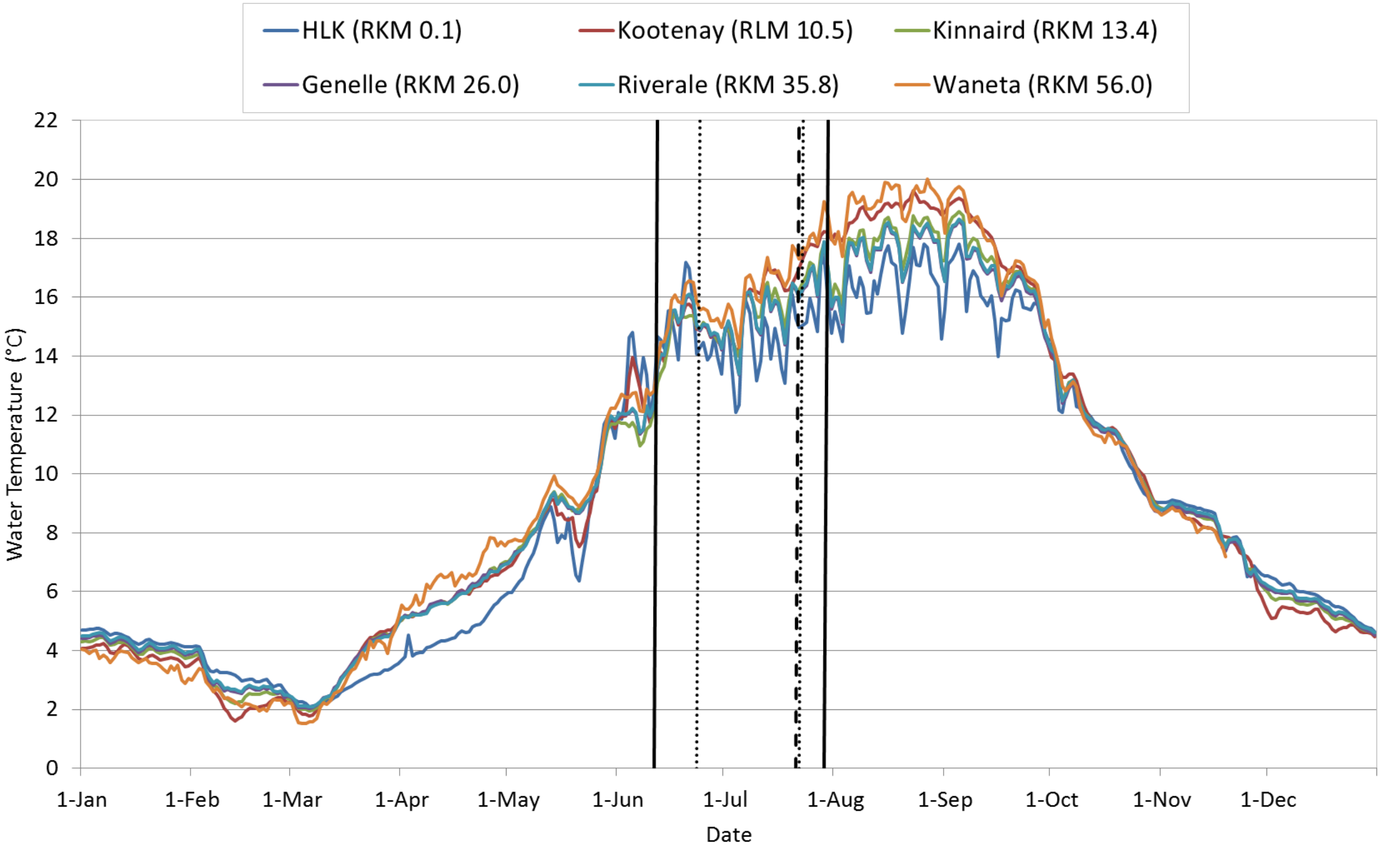


Figure 5a. Mean daily water temperature (°C) of the lower Columbia River in 2019. Data was recorded at locations of Hugh L. Keenleyside dam (HLK; rkm 0.1), Kootenay Eddy (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), Rivervale (rkm 35.8) and Waneta (rkm 56.0). Missing data is due to lost or damaged temperature loggers. The solid vertical bars represent the first and last estimated spawning date at the Waneta site in 2019. The dotted and dashed vertical bars represent the first and last estimated spawning dates at Kinnaird and ALH, respectively. Estimated spawning dates were based on the developmental stage of collected embryos and/or larvae.

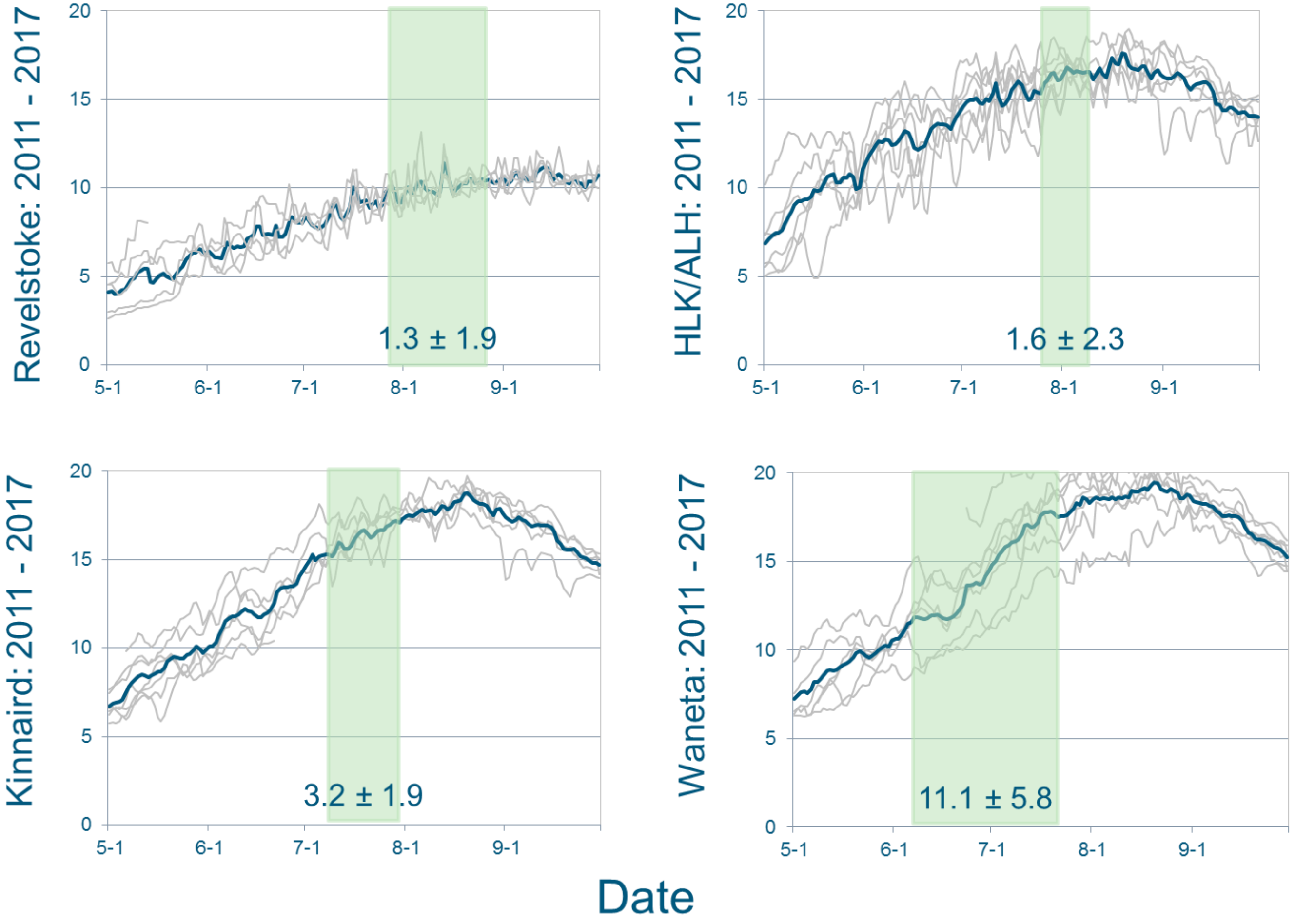


Figure 5b. Mean daily temperature (°C) for up to 18 years at the Revelstoke (Middle Columbia River), ALH, Kinnaird and Waneta spawning areas. Blue line indicates mean temperature over the summarized duration of observations. Green blocks and associated values indicate estimated spawning period and number of spawning events (mean +/- SD) over the summarized duration of observations.

3.2 Spawn Monitoring

3.2.1 *Embryo and Larval Sampling Effort and Collection*

Downstream Location – Waneta (rkm 56.0)

Egg mats (n=4) and drift nets (n=4) were deployed on June 7 and sampling continued until August 7. During the sampling period, water temperatures ranged from 12.1 to 19.6°C (Figure 5a) and water depth (mean ± SD) was 4.6 ± 1.4 m and 4.6 ± 1.3 m for egg mats and drift nets, respectively. Total sampling effort for egg mats and drift nets was 8,738 hours and 436 hours, respectively (Table 5 and 6). Single set effort was 57.5 ± 34.6 hours and 3.0 ± 1.0 hours for egg mats and drift nets, respectively.

A total of 826 embryos (egg mat, n=105; drift net, n=721) and 129 larvae (egg mat, n=2; drift net, n=127) were captured at Waneta between the dates of June 17 and August 2 (Table 5 and 6). The largest daily egg mat sample was 38 (embryos, n=38; larvae, n=0) collected on June 24 representing 0.36 of total egg mat sample collection. The largest daily drift net sample was 508 (embryos, n=508; larvae, n=0) collected on June 24 representing 0.60 of total drift net sample collection. All live embryos (n=645) were stage and transported to the SIF. Live larvae (n=33) were transported to the SIF while the remaining larvae were preserved for staging. Hatched larvae (n=419) were transported to the conservation hatchery.

Upstream Location – Kinnaird (rkm 13.4 to rkm 18.2)

Egg mats (n=1; rkm 14.5) and drift nets were deployed at rkm 14.5 (n=4) and rkm 18.2 (n=4) between the dates of June 18 and June 25 and sampling continued until August 7. During the sampling period, water temperatures ranged from 14.0 to 18.0°C (Figure 5a) and sampling water depth was 4.4 ± 1.3 m. Total egg mat sampling effort was 836 hours and mean single set effort was 83.6 ±37.1 hours (Table 5 and 6).Total sampling effort for drift nets was 1,466 hours. The majority of drift net sampling was over a short period of time (3.6 ± 0.6 hours) with some longer sets throughout the monitoring period (33.3 ± 11.8 hours).

A total of 1 embryo (rkm 14.5) and 6 larvae (rkm 18.2; Table 5 and 6) were collected between July 16 and July 29. The embryo was transferred to the SIF while all larvae were dead upon capture and preserved. One larvae was transported from the SIF to the conservation hatchery.

Upstream Location – ALH (rkm 0.1)

Egg mats (n=4) and drift nets (n=4) were deployed on June 18 and 20, respectively, and sampling continued until August 7. During the sampling period, water temperatures ranged from 12.1 to 17.3°C (Figure 5a). Total egg mat sampling effort was 2,860 hours (Table 5 and 6). Mean daily egg mat sampling water depth was 6.2 ± 1.8 m and mean single set effort was 77.3 ± 31.6 hours. Total drift net sampling effort was 1,311 hours (Table 5 and 6). Mean daily drift net sampling water depth was 6.0 ± 1.9 m and single set effort was 17.5 ± 16.7 hours.

A total of 3 embryos were collected between July 24 and 26 and 6 larvae were collected between July 30 and August 1 (Table 5 and 6). One larvae was alive and transferred to the SIF. The remaining larvae were dead upon capture and preserved. No ALH larvae survived in the SIF.

Table 5. White Sturgeon embryo and larvae collection and sampling effort for monitoring locations in the lower Columbia River including Waneta (rkm 56.0), downstream of Kinnaird (rkm 12.8, rkm 13.4, rkm 14.5, rkm 15.0, rkm 15.6, rkm 16.9, rkm 17.3, rkm 18.2, rkm 19.2), Kootenay (rkm 10.5), downstream Arrow Lakes Generating Station (ALH; rkm 6.0), ALH (rkm 0.1) and Hugh L. Keenleyside dam (HLK; rkm 0.1) for years 2008 through 2019.

Year	Location	Egg Collection Mats			Drift Nets		
		Embryo	Larvae	Effort (hrs)	Embryo	Larvae	Effort (hrs)
2008	Waneta	3,456	7	19,428	494	220	72
	rkm 18.2	0	0	16,493	0	1	164
2009	Waneta	1,715	2	21,964	77	39	90
	rkm 18.2	-	-	-	0	5	976
	rkm 6.0	-	-	-	0	0	3,091
2010	Waneta	4,003	16	18,204	888	89	113
	rkm 18.2	0	0	10,600	1	8	2,104
	ALH	12	0	3,608	30	115	2,084
2011	Waneta	2,318	9	19,882	234	16	50
	rkm 18.2	-	-	-	2	32	1,400
	rkm 14.5	-	-	-	0	0	154
	rkm 10.5	-	-	-	0	0	993
	HLK	-	-	-	0	0	461
	ALH	2	0	3,614	183	308	2,538
2012	Waneta	226	2	16,627	134	15	48
	rkm 18.2	-	-	-	0	0	197
	ALH	-	-	-	6	0	2,929
2013	Waneta	410	0	14,739	-	-	-
	rkm 18.2	-	-	-	0	4	363
	rkm 14.5	-	-	-	0	1	154
	ALH	-	-	-	0	0	680
2014	Waneta	5,729	5	19,362	33	62	43
	rkm 18.2	-	-	-	5	8	1,514
	rkm 17.3	-	-	-	0	1	128
	rkm 16.9	-	-	-	0	2	43
	rkm 15.6	-	-	-	0	0	77
	rkm 15.0	-	-	-	0	0	106
	rkm 14.5	-	-	-	1	2	670
	ALH	0	0	1,808	0	0	857

Table 5 (Cont.). White Sturgeon embryo and larvae collection and sampling effort for monitoring locations in the lower Columbia River including Waneta (rkm 56.0), downstream of Kinnaird (rkm 12.8, rkm 13.4, rkm 14.5, rkm 15.0, rkm 15.6, rkm 16.9, rkm 17.3, rkm 18.2, rkm 19.2), Kootenay (rkm 10.5), downstream Arrow Lakes Generating Station (ALH; rkm 6.0), ALH (rkm 0.1) and Hugh L. Keenleyside dam (HLK; rkm 0.1) for years 2008 through 2019.

Year	Location	Egg Collection Mats			Drift Nets		
		Embryo	Larvae	Effort (hrs)	Embryo	Larvae	Effort (hrs)
2015	Waneta	245	1	22,016	8	55	275
	rkm 13.4	-	-	-	0	0	533
	rkm 14.5	-	-	-	0	1	272
	rkm 16.9	-	-	-	0	4	186
	rkm 17.3	-	-	-	0	1	187
	rkm 18.2	-	-	-	0	2	1,767
	rkm 19.2	-	-	-	0	0	91
	ALH	-	-	-	0	1	1,373
2016	Waneta	1270	4	13,831	5203	955	965
	rkm 12.8	-	-	-	0	0	901
	rkm 13.4	-	-	-	0	0	118
	rkm 14.5	-	-	-	0	3	381
	rkm 16.9	-	-	-	0	5	121
	rkm 17.3	-	-	-	0	1	122
	rkm 18.2	-	-	-	0	8	990
	ALH	-	-	-	0	0	1006
2017	Waneta	561	2	10,377	1,914	582	913
	rkm 13.4	-	-	-	1	2	416
	rkm 14.5	-	-	-	0	8	433
	rkm 16.9	-	-	-	0	0	78
	rkm 18.2	-	-	-	0	4	363
	ALH	-	-	-	511	159	2,146
2018	Waneta	455	17	6,456	9,515	570	1,258
	rkm 13.4	-	-	-	0	2	1,071
	rkm 14.5	-	-	-	0	1	707
	rkm 18.2	-	-	-	0	1	979
	ALH	-	-	-	3	14	2,290
2019	Waneta	105	2	8,738	721	127	437
	rkm 14.5	0	0	836	1	0	1,335
	rkm 18.2	-	-	-	0	6	131
	ALH	0	0	2,860	3	6	1,311

Table 6. Summary of the total effort, the number of embryos and larvae collected, and the estimated number of spawning days from 2008-2019 for the Waneta, Kinnaird, and ALH spawning locations.

Location	Sampling Year											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Waneta												
Total Effort	19,500	22,054	18,317	19,932	16,675	14,739[1]	19,405	22,291	14,796	11,290	7,714	9,175
No. of Embryos	3,950	1,792	4,891	2,552	360	410	5,762	253	6,473	2,475	9,970	826
No. of Larvae	220	41	105	25	17	0	67	56	959	584	587	129
No. of Spawning Days	17	15	27	19	18	12	5	6	13	17	21	14
Kinnaird												
Total Effort	16,657[2]	976[2]	2,104[2]	2,547[2]	197[2]	517[2]	2,538[2]	3,036[2]	2,633[2]	1,289[2]	2,758[2]	2,302
No. of Embryos	0	0	1	2	0	0	6	0	0	1	0	1
No. of Larvae	1	5	8	32	0	5	13	8	17	14	4	6
No. of Spawning Days	n/a	n/a	n/a	n/a	n/a	2	3	4	6	1	4	4
ALH												
Total Effort	-	-	5,692	6,152	2,929[2]	680[2]	2,665	1,373[2]	1,006[2]	2,146[2]	2290[2]	4,171
No. of Embryos	-	-	42	185	6	0	0	0	0	511	3	3
No. of Larvae	-	-	115	308	0	0	0	1	0	159	14	6
No. of Spawning Days	-	-	n/a	5	n/a	n/a	n/a	n/a	n/a	3	3	2

[1] No drift net sampling effort

[2] No egg mat sampling effort

3.2.2 *Developmental Staging and Estimated Spawning Dates*

Embryos and larvae were assigned a developmental stage based on Dettlaff et al. (1993) to calculate an estimated date of fertilization. Stages were generalized compared to previous sampling years (BC Hydro 2015a) to reduce handling of collected embryos and larvae. Samples collected in years 2012 to 2019 ranged from newly fertilized embryos to larvae (Table 7a and 7b).

Based on staged embryos and yolk-sac larvae, an estimated 14 discrete spawning days occurred at Waneta between the dates of June 12 and July 30 (Table 8). All of these events occurred on the descending limb of the hydrograph. Spawning was estimated to have occurred July 23 to 24 at ALH and on four days between June 24 and July 23 at Kinnaird (Table 8).

Estimated spawning dates at locations of Waneta, Kinnaird, and ALH for sampling years 2011 through 2019 are provided in Table 9. Spawning has generally been estimated to occur at Waneta in mid-June to late July and at Kinnaird in early to late July. Estimated spawning dates at ALH have been early July to early August.

Table 7a. Proportion of White Sturgeon embryos and larvae collected across different developmental stages from lower Columbia River spawn monitoring locations of Waneta (rkm 56.0), Kinnaird (rkm 13.4 to rkm 18.2), and Arrow Lakes Generating Station (ALH; rkm 0.1) in 2019. Developmental stages are based on Dettlaff et al. (1993). To limited handling of embryos and larvae, developmental stages were generalized compared to previous collection years (BC Hydro 2015).

Developmental Category	Stage	Waneta		Kinnaird		ALH	
		n	*Prop.*	*n*	*Prop.*	*n*	*Prop.*
Cleavage - Gastrulation	1 - 14	534	0.69	1	0.14	0	0.00
Yolk Plug	15 - 18	42	0.05	0	0.00	0	0.00
Neurulation - Heart formation - Pre-Hatch	19 - 35	75	0.10	0	0.00	3	0.33
Yolk-Sac Larvae	36 - 45	127	0.16	6	0.86	6	0.67

Table 7b. Proportion of White Sturgeon embryos and larvae collected across different developmental stages from lower Columbia River spawning locations of Waneta (rkm 56.0), Kinnaird (rkm 12.8 to 18.2), and Arrow Lakes Generating Station (ALH); rkm 0.1) in years 2012 to 2019.

Developmental Category	Stage	Waneta		Kinnaird		ALH	
		n	*Prop.*	*n*	*Prop.*	*n*	*Prop.*
Cleavage - Gastrulation	1 - 14	17,114	0.68	3	0.04	361	0.57
Yolk Plug	15 - 18	3,209	0.13	1	0.01	94	0.15
Neurulation - Heart formation - Pre-Hatch	19 - 35	2,659	0.10	1	0.01	14	0.02
Yolk-Sac Larvae	36 - 45	2,353	0.09	66	0.93	166	0.26

Table 8. Estimated spawning dates in the lower Columbia River during 2019 at locations of Waneta (rkm 56.0), and ALH (rkm 0.1). Dates are determined through back calculation from date of capture based on developmental stage of each sample.

Spawning Day	Date
Waneta	
1	12-Jun-19
2	13-Jun-19
3	16-Jun-19
4	17-Jun-19
5	22-Jun-19
6	23-Jun-19
7	24-Jun-19
8	25-Jun-19
9	26-Jun-19
10	28-Jun-19
11	12-Jul-19
12	14-Jul-19
13	16-Jul-19
14	30-Jul-19
Kinnaird	
1	24-Jun-19
2	10-Jul-19
3	12-Jul-19
4	23-Jul-19
ALH	
1	23-Jul-19
2	24-Jul-19

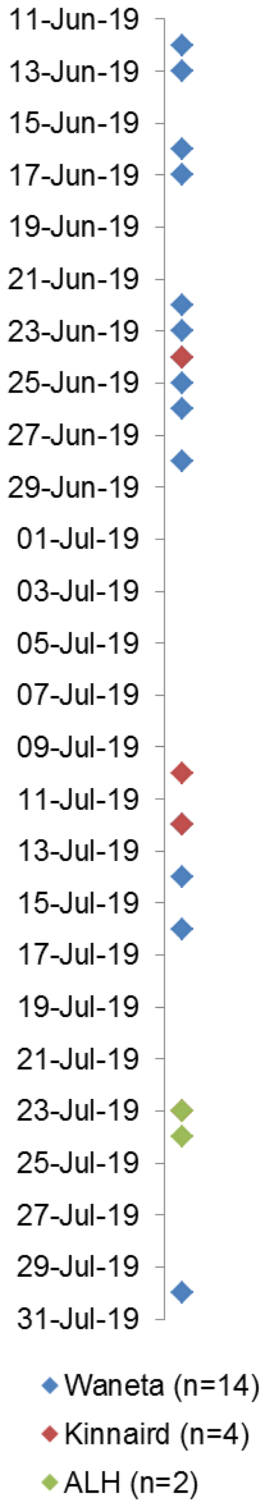


Table 9. Estimated spawning days and duration for White Sturgeon at lower Columbia River spawn monitoring locations of Arrow Lakes Generating Station (ALH; rkm 0.1), Kinnaird (rkm 12.8 to 19.2), and Waneta (rkm 56.0) for years 2011 through 2019. Estimated spawning duration was based on the developmental stage of collected embryos or larvae. Yearly data was excluded due for reasons of poor condition of samples collected inhibiting assignment of developmental stage or no samples were collected.

Location	Year	Number of Estimated Spawning Days	Duration		Daily Mean Water Temperature (°C)	
			Start	End	Minimum	Maximum
ALH	2011	5	01-Aug	05-Aug	14.8	16.1
ALH	2017	3	17-Jul	19-Jul	12.4	17.4
ALH	2018	3	04-Jul	07-Jul	13.7	15.3
ALH	2019	2	23-Jul	24-Jul	15.0	15.1
Kinnaird	2013	2	23-Jul	27-Jul	16.8	18.1
Kinnaird	2014	3	14-Jul	22-Jul	16.5	17.8
Kinnaird	2015	4	02-Jul	09-Jul	16.7	19.0
Kinnaird	2016	6	03-Jul	30-Jul	13.0	19.2
Kinnaird	2017	1	10-Jul	10-Jul	15.6	16.0
Kinnaird	2018	4	5-Jul	13-Jul	14.9	16.6
Kinnaird	2019	4	24-Jun	23-Jul	14.0	16.5
Waneta	2011	19	30-Jun	03-Aug	11.8	18.1
Waneta	2012	18	28-Jun	22-Jul	13.0	16.0
Waneta	2013	12	18-Jun	18-Jul	12.8	19.9
Waneta	2014	5	21-Jun	15-Jul	11.3	18.7
Waneta	2015	6	11-Jun	21-Jun	n/a	n/a
Waneta	2016	13	03-Jun	25-Jun	12.2	19.4
Waneta	2017	17	11-Jun	6-Jul	13.3	16.6
Waneta	2018	21	12-Jun	15-Jul	11.9	18.0
Waneta*	2019	14	12-Jun	30-Jul	15.1	20.0

*Temperature loggers installed at the upper and lower boundaries of spawning area

3.2.3 *Streamside Incubation Facility*

Daily air and water temperatures recorded at the streamside facility are illustrated in Figure 6 and 7. Mean (± SD), minimum, and maximum air and water temperatures are provided in Table 10. Despite elevated air temperatures in the SIF, water temperatures recorded from the LCR and facility tanks were similar (Table 10).

Live embryos (n=645) and larvae (n=33) collected at Waneta were transferred to the SIF for incubation (Figure 8). Three embryos and one larvae were collected at ALH and transferred to the SIF incubation. One embryo collected at Kinnaird was transferred to the SIF while all larvae (n=6) were dead upon capture. Following incubation, larvae originating from Waneta (n=418) and Kinnaird (n=1) were transported to the conservation hatchery. No ALH larvae survived to time of transportation. Abundance and survival for sampling years 2014 through 2019 are provided in Tables 11 and 12, respectively. In the spring of 2020, 200 wild progeny from 2019 collections were released into the LCR with the remaining fish to be released in the Middle Columbia River.

Table 10. Mean (± SD), minimum, and maximum air and water temperatures recorded at the location of the Streamside Incubation Facility in 2019. Temperature loggers were stationed to record inside air, lower Columbia River (LCR) water, and SIF tank water temperatures (°C).

	Temperature (°C)		
Source	Mean ±SD	Minimum	Maximum
Hatchery Air	21.5 ± 6.9	10.96	41.75
River Intake	16.0 ± 1.2	13.31	18.62
Hatchery Lower Trough	16.4 ± 1.3	13.48	21.3
Hatchery Upper Trough	16.4 ± 1.3	13.45	22.02

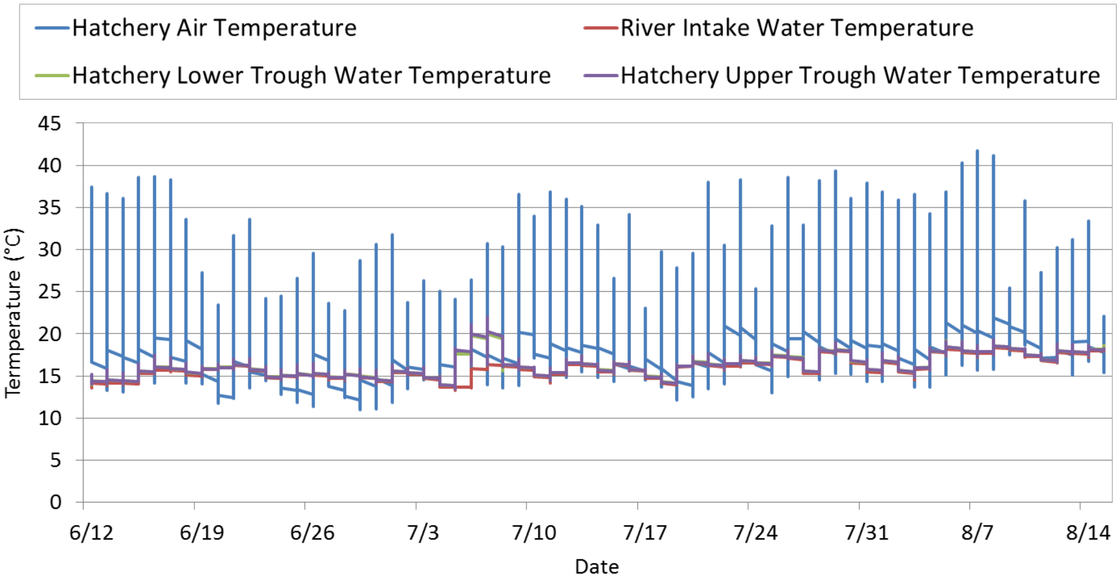


Figure 6. Hourly temperature (°C) recorded at the lower Columbia River (LCR) Streamside Incubation Facility in 2019. Data includes air temperature inside the facility, and water temperatures of the LCR and incubation tanks.

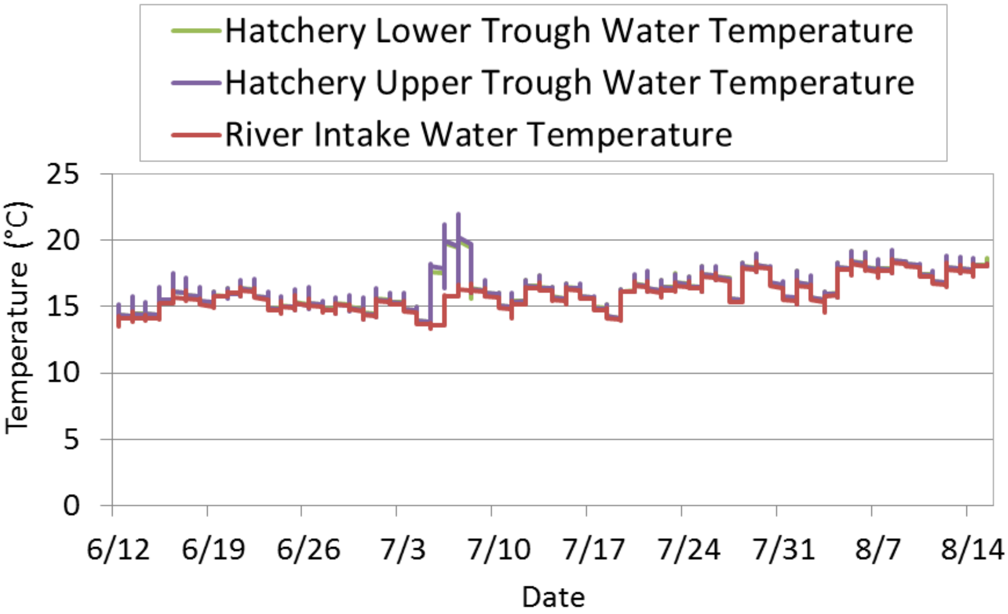


Figure 7. Comparison of hourly temperature (°C) of river water and the lower and upper troughs of the lower Columbia River Streamside Incubation Facility in 2019.

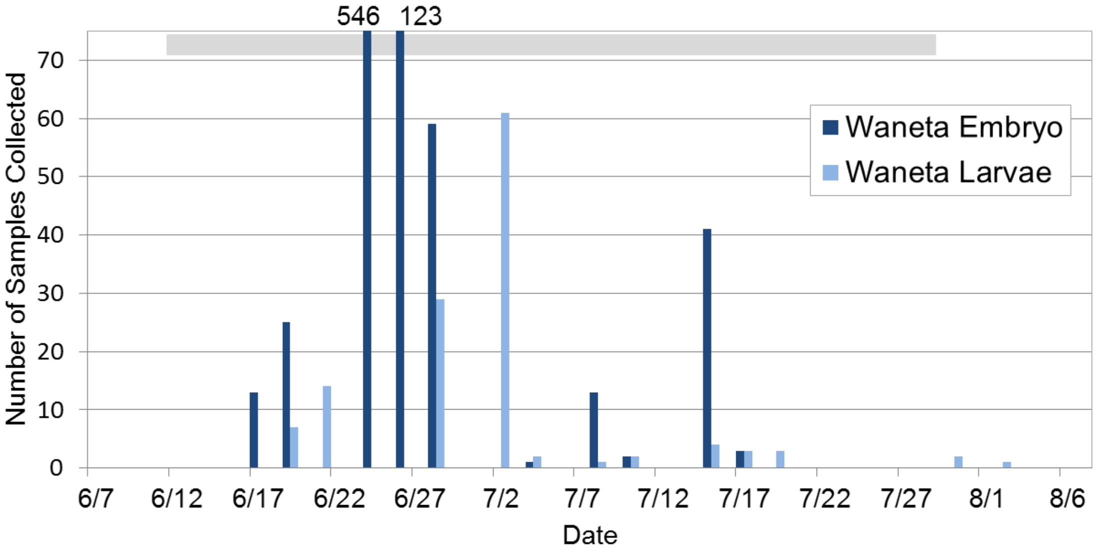


Figure 8. Embryos and larvae collected by egg mat and drift net at Waneta spawn monitoring site in the lower Columbia River during the 2019 sampling period (June 7 though August 7). All live embryos and larvae were transferred to the Streamside Incubation Facility (SIF). Horizontal grey bar represents duration of estimated spawning based on developmental stages of collected embryos and larvae at Waneta (June 12 to July 14).

Table 11. Numbers of embryos and larvae collected, incubated at the streamside incubation facility (SIF), and transferred to the hatchery from 3 spawning locations in the lower Columbia River, 2014-2019.

		Total Collected		Total Transferred to SIF		Total Transferred to the Hatchery		Total at time of release
Year	Location	Embryos	Larvae	Embryos	Larvae	Embryos	Larvae	
2019	Waneta	826	129	645	33	0	423	280*
	Kinnaird	1	0	1	0	0	1	1
	ALH	3	6	3	1	0	0	0
2018	Waneta	11,197	587	9,970	76	0	2,119	1,068*
	Kinnaird	0	4	0	0	0	0	0
	ALH	5	14	3	2	0	5	4
2017	Waneta	2,475	584	2,475	31	22	1,391	828
	Kinnaird	1	14	0	0	0	0	0
	ALH	511	159	1	0	507	0	55
2016	Waneta	6,473	959	6,473	286	0	2,245	1,224
	Kinnaird	0	17	0	3	0	2	1
	ALH	0	0	0	0	0	0	0
2015	Waneta	253	56	216	5	132	56	63
	Kinnaird	0	8	0	0	0	0	0
	ALH	0	1	0	0	0	0	0
2014	Waneta	5,762	67	5,176	17	0	1,951	1,108
	Kinnaird	6	13	3	0	0	2	0
	ALH	0	0	0	0	0	0	0

*A maximum of 200 fish were released in the lower Columbia River. All remaining fish were released in the middle Columbia River

Table 12. Annual survival (all sites and events combined) in both the streamside Incubation Facility (SIF) and in the conservation hatchery, 2014-2019.

Year	Survival in SIF	Survival in hatchery
2019	0.61	0.66
2018	0.21	0.50
2017	0.55	0.46
2016	0.33	0.55
2015	0.25	0.34
2014	0.38	0.57

3.3 Population Monitoring, Abundance, and Characteristics

3.3.1 *Fish Capture and Handling*

The biannual stock assessment program was initiated in spring 2013. Sampling was continued twice a year (spring and fall) in the Transboundary Reach extending from HLK in Castlegar British Columbia, Canada, to Gifford Washington, USA, until fall 2019. Results are presented for data collected in the Canadian portion of the LCR.

Within Canada, spring 2019 stock assessment was conducted by setting 128 lines with 12 hooks each over 15 days from May 20 to June 5 and June 10. The fall stock assessment was conducted over 13 days on September 15 to 21 and October 6 to 11 by setting 115 lines of 12 hooks each. Sampling effort for the spring and fall assessments was 2,565 hours and 2,320 hours, respectively. Set line deployment (mean ± SD) during the spring and fall assessments was 20.0 ± 2.4 hours and 20.2 ± 3.0 hours at water depths of 8.2 ± 3.6 m and 8.6 ± 3.7 m and water temperatures of 10.5 ± 1.5°C and 15.0 ± 2.1°C, respectively.

Within Canada, total White Sturgeon captures of 2019 was 341 and 436 (CPUE of 0.133 and 0.188) during the spring and fall stock assessments, respectively (Table 13 and 14). Across all sampling years (2013-2019), number of captures was highest in sampling zone 1 (82 to 319 captures; CPUE 0.088 to 0.336) and lowest in sampling zone 4 (1 to 31 captures; CPUE 0.003 to 0.075; sampling zones represent 11.2 km increments; consecutively numbered 1 through 5 from HLK to Canada/Us Border). A total of 3,692 captures have occurred over the six sampling years (2013 – 2018) within the Canadian portion of the LCR (Table 13). Of the total Canadian captures, 208 individuals were not previously handled during any White Sturgeon monitoring (new fish; Table 13).

Table 13. Total number of White Sturgeon captured during the 2013 through 2019 spring and fall stock assessments in the lower Columbia River (LCR), Canada. Unmarked fish were considered new captures (i.e., not previously handled by researchers; does not include hatchery origin fish).

Year	Survey	Total	Wild	Hatchery Origin	New Fish	Water Temp (°C)
2013	Spring	117	80	37	23	6.1 ± 0.8
2013	Fall	250	93	157	29	15.9 ± 0.6
2014	Spring	194	93	101	21	7.5 ± 0.7
2014	Fall	358	83	275	35	15.7 ± 0.7
2015	Spring	295	78	217	15	8.9 ± 0.5
2015	Fall	360	74	286	20	13.7 ± 0.3
2016	Spring	426	74	352	8	8.9 ± 0.5
2016	Fall	370	90	280	15	13.7 ± 0.9
2017	Spring	175	34	141	8	7.4 ± 1.1
2017	Fall	396	60	336	16	14.9 ± 0.9
2018	Spring	328	40	288	4	10.5 ± 1.1
2018	Fall	423	87	336	14	14.6 ± 0.7
2019	Spring	341	63	278	15	10.5 ± 1.5
2019	Fall	436	71	365	14	15.0 ± 2.1
Total	ALL	4,469	1,020	3,449	237	-

Table 14. Total number of White Sturgeon captured and catch per unit effort (CPUE) by sampling zone for the 2013 through 2019 spring and fall stock assessments in the lower Columbia River (LCR), Canada. Sampling zones represent 11.2 km increments starting from Hugh L. Keenleyside Dam and moving downstream to the US Border.

	Total Capture (CPUE)											
	1		2		3		4		5		LCR	
2013 Spring	82	(0.088)	13	(0.023)	7	(0.012)	2	(0.044)	13	(0.027)	117	(0.039)
2013 Fall	117	(0.203)	42	(0.090)	37	(0.073)	16	(0.048)	38	(0.083)	250	(0.106)
2014 Spring	148	(0.176)	29	(0.058)	8	(0.021)	2	(0.006)	7	(0.017)	194	(0.079)
2014 Fall	222	(0.227)	55	(0.138)	33	(0.078)	13	(0.050)	35	(0.079)	358	(0.143)
2015 Spring	227	(0.223)	44	(0.113)	13	(0.025)	5	(0.015)	6	(0.014)	295	(0.109)
2015 Fall	220	(0.229)	43	(0.165)	50	(0.106)	10	(0.030)	37	(0.088)	360	(0.147)
2016 Spring	319	(0.336)	57	(0.152)	25	(0.053)	2	(0.009)	23	(0.065)	426	(0.179)
2016 Fall	202	(0.230)	62	(0.170)	62	(0.118)	10	(0.043)	34	(0.085)	370	(0.154)
2017 Spring	133	(0.143)	22	(0.060)	13	(0.031)	1	(0.003)	6	(0.019)	175	(0.074)
2017 Fall	237	(0.230)	53	(0.164)	58	(0.116)	15	(0.074)	33	(0.087)	396	(0.162)
2018 Spring	253	(0.270)	36	(0.110)	23	(0.047)	2	(0.008)	14	(0.039)	328	(0.100)
2018 Fall	235	(0.247)	39	(0.174)	102	(0.177)	18	(0.075)	29	(0.075)	423	(0.178)
2019 Spring	229	(0.268)	30	(0.104)	31	(0.071	23	(0.051)	28	(0.053)	341	(0.133)
2019 Fall	208	(0.227)	65	(0.201)	80	(0.176)	31	(0.159)	31	(0.159)	52	(0.130)

3.3.2 *Mark-Recapture Analyses*

We provide a brief summary of the results in this section but the full methods and results are available in Appendix 1. Please note this is an ongoing analysis and as such the results are to be considered draft and interpreted accordingly.

From a full compiled dataset of 13,068 White Sturgeon captures between 2013 and 2018, a total of 9 cases were removed due to erroneous PIT tag numbers, 69 cases were removed due to unknown hatchery / wild designation, and 6 cases were removed due to duplicated effort data. Of the resulting dataset of 12,984 cases, a total of 112 cases were within-season recaptures and were removed from analysis, resulting in a dataset of 12,872 cases. Of these, no year class information was available for 407 cases. All 407 cases were removed from analysis. The final dataset was divided by country of sampling, resulting in a dataset of 8,917 captures of 6,956 unique PIT tags in the US and 3,548 captures of 2,905 unique PIT tags sampled in Canada. The full capture dataset used in the analysis is reported in CLBMON-29 monitoring report (BC Hydro 2019).

In all sampling years, both hatchery-reared and wild fish were captured in both spring and fall seasons. Hatchery-reared fish were more abundant than wild fish within each year/season, with the ratio of hatchery to wild fish captured ranging between 1.8 (spring 2013) and 7.3 (fall 2015 and spring 2018), with a median value of 5.9. Fork lengths of hatchery-reared fish ranged between 26 cm and 208 cm (median of 99 cm), whereas fork lengths of wild fish ranged between 54 cm and 299 cm, with a median value of 193 cm (Figure 9).

The median value of hatchery-reared fish generally increased between sampling years for fall samples, from 93 cm in fall 2013, to 95 cm in fall 2014, and fluctuating between 97 cm and 103 cm between fall 2015 and fall 2018. In spring samples, the trend was not apparent, with median fork lengths increasing from 97 cm in spring 2013 to 103-106 cm between spring 2014 and spring 2017, then decreasing to 97 cm in spring 2018. However, in spring 2018, sampling was only performed in Canada and not in the US portion of the transboundary area, which likely resulted in decreased fork lengths, as detailed below, in the growth analysis. For wild sturgeon, median values of fork length in spring sessions were generally stable across years, ranging between 186 cm and 198 cm; however, in spring 2018, median values decreased to 178, similar to those of hatchery fish, likely due to lack of sampling in the US portion of the transboundary area. For fall sampling, median fork length values were mostly stable, with a slight decrease across years, from 196 cm in fall 2013 with a small decrease from 196-200 cm in fall 2013 and fall 2014 to 192-196 cm in fall 2015-2017. In fall 2018, median fork lengths decreased to 189 cm, despite sampling in both Canada and the US.

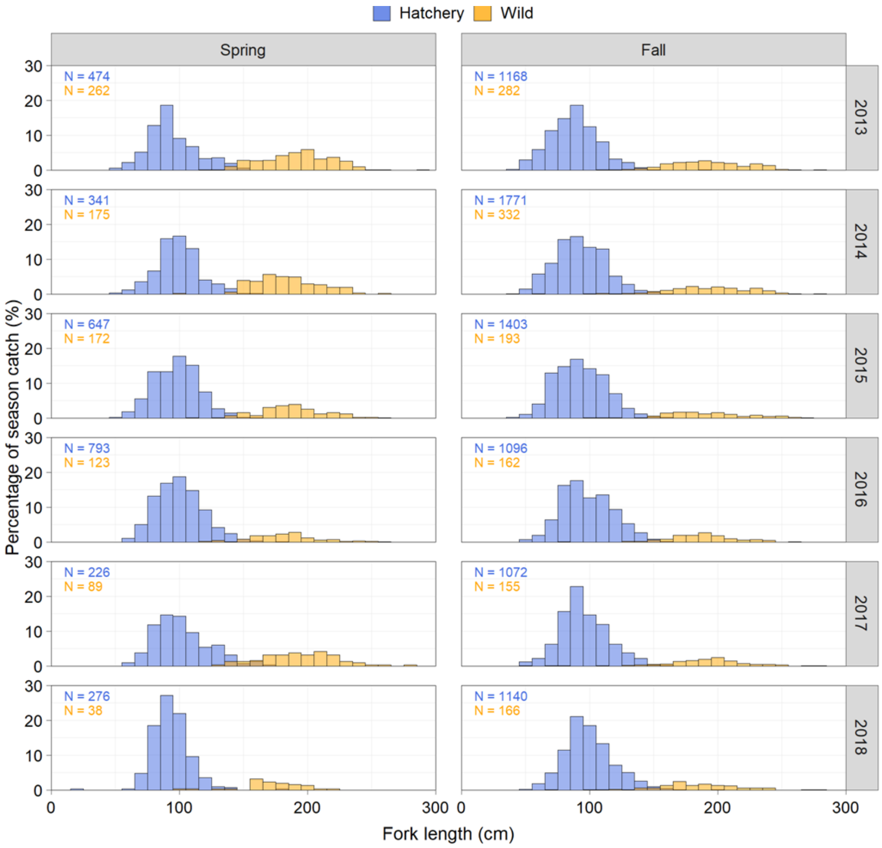


Figure 9. Length frequency plot of captured sturgeon by stock assessment sampling event, 2013-2018. Captures represent sampling conducted through the entire Transboundary Reach.

Sampling effort covered the entire transboundary reach study area (Figure 10), with fish distributed throughout all habitats (Figure 11). Within Canada, sturgeon were distributed in higher numbers in the upstream stretch of river near HLK dam compared to habitats located downstream closer to Trail BC or the US Border (Figure 12). The number of sturgeon captured in each sampling year in the transboundary area fluctuated between years and seasons (Figure 12). For both wild and hatchery-reared fish, fewer fish were captured in spring samples than in fall samples. Similarly, there were fewer recaptures in spring samples than fall samples. The sampling in fall 2014 resulted in the highest number of captured sturgeon, both hatchery-reared and wild. The lowest number of captured hatchery-reared was recorded in spring 2017, whereas the lowest number of captured wild sturgeon was recorded in spring 2018 (due to the lack of sampling in the US during that sampling season).

In the Canadian portion of the transboundary area, there were seasonal fluctuations in numbers of captured fish; however, the pattern was not as strong as for the combined dataset and was not apparent in all years (e.g., spring 2016). The greatest number of hatchery-reared sturgeon was captured in spring 2016, whereas the greatest number of wild sturgeon was recorded in fall 2013. The lowest numbers of hatchery-reared and wild sturgeon were captured in spring 2013 and spring 2017, respectively.

In the US portion of the transboundary area, seasonal fluctuations in the number of captured fish were very pronounced and apparent throughout the 2013-2018 sampling period. The greatest number of captured fish, both hatchery-reared and wild, was recorded in fall 2014. The lowest numbers of hatchery-reared and wild sturgeon were captured in spring 2017 and spring 2016, respectively.

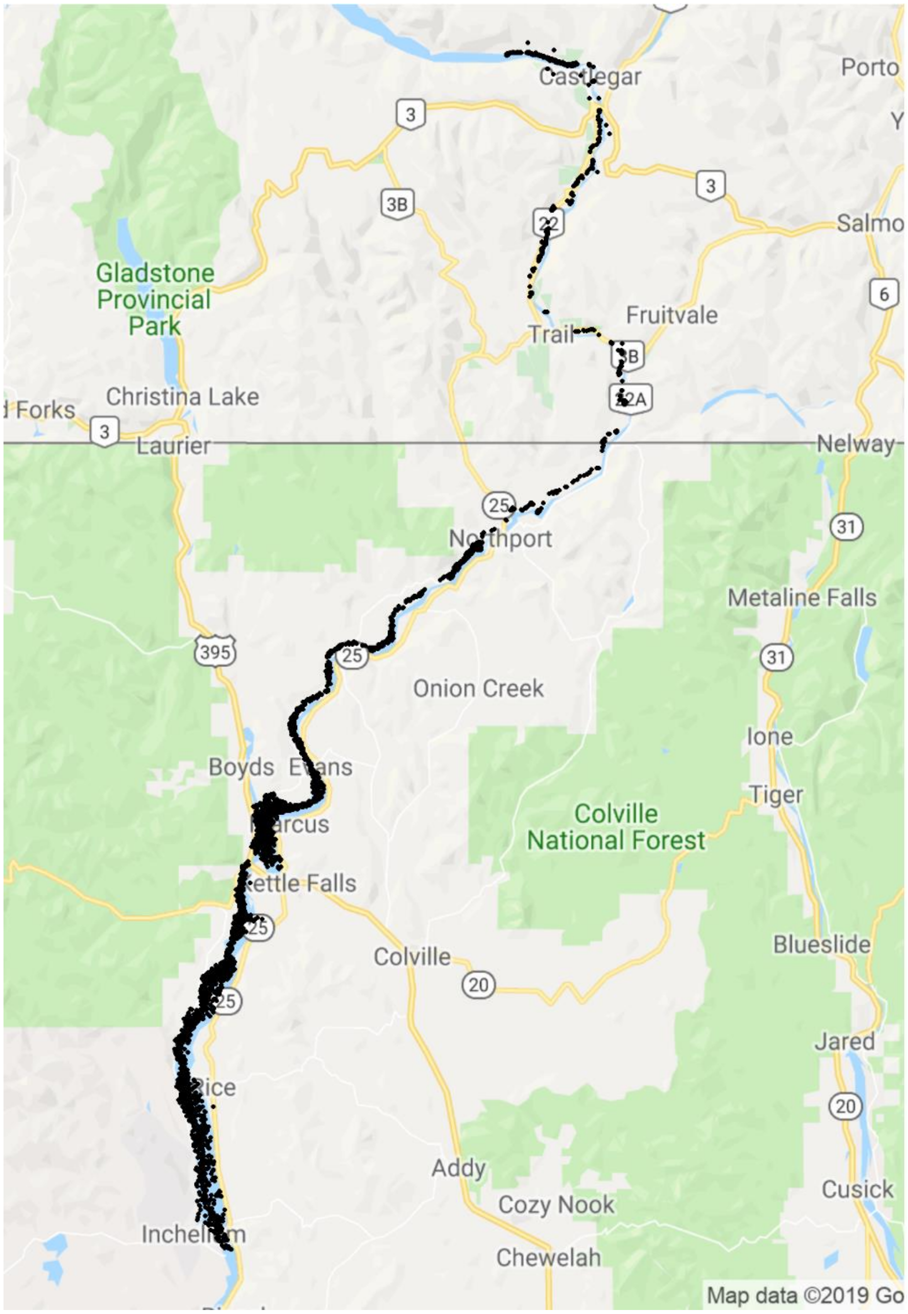


Figure 10. Spatial distribution of sampling efforts in the transboundary reach during the 2013-2018 study period.

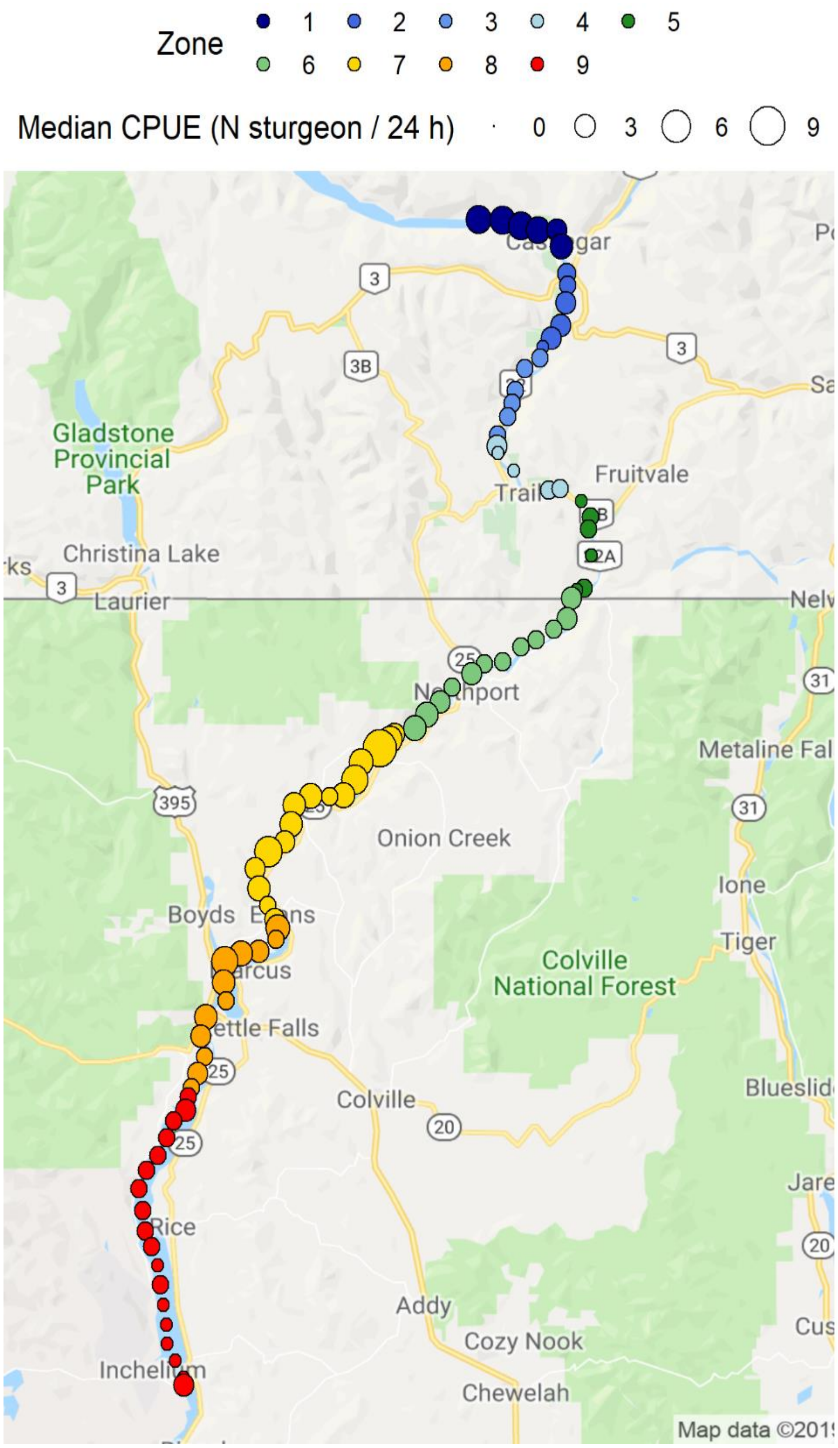


Figure 11. Spatial distribution of White Sturgeon CPUE in efforts with positive fish catches throughout the transboundary area between 2013 and 2018; point size corresponds to number of median value of CPUE at the sampling point (RKM values rounded to 2 km resolution). Note that this figure does not include efforts with zero captured fish.

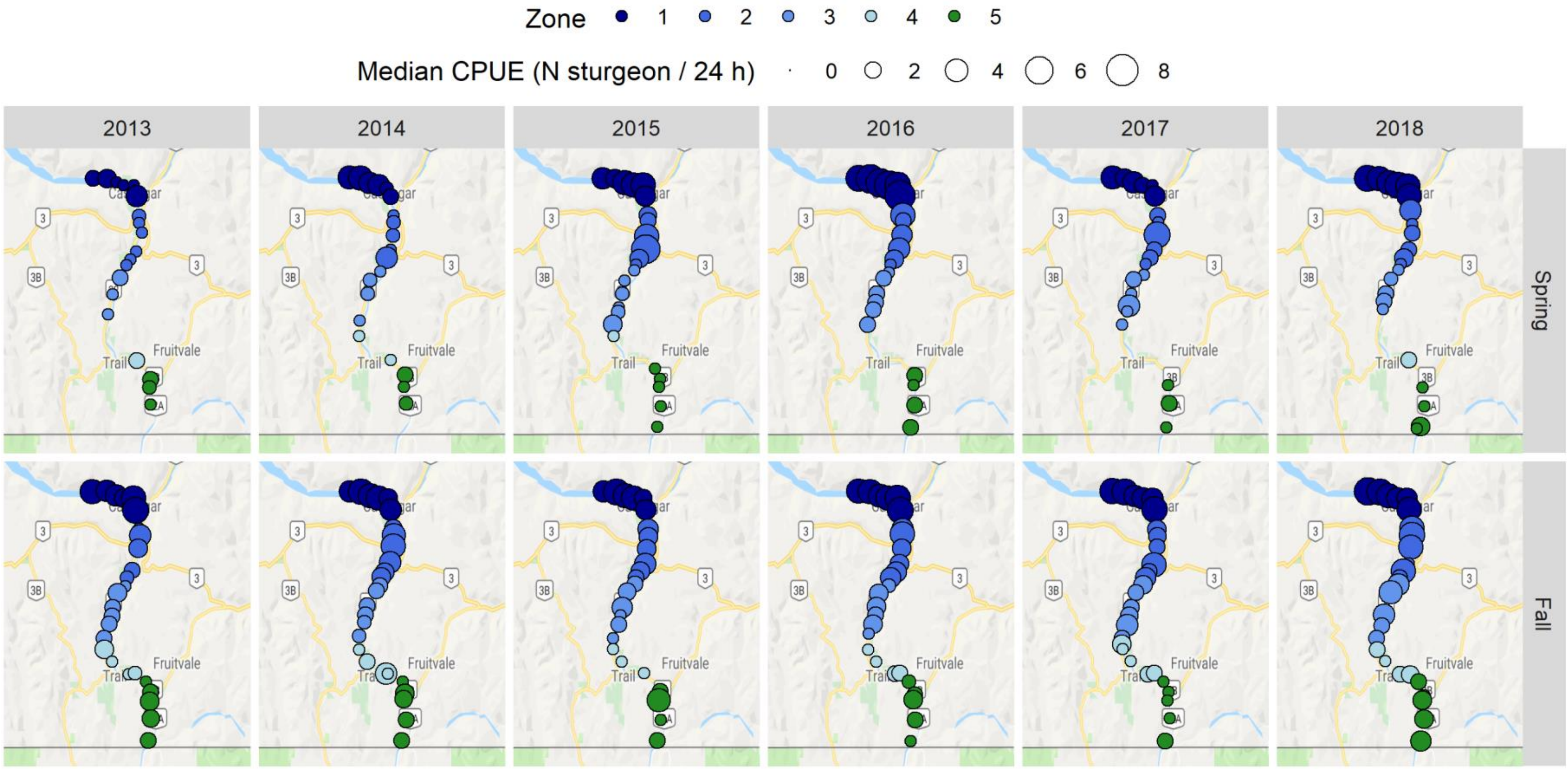


Figure 12. Spatial distribution of White Sturgeon CPUE in efforts with positive fish catch in the Canadian portion of the transboundary area between 2013 and 2018; point size corresponds to number of median value of CPUE at the sampling point (RKM values rounded to 2 km resolution). Note that this figure does not include efforts with zero captured fish.

Out of the set of CJS models constructed for mark-recapture data collected in the Canadian portion of the transboundary area, the model with the best support (as indicated by QAICc) estimated survival as a constant, and recapture probability as a function of time and age (Table 15). Wild fish were assumed to be the same age as the 2001 year class in the model because their true age was unknown. Out of the set of POPAN models constructed for mark-recapture data collected in the US, the model with the best support (as indicated by QAICc) estimated survival as a function of year class, recapture probability as a multiplicative function of time and age, probability of entry as a function of age, and super population as a function of year class (Table 16).

Table 15. Comparisons of the converged CJS models developed for White Sturgeon in the Canadian portion of the transboundary area of the Upper Columbia River between 2013 and 2018. Models are arranged in order of QAICc. The specifications of survival (Phi) and recapture rates (p) are indicated for each model, as well as the number of model parameters (npar), and QAICc statistics

Phi	p	npar	QAICc	ΔQAICc	QAICc weight
Constant	Time + Age	13	7052.3	0.0	0.6
Constant	YearClass + time	19	7053.5	1.2	0.3
YearClass	YearClass + time	26	7058.1	5.7	0.0
YearClass	Time + Age	20	7061.4	9.1	0.0
Constant	Age + YearClass + Season	11	7080.6	28.3	0.0
YearClass	Time	19	7081.6	29.3	0.0
YearClass	YearClass	16	7082.1	29.8	0.0
YearClass	Age + YearClass + Season	18	7085.2	32.8	0.0
Constant	Age	3	7098.3	46.0	0.0
YearClass	Age	10	7098.9	46.6	0.0
Constant	Age * Season	5	7099.7	47.3	0.0
YearClass	Age * Season	12	7100.3	47.9	0.0

Table 16. Comparisons of the top 20 converged POPAN models developed for White Sturgeon in the Canadian portion of the transboundary area of the Upper Columbia River between 2013 and 2018. Models are arranged in order of QAICc. The specifications of survival (Phi), recapture rates (p), probability of entry (pent), and superpopulation (N) are indicated for each model, as well as the number of model parameters (npar), and QAICc statistics

Phi	p	pent	N	npar	QAICc	ΔQAICc	QAICc weight
YearClass	time * Age	Age	YearClass	42	8007.7	0.0	1.0
YearClass	time + (Age + Age^2)	Age	YearClass	32	8096.7	89.0	0.0
YearClass	time * (Age + Age^2)	Age	Constant	47	8099.5	91.8	0.0
YearClass	time + Age	Age	YearClass	31	8131.4	123.7	0.0
Constant	time + (Age + Age^2))	Age	YearClass	25	8155.4	147.7	0.0
YearClass	Season * YearClass	Age	YearClass	34	8204.1	196.4	0.0
YearClass	time + (Age + Age^2)	Age	Constant	25	8216.8	209.1	0.0
Constant	time + Age	Age	YearClass	24	8220.9	213.2	0.0
YearClass	Season * YearClass	Age	Constant	27	8222.8	215.1	0.0
Constant	time + (Age + Age^2)	Constant	YearClass	24	8233.0	225.3	0.0
YearClass	time + Age	Age	Constant	24	8247.5	239.8	0.0
YearClass	Age * Season	Age	YearClass	22	8290.3	282.6	0.0
Constant	Season * YearClass	Age	YearClass	27	8315.2	307.5	0.0
YearClass	time + (Age + Age^2)	Constant	Constant	24	8331.0	323.3	0.0
YearClass	Age + Age^2	Age	YearClass	21	8346.1	338.4	0.0
Constant	Season * YearClass	Age	Constant	20	8357.2	349.5	0.0
Constant	Age * Season	Age	YearClass	15	8384.6	376.9	0.0
YearClass	Age * Season	Age	Constant	15	8390.7	383.0	0.0
YearClass	time + Age	Constant	Constant	23	8402.9	395.2	0.0
Constant	time + Age	Constant	YearClass	23	8416.0	408.3	0.0

The model-averaged survival estimates based on CJS models was high (~0.96), with uncertainty that varied with year class (Figure 13 and Table 17). Uncertainty in estimates (as the difference between upper and lower 95% confidence limits) ranged between 13% of the mean (year classes 2001, 2002, 2005, and wild fish) and 27% of the mean (year class 2003). Survival estimates from the POPAN model were usually lower and less uncertain than those from the CJS model, although confidence intervals of the two sources of estimates overlapped for most year classes.

CJS models with a recapture probability that included second-degree polynomial functions of age did not converge, leading to a pronounced difference in estimation of recapture probabilities between CJS and POPAN models (Figure 14). While POPAN recapture probabilities for young ages were essentially zero in the earlier sessions, they were considerably higher in CJS estimates. In all sampling events, both models estimated a lower recapture probability for younger fish, which reflects the recruitment of the youngest year classes to gear, as observed by the increased captures of year classes 2009 and younger. Although in the US portion of the transboundary area recapture probabilities in the spring were consistently lower than those in the fall, no consistent seasonal trends were observed for recapture probabilities in the Canadian portion of the transboundary area.

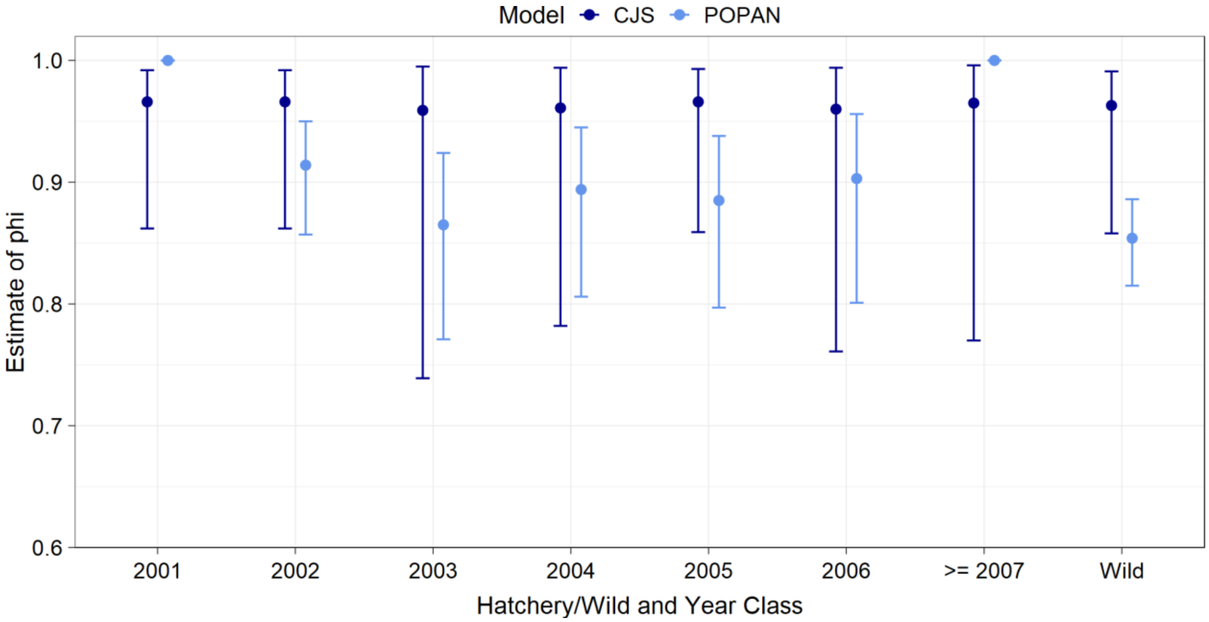


Figure 13. Comparison of model-averaged survival (phi) estimates across CJS and POPAN models of sturgeon mark-recapture in the Canadian portion of the transboundary area.

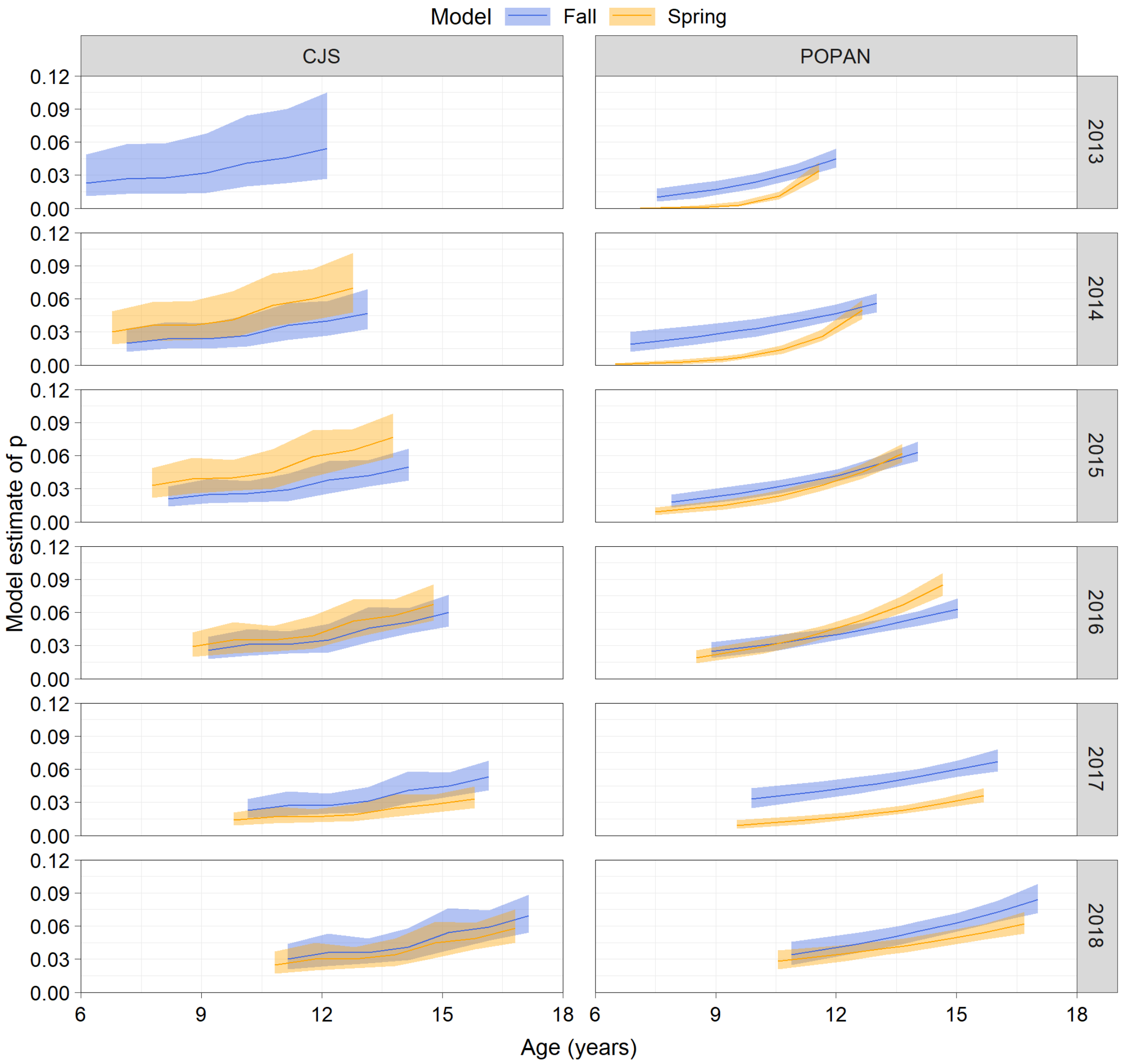


Figure 14. Comparison of model-averaged recapture (p) estimates for CJS and POPAN models – for the Canadian portion of the transboundary area. For wild fish, ages were assumed to be same as for year class 2001.

Table 17. Estimated survival probabilities of White Sturgeon from model-averaged CJS and POPAN models for the Canadian portion of the transboundary area

	CJS			POPAN		
Year class	Estimate	LCL	UCL	Estimate	LCL	UCL
2001	0.966	0.862	0.992	1.000	1.000	1.000
2002	0.966	0.862	0.992	0.914	0.857	0.950
2003	0.959	0.739	0.995	0.865	0.771	0.924
2004	0.961	0.782	0.994	0.894	0.806	0.945
2005	0.966	0.859	0.993	0.885	0.797	0.938
2006	0.960	0.761	0.994	0.903	0.801	0.956
≥ 2007	0.965	0.770	0.996	1.000	1.000	1.000
Wild	0.963	0.858	0.991	0.854	0.815	0.886

Population abundance estimates from CJS models fluctuated between sampling events (Table 18). For most year classes, CJS population abundance estimated for fall 2018 was lower than the mean estimate from fall 2013, with values ranging from 48% from the initial estimate (year class 2005) to 85% of the initial estimate (year class 2006). Only year class 2003 had an estimated increase in abundance (26% relative to initial estimate). Overall, estimated CJS population abundances remained stable or declined throughout the 2013-2018 study, although the extent of change depended on year class.

POPAN-based estimates of year class abundance generally indicated a decrease in abundance between spring 2013 and fall 2018 (Table 19), except for year classes ≥2007, which were estimated to increase in abundance over time due to the increasing recruitment to gear, and year class 2001, which remained stable (increase of 1.6%). In fall 2018, estimated populations abundances by year class ranged between 46% of the estimated abundance in spring 2013 (for wild fish) to 71% of the abundance in spring 2013 (for year class 2006). In fall 2018, year classes ≥2007 increased in abundance by 31% relative to abundance in spring 2013, and the abundance of the year class 2001 was similar to the 2013 spring estimate.

Combined across all year classes, CJS abundance estimates indicated a stable or decreasing population abundance, as abundances generally fluctuated between sampling events but did not exhibit a directional trend over time. Mean abundance was estimated to be 9,247 fish in fall 2013 (95% CI of 4,622 – 18,498 fish) and a total of 6,085 fish in fall 2018 (95% CI of 4,566 – 8,109). The mean abundance estimate in 2018 (6,085 fish) represents a decrease of 34% relative to the abundance estimated in fall 2013, or a 2% increase relative to the abundance estimated in spring 2014. In contrast, POPAN estimates consistently decreased from 9,707 fish in fall 2015 (95% CIs of 5,692 – 13,721 fish) to 7,112 fish (95% CIs of 6,259 – 7,966 fish) in fall 2018, which is a 27% reduction in the mean abundance estimate relative to the abundance estimated in spring 2013, or a 26% decrease relative to the abundance estimated in fall 2013.

Table 18. Estimated population abundance of White Sturgeon (means with 95% confidence interval) from model-averaged CJS models for the Canadian portion of the transboundary area.

Model	Year	Season	Year class								Total
			2001	2002	2003	2004	2005	2006	≥2007	Wild	
CJS	2013	Fall	1325 (653 - 2687)	1441 (710 - 2923)	266 (110 - 641)	1015 (450 - 2286)	1328 (604 - 2920)	1021 (457 - 2279)	1381 (621 - 3071)	1471 (743 - 2910)	9247 (4622 - 18498)
	2014	Spring	829 (525 - 1308)	806 (508 - 1280)	260 (135 - 499)	559 (301 - 1040)	577 (313 - 1062)	946 (537 - 1667)	1054 (592 - 1875)	913 (595 - 1399)	5943 (3926 - 8998)
	2014	Fall	1319 (837 - 2079)	1001 (619 - 1618)	388 (200 - 751)	875 (472 - 1621)	1402 (802 - 2452)	1003 (544 - 1846)	1585 (886 - 2834)	1558 (1016 - 2388)	9129 (6013 - 13859)
	2015	Spring	802 (561 - 1148)	709 (487 - 1031)	238 (131 - 434)	579 (341 - 986)	679 (411 - 1122)	865 (522 - 1434)	963 (579 - 1602)	977 (701 - 1362)	5813 (4279 - 7899)
	2015	Fall	1078 (732 - 1589)	943 (627 - 1418)	469 (264 - 833)	859 (496 - 1487)	1049 (627 - 1755)	1060 (613 - 1835)	1351 (791 - 2307)	1275 (883 - 1839)	8084 (5804 - 11261)
	2016	Spring	786 (552 - 1121)	840 (588 - 1198)	309 (174 - 548)	609 (360 - 1031)	516 (299 - 892)	955 (576 - 1584)	925 (550 - 1557)	905 (644 - 1272)	5845 (4372 - 7815)
	2016	Fall	793 (553 - 1138)	861 (600 - 1237)	259 (138 - 488)	740 (444 - 1235)	997 (628 - 1585)	941 (559 - 1585)	1193 (720 - 1974)	980 (695 - 1381)	6765 (5070 - 9027)
	2017	Spring	1622 (1103 - 2387)	1351 (893 - 2042)	629 (344 - 1149)	1198 (688 - 2084)	1356 (799 - 2302)	1546 (881 - 2713)	1837 (1060 - 3184)	1740 (1183 - 2559)	11279 (8093 - 15718)
	2017	Fall	1038 (728 - 1479)	868 (592 - 1272)	221 (109 - 448)	746 (438 - 1269)	880 (534 - 1451)	1109 (655 - 1876)	1184 (700 - 2001)	1111 (778 - 1587)	7156 (5318 - 9631)
	2018	Spring	963 (677 - 1370)	891 (616 - 1290)	358 (199 - 642)	649 (379 - 1110)	866 (532 - 1411)	907 (527 - 1558)	955 (556 - 1641)	979 (681 - 1408)	6568 (4883 - 8836)
	2018	Fall	850 (606 - 1192)	609 (414 - 895)	336 (192 - 586)	687 (418 - 1129)	637 (388 - 1048)	866 (515 - 1456)	1058 (642 - 1744)	1042 (743 - 1461)	6085 (4566 - 8109)

Table 19. Estimated population abundance of White Sturgeon (means with 95% confidence interval) from model-averaged POPAN models for the Canadian portion of the transboundary area.

Model	Year	Season	Year class								Total
			2001	2002	2003	2004	2005	2006	≥2007	Wild	
POPAN	2013	Spring	1028 (896 - 1160)	1249 (951 - 1548)	576 (350 - 801)	1112 (613 - 1610)	1213 (568 - 1859)	1506 (444 - 2568)	1186 (-232 - 2605)	1836 (1524 - 2148)	9707 (5692 - 13721)
	2013	Fall	1033 (920 - 1147)	1214 (972 - 1456)	550 (343 - 756)	1086 (663 - 1510)	1188 (683 - 1693)	1515 (707 - 2322)	1317 (288 - 2345)	1728 (1479 - 1977)	9631 (6585 - 12677)
	2014	Spring	1037 (937 - 1137)	1153 (968 - 1339)	506 (308 - 705)	1029 (647 - 1411)	1123 (744 - 1503)	1470 (865 - 2075)	1411 (626 - 2196)	1567 (1382 - 1753)	9297 (6986 - 11609)
	2014	Fall	1040 (950 - 1131)	1122 (972 - 1272)	485 (290 - 679)	1003 (642 - 1364)	1095 (796 - 1393)	1458 (989 - 1928)	1490 (877 - 2103)	1484 (1334 - 1634)	9177 (7395 - 10959)
	2015	Spring	1043 (958 - 1127)	1065 (949 - 1182)	446 (250 - 642)	946 (585 - 1307)	1029 (805 - 1254)	1399 (1041 - 1758)	1548 (1038 - 2057)	1348 (1229 - 1467)	8825 (7446 - 10203)
	2015	Fall	1045 (964 - 1125)	1032 (933 - 1130)	424 (227 - 621)	914 (549 - 1279)	993 (814 - 1172)	1369 (1081 - 1657)	1595 (1151 - 2038)	1269 (1164 - 1374)	8640 (7537 - 9743)
	2016	Spring	1046 (968 - 1124)	979 (889 - 1069)	390 (190 - 589)	860 (482 - 1238)	931 (784 - 1077)	1305 (1065 - 1546)	1629 (1223 - 2036)	1154 (1054 - 1255)	8295 (7372 - 9217)
	2016	Fall	1047 (970 - 1124)	949 (859 - 1038)	370 (169 - 572)	830 (442 - 1218)	896 (764 - 1029)	1271 (1052 - 1490)	1658 (1271 - 2045)	1089 (987 - 1191)	8111 (7282 - 8939)
	2017	Spring	1048 (971 - 1125)	898 (799 - 997)	339 (137 - 541)	777 (375 - 1178)	835 (701 - 968)	1202 (984 - 1420)	1679 (1300 - 2058)	986 (877 - 1095)	7764 (6969 - 8558)
	2017	Fall	1049 (972 - 1126)	871 (765 - 977)	323 (120 - 526)	750 (341 - 1160)	804 (666 - 942)	1169 (947 - 1392)	1697 (1319 - 2075)	934 (821 - 1048)	7599 (6798 - 8399)
	2018	Spring	1049 (972 - 1127)	822 (700 - 943)	294 (93 - 496)	699 (280 - 1117)	745 (592 - 897)	1099 (856 - 1343)	1709 (1329 - 2090)	842 (720 - 963)	7259 (6438 - 8080)
	2018	Fall	1050 (972 - 1128)	799 (670 - 928)	281 (80 - 482)	675 (252 - 1099)	718 (558 - 879)	1069 (814 - 1324)	1720 (1334 - 2106)	800 (675 - 925)	7112 (6259 - 7966)

3.3.3 *Fork Length, Weight, and Relative Weight*

Fork length (cm; mean ± SD) of all White Sturgeon collected within Canada during the spring and fall 2019 stock assessments was 114.3 ± 36.9 cm and 111.5 ± 35.1 cm, respectively (Table 20). Fork length (mean ± SD) of hatchery origin fish captured during the spring and fall was 98.4 ± 13.1 cm and 97.6 ± 13.4 cm, respectively. Fork length for wild fish captured in the spring and fall was 184.4 ± 23.7 cm and 182.9 ± 22.7 cm, respectively. These results are similar to previous years of stock assessments conducted within the Canadian portion of the LCR (Table 20).

Weight of hatchery origin fish captured within Canada during the spring and fall was 6.4 ± 3.1 kg and 6.1 ± 2.9 kg, respectively. Wild origin fish weight was 50.3 ± 20.1 kg and 48.1 ± 17.4 kg for spring and fall captures, respectively. These results were similar to those recorded over the previous stock assessments (Table 21).

Relative weight (W_r) for wild origin fish captured in 2019 during the spring and fall stock assessments was 82.3 ± 8.2 and 81.2 ± 9.0, respectively. Relative weight for hatchery origin fish captured in 2019 during the spring and fall stock assessments was 80.1 ± 7.1 and 77.8 ± 6.9, respectively. Relative weight for all White Sturgeon captured within Canada over the period of the stock assessment (2013 – 2019) was similar (Table 22).

Table 20. Fork length (cm; mean ± SD) for wild and hatchery origin White Sturgeon captured during the transboundary stock assessments (2013-2019). Data presented here includes fish captured in Canada. Sampling efforts extended from Hugh L. Keenleyside Dam in Castlegar British Columbia, Canada, to the Canada/USA border. For USA data see BC Hydro (2016).

Year	Survey	Wild	Hatchery Origin	All Captures
2013	Spring	184.3 ± 19.0	102.3 ± 14.7	160.4 ± 41.5
2013	Fall	182.3 ± 17.8	93.4 ± 16.5	126.5 ± 46.3
2014	Spring	179.4 ± 17.2	103.8 ± 13.0	140.1 ± 40.8
2014	Fall	182.0 ± 18.3	97.1 ± 15.5	116.8 ± 39.4
2015	Spring	184.1 ± 16.5	99.6 ± 14.5	122.0 ± 40.2
2015	Fall	182.1 ± 18.0	98.2 ± 13.6	115.5 ± 37.0
2016	Spring	177.2 ± 19.9	98.6 ± 11.4	112.2 ± 32.6
2016	Fall	182.6 ± 27.5	95.8 ± 13.1	116.8 ± 40.5
2017	Spring	180.4 ± 21.5	98.3 ± 14.2	114.2 ± 36.2
2017	Fall	183.5 ± 18.6	97.8 ± 12.6	110.8 ± 33.7
2018	Spring	177.5 ± 23.5	98.1 ± 12.7	107.8 ± 29.8
2018	Fall	179.6 ± 23.3	99.2 ± 13.7	115.8 ± 36.4
2019	Spring	184.4 ± 23.7	98.4 ± 13.1	114.3 ± 36.9
2019	Fall	182.9 ± 22.7	97.6 ± 13.4	111.5 ± 35.1

Table 21. Weight (kg; mean ± SD) for wild and hatchery origin White Sturgeon capture during the transboundary stock assessments (2013-2019). Data presented here includes fish captured in Canada. Sampling efforts extended from Hugh L. Keenleyside Dam in Castlegar British Columbia, Canada, to the Canada/USA border. For USA data see BC Hydro (2016).

Year	Survey	Wild	Hatchery Origin	All Captures
2013	Spring	53.6 ± 16.2	7.7 ± 4.2	40.2 ± 25.1
2013	Fall	48.2 ± 16.9	5.8 ± 3.6	21.6 ± 23.2
2014	Spring	43.7 ± 13.9	7.7 ± 3.1	25.0 ± 20.5
2014	Fall	47.4 ± 17.7	6.3 ± 3.5	15.9 ± 19.6
2015	Spring	48.1 ± 14.0	7.0 ± 3.9	17.9 ± 19.8
2015	Fall	44.3 ± 15.5	6.4 ± 2.9	14.2 ± 17.1
2016	Spring	41.2 ± 15.3	6.5 ± 2.4	12.6 ± 14.8
2016	Fall	46.4 ± 16.5	6.0 ± 2.6	15.8 ± 19.3
2017	Spring	45.0 ± 18.5	6.4 ± 3.0	13.9 ± 17.5
2017	Fall	48.4 ± 16.2	6.3 ± 2.9	12.6 ± 16.3
2018	Spring	45.2 ± 16.9	6.2 ± 2.9	10.9 ± 14.31
2018	Fall	45.1 ± 17.8	6.4 ± 3.1	14.4 ± 17.8
2019	Spring	50.3 ± 20.1	6.4 ± 3.1	14.5 ± 19.3
2019	Fall	48.1 ± 17.4	6.1 ± 2.9	12.9 ± 17.2

Table 22. Relative weight (W_r; mean ± SD) for wild and hatchery origin White Sturgeon collected during the transboundary stock assessments (2013-2019). Data presented here includes fish captured in Canada. Sampling efforts extended from Hugh L. Keenleyside Dam in Castlegar British Columbia, Canada, to the Canada/USA border. For USA data see BC Hydro (2016).

Year	Survey	Wild	Hatchery Origin	All Captures
2013	Spring	91.3 ± 9.6	83.1 ± 9.6	88.9 ± 10.3
2013	Fall	84.0 ± 8.5	81.4 ± 8.7	82.4 ± 8.7
2014	Spring	80.8 ± 7.4	82.2 ± 7.2	81.5 ± 7.3
2014	Fall	83.0 ± 12.6	80.3 ± 7.4	80.9 ± 8.9
2015	Spring	82.1 ± 8.9	83.0 ± 7.8	82.7 ± 8.1
2015	Fall	77.5 ± 8.0	80.3 ± 7.4	79.7 ± 7.6
2016	Spring	78.0 ± 7.9	82.6 ± 12.1	81.8 ± 11.5
2016	Fall	79.6 ± 12.1	81.2 ± 9.4	80.8 ± 10.1
2017	Spring	79.2 ± 7.4	80.6 ± 9.6	80.3 ± 9.5
2017	Fall	81.8 ± 13.6	80.1 ± 9.4	80.3 ± 10.1
2018	Spring	82.2 ± 20.2	78.1 ± 13.0	78.6 ± 7.2
2018	Fall	81.0 ± 8.9	77.8 ± 10.5	78.5 ± 7.9
2019	Spring	82.3 ± 8.2	80.1 ± 7.1	80.5 ± 7.4
2019	Fall	81.2 ± 9.0	77.8 ± 6.9	78.3 ± 7.3

3.3.4 *Fork Length Frequency*

In 2019, all hatchery origin fish captured were <150 cm and wild origin fish were typically >150cm (Figure 15). Grouping fork length into bins of 10 cm (e.g., 70-79 cm), fish captured in Canada were predominantly represented by hatchery origin fish at fork lengths of 80 to 110 cm (Table 23). Wild fish were predominantly larger in fork length (170 to 210 cm).

Table 23. Proportion of fork length frequency of White Sturgeon captured in the lower Columbia River during the 2019 spring and fall stock assessments. The three predominant fork length bins (10 cm) within each origin category are highlighted bold for comparison.

FL (cm)	Hatchery	Wild	All
>50	0.000	0.000	0.000
50-59	0.000	0.000	0.000
60-69	0.005	0.000	0.004
70-79	0.073	0.000	0.060
80-89	**0.194**	0.000	**0.161**
90-99	**0.299**	0.000	**0.247**
100-109	**0.249**	0.007	**0.207**
110-119	0.128	0.022	0.109
120-129	0.034	0.007	0.030
130-139	0.011	0.000	0.009
140-149	0.008	0.015	0.009
150-159	0.000	0.052	0.009
160-169	0.000	0.112	0.019
170-179	0.000	**0.209**	0.036
180-189	0.000	0.157	0.027
190-199	0.000	**0.172**	0.030
200-209	0.000	**0.164**	0.028
210-219	0.000	0.052	0.009
220-229	0.000	0.015	0.003
230-239	0.000	0.007	0.001
240+	0.000	0.007	0.001

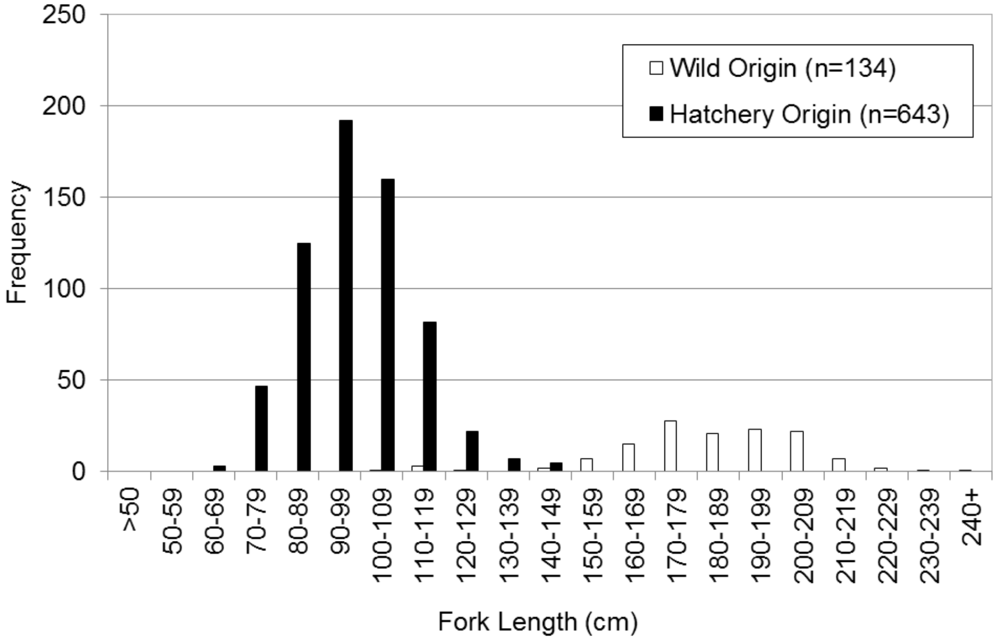


Figure 15. Fork length frequency of hatchery (median 97.5 cm) and wild (median 183.0 cm) origin White Sturgeon captured in the lower Columbia River during the 2019 spring and fall stock assessments.

3.4 Acoustic Tagging and Telemetry

A large scale analysis of the telemetry data is being conducted that incorporates 2008-2019 and results of this work are not yet available. Results will be updated in 2021 when complete. Results from 2008-2017 are presented in this report.

The movements of 101 adults (52 females, 48 males and one individual of unknown sex) tagged with acoustic transmitters were examined during 2008 through 2017. A total of 103,642 detection days were recorded with a mean (± SD) of 1,019.5 ± 961.7 and 1,044.8 ± 902.0 detection days for females and males, respectively. Habitat use was highest in the upper section of the river (e.g., Robson reach, rkm 0.1, 2.5, and 6.5) with marginal differences between females and males (Figure 16).

Site fidelity was calculated for both males and females as the maximum proportion of time spent at specific receiver locations (unique rkm) or within larger river zones in the lower Columbia River, between January 2008 and December 2017. Males and females spent 0.65 ± 0.18 and 0.63 ± 0.23 of their time at unique receiver locations, respectively (Table 24). When site fidelity was calculated by river zone, the amount of time increased, to 0.88 ± 0.16 and 0.87 ± 0.18 for males and females, respectively (Table 24).

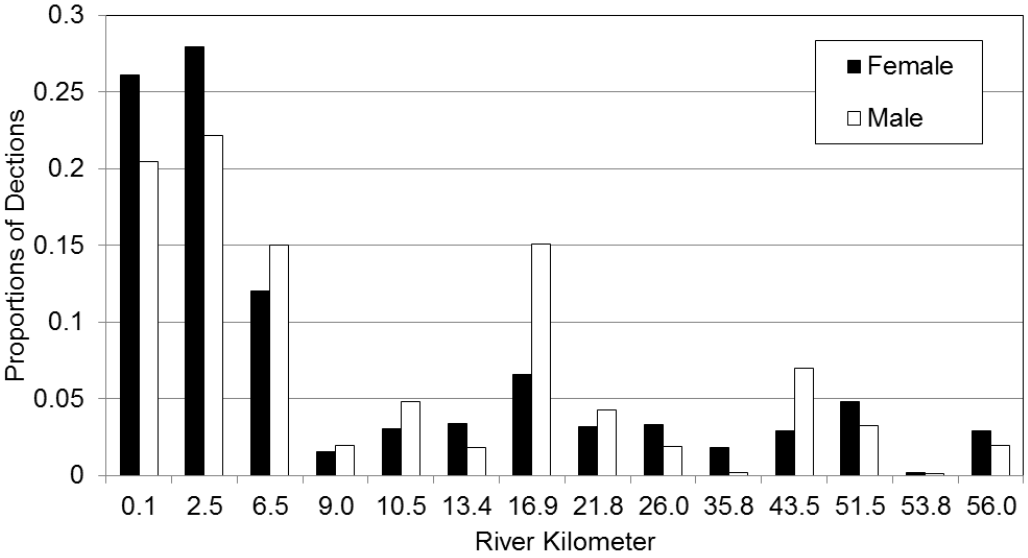


Figure 16. The proportion of detection days by river kilometer of female (n = 52) and male (n = 48) adult White Sturgeon implanted with acoustic transmitters in the lower Columbia River, 2008-2017.

Table 24. The maximum proportion of time (mean ± SD) spent by adult White Sturgeon (male and female) at specific receiver locations (unique river kilometers; rkm) or within larger river zones in the lower Columbia River, between January 2008 and December 2017. River zones represent 11.2 rkm increments starting from Hugh L. Keenleyside Dam extending downstream to the US Border. Data are summarized as the proportion of total detections recorded at receiver locations (n=24) and within the larger river zone (n=5).

		Maximum Proportion of Total Detections	
Sex	N	By RKM	By Zone
Combined	101	0.64 ± 0.20	0.87 ± 0.17
Male	48	0.65 ± 0.18	0.88 ± 0.16
Female	52	0.63 ± 0.23	0.87 ± 0.18

Residency to river zones was examined by the proportion of time spent by individual adult White Sturgeon (male, n=48; female, n=52) detected within 5 river zones of the lower Columbia River, Canada. Individuals were assigned to one of four categories representing the proportion of their detections recorded within each zone. Categories were organized by proportional increments of 0.25. Individuals with site fidelity ≥0.75 for a given river zone were assigned as residents of that zone. A total of 80 individuals were assigned residency of a zone (Table 25; Figure 17). Residency was highest in zone 1, with 44 individuals (22 males and 22 females) spending greater than 0.75 of their time in this zone.

In 2017, 11 adults (5 males, 6 females; Figure 18) were identified for suspected spawn related movements. The highest proportion of adults identified at a suspected spawning location was detected at rkm 56.0 (0.45). The majority of males (0.60) and females (0.83) were detected at rkm 26.0 and 56.0, respectively. Two adults were suspected as a resident of the Upper section but neither remained during the spawning period. All individuals detected in the Middle section (n=5) and Lower (n=4) sections remained within the respective section during spawn related movements.

Over the period of the study (2008 – 2017), a number of adult White Sturgeon (n=125) were identified to have made movements that appeared to be spawning related during June – August (Table 26). Spawning related movements tended to remain within the river section the individual was originally detected. However, a proportion of individuals in each river section exhibited putative spawning migrations to adjoining river sections; up to 0.50 individuals originally detected in the Upper section.

Suspected spawning related distance travelled was highest for fish migrating to the Lower (19.6 ± 15.2 km) and Upper (13.7 ± 15.0 km) sections (Table 27). Travel time to the suspected spawning sites was similar between Upper (10.7 ± 18.7 days) and Lower (10.0 ± 15.0 days), where time spend on the site was slightly lower at the Upper section (23.2 ± 16.9 days) compared to the Lower (28.4 ± 17.2 days). Suspected spawning related distance and travel time to the Middle section was relatively lower (7.1 ± 6.4 km and 6.8 ± 11.8 days, respectively), where the time spent at the Middle section spawning site was the greatest (33.3 ± 30.4 days) (Table 27).

Table 25. The number of adult White Sturgeon (male, n=48; female, n=52) by proportion of time spent within 5 river zones of the lower Columbia River, Canada, in 2008 through 2017. Individuals were assigned to one of four categories representing the proportion of their detections recorded within each zone. Categories were based on proportional increments of 0.25. Site fidelity to a river zone was assigned to individual's detected ≥0.75 of the time within that zone (bolded). River zones represent 11.2 rkm increments starting from Hugh L. Keenleyside Dam extending downstream to the US Border.

Sex	Proportion of Detections	River Zone				
		1	2	3	4	5
Combined	0.00 - 0.24	43	80	96	90	82
Combined	0.25 - 0.49	6	5	2	2	2
Combined	0.50 - 0.74	9	3	1	2	3
Combined	0.75 - 1.00	**43**	**13**	**2**	**7**	**14**
Male	0.00 - 0.24	20	35	46	43	41
Male	0.25 - 0.49	1	4	0	1	1
Male	0.50 - 0.74	5	1	1	1	0
Male	0.75 - 1.00	**22**	**8**	**1**	**3**	**6**
Female	0.00 - 0.24	22	45	49	46	40
Female	0.25 - 0.49	5	1	2	1	1
Female	0.50 - 0.74	4	2	0	1	3
Female	0.75 - 1.00	**21**	**4**	**1**	**4**	**8**

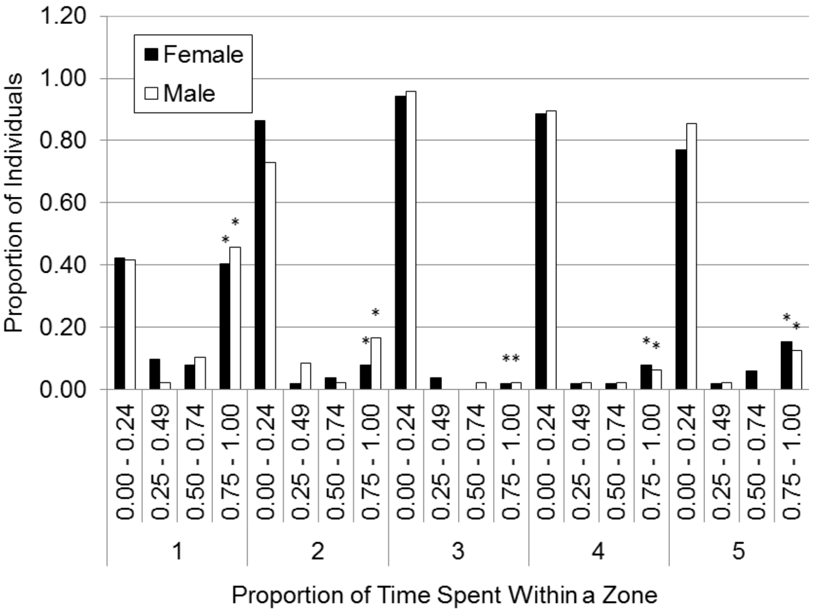


Figure 17. The proportion of acoustically tagged male (n=48) and female (n=52) adult White Sturgeon detected within each sampling zone of the lower Columbia River, Canada, in 2008 through 2017. Individuals were assigned to one of four categories representing the proportion of their detections recorded within each zone. Categories were based on proportional increments of 0.25. Site fidelity to a river zone was assigned to individual's detected ≥0.75 of the time within that zone and is marked with an asterisk for comparison. River zones represent 11.2 rkm increments starting from Hugh L. Keenleyside Dam extending downstream to the US Border.

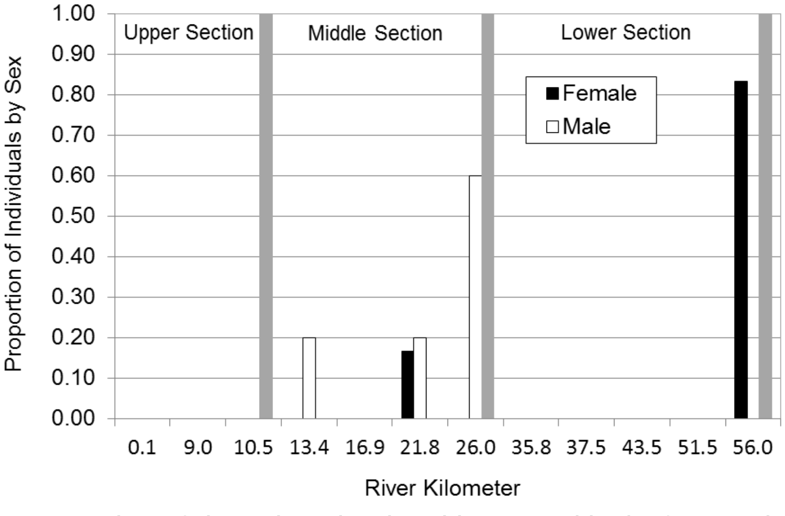


Figure 18. Proportion of detections by river kilometer (rkm) of acoustically tagged female (n=6) and male (n=5) White Sturgeon identified for suspected spawn related movements in the lower Columbia River (LCR) in 2017. The LCR was divided into three sections including: Upper (HLK [rkm 0.1] to Kootenay River Confluence [rkm 10.5]), Middle (downstream Kootenay River Confluence to Birchbank [rkm 29]), and Lower (downstream Birchbank to Waneta [rkm 56.0]).

Table 26. The proportion by river section of adult White Sturgeon (n=124) implanted with acoustic transmitters identified for suspected spawn related movements (June to August) within and outside the suspected residency section (originally detected) in the lower Columbia River (LCR) in years 2008 through 2017. The LCR was divided into three sections including: Upper (HLK [river kilometer 0.1; rkm] to Kootenay River Confluence [rkm 10.5]), Middle (downstream Kootenay River Confluence to Birchbank [rkm 29]), and Lower (downstream Birchbank to Waneta [rkm 56.0]).

	Suspected Spawning Site n (proportion)		
Suspected Residency	Upper	Middle	Lower
Upper	15 (0.39)	19 (0.50)	4 (0.11)
Middle	4 (0.07)	28 (0.51)	23 (0.42)
Lower	5 (0.16)	2 (0.06)	25 (0.81)

Table 27. Mean (± SD) distance travelled (km), travel time (days), and total time on site (days) for suspected spawn related movements of adult White Sturgeon implanted with acoustic tags (n=125) in the lower Columbia River (LCR), 2008 to 2017. The LCR was divided into three sections including: Upper (HLK [river kilometer 0.1; rkm] to Kootenay River Confluence [rkm 10.5]), Middle (downstream Kootenay River Confluence to Birchbank [rkm 29]), and Lower (downstream Birchbank to Waneta [rkm 56.0]).

Suspected Spawning Site	n	Distance Travelled (km)	Travel Time (Days)	Time Spent on Site (Days)
Upper	24	13.7 ± 15.0	10.7 ± 18.7	23.2 ± 16.9
Middle	50	7.1 ± 6.4	6.8 ± 11.8	33.3 ± 30.4
Lower	51	19.6 ± 15.2	10.0 ± 15.0	28.4 ± 17.2
LCR	125	13.4 ± 13.5	8.8 ± 14.6	29.0 ± 23.4

4.0 DISCUSSION

The primary objectives of this monitoring program were to describe adult White Sturgeon life history, biological, and population characteristics. Through the twelfth year of this work, we have been successful in quantifying fish condition, estimating timing and duration of spawning, identifying environmental spawning cues, and describing spawning-related movements and habitat use of adult White Sturgeon in the LCR. With more than a decade of data collection complete, more comprehensive analyses are underway to evaluate program objectives and inform remaining uncertainties. Further, this program was initially responsible for the collection of sexually mature White Sturgeon to use as broodstock but results have led to rearing naturally produced offspring collected from the wild for the Conservation Aquaculture Program. Data collection will continue in the following years to build on the estimates of population abundance and survival presented in this report. These results are actively being used in discussions around recovery planning going forward. Outstanding issues identified by the WUP Fisheries Technical Committee (FTC) during the creation of the Columbia Water Use Plan, as provided in the Terms of Reference for this program, are described and addressed in Table 28.

Table 28. Outstanding issues identified by the WUP Fisheries Technical Committee (FTC) in the Terms of Reference for this monitoring program.

FTC Outstanding Issue	Current Status
As the annual average number of spawning days at Waneta Eddy appears small relative to the adult population size and the approximate female reproductive cycle, this adult monitoring program may identify additional spawning sites.	After collecting early life history data for the first several years of the program, spawning days are not viewed as a reliable indicator of the adult breeding population, given uncertainties in how efficient the methodology is when comparing among years. This inefficiency is driven by annual changes in hydrology and uncertainties regarding the exact geographical locations where spawning (i.e., release of eggs) occurs. This is true even for spawning sites where large amounts of data have been collected (Waneta). Genetic analyses has identified >100 adults spawning annually in the Canadian portion of the Columbia River (Jay et al. 2014), with additional adults spawning at two locations downstream. There are now 5 known spawning sites in the transboundary section of the Columbia River. Additional genetic work is planned starting in 2020 to confirm contributions of adults to spawning events detected as collections of wild embryos and larvae serve as the basis for the conservation aquaculture program.
Changes in movement and spawning behaviour in response to management responses (relative to the baseline established through this monitoring program) may reveal that additional spawning sites (and sub populations) exist in the LCR.	Additional spawning sites have been identified through analysis of adult movements (e.g., ALH spawning area in 2010) and through the collection of larvae downstream from suspected locations (e.g., Kinnaird 2007 to current). Currently, known spawning sites in Canada are being monitored annually and spawning related movements are evaluated in order to identify any further locations. Ongoing analyses using long-term telemetry data are being conducted to further address this question.
Baseline information acquired through this monitoring program may verify that the abundance of adult White Sturgeon in the LCR will not be adversely affected by management response	Revised abundance estimates for wild adult White Sturgeon are being conducted through the entire Transboundary Reach under a new stock assessment program, with a revised population estimate provided in Appendix 1.

FTC Outstanding Issue	Current Status
measures.	
Of equal importance to the maintenance of the remaining White Sturgeon population; are there sufficient adults to continue the Conservation Aquaculture Program?	Based on both previous genetic studies and the success in collecting wild-origin progeny, sufficient breeding adults remain to support a conservation aquaculture program. In the short-term, the aquaculture program needs to center on using wild collected embryos and larvae as they are critical to preserving the genetic diversity of the existing wild adults. The wild population is ageing and, while senesce has not been shown for sturgeon, fewer spawners should be available in the coming years due to natural processes like increased time between spawning events for older adults and loss of individuals through mortality. Further, results from other monitoring programs (CLBMON-29 Lower Columbia River Juvenile Sturgeon Detection Program) indicate that genetic diversity has not been maintained using broodstock. It is expected that when hatchery-origin sturgeon reach sexual maturity and begin contributing to spawning events in the wild, the genetic diversity of the progeny produced would be compromised. This revised aquaculture program has resulted in suspending the traditional broodstock program as of 2014, with 175 individual adults (97 males and 78 females) having contributed to the Conservation Aquaculture Program since 2001.

4.1 Streamside Incubation Facility

A key component of the recovery program for LCR White Sturgeon has been the supplementation of the existing wild population through the release of hatchery produced and reared juvenile White Sturgeon (Hildebrand and Parsley 2013). The program was initiated in 2001 through the annual capture of broodstock and the original goals of the conservation aquaculture program were to:

I. Prevent extirpation of the LCR White Sturgeon.

II. Retain genetic diversity of the existing wild adults.

Since the Conservation Aquaculture Program was initiated with the use of mature adults as broodstock, 136,914 hatchery-reared juvenile White Sturgeon have been released into the Transboundary Reach from 2002 to 2014 (yearly releases ranging from 2,455 in 2014 to 21,603 in 2005). These juveniles are known to be in high abundance and objective 1 is considered by the UCWSRI to have largely to be met. As a result, the pilot streamside incubation facility was developed by the UCWSRI TWG to focus on retaining the genetic diversity of the existing wild adults while suitable numbers are still spawning. This was based on the results of genetic work by Jay et al. (2014). The main goals of the facility were ranked by TWG members to be:

1. Maximize genetic diversity [increase effective population size (N_e) and decrease relatedness (rxy)] of supplemental progeny compared to current aquaculture program by representing a larger proportion of wild spawning adults.

2. Rear supplemental progeny in a more natural rearing environment to reduce hatchery effects and provide for imprinting to a specific river location.

Results from the 2014 pilot year for the SIF were successful, with over 1,000 wild origin juveniles released into the LCR. The SIF was then implemented as the sole component of the conservation aquaculture program for the next several years. Collections of embryos and larvae were low in 2015, which was one of the driest and warmest years since regulation of the Columbia River began. While a larger number of embryos and larvae were not available in 2015 at the Canadian spawning sites, it should be noted that a significant number of wild feeding age larvae were collected downstream of Northport in the US and were raised for release into Lake Roosevelt. The last several years' collections were all successful with 800, 607, 200, and 200 wild-origin juveniles released from the 2016, 2017, 2018, and 2019 year classes, respectively. While annual variability in numbers of embryos and larvae collected for conservation aquaculture was initially expected as part of this revised plan, release strategies have been adjusted to reflect higher than anticipated survival following release. With a maximum of 200 fish produced for release, the wild-origin progeny collection approach has been further focused on ensuring all spawning events and spawning locations are represented in progeny released. Importantly, sampling effort needs to be consistent and balanced across the entire spawning distribution to maximize genetic diversity. While validation is still required through the juvenile monitoring program, the revised minimum size at release targets (200 grams) should help improve survival following release. At the conservation hatchery, survival from the time larvae are transferred to the time of stocking has also been good, with over 50% survival to date. Further refinements to methods during incubation at the SIF near Waneta and while at the conservation hatchery will be explored to improve survival further.

4.2 Spawn Monitoring

For White Sturgeon throughout their range, it is generally thought that the spawning period is protracted and occurs in the late spring and early summer months (May to July) with specific timing dependent on environmental cues (e.g., temperature, flows; Parsley and Beckman 1994). In 2018, peak flows on the Columbia River were the second highest recorded since 1997 (Table 29) while in 2019 they were slightly below average. Similar to 2018, peak freshet was early in 2019, happening prior to June. Spawning wasn't observed until mid-June when temperatures reached 14^{o}C. While the period over which spawning occurs at the two upstream locations can be up to a month in duration (e.g. 27 days at Kinnaird in 2016), it is generally much shorter compared to Waneta and has only ever been observed over a few days at ALH (e.g., 3 days in 2018 and 2 in 2019). At ALH, the timing of spawning activity was similar to previous years, occurring in late July. Since 2012, spawning at ALH was detected in 2015 (only a single larvae), 2017, 2018 and 2019. It is unknown if the intermittent use of this spawning area (7 of 10 years monitoring has occurred) will change as additional hatchery-origin spawners reach maturity and begin contributing as documented in the sex and stage of maturity program under CLBMON-29 (BC Hydro 2019). Tracking annual use through continued spawn monitoring will be important to identifying a change in spawning frequency over time and help monitor effectiveness of possible future restoration programs being evaluated at the ALH site under CLBWORKS-27 Lower Columbia White Sturgeon Habitat Restoration Options. Given the variability in the start and duration of spawning activity at Kinnaird and ALH, monitoring is required for approximately 6 weeks from late June to early August to ensure spawning is detected.

Table 29. Estimated number of annual spawning events at the Waneta Spawning area from 2001-2018 in relation to peak flows on the Columbia River. Grey highlighted rows represent years where flows exceeded 200 kcfs at the international border on the Columbia River.

Year	Peak discharge (cfs)	Peak freshet date	Estimated number of spawning events	% of Spawning events Occurring on the descending limb of the hydrograph
1997*	302,452	6-June	N/A	N/A
2001	114,651	26-May	7	100
2002	230,412	30-June	9	56
2003	150,526	5-June	9	100
2004	135,089	14-June	9	100
2005	166,521	10-June	12	100
2006	227,250	25-May	N/A	N/A
2007	185,984	9-June	10	100
2008	216,651	4-June	17	100
2009	173,948	2-June	15	100
2010	181,245	21-June	18	63
2011	267,000	14-June	8	88
2012	280,400	28-June	18	100
2013	202,000	1-July	12	100
2014	221,000	28-May	5	100
2015	155,382	3-June	6	100
2016	157,083	29-May	13	100
2017	246,934	9-June	17	100
2018	282,365	28-May	21	100
2019	136,799	18-May	14	100

* monitoring of White Sturgeon spawning at Waneta was not conducted

Despite considerable effort and spatial distribution of sampling gear, few dispersing larvae were collected within the vicinity of Kinnaird and the exact location of the spawning area remains unknown. 2019 represents 12 straight years where spawning has occurred in the Kinnaird area and increased telemetry work in that area will hopefully lead to refining the location of spawning within the 8km reach. Determining capture efficiency of both embryo and larval samples between gear types is important when identifying exact spawning locations of unknown areas. Egg mats have been consistently used at Waneta for the collection of White Sturgeon embryos since the spawning location was first described in 1993 (Hildebrand and Parsley 2013). At the upstream locations (ALH and Kinnaird), the use of drift nets has been more effective in collecting embryos or larvae. For spawning areas where the exact geographical location is uncertain, drift nets are more effective as they can represent all areas upstream of the sampling location. Though egg mats are effective when the main areas of egg deposition have been identified, drift nets should be used primarily when attempting to assign a general location where spawning may be occurring. To address the objectives of this program as it relates to describing new spawning areas, it is recommended that use of egg mats be restricted to Waneta, and that drift nets are the primary technique used in areas where spawning locations are uncertain (e.g., Kinnaird).

4.3 Population Monitoring, Abundance, and Characteristics

Prior to 2013, the broodstock program served as the sole method of providing information on the biology of the population (e.g., length frequency, growth rates, population estimates). The systematic stock assessment program was initiated to address uncertainties in abundance and survival rate estimates of the LCR White Sturgeon population. Using life history and biological data collected using capture-mark-recapture methods, the program is estimating growth rates across females, males, and immature fish (<150 cm fork length), fish condition, age class structuring, and possible density dependent responses as the hatchery population increases. This information is required to inform discussions around LCR White Sturgeon population dynamics and assess trends within the population.

Preliminary estimates for abundance and survival were made using the combined US and Canada stock assessment results from 2013-2018. Refinements to those models have been ongoing, with additional data from 2019 to be incorporated in the coming years. The initial estimates include both hatchery and wild origin and it should be noted that the total population abundance estimates presented in this report (Appendix 1) are based on initial analyses and as such, should be interpreted with caution. As the final analysis of these data is completed, more robust estimates of abundance that include both wild and hatchery-origin sturgeon are expected which can be used in recovery planning. Additional years of stock assessment surveys have been recommended by the UCWSRI TWG as part of the recovery program to improve confidence in the estimates being produced.

4.4 Acoustic Tagging and Telemetry

The long-term telemetry dataset collected as part of this program is being analyzed now that 10 years of data have been collected. This work, through collaboration with the University of Northern BC and other recovery team partners is ongoing. General results to date have found that White Sturgeon in the LCR tend to select deep, slow moving sections of the river which do not appear to be limited under the current operating regime. Adult movements are low and have been similar across all years evaluated with activity generally occurring during the summer months for assumed foraging or spawning. Adult male and female White Sturgeon spent 64 and 63% of their time at a single location, respectively. When movements were evaluated at a larger reach scale (11.2 rkm increments), residency to those areas increased to 88% and 87% for males and females, respectively (Table 26). White Sturgeon residing in the Middle (Kinnaird to Genelle) and Lower sections (Trail to Waneta) of the LCR were observed migrating within the respective section of residency for suspected spawning related movements. This behavior is similar to observations made in previous years where suspected spawning related movements revealed that resident adults within the Upper river section tend to migrate to adjacent downstream spawning areas (Middle section). A small portion of adults monitored in this study exhibited putative spawning migrations to adjoining river areas indicating mixing of adults throughout the river.

Though current results from the telemetry monitoring program reveal patterns of habitat use and possible spawning related movements, caution is advised when interpreting results presented, as the long-term movement patterns of White Sturgeon will be analyzed using a more complex analytical approach now that the majority of tags have reached end of life. These analyses are intended to address how the biology of the species, environmental variables (e.g., temperature), and the operation of the river may influence White Sturgeon habitat use or movements. At the present time, there are sufficient numbers of adults with active acoustic transmitters so additional telemetry tagging is not planned in the coming years. Data will continue to be collected in a systematic fashion using the longitudinal array of receivers in the LCR. An in-depth analysis incorporating all movement data is ongoing to address this management question.

5.0 RECCOMENDATIONS

1. Continue monitoring spawning activity at all locations to ensure progeny collection for the conservation aquaculture program and to monitor frequency of use over time as the hatchery segment of the population begins reaching maturity and contributing to spawning events.

    a. Given the variability in the timing of spawning at both the ALH and Kinnaird sites, a 6 week monitoring period from late June through early August is recommended to ensure spawning is detected.

2. Drift nets maximize catch per unit effort of embryos and larvae from locations upstream of the sampling equipment and should continue to be used as the

primary collection method in areas where the exact geographical boundary of the spawning location remains unknown (e.g., in the vicinity of Kinnaird).

   a. Egg mats should continue to be used at Waneta and HLK/ALH in the same consistent fashion as previous years sampling.

   b. Consider deploying additional drift net stations downstream of Kinnaird to help determine where larvae may be originating from.

3. Continue to collect tissue samples from offspring (larvae) at the different spawning areas and from wild juveniles and adults for future genetic analyses.

4. Evaluate a fine scale (< 1km intervals) acoustic array near Kinnaird to describe adult movements in this area during the spawning window. If possible, tag mature females (e.g., F4) with short-term tags (~6 month battery life).

   a. Additional range testing should be conducted throughout the LCR to describe detection probabilities for each unique receiver station.

5. Continue coordinated stock assessment program with US agencies to improve our confidence in the abundance of White Sturgeon in the Transboundary Reach.

   a. Develop models to estimate survival and abundance that can be updated annually as additional survey data are collected.

6. Development of a database that could store all life history data and telemetry data among researchers and industries.

7. Continue to evaluate and discuss the streamside incubation facility with UCWSRI partners.

6.0 REFERENCES

Auer, N. A., and E. A. Baker. 2002. Duration and drift of larval Lake Sturgeon in the Sturgeon River, Michigan. Journal of Applied Ichthyology. 18: 557 – 564.

BC Hydro. 2009. Columbia Water Use Plan. Lower Columbia River White Sturgeon Broodstock Acquisition Program: 2008 Data Report. Prepared by BC Hydro Water License Requirements, Castlegar, BC. 19 p. + 3 app.

BC Hydro. 2011. Lower Columbia River adult White Wturgeon monitoring: 2009 & 2010 investigations data report. Report prepared by BC Hydro Water License Requirements, Castlegar, B.C.

BC Hydro. 2013. Lower Columbia River Adult White Sturgeon Monitoring Program: 2011 Investigations Data Report. Reported by BC Hydro Water License Requirements, Castlegar, B.C.

BC Hydro. 2015a. Lower Columbia River Adult White Sturgeon Monitoring Program (CLBMON-28). Years 5 and 6 Data Report. Report by BC Hydro, Castlegar. 83 pp.

BC Hydro. 2015b. Lower Columbia River Adult White Sturgeon Moniroting Program (CLBMON-28). Year 7 Data Report. Report by BC Hydro, Castlegar, 53.pp.

BC Hydro. 2016a. Lower Columbia River Adult White Sturgeon Monitoring Program (CLBMON-28). Year 8 Data Report. Report by BC Hydro, Castlegar, 56 pp.

BC Hydro. 2016b. Lower Columbia River Juvenile Detection Program (CLBMON-29). Year 8 Data Report. Report by BC Hydro, Castlegar, BC. 88 pp.

BC Hydro. 2017. Lower Columbia River Adult White Sturgeon Monitoring Program (CLBMON-28). Year 9 Data Report. Report by BC Hydro, Castlegar, 58 pp.

BC Hydro. 2018. Lower Columbia River Adult White Sturgeon Monitoring Program (CLBMON-28). Year 10 Data Report. Report by BC Hydro, Castlegar, 67 pp.

BC Hydro. 2019. Lower Columbia River Adult White Sturgeon Monitoring Program (CLBMON-28). Year 11 Data Report. Report by BC Hydro, Castlegar, 73 pp.

BC Hydro. 2020. Lower Columbia River Juvenile Detection Program (CLBMON-29). Year 11 and 12 Data Report. Report by BC Hydro, Castlegar, 80 pp.

Beamesderfer, R. C. 1993. A standard weight (*Ws*) equation for White Sturgeon. California Fish and Game 79:63–69.

Dettlaff, T. A., A. S. Ginsburg, and O. I. Schmalhausen. 1993. Sturgeon Fishes Developmental Biology and Aquaculture. Springer-Verlag. Berlin.

Drauch Schreier, A., D. Gille, B. Mahardja, and B. May. 2011. Neutral markers confirm the octoploid origin and reveal spontaneous autoploidy in white sturgeon, *Acipenser transmontanus*. Journal of Applied Ichthyology, 27:24-33.

FFSBC. 2015. Columbia White Sturgeon conservation aquaculture program. Fresh Water Fisheries of British Columbia (FFSBC). Report prepared for BC Hydro, Water license Requirements, Castlegar, BC; 20 p. + 4 app. Available at _www.bchydro.com.

FFSBC. 2016. Columbia White Sturgeon conservation aquaculture program. Fresh Water Fisheries of British Columbia (FFSBC). Report prepared for BC Hydro, Water License Requirements, Castlegar, BC; 13 p. +3 app. Available at _www.bchydro.com.

FFSBC. 2017. Columbia White Sturgeon conservation aquaculture program. Fresh Water Fisheries of British Columbia (FFSBC). Report prepared for BC Hydro, Water License Requirements, Castlegar, BC; 18 p. +2 app. Available at _www.bchydro.com.

FFSBC. 2018. Columbia White Sturgeon conservation aquaculture program. Fresh Water Fisheries of British Columbia (FFSBC). Report prepared for BC Hydro, Water License Requirements, Castlegar, BC; 16 p. Available at _www.bchydro.com.

FFSBC. 2020. Columbia White Sturgeon conservation aquaculture program. Fresh Water Fisheries of British Columbia 9FFSBC). Report prepared for BC Hydro, Water License Requirements, Castlegar, BC; 30 p. Available at www.bchydro.com.

Golder Associates Ltd. 2002. White Sturgeon spawning at Waneta, 2001 investigations and historical data summary. Report prepared for Columbia Power Corporation, Castlegar, BC. Golder Report No. 0128966F: 46p. + 7 app.

Golder Associates Ltd. 2006. Upper Columbia White Sturgeon Stock Monitoring and Data Management Program: Synthesis Report, 1 November 2003 - 31 March 2006. Report prepared for British Columbia Ministry of Environment, Nelson, B.C. Golder Report No. 05-1480-025F: 55 p. + 2 app. + plates.

Golder Associates Ltd. 2009a. Lower Columbia River adult White Sturgeon monitoring: 2008 investigations data report. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 08-1480-0032F: 32 p. + 2 app.

Golder Associates Ltd. 2009b. Lower Columbia River juvenile White Sturgeon detection: 2008 investigations data report. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 08-1480-0040F: 24 p. + 2 app.

Golder Associates Ltd. 2010. White Sturgeon spawning at Waneta, 2009 investigations. Data Report prepared for Columbia Power Corporation, Castlegar, B.C. Golder Report No. 09-1480-0034F: 20 p. + 1 app.

Golder Associates Ltd. 2012. Waneta White Sturgeon spawning: 2011 investigations. Data Report prepared for Columbia Power Corporation, Castlegar, B.C. Golder Report No. 10-1492-0149D: 22 p.

Golder Associates Ltd. 2013. Waneta White Sturgeon spawning: 2012 investigations. Data Report prepared for Columbia Power Corporation, Castlegar, B.C. Golder Report No. 1021492-0031D: 26 p. +1 App.

Golder Associates Ltd., and LGL Ltd. 2014. Waneta White Sturgeon egg predation and spawn monitoring at Waneta: 2013 investigation. Data Report prepared for Columbia Power Corporation, Castlegar, B.C. and LGL Environmental Ltd. Golder Report No. 13-1492-0009: 64 p +1 App.

Gregory, R., and G. Long. 2008. Summary and Key Findings of Upper Columbia River White Sturgeon Recruitment Failure Hypothesis Review. Prepared for the Upper Columbia River White Sturgeon Technical Working Group.

Hedrick, R. P., T. S. McDowell, and R. Rosemark. 1991. Two cell lines from white sturgeon. Transactions of American Fisheries Society, 120: 528-534.

Hildebrand, L., C. McLeod, and S. McKenzie. 1999. Status and management of White Sturgeon in the Columbia River in British Columbia, Canada: an overview. Journal of Applied Ichthyology 15: 164-172.

Hildebrand, L. R., and M. Parsley. 2013. Upper Columbia White Sturgeon Recovery Plan – 2012 Revision to the Upper Columbia White Sturgeon Recovery Initiative.

Howell, M. D., and J. G. McLellan. 2006. Lake Roosevelt White Sturgeon recovery project. Annual Progress Report, January 2004 - March 2005. Prepared for the U.S. Department of Energy, Bonneville Power Administration, Environment, Fish and Wildlife. Project Number: 1995-027-00. 103 p. + 4 app.

Irvine, R. L., D. C. Schmidt, and L. R. Hildebrand. 2007. Population Status of White Sturgeon in the Lower Columbia River within Canada. Transactions of the American Fisheries Society, 136(6): 1472-1479.

Jay, K. J. 2014. Estimating effective number of breeding adults, reproductive success and spawning duration for White Sturgeon in the Upper Columbia River, Canada. M.Sc. Thesis. Michigan State University, USA.

Jay, K., J. A. Crossman, and K. T. Scribner. 2014. Estimates of effective number of breeding adults and reproductive success for White Sturgeon. Transactions of the American Fisheries Society, 143:1204-1216.

McAdam, S. O. 2011. Effects of substrate condition on habitat use and survival by White Sturgeon (Acipenser transmontanus) larvae and potential implications for recruitment. Canadian Journal of Fisheries and Acquatic Sciences; 68: 812 – 822.

McCabe, G. T., and L. G. Beckman. 1990. Use of an artificial substrate to collect White Sturgeon eggs. California Fish and Game, 76(4): 248 – 250.

McCabe, G. T., and C. A. Tracy. 1993. Spawning characteristics and early life history of White Sturgeon *Acipenser transmontanus* in the lower Columbia River. Report A, pages 19 – 46. *In*: R.C. Beamesderfer and A.A. Nigro (editors). Volume 1: Status and habitat requirements of the White Sturgeon populations in the Columbia River downstream from McNary Dam. Final report to Bonneville Power Administration, Portland, Oregon.

Moser, M. L., M. Bain, M. R. Collins, N. Haley, B. Kynard, J. C. O'Herron II, G. Rogers, and T. S. Squiers. 2000. A Protocol for use of shortnose and Atlantic Sturgeons. NOAA Technical Memorandum NMFS-OPR-18. Available: nmfs.gov/prot_res/prot_res.html.

Nigro, A. A., B. E. Rieman, J. C. Elliot, and D. R. Engle. 1988. Status and habitat requirements of White Sturgeon populations in the Columbia River downstream from McNary Dam. Annual Progress Report (July 1987-March 1988) to Bonneville Power Administration, Portland, Or. 140 p.

Parsley, M. J. and L. G. Beckman. 1994. White Sturgeon spawning and rearing habitat in the lower Columbia River. North American Journal of Fisheries Management, 14: 812-827.

Parsley, M. J., E. Kofoot, and T. J. Blubaugh. 2010. Mid Columbia Sturgeon Incubation and Rearing Study (Year 1 – 2009). Report prepared for BC Hydro, Castlegar, B.C. 23 p + 1 app.

Schreier, A.D., B. May, and D.A. Gille. 2013. Incidence of spontaneous autoploidy in cultured populations of white sturgeon, *Acipenser transmontanus*. Aquaculture, 416-417: 141-145.

Terraquatic Resource Management. 2011. Arrow Lakes Generating Station White Sturgeon spawn monitoring program – 2011. Prepared for Columbia Power Corporation. 19 pp.

Upper Columbia White Sturgeon Recovery Initiative. 2006. Upper Columbia River Adult White Sturgeon Capture Transport and Handling Manual. Prepared for the Upper Columbia White Sturgeon Recovery Initiative. 20 p. + app.

Upper Columbia White Sturgeon Recovery Initiative. 2012. Upper Columbia White Sturgeon Recovery Plan – 2012 Revision. Prepared for the Upper Columbia White Sturgeon Recovery Initiative. 129p. + 1 app. Available at: www.uppercolumbiasturgeon.org

Wege, G. W., and R. O. Anderson. 1978. Relative weight (Wr) : a new index of condition for largemouth bass. In: New approaches to the management of small impoundments (Eds.: G. D. Novinger, and J. G. Dillard). Pp 79-91. Bethesda, MD: North Central Division, American Fisheries Society, Special Publication No. 5.

7.0 **Appendix 1:** Analysis of transboundary White Sturgeon population abundance and survival estimates based on 2013-2017 mark-recapture data.

This appendix includes results from work to analyze data collected from the coordinated stock assessment program. Please note that this is an ongoing project and as such, all results are considered as draft and are to be interpreted with caution.

ERROR! UNKNOWN DOCUMENT PROPERTY NAME.

REPORT

Analysis of transboundary White Sturgeon population abundance and survival estimates based on 2013-2017 mark-recapture data

Submitted to:

Dr. James Crossman
BC Hydro
601 18th Street
Castlegar, BC
V1N 4G7

Submitted by:

Golder Associates Ltd.
201 Columbia Avenue, Castlegar, British Columbia, V1N 1A8, Canada

+1 250 365 0344

30 September 2019

DRAFT

Table of Contents

DRAFT

ANNEXE A TABLES

DRAFT

ANNEXE B FIGURES

DRAFT

DRAFT

ANNEXE C APPENDIC

DRAFT

BACKGROUND

The White Sturgeon population in the transboundary area of the Columbia River has been augmented by releases of hatchery-reared sturgeon throughout 2002-2014. The analysis of population dynamics of the overall White Sturgeon population, which includes a mix of wild and hatchery-reared sturgeon, is the focus of this report. Between 2013 and 2018, White Sturgeon mark and recapture data were collected in the transboundary area using set-lines. These data were used to construct mark-recapture models to provide survival, recapture, and abundance estimates for the population. In addition, the collected data were used to assess length frequency distribution, examine growth patterns, and estimate extents of movement by individual fish within and between Canada and the US.

OBJECTIVES

This report addresses the following objectives:

Estimate survival and recapture of wild and hatchery-reared White Sturgeon in the transboundary area

Estimate population abundance of wild and hatchery-reared White Sturgeon in the US, Canada, and the combined transboundary area

Examine and characterize fish relocations between recaptures within and across years

METHODS

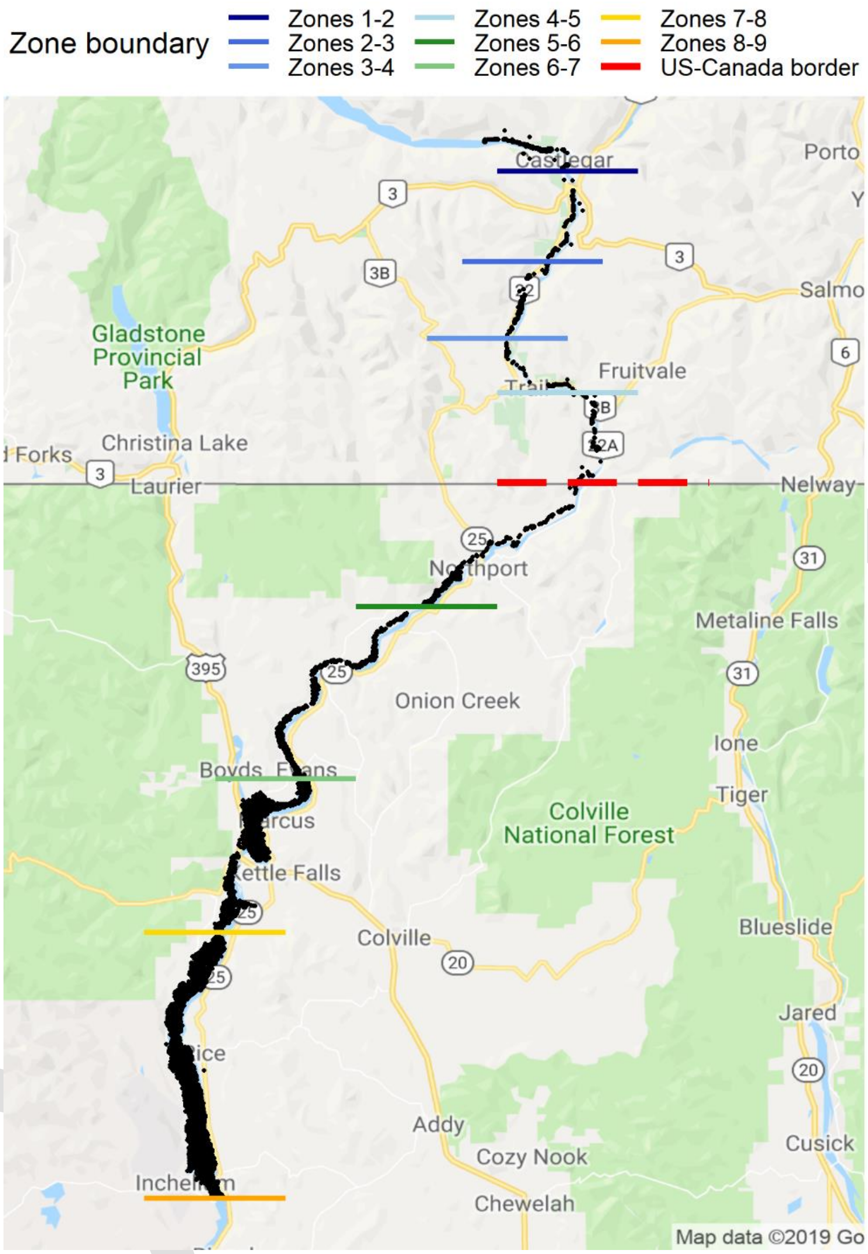
All data compilation, cleaning, and analysis were performed in R v. 3.5.3 (R Core Team 2019).

Data Compilation

Mark-recapture data were collected by three agencies (BC Hydro, Colville Confederated Tribes [CCT], and Spokane Tribe of Indians [STOI]) in spring and fall periods from 2013 through 2018 (“2013-2018”). The data were compiled into a single data set that included information on effort (e.g., date/time and GPS coordinates of sampling) and biological data on sturgeon (e.g., fork length and weight and PIT tag). The unique PIT tag numbers were used to identify sturgeon capture and recapture events. The unique PIT tag numbers were also used to retrieve release data for hatchery fish, including weight and fork length, year-class, and country of release.

GPS coordinates were used to calculate river kilometre (RKM) values for each sampling location. These RKM values were used to estimate relocation distances for fish that were recaptured during the 2013-2018 sampling period. Sampling locations were also characterized using zones. The Canadian portion of the transboundary area was divided into five distinct habitat zones, each approximately 11 km in length; in the US, sampling locations were divided into nine habitat zones, of which the four upstream-most were included in the sampling area for this study (**Figure 1**), and the remaining five zones were designated downstream of the sampling area, ranging between Grand Coulee Dam and Gillford Ferry. These zones were not sampled, however hatchery-reared fish from the 2017 year-class were released there in 2008.

DRAFT



ANNEXE D **Figure 1: Locations sampled for White Sturgeon during 2013-2018 (black points), showing the downstream cutoffs for the nine habitat zones, as well as the US-Canada border (which also serves as the boundary between zone 5 and 6).**

Data Cleaning

Fish with PIT tags that did not have conclusive information about whether the fish was hatchery-reared or a wild sturgeon were removed from analysis, as were hatchery-reared fish with no information on year-class or country of original release.

Data Summary

All data analysis and visualization were performed in R v. 3.5.3 (R Core Team 2019) using the package ggplot2 (Wickham 2016).

Length, Weight, and Year-class Characteristics

Sturgeon mark-recapture data were used to produce length frequency plots of hatchery-reared and wild fish, plotted by year and season of sampling. In addition, the length distribution of hatchery-reared year-classes within each season's catch was plotted. All analyses of body length used fork length data.

Sturgeon mark-recapture data of hatchery-reared fish were used to estimate von Bertalanffy growth curves. Four growth curves were constructed:

A single growth curve that was fit to the entire data set (i.e., a common growth model)

A growth curve with separate parameters (L_∞, K, and t_0) for fish that were originally released in Canada and in the US (i.e., a country of release model)

A growth curve with separate parameters for fish that were captured in Canada and in the US (i.e., a country of residency model)

A growth curve with separate parameters by both country of release and country of residency (i.e., the most general model)

These four models were created to estimate whether the location of release and residency affected growth. Models 2 and 3 were tested against Model 1 to assess whether there was support for the additional complexity to describe growth separately by country of original release or country of residency, respectively. Model 4 was tested against both Model 2 and Model 3, to assess whether grouping by both country or release and country of residency was a better fit for the data than grouping by only one of the characteristics.

Weight-length plots and regressions were produced for weight-length data at recapture (both wild and hatchery fish), weight-length data at recapture (hatchery fish only, by year-class), and weight-length data at original hatchery release (by year-class and all year-classes combined). Predicted weight-at-length values were estimated by year-class (and for all year-classes combined) at four values of length: 29 cm and 40 cm at original hatchery release, and 100 cm and 150 cm at recapture. The values (and their 95% confidence intervals) were plotted by year-class, to visualize the differences in weight-at-length between the year-classes at small and large fork lengths at both original hatchery release and at recapture. These plots were used to visualize differences in growth between year-classes.

Growth rate was calculated as the percent change in body weight per day. Growth rate was then plotted against weight at previous capture, by country of original release of hatchery fish, country of recapture, and season of capture and recapture.

DRAFT

Spatial Distribution

The positions of each sampling location (overnight set-line) were plotted on Google Earth maps using the R package ggmap (Kahle and Wickham 2013). To characterize relative fish abundance, proportion positive catch and catch per unit effort (CPUE) values were calculated. Proportion positive catch was calculated as the proportion of set-lines that caught at least one White Sturgeon in each combination of year, season, and habitat zone out of total deployed lines. For set-lines that captured fish, a CPUE value was calculated for each sampling location. Due to data entry errors, many deployments had incorrect date/time stamps for gear removal, e.g., deployments of ~1 h (where the wrong date was entered). The median value of all gear deployment lengths was 25 h; therefore, CPUE was calculated as the number of sturgeon captured in each gear deployment, divided by 25 h, and multiplied by 24 h, to estimate the number of sturgeon captured per 24 h of gear deployment. To visualize the spatial patterns of CPUEs, individual CPUE values were grouped by RKM values (rounded to the nearest 2 km), and median CPUE values were calculated for each RKM value. Median CPUE values calculated over the entire 2013-2018 sampling program were calculated and plotted for the entire transboundary area. In addition, for the Canadian portion of the transboundary area, median CPUE values were calculated for season/year, using the same clusters of gear deployment for each 2 km section of the river.

Movement Patterns

Summarization of movement patterns included movement across the US-Canada border, movement between the habitat zones described in Section 0, and movement relative to RKM values recorded at each recapture event. For hatchery fish, two types of movement across the US-Canada border were possible: 1) movement after original release but before recapture in the 2013-2018 mark-recapture program, and 2) movement between capture events during the 2013-2018 mark-recapture program. To estimate movement patterns of hatchery fish across the US-Canada border prior to each fish's initial capture in the 2013-2018 sampling, each tag's country of original release (i.e., stocking country) and country of first recapture during the 2013-2018 study were recorded. The percentage of fish that moved across the border was calculated by year-class and original release country.

To estimate movement patterns between subsequent recaptures during the 2013-2018 sampling, the RKM and habitat zone associated with each capture and subsequent recapture event were recorded for all tags. Fish percentages were calculated by habitat zone of capture and subsequent recapture to estimate the extent of movement between zones. The RKM values of each capture and subsequent recapture were used to estimate distance of movement (in km), direction of movement (up- or downstream), and average movement speed (km/day). These were used to create plots to visualize the extent of movement and characterize movement patterns relative to country of residency, season of capture and recapture, and period of time between capture and recapture.

Sturgeon movement distances were characterized in relation to 1) movement across the US-Canada border, and 2) movement between the five habitat zones described in Section 0, as well as distance and direction of relocations, minimum and maximum RKM value associated with each tag, and timing (i.e., season and period of time between capture and recapture).

Modeling

Multiple mark-recapture models were constructed to estimate survival, recapture probabilities, and population abundance for wild and hatchery fish in the US and Canada. Survival, recapture, and population abundance

DRAFT

estimates were produced separately for wild and hatchery-reared fish, as well as by sampling area (Canada / US / combined transboundary area). Fish that were removed from the population (either via culling that began in 2015 or by relocation from the river) were coded as mortalities upon sampling, to account for the change in number of tags at large.

The full data set was split into two separate files, by country of sampling. This was done due to three reasons:

1) Since no sampling was undertaken in spring 2018 in the US, it was not possible to analyze the combined US/Canada data set using a single model without omitting the spring 2018 data collected in Canada.

In spring 2016 and 2017, the spatial distribution of samples taken in the US was limited, with no sampling performed in zone 6 in spring 2017 and no sampling performed in zones 6 and 7 in spring 2018. Due to the skewed spatial distribution, these spring samples also had to be removed from analysis. If the US/Canada data were analyzed together, the data collected in Canada during these sampling sessions would also have to be removed.

Lastly, the sturgeon harvest fishery, which took place in the US in summer 2017 and summer 2018, was likely to affect survival in the US, but not in Canada, due to the low rate of movement between the two countries (Golder 2018).

Therefore, the overall data set was analyzed using four separate sets of models – a set of Cormack-Jolly-Seber (CJS) and POPAN (a parameterization of the Jolly-Seber model) for data collected in the Canadian portion of the transboundary area and a set of CJS and POPAN models for data collected in the US. In the CJS formulation of an open population, only two parameters are modeled – the survival probability and the recapture prob of fish. The POPAN model parameterization is more complex, with four parameters – probability of survival, probability of recapture, probability of entering the population, and a super-population value. The probabilities of survival and recapture are similar to the CJS parameterization. The super-population is a purely mathematical construct, and can be thought of as a reservoir of animals that may enter the population during the course of the study. The probability of entry is the probability of a new animal from the super-population entering the population (via birth or immigration).

To account for differences in survival rates of hatchery fish from different brood years, year-class was included as a predictor in the models. This variable used the actual year-class information available for each fish in the data set, with two exceptions:

1) year-class was coded as “Wild” for wild fish, and

in the US, fish of the youngest year-classes (2010-2013) were binned together into a year-class of ≥2010, since the rare captures of each of these year-classes led to model convergence difficulties if these years were included as separate year-classes. In Canada, where fewer fish from late year-classes were observed, fish of year-classes 2008 and later were binned together into a year-class of ≥2009.

Multiple Cormack-Jolly-Seber (CJS) and POPAN models were constructed to assess the effects of year-class, age, and time on survival and recapture. Output models were tested for goodness-of-fit and compared using quasi-Akaike information criterion (QAIC). Non-converged models were removed from analysis, and the remainder underwent a model selection process using QAIC. The best model (i.e., the model with the lowest QAIC) was used to produce estimates of survival and recapture. of survival, recapture, and population

DRAFT

abundance. Note that CJS-based abundance estimates are expected to be less precise than the POPAN estimates and should only be used for comparison purposes. All data analyses were performed in R v. 3.5.3 (R Core Team 2019) and MARK (White and Burnham 1999) through the package ‘RMark’ (Laake 2013).

Cormack-Jolly-Seber – US

Multiple CJS models were constructed to assess the effects of year-class, season, and time on survival and recapture of sturgeon in the US portion of the transboundary area.

The following specifications of survival were used:

As constant

As function of sampling occasion

As function of season

As function of year-class (where wild fish are assigned to “Wild” and fish of year-class 2010 and later were assigned to year-class ≥2010)

As function of whether a harvest fishery took place

As a multiplicative function between year-class and whether a harvest fishery took place

The following specifications of recapture probabilities were used:

As constant

As function of season

As function of sampling occasion

As a multiplicative function of year-class and season

As a multiplicative function of year and sampling occasion (where recapture rates were forced to be the same between the two spring sampling efforts within each year-class, and the same between the two spring sampling efforts and the first fall sampling for year-classes 2002, 2009, and ≥2010). The forcing was performed to assist parameter estimation, and it was based on preliminary modeling, where recapture rates in these occasions were shown to be similar.

Output models were tested for goodness-of-fit and compared using quasi-Akaike information criterion (QAIC). The best model (i.e., the model with the lowest QAIC) was used to produce estimates of survival and recapture. Population abundance estimates were calculated for different year-classes, as well as by hatchery/wild, and by occasion.

DRAFT

POPAN – US

Multiple POPAN models were constructed to assess the effects of year-class, season, and time on survival, recapture, and to estimate population abundance in the Canadian portion of the transboundary area. Two sets of POPAN models were run – one that models no recruitment (i.e., probability of entry into the population, `pent`, is set to zero), and one that models recruitment for the younger year-classes (2008, 2009, and ≥ 2010), which are not fully recruited to gear (based on preliminary analysis). The specification of survival, recapture, and super population were nearly identical between the two sets, with a single difference – in the model set that included recruitment of the younger year-classes, the recapture rates for the first and third occasion (i.e., same sampling season) were set to be the same for the 2008, 2009, and ≥ 2010 year-classes, to make the first population size identifiable.

The following specifications of survival were used:

As constant

As function of sampling occasion

As function of year-class (where wild fish are assigned to "Wild" and fish of year-class 2010 and later were assigned to year-class ≥2010)

As function of whether a harvest fishery took place

As a multiplicative function between year-class and whether a harvest fishery took place

As an additive function between year-class and whether a harvest fishery took place

The following specifications of recapture probabilities were used:

As constant

As function of season

As function of sampling occasion

As multiplicative function of season and year-class

As additive function of season and year-class

As multiplicative function of sampling occasion and year-class

As additive function of sampling occasion and year-class

The probability of entry into the population was modeled as:

Constant (set to zero)

Function of year-class for the younger year-classes (2008, 2009, and ≥2010) and as constant (set to zero) for older year-classes and for wild fish.

DRAFT

The super population was modeled as function of year-class.

Output models were tested for goodness-of-fit and compared using quasi-Akaike information criterion (QAIC). The best model (i.e., the model with the lowest QAIC) was used to produce estimates of survival, recapture, and abundance estimates. Population abundance estimates were calculated for different year-classes, as well as by hatchery/wild, and by occasion.

Cormack-Jolly-Seber – Canada

Multiple CJS models were constructed to assess the effects of year-class, season, and time on survival and recapture in the Canadian portion of the transboundary area.

The following specifications of survival were used:

As constant

As function of sampling occasion

As function of year-class (where wild fish are assigned to “Wild” and fish of year-class 2009 and later were assigned to year-class ≥2009)

The following specifications of recapture probabilities were used:

As constant

As function of sampling occasion

As function of season

As multiplicative function of season and year-class

As additive function of season and year-class

As multiplicative function of sampling occasion and year-class

As additive function of sampling occasion and year-class

Output models were tested for goodness-of-fit and compared using quasi-Akaike information criterion (QAIC). The best model (i.e., the model with the lowest QAIC) was used to produce estimates of survival and recapture. Population abundance estimates were calculated for different year-classes, as well as by hatchery/wild, and by occasion.

DRAFT

POPAN – Canada

Similar to the modeling approach used for the US POPAN models, two sets of models were constructed, where one set modeled no recruitment (i.e., pent set to zero) and the other set modeled recruitment for the youngest year-classes (2008, and ≥2009), since these year-classes were not fully recruited to gear based on preliminary analysis. In the second set of models, the recapture rates for spring 2013 and spring 2014 were set to be the same for the 2008 and ≥ 2009 year-classes, to make the first population size identifiable within the limitations of the POPAN model specification – in POPAN model structure, the initial probabilities of entrance and recapture are confounded if both use a fully occasion-dependent specification.

The following specifications of survival were used:

As constant

As function of sampling occasion

As function of year-class

The following specifications of recapture probabilities were used:

As constant

As function of sampling occasion

As function of season

As a multiplicative function of year-class and season

As multiplicative function of season and year-class

As additive function of season and year-class

As multiplicative function of sampling occasion and year-class, where recapture rates were forced to be the same between spring 2013 and spring 2014 for year-classes 2007, 2008, and ≥2009. The forcing was performed to assist parameter estimation, and it was based on preliminary modeling, where recapture rates in these occasions were shown to be similar.

DRAFT

The following specifications of probability of entry into the population were used:

Constant (set to zero)

Function of year-class for the younger year-classes (2007, 2008, and ≥2009) and as constant (set to zero) for older year-classes and for wild fish

The super population was modeled as function of year-class.

Output models were tested for goodness-of-fit and compared using quasi-Akaike information criterion (QAIC). The best model (i.e., the model with the lowest QAIC) was used to produce estimates of survival, recapture, and abundance estimates. Population abundance estimates were calculated for different year-classes, as well as by hatchery/wild, and by occasion.

Sensitivity to Sampling Design

To assess the impact of potential changes to the sampling design, the combined 2013-2018 data set was used in a sensitivity analysis. Three sampling designs were used in the assessment:

1) Sampling in fall season only

Sampling every other year, but including both spring and fall seasons

Sampling every other year, but only including fall season

For each scenario, the non-applicable data were removed from the combined 2013-2018 data set and the reduced data set was used to rerun the CJS and POPAN models detailed in Sections 0-0. With an increasing reduction in data relative to the original dataset (e.g., removing both every other year of data and all spring-collected data), some models were simplified to accommodate the reduced information available.

The analysis resulted in 12 sets of models (three scenarios, two types of models [POPAN and CJS], and two countries. For each set of models, output models were tested for goodness-of-fit and compared using quasi-Akaike information criterion (QAIC). The best model within each of the 12 model sets (i.e., the model with the lowest QAIC) was used to produce estimates of survival, recapture, and abundance estimates. Population abundance estimates were calculated for different year-classes, as well as by occasion. Population estimates (mean and 95% confidence intervals) were then compared to the original CJS- and POPAN-based population estimates, derived from the full 2013-2018 data set for both US and Canada populations.

Spatial Mark-Recapture Analysis

The feasibility of incorporation of spatial distribution into mark-recapture analysis was investigated. Several R packages for analysis of spatial mark-recapture are available, such as secr (Effort 2019), linearsecr (Efford 2017), and openCR (Effort 2019b). The feasibility of modeling the sturgeon mark-recapture data using these types of models was assessed.

DRAFT

RESULTS

Data Cleaning

From a full compiled data set of 13,068 White Sturgeon captures between 2013 and 2018, a total of 9 cases were removed due to erroneous PIT tag numbers, 69 cases were removed due to unknown hatchery / wild designation, and 6 cases were removed due to duplicated effort data. Of the resulting data set of 12,984 cases, a total of 112 cases were within-season recaptures and were removed from analysis, resulting in a data set of 12,872 cases. Of these, no year-class information was available for 407 cases. All 407 cases were removed from analysis. The final data set was divided by country of sampling, resulting in a data set of 8,917 captures of 6,956 unique PIT tags in the US and 3,548 captures of 2,905 unique PIT tags sampled in Canada.

ANNEXE E **Table 1: Details of White Sturgeon captures removed from the data set.**

Number of White Sturgeon captures	Reason for removal
9	Erroneous PIT number (wrong number of digits)
69	Unknown hatchery / wild designation
6	Duplicated effort data (GRTS number within year/season)
407 (287 sampled in the US, 120 sampled in Canada)	Hatchery fish with no known year-class

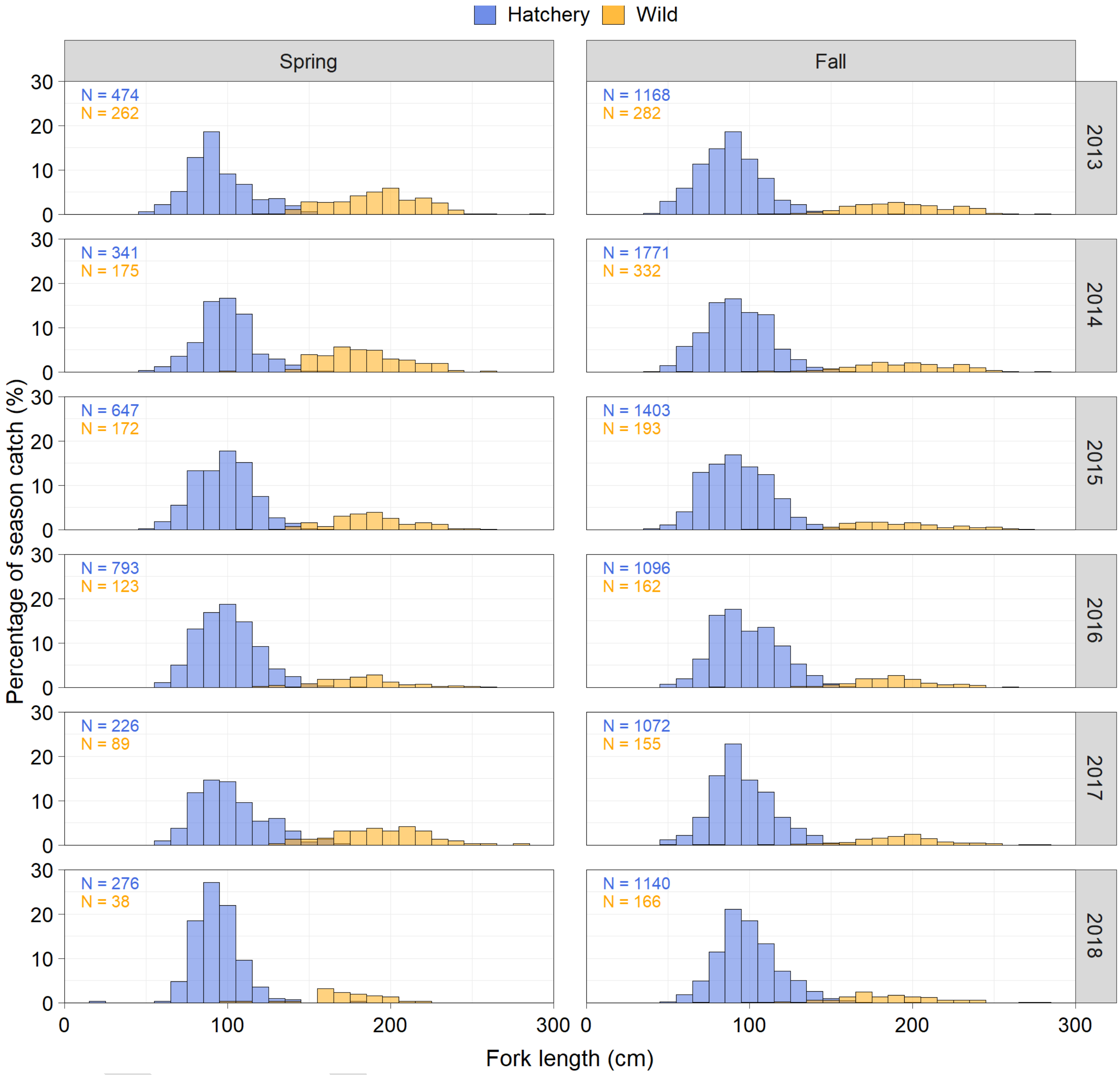
Data Summary

Length, Weight, and Year-class Characteristics

In all sampling years, both hatchery-reared and wild fish were captured in both spring and fall seasons (**Figure 2**). Hatchery-reared fish were more abundant than wild fish within each year/season, with the ratio of hatchery to wild fish captured ranging between 1.8 (spring 2013) and 7.3 (fall 2015 and spring 2018), with a median value of 5.9. Fork lengths of hatchery-reared fish ranged between 26 cm and 208 cm (median of 99 cm), whereas fork lengths of wild fish ranged between 54 cm and 299 cm, with a median value of 193 cm.

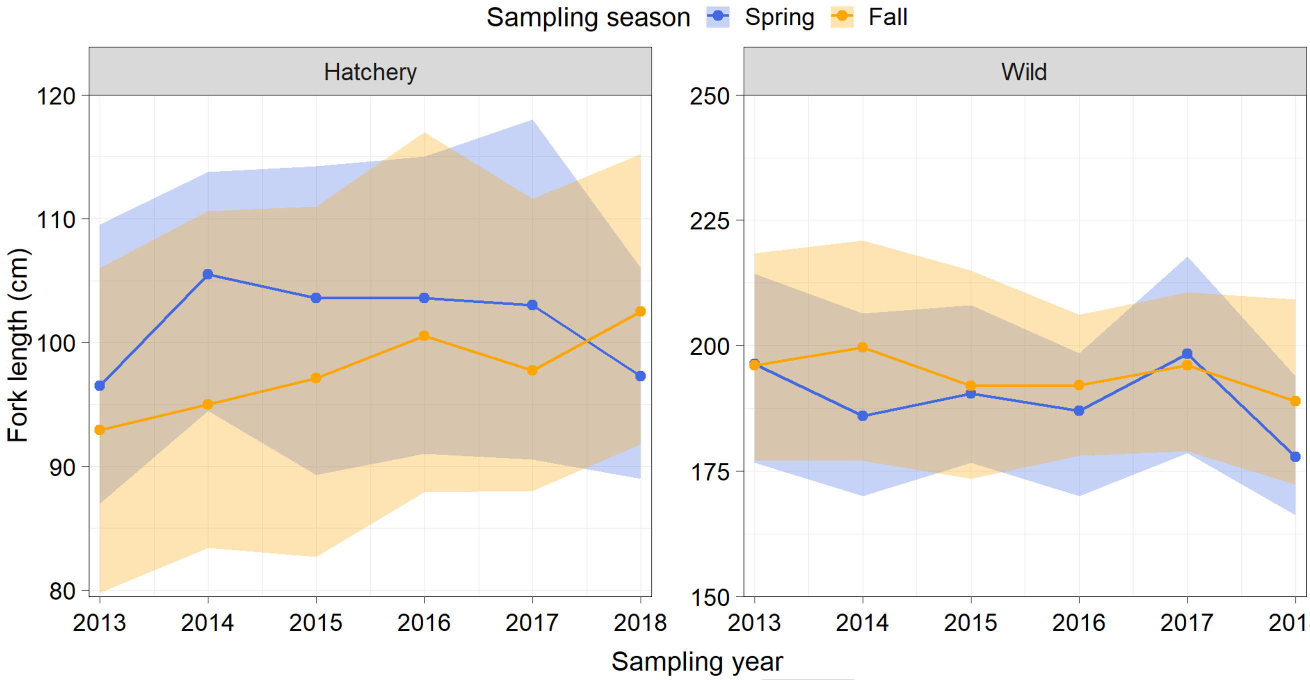
The median value of hatchery-reared fish generally increased between sampling years for fall samples (**Figure 3**), from 93 cm in fall 2013, to 95 cm in fall 2014, and fluctuating between 97 cm and 103 cm between fall 2015 and fall 2018. In spring samples, the trend was not apparent, with median fork lengths increasing from 97 cm in spring 2013 to 103-106 cm between spring 2014 and spring 2017, then decreasing to 97 cm in spring 2018. However, in spring 2018, sampling was only performed in Canada and not in the US portion of the transboundary area, which likely resulted in decreased fork lengths, as detailed below, in the growth analysis. For wild sturgeon, median values of fork length in spring sessions were generally stable across years, ranging between 186 cm and 198 cm; however, in spring 2018, median values decreased to 178, similar to those of hatchery fish, likely due to lack of sampling in the US portion of the transboundary area. For fall sampling, median fork length values were mostly stable, with a slight decrease across years, from 196 cm in fall 2013 with a small decrease from 196-200 cm in fall 2013 and fall 2014 to 192-196 cm in fall 2015-2017. In fall 2018, median fork lengths decreased to 189 cm, despite sampling in both Canada and the US.

DRAFT



ANNEXE F **Figure 2: Length frequency of captured White Sturgeon by sampling event.**

D

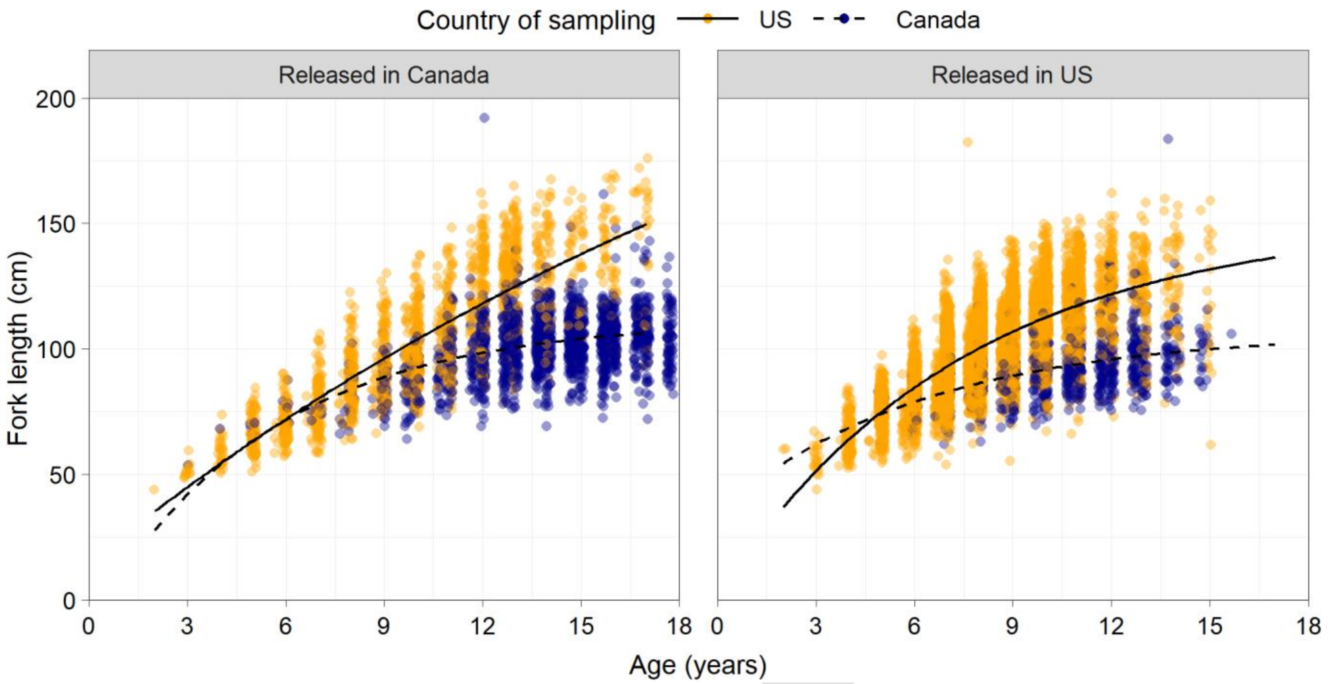


ANNEXE G **Figure 3: Median (lines/points) and 25th and 75th quantile values (ribbons) of fork lengths of hatchery-reared and wild White Sturgeon captured in spring and fall sessions between 2013 and 2018. Data shown are summary statistics of the full length frequency distribution shown in Figure 2.**

DRAFT

In the von Bertalanffy growth analysis, both the model with separate parameters by country of original release or by country of residency were significantly different from the simplest model (a single growth curve for all data (*P*<0.001 for both). This indicates significant differences in growth between hatchery-reared sturgeon originally released in the US and in Canada, as well as between hatchery-reared fish that reside in the US and those that reside in Canada. The most complex model, which accounted for both country of original release and country of residency, was tested against the two models containing only one of these effects. In both cases, the complex model was significantly different from either of the simpler models (*P*<0.001 for both). This suggests that both country of original release and country of residency affected the growth of hatchery-reared White Sturgeon. Of the four groups, fish that were released in the US and moved to Canada had the lowest asymptotic length (L_∞), at 107.8 cm, whereas fish that were originally released in Canada but moved to the US had the highest asymptotic length (**Figure 4**; **Table 2**). While this high asymptotic length is not likely to represent actual asymptotic length of the group (since growth data for older fish is not yet available), it is nevertheless indicative of the larger size attained by this group relative to the other three groups, as well as the lack of growth attenuation at ages 15-18 that was observed for the other groups.

Sigmoid growth curves were fitted to the data, in an attempt to identify the point of inflection, where sturgeon commence feeding on fish (at approximately 10 years of age). Although the models were fitted successfully, the extent of the data was insufficient to identify a biologically relevant point of inflection (data not shown).



ANNEXE H Figure 4: Fork length vs age of hatchery-reared White Sturgeon, with fitted von Bertalanffy curves by country of sampling and country of original release; equation parameters are provided in Table 2.

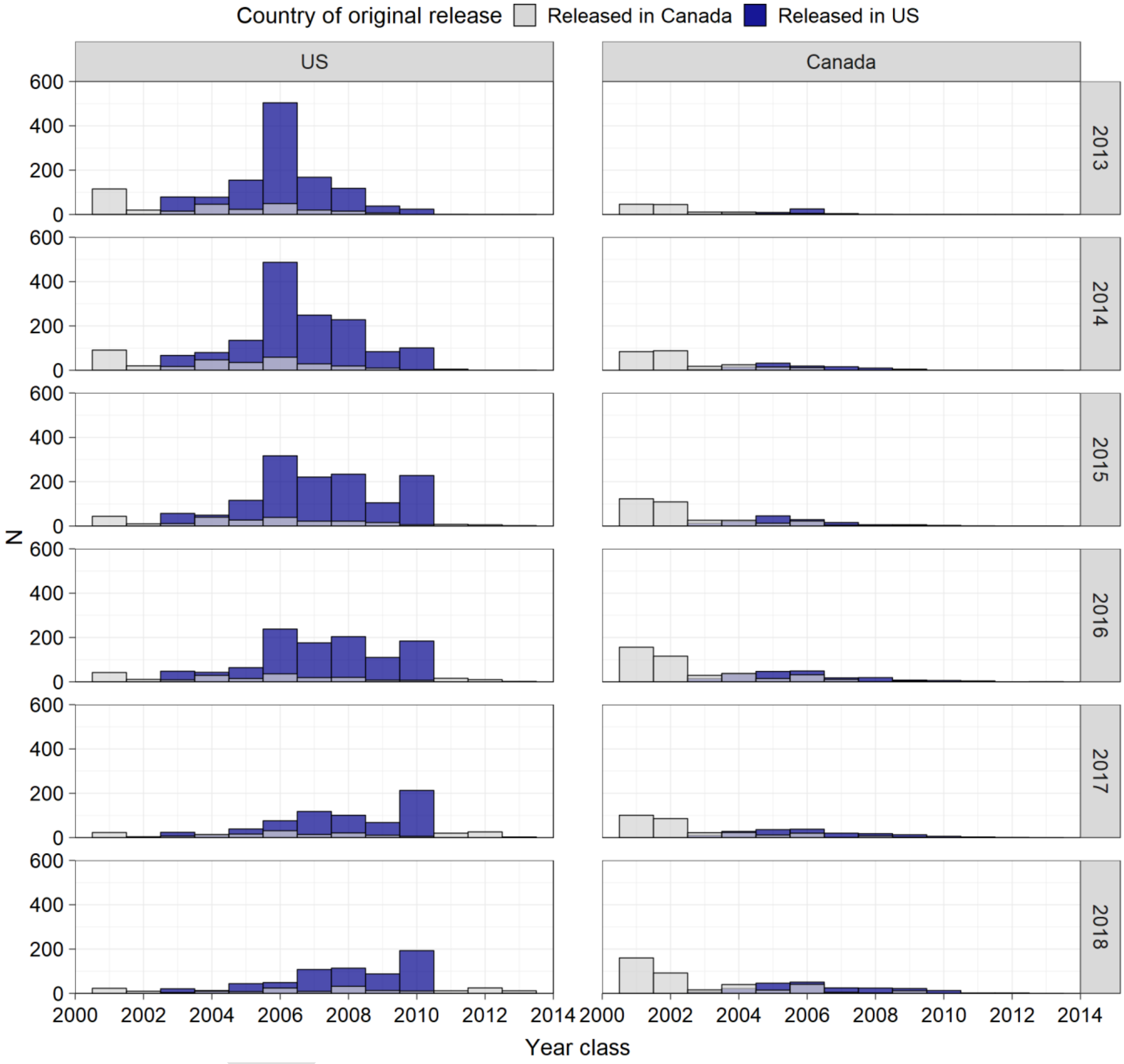
ANNEXE I Table 2: Estimated von Bertalanffy growth curve parameters curves by country of sampling and country of original release; parameters are describing the curves shown in Figure 4.

Release country	Residency country	L_∞	K	t_0
Canada	Canada	111.4	0.195	0.285
Canada	US	271.3	0.045	-1.279
US	Canada	107.8	0.159	-2.654
US	US	148.7	0.148	-0.173

Throughout the 2013-2018 sampling program, hatchery fish originally released in the US dominated the catch in the US, whereas hatchery fish originally released in Canada dominated the catch in the Canadian portion of the transboundary area (**Figure 5**; **Table 3**). The effect of fish culling and the harvest fishery in the US became apparent over time. While in the 2013-2014 sampling the 2006 year-class was the dominant, its relative proportion decreased strongly in 2015, and by 2017, the 2006 year-class was only the fourth largest out of the caught hatchery fish. In the US, the annual proportion of hatchery-released fish that were originally released in Canada ranged from 16% in 2015 to 24% in 2018 (median of 20%). Beginning in 2015, the 2010 year-class became prominent in the US catch, likely because the fish were large enough to be fully recruited to gear.

DRAFT

In Canada, the 2001-2002 year-classes (both originally released in Canada) were the most dominant portions of the catch throughout the 2013-2018 sampling effort. In Canada, the annual proportion of hatchery-released fish that were originally released in the US ranged from 28% in 2013 to 38% in 2017 (median of 32%).



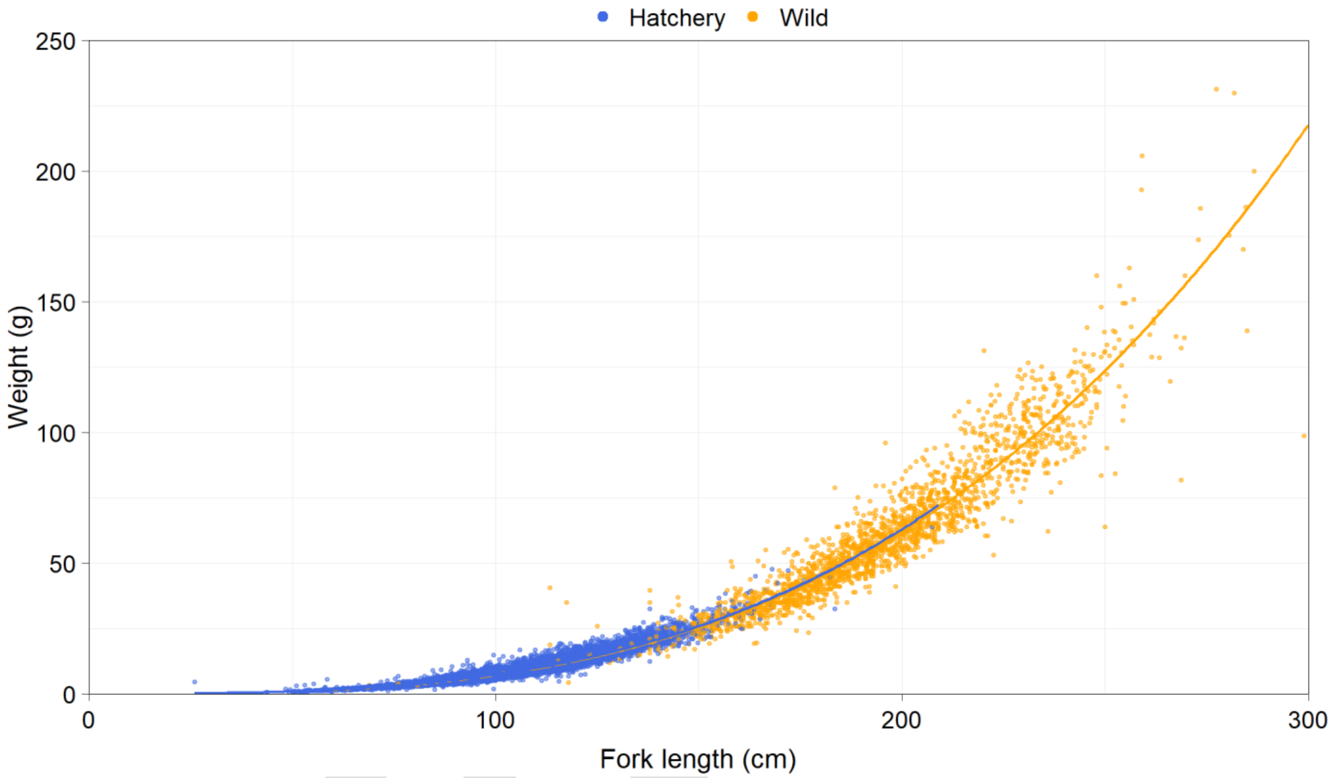
ANNEXE J **Figure 5: Distribution of year-class information of hatchery-reared White Sturgeon, by country of original release and by year and country of sampling.**

DRAFT

ANNEXE K **Table 3: Counts of hatchery-released year-classes captured in the US and Canada by sampling year (values shown in Figure 5). Values include between-session (but not within-session) recaptures.**

Sampling country	Year-class		Sampling year				
		2013	2014	2015	2016	2017	2018
US	2001	100	86	43	42	22	20
US	2002	20	19	10	11	4	10
US	2003	89	80	64	55	30	24
US	2004	117	121	83	72	26	23
US	2005	175	167	136	79	54	51
US	2006	516	518	331	274	103	72
US	2007	185	272	239	195	130	116
US	2008	128	238	246	224	117	142
US	2009	45	94	121	118	79	100
US	2010	24	103	229	191	212	193
US	2011	1	5	8	16	21	12
US	2012	-	-	6	10	25	24
US	2013	-	-	2	2	5	14
Canada	2001	45	82	120	154	100	155
Canada	2002	45	87	106	111	85	89
Canada	2003	13	23	38	43	30	21
Canada	2004	16	40	47	73	49	62
Canada	2005	12	47	59	62	48	61
Canada	2006	30	31	50	78	56	90
Canada	2007	4	16	20	29	20	30
Canada	2008	1	11	8	19	26	26
Canada	2009	-	7	9	11	15	34
Canada	2010	-	-	3	6	6	13
Canada	2011	-	-	1	4	3	2
Canada	2012	-	-	-	-	1	2
Canada	2013	-	-	-	1	-	-

In the weight-length plots of hatchery-reared and wild fish, some overlap existed between the two types of fish. The fork lengths of hatchery-reared fish ranged from 26 cm to 208 cm, whereas the fork lengths of wild fish ranged from 54 cm to 299 cm. The weight-length slope was not significantly different between hatchery and wild fish (P=0.9), whereas the main effect of hatchery/wild was significant (P=0.004), indicating an additive difference between the two stocks of fish. However, the relative difference in weights (i.e., effect size) between hatchery-reared and wild fish was low (1.7% throughout the overlapping fork lengths, with slightly higher weights predicted for hatchery-reared fish than for wild fish).

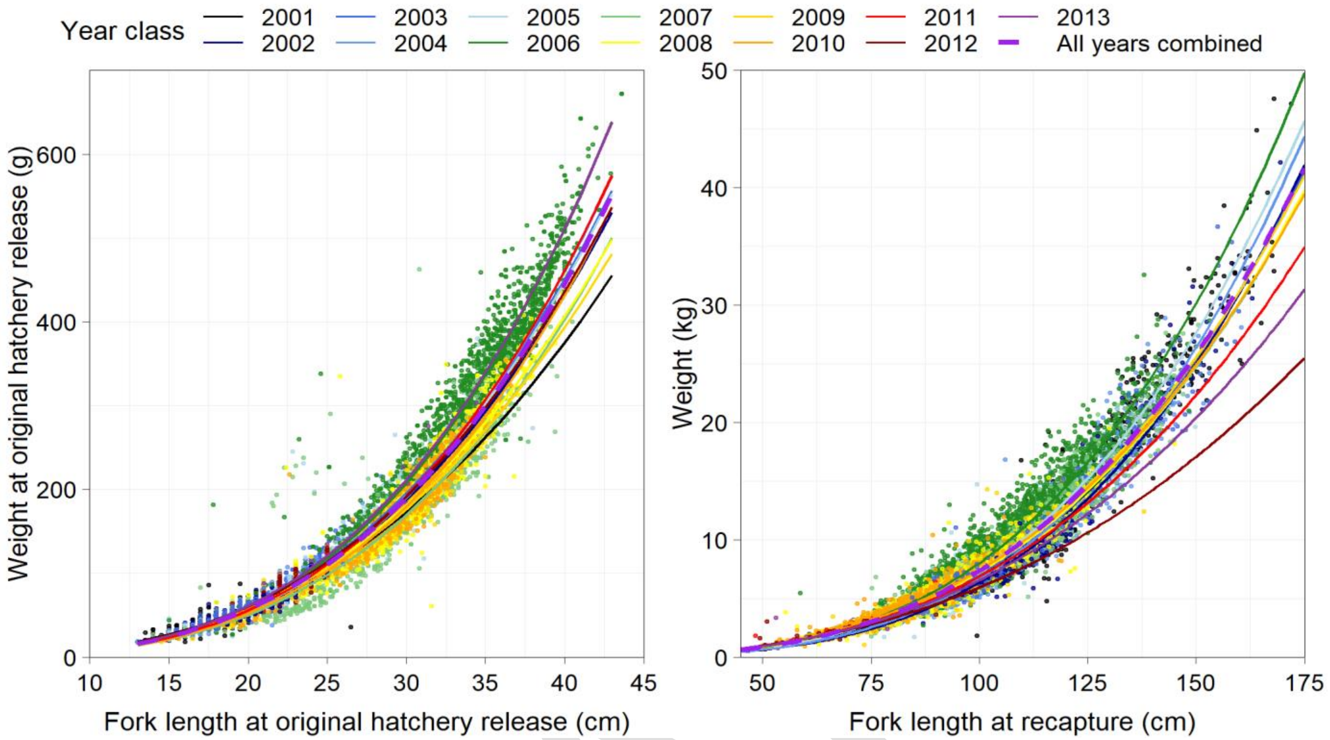


ANNEXE L **Figure 6: Weight-length scatterplots of White Sturgeon captured in the transboundary area throughout 2013-2018 sampling.**

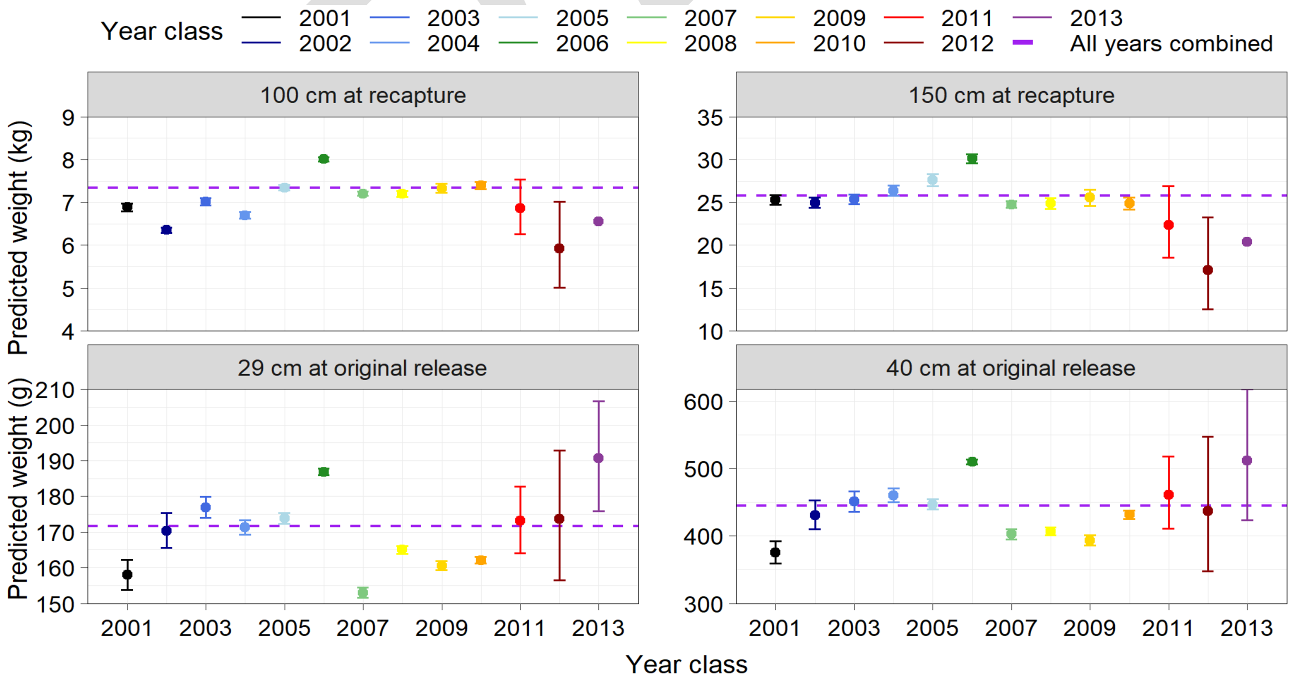
DRAFT

The weight-length regressions for hatchery fish by year-class indicated that at original release, year-classes 2006 and 2013 had considerably greater weight at length than the other year-classes, followed by 2003, 2011, and 2005 year-classes (**Figure 7**; **Figure 8**). Note that the two fork length values selected for visualization in **Figure 8** represent approximately the median and the 99th quantile of original release lengths and recapture lengths.
At original release, year-classes 2001 and 2007-2009 had considerably lower weight at length than the remaining year-classes (or all data combined; **Figure 7** and **Figure 8**). However, note that length distributions between released year-classes did not fully overlap, which makes comparisons between some year-classes less robust.

At recapture, year-class 2006 remained the year-class with the greatest weight at length. Several year-classes that had low weight at length at release (e.g., 2001, 2007-2009) did not have low weight at length at recapture, with weight at length values similar to those of the overall population. On the other hand, year-classes 2012 and 2013 did not exhibit strong growth, and while weight at length values at release were similar or higher than the population average, the recapture weight-at-length predictions were lower than population average. That said, recapture data for these year-classes are limited, and predictions are likely to change as more fish are sampled.



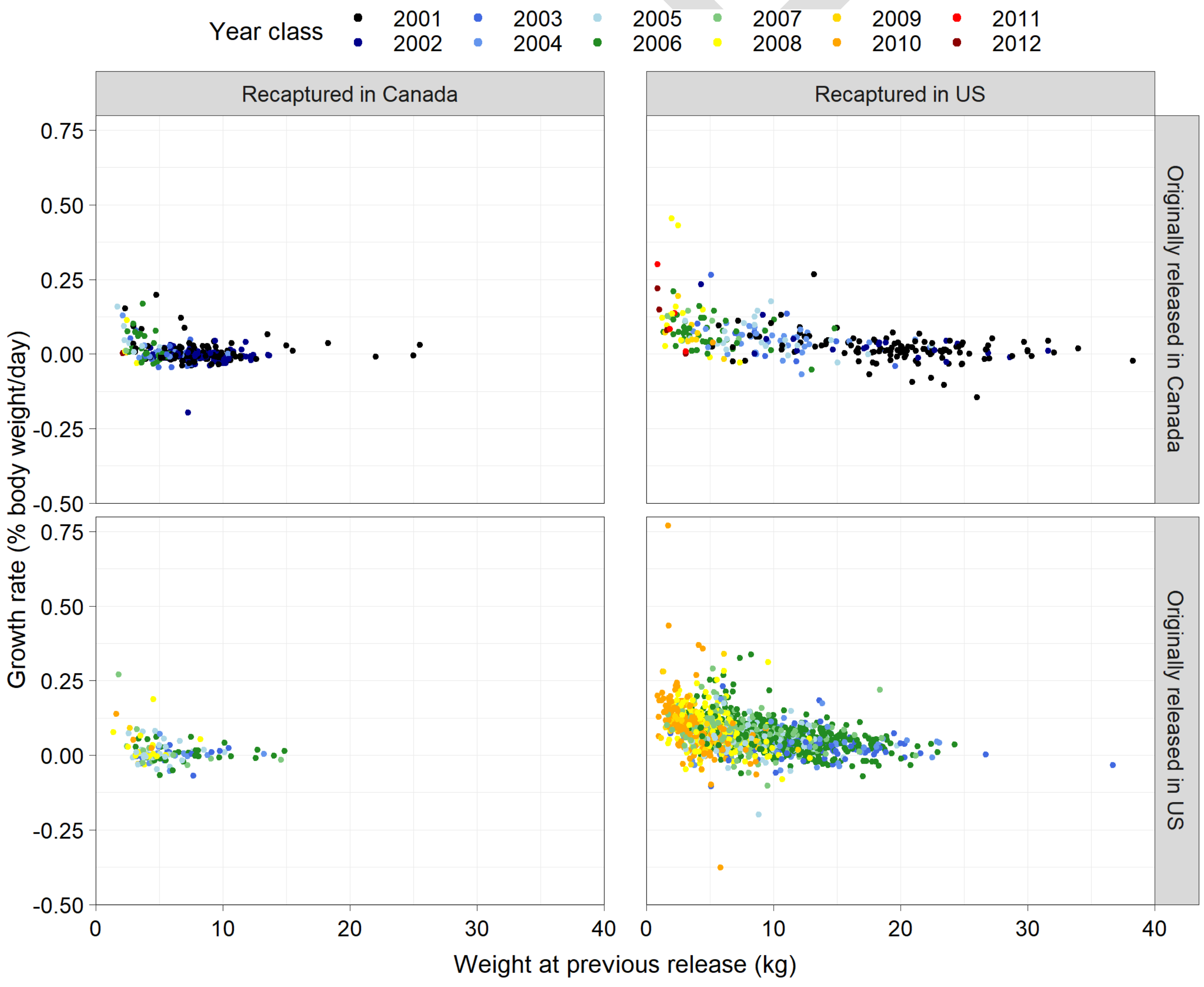
ANNEXE M **Figure 7: Weight-length scatterplot and regression curves of original release and subsequent recapture weight and length values of hatchery-reared White Sturgeon between 2013 and 2018.**



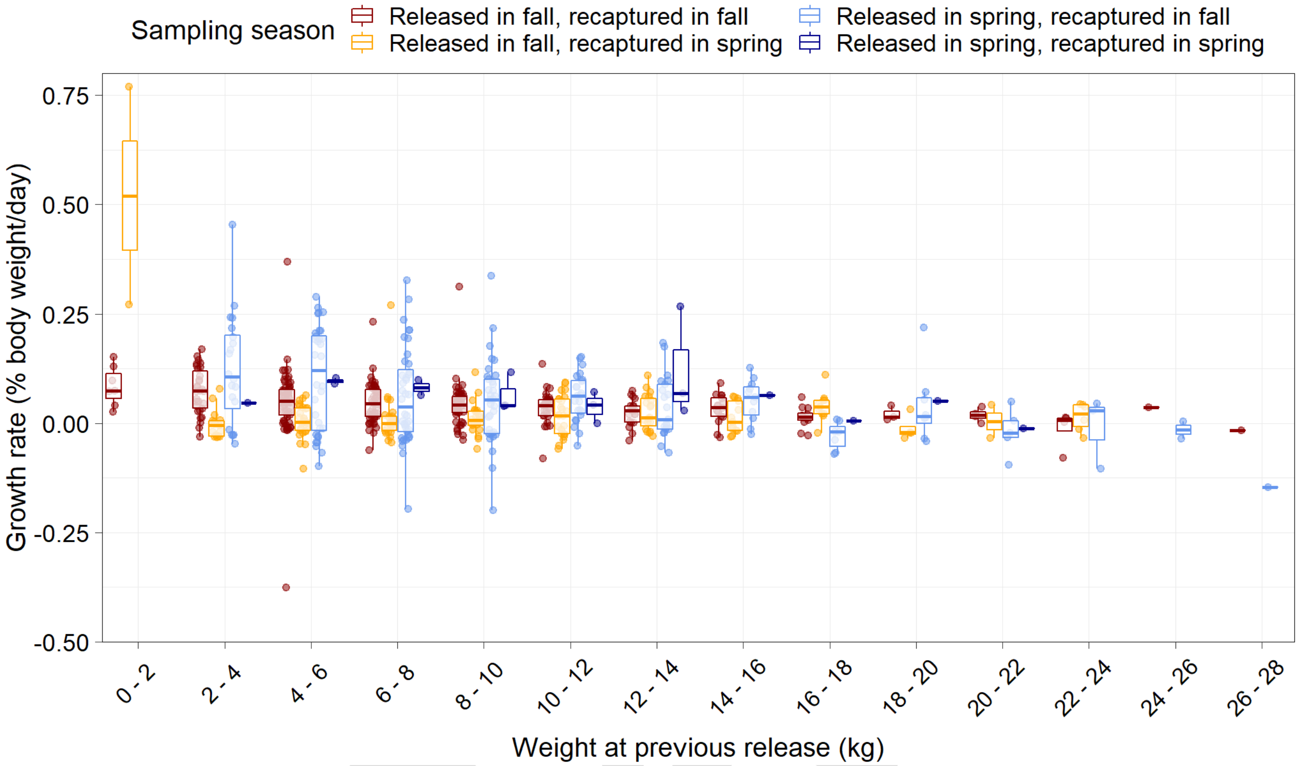
ANNEXE N **Figure 8: Predicted weights at two original release and two subsequent recapture fork lengths (values from models in Figure 7). Error bars are 95% CIs (not shown for year-class 2013 in top panels due to excessive uncertainty).**

As expected, growth rate (as percent body weight / day) declined with body weight at previous release (**Figure 9**), as larger fish grow at a slower rate. Fish that were originally released in Canada and remained in Canada generally had lower body weight at previous capture than fish that moved to the US. For example, year-class 2001 fish recaptured in Canada had body weights at previous capture ranging between 2.3 kg and 25.5 kg (median of 7.4 kg), whereas fish recaptured in the US had body weights at previous capture ranging between 5.2 kg and 38.3 kg (median of 20.0 kg). This pattern was observed for multiple year-classes (2001-2007 and 2009) and reflects the differences in growth between the two countries, as shown in **Figure 4**.

Growth generally differed by season (**Figure 10**), as expected, since fish are more likely to accumulate weight faster during the summer period. Fish that were captured in the fall and recaptured in the spring of the following year generally had the lowest growth, except for two recaptures of small fish (≤2 kg) with a high growth rate. In comparison, fish that were released in the spring and recaptured in the fall of the same year had the largest, albeit also highly variable, growth rates.



ANNEXE O **Figure 9: Growth (as percent body weight per day) of hatchery-reared White Sturgeon captured in the study area between 2013 and 2018.**



ANNEXE P **Figure 10: Growth (as percent body weight per day) of hatchery-reared White Sturgeon captured in the study area within one year from previous capture, between 2013 and 2018. Four points of fish with weights of 30.0-36.7 kg were removed for readability.**

DRAFT

Mark-Recapture Data

The number of sturgeon captured in each sampling year in the transboundary area fluctuated between years and seasons (**Table 4**). For both wild and hatchery-reared fish, fewer fish were captured in spring samples than in fall samples. Similarly, there were fewer recaptures in spring samples than fall samples. The sampling in fall 2014 resulted in the highest number of captured sturgeon, both hatchery-reared and wild. The lowest number of captured hatchery-reared was recorded in spring 2017, whereas the lowest number of captured wild sturgeon was recorded in spring 2018 (due to the lack of sampling in the US during that sampling season).

In the Canadian portion of the transboundary area, there were seasonal fluctuations in numbers of captured fish (**Table 5**); however, the pattern was not as strong as for the combined data set (**Table 4**) and was not apparent in all years (e.g., spring 2016). The greatest number of hatchery-reared sturgeon was captured in spring 2016, whereas the greatest number of wild sturgeon was recorded in fall 2013. The lowest numbers of hatchery-reared and wild sturgeon were captured in spring 2013 and spring 2017, respectively.

In the US portion of the transboundary area, seasonal fluctuations in the number of captured fish were very pronounced (**Table 6**) and apparent throughout the 2013-2018 sampling period. The greatest number of captured fish, both hatchery-reared and wild, was recorded in fall 2014. The lowest numbers of hatchery-reared and wild sturgeon were captured in spring 2017 and spring 2016, respectively.

DRAFT

ANNEXE Q **Table 4: Number of White Sturgeon marked and recaptured in each sampling event in the transboundary area.**

Hatchery/ Wild	Sampling event	Number captured		Number recaptured											
		Total	New[1]	2013		2014		2015		2016		2017		2018	
				Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Hatchery	2013 spring	483	483	0	58	12	83	25	50	31	39	7	18	0	20
	2013 fall	1199	1140	0	0	19	129	46	79	60	57	13	61	5	57
	2014 spring	353	321	0	0	0	36	11	27	20	30	4	10	1	15
	2014 fall	1793	1539	0	0	0	0	65	119	54	92	21	64	8	86
	2015 spring	662	511	0	0	0	0	0	44	20	32	15	31	9	27
	2015 fall	1424	1099	0	0	0	0	0	0	41	62	7	59	11	62
	2016 spring	818	587	0	0	0	0	0	0	0	9	2	14	22	6
	2016 fall	1135	804	0	0	0	0	0	0	0	0	3	4	7	8
	2017 spring	235	162	0	0	0	0	0	0	0	0	0	12	7	6
	2017 fall	1130	848	0	0	0	0	0	0	0	0	0	0	7	55
	2018 spring	287	207	0	0	0	0	0	0	0	0	0	0	0	7
	2018 fall	1223	861	0	0	0	0	0	0	0	0	0	0	0	0
Wild	2013 spring	264	264	0	19	15	40	19	21	11	14	7	13	3	16
	2013 fall	278	259	0	0	12	20	10	14	6	14	10	6	3	15
	2014 spring	175	148	0	0	0	16	10	9	10	4	5	8	4	10
	2014 fall	327	251	0	0	0	0	13	9	8	6	6	10	2	12
	2015 spring	172	120	0	0	0	0	0	3	6	12	4	7	4	7
	2015 fall	189	133	0	0	0	0	0	0	6	7	5	10	3	7
	2016 spring	123	76	0	0	0	0	0	0	0	5	1	4	1	1
	2016 fall	161	99	0	0	0	0	0	0	0	0	3	8	2	7
	2017 spring	87	46	0	0	0	0	0	0	0	0	0	1	0	7
	2017 fall	152	85	0	0	0	0	0	0	0	0	0	0	0	5
	2018 spring	38	16	0	0	0	0	0	0	0	0	0	0	0	0
	2018 fall	165	78	0	0	0	0	0	0	0	0	0	0	0	0

Table excludes fish that were omitted from analysis

[1] = fish that were not recorded in previous sessions of the mark-recapture program (but may have tags from marking unrelated to the ongoing program).

DRAFT

ANNEXE R Table 5: Number of White Sturgeon marked and recaptured in each sampling event, Canada only.

Hatchery/ Wild	Sampling event	Number captured		Number recaptured											
		Total	New[1]	2013		2014		2015		2016		2017		2018	
				Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Hatchery	2013 spring	31	31	0	1	1	1	1	2	5	1	2	2	0	2
	2013 fall	148	147	0	0	1	4	10	7	8	9	4	14	5	13
	2014 spring	99	97	0	0	0	3	3	2	5	7	4	4	1	5
	2014 fall	264	255	0	0	0	0	8	10	10	9	5	9	8	22
	2015 spring	209	186	0	0	0	0	0	7	8	6	12	9	9	8
	2015 fall	280	250	0	0	0	0	0	0	15	8	5	14	11	11
	2016 spring	352	299	0	0	0	0	0	0	0	8	2	13	22	5
	2016 fall	279	228	0	0	0	0	0	0	0	0	3	4	7	8
	2017 spring	140	102	0	0	0	0	0	0	0	0	0	5	7	3
	2017 fall	330	255	0	0	0	0	0	0	0	0	0	0	7	7
	2018 spring	287	207	0	0	0	0	0	0	0	0	0	0	0	7
	2018 fall	334	239	0	0	0	0	0	0	0	0	0	0	0	0
Wild	2013 spring	85	85	0	5	10	5	9	6	7	6	4	4	3	6
	2013 fall	98	93	0	0	9	4	7	5	4	9	2	0	3	8
	2014 spring	94	75	0	0	0	5	7	3	9	3	3	2	4	8
	2014 fall	93	79	0	0	0	0	7	4	2	3	1	5	2	6
	2015 spring	86	56	0	0	0	0	0	1	3	7	1	4	4	6
	2015 fall	77	58	0	0	0	0	0	0	2	4	3	2	3	4
	2016 spring	73	46	0	0	0	0	0	0	0	4	1	3	1	1
	2016 fall	89	53	0	0	0	0	0	0	0	0	1	3	2	5
	2017 spring	35	19	0	0	0	0	0	0	0	0	0	0	0	3
	2017 fall	61	38	0	0	0	0	0	0	0	0	0	0	0	3
	2018 spring	38	16	0	0	0	0	0	0	0	0	0	0	0	0
	2018 fall	86	36	0	0	0	0	0	0	0	0	0	0	0	0

Table excludes fish that were omitted from analysis

[1] = fish that were not recorded in previous sessions of the mark-recapture program (but may have tags from marking unrelated to the ongoing program).

DRAFT

ANNEXE S **Table 6: Number of White Sturgeon marked and recaptured in each sampling event, US only.**

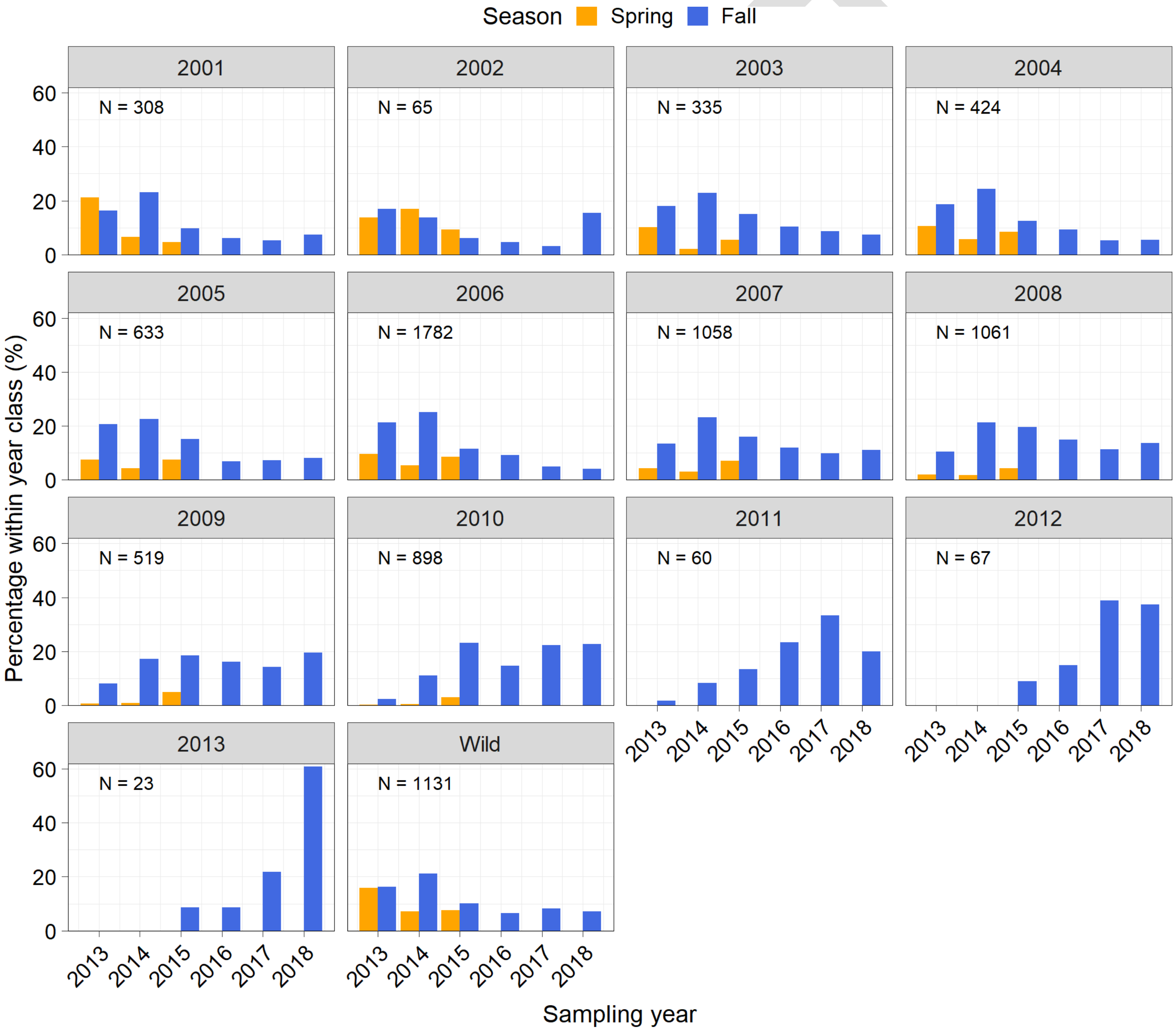
Hatchery/ Wild	Sampling event	Number captured		Number recaptured											
				2013		2014		2015		2016		2017		2018	
		Total	New[1]	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Hatchery	2013 spring	452	452	0	57	11	82	24	48	26	38	5	16	No sampling	18
	2013 fall	1051	993	0	0	18	125	36	72	52	48	9	47		44
	2014 spring	254	224	0	0	0	33	8	25	15	23	0	6		10
	2014 fall	1529	1284	0	0	0	0	57	109	44	83	16	55		64
	2015 spring	453	325	0	0	0	0	0	37	12	26	3	22		19
	2015 fall	1144	849	0	0	0	0	0	0	26	54	2	45		51
	2016 spring	466	288	0	0	0	0	0	0	0	1	0	1		1
	2016 fall	856	576	0	0	0	0	0	0	0	0	0	0		0
	2017 spring	95	60	0	0	0	0	0	0	0	0	0	7		3
	2017 fall	800	593	0	0	0	0	0	0	0	0	0	0		48
	2018 spring	No sampling													
	2018 fall	889	622	0	0	0	0	0	0	0	0	0	0		0
Wild	2013 spring	179	179	0	14	5	35	10	15	4	8	3	9		10
	2013 fall	180	166	0	0	3	16	3	9	2	5	8	6		7
	2014 spring	81	73	0	0	0	11	3	6	1	1	2	6		2
	2014 fall	234	172	0	0	0	0	6	5	6	3	5	5		6
	2015 spring	86	64	0	0	0	0	0	2	3	5	3	3		1
	2015 fall	112	75	0	0	0	0	0	0	4	3	2	8		3
	2016 spring	50	30	0	0	0	0	0	0	0	1	0	1		0
	2016 fall	72	46	0	0	0	0	0	0	0	0	2	5		2
	2017 spring	52	27	0	0	0	0	0	0	0	0	0	1		4
	2017 fall	91	47	0	0	0	0	0	0	0	0	0	0		2
	2018 spring	No sampling													0
	2018 fall	79	42	0	0	0	0	0	0	0	0	0	0		0

Table excludes fish that were omitted from analysis

[1] = fish that were not recorded in previous sessions of the mark-recapture program (but may have tags from marking unrelated to the ongoing program).

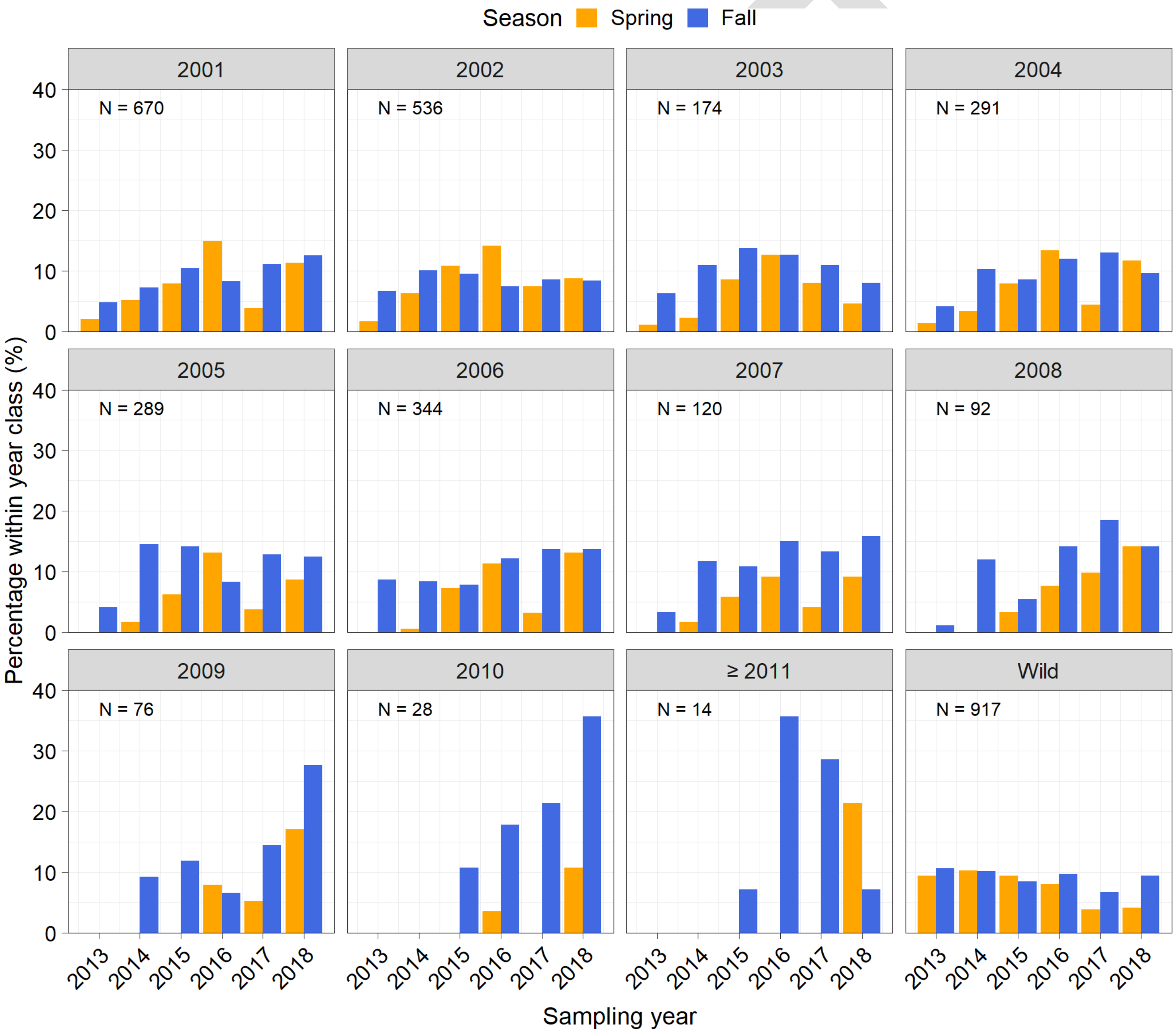
DRAFT

In the US, the temporal distribution of sturgeon between sampling events differed by year-class (**Figure 11**). Older year-classes (2001-2006) were generally captured more often in earlier years (2013-2016), with a marked decrease in relative captures in 2017 and 2018. One exception was year-class 2002; the percent catch of these fish was higher in 2018 than throughout 2014-2017. Intermediate year-classes (2007-2008) had an increase in percent catch between 2013 and 2014, followed by a slight decrease and stable captures throughout 2016-2018. Year-classes 2009-2010 increased in percent catch between 2013 and 2015 and remained stable throughout 2016-2018. These year-classes are likely fully recruited to gear as of 2018 sampling. In comparison, the youngest year-classes (2011-2013) are likely not fully recruited to gear, with low total capture numbers and increased percent catch in later years. Wild fish were observed most often in 2013 and 2014, with reduced, but stable, percent catch values between 2015 and 2018.



ANNEXE T **Figure 11: Distribution of sturgeon captures in the US as percent catch within each year-class (each panel sums to 100% across years and seasons).**

In Canada, the temporal distribution of sturgeon between sampling events also differed by year-class (**Figure 12**). As opposed to the trend seen in the US (**Figure 11**), most year-classes (except for 2006 year-class and wild fish) were generally captured less often in the beginning of the study (2013) than in later years. While older and intermediate year-classes (2001-2007) generally had a relatively stable percent catch values throughout 2016-2018, the younger year-classes (2009 and on) showed a clear increase in percent catch in the later years of sampling. While this is similar to the increase in percent catch seen in young year-classes in the US, the year-classes that display this pattern differ – in the US, increases in relative capture numbers throughout 2015-2018 were not clearly observed in either 2009 or 2010 year-classes. Wild fish were observed most often in 2013 and 2014, with reduced, but stable, percent catch values between 2015 and 2018 during the fall season, and reduced but stable percent catch values in 2017 and 2018 spring sampling.



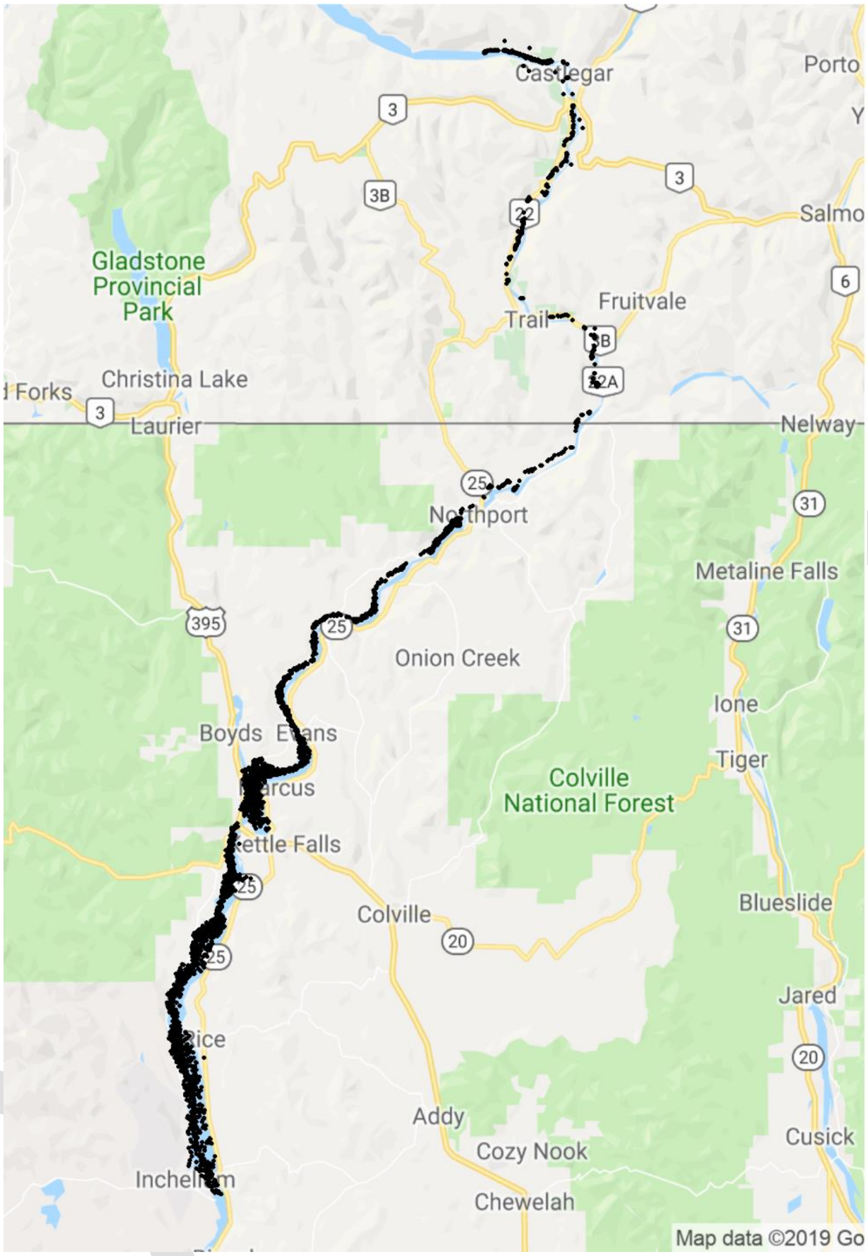
ANNEXE U Figure 12: Distribution of sturgeon captures in the Canadian portion of the transboundary area as percent catch within each year-class (each panel sums to 100% across years and seasons). Year-classes 2011-2013 were combined for ease of presentation due to low recapture rates.

Spatial Distribution

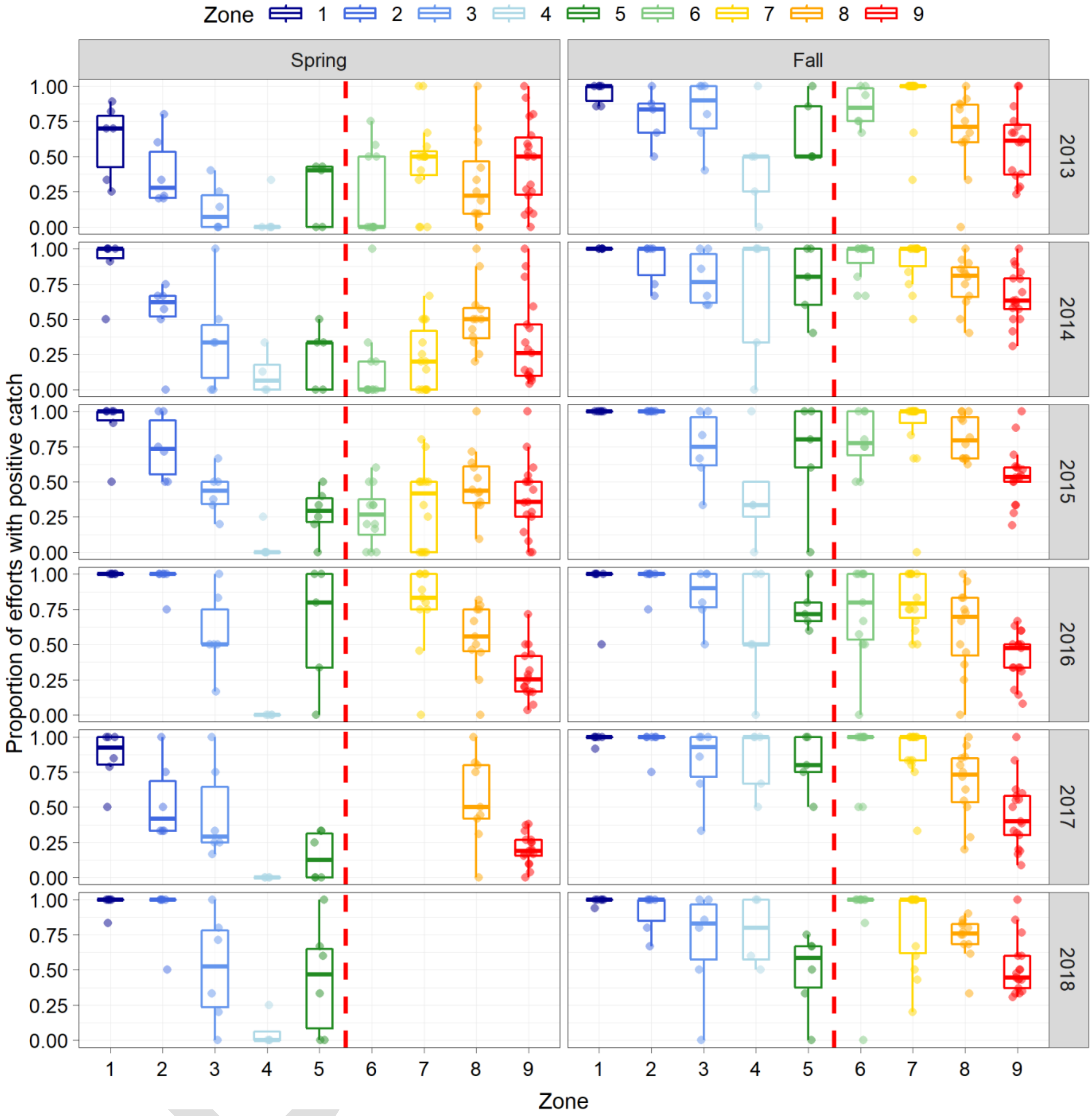
The 2013-2018 sampling performed in the transboundary reach extended from the Hugh L. Keenleyside Dam in Canada to Lake Roosevelt in the US (**Figure 13**). The proportion of efforts with positive catch (i.e., that had non-zero catches) differed by zone, year and season (**Figure 14**). Habitat zone 1 generally had very high proportions of positive catch, with the exception of spring 2013, when lower values were recorded. In the spring, the proportion positive catch decreased in the downstream direction, with values progressively lower throughout habitat zones 2 and 3, and very low springtime positive catch in habitat zone 4. In the US, proportion positive catch did not exhibit spatial patterns in spring 2013-2015; however, in spring 2016, spring 2017, and throughout the 2013-2018 fall sampling, proportion positive catch was overall higher in habitat zone 6, intermediate in habitat zone 7, and lowest in habitat zone 8.

The CPUE of sampling efforts with positive catch varied spatially (**Figure 15**). In the US, median CPUE values of efforts with positive catch were higher in habitat zones 7 and 8 when compared to habitat zone 9 (**Figure 15**). In Canada, median CPUE values were higher in habitat zone 1 compared to habitat zones 2-5 (**Figure 15**). However, median CPUE values within habitat zones differed by year and season (**Figure 16**). While median CPUE values in habitat zone 1 were generally high (except for spring 2013), CPUE in habitat zone 2 was low in some sampling seasons (e.g., spring 2013 and 2014) but high in others (e.g., spring 2016 and fall 2018). Habitat zone 3 generally had lower median CPUE values in the fall, with similar values between the six years of sampling. Median CPUE values in efforts with positive catch in habitat zones 3 and 5 were generally similar between the two zones and low-to-intermediate when compared to other zones within Canada.

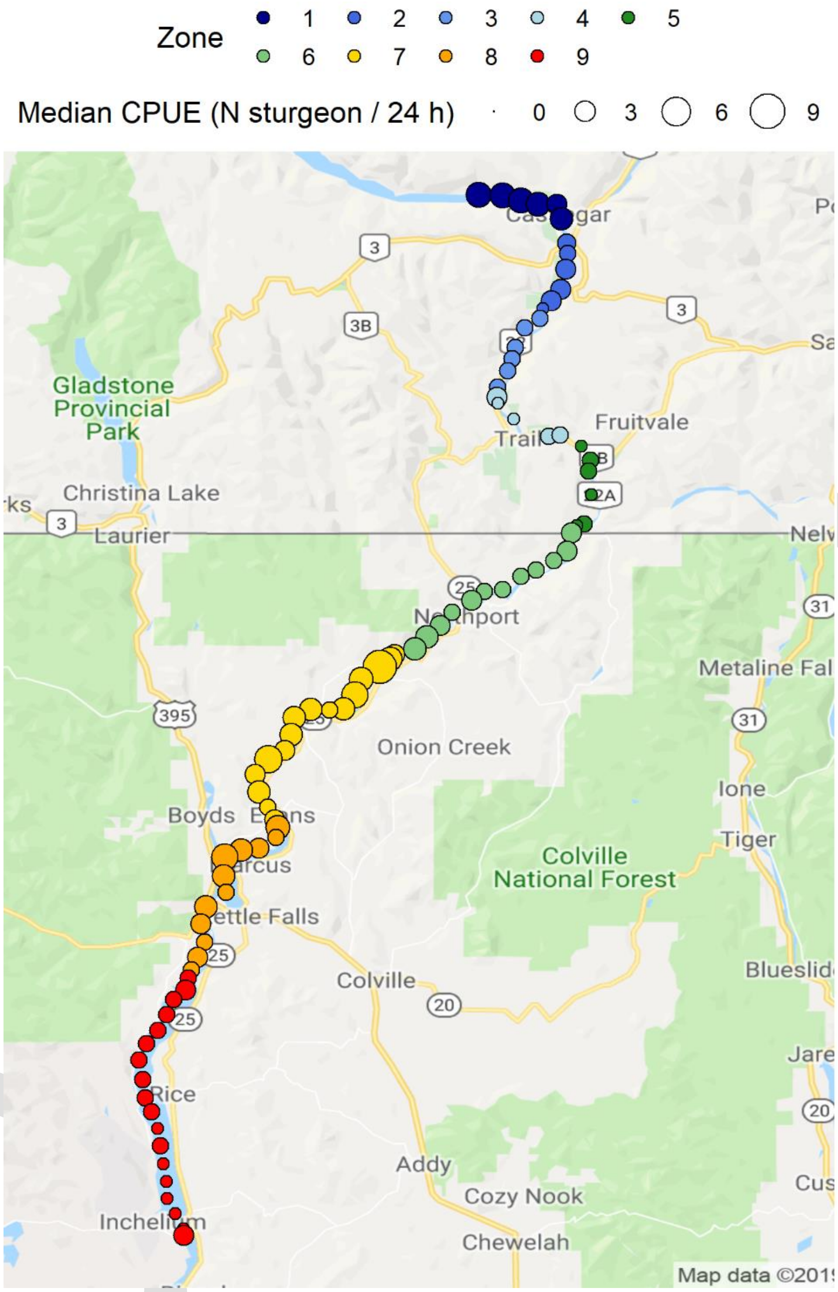
DRAFT



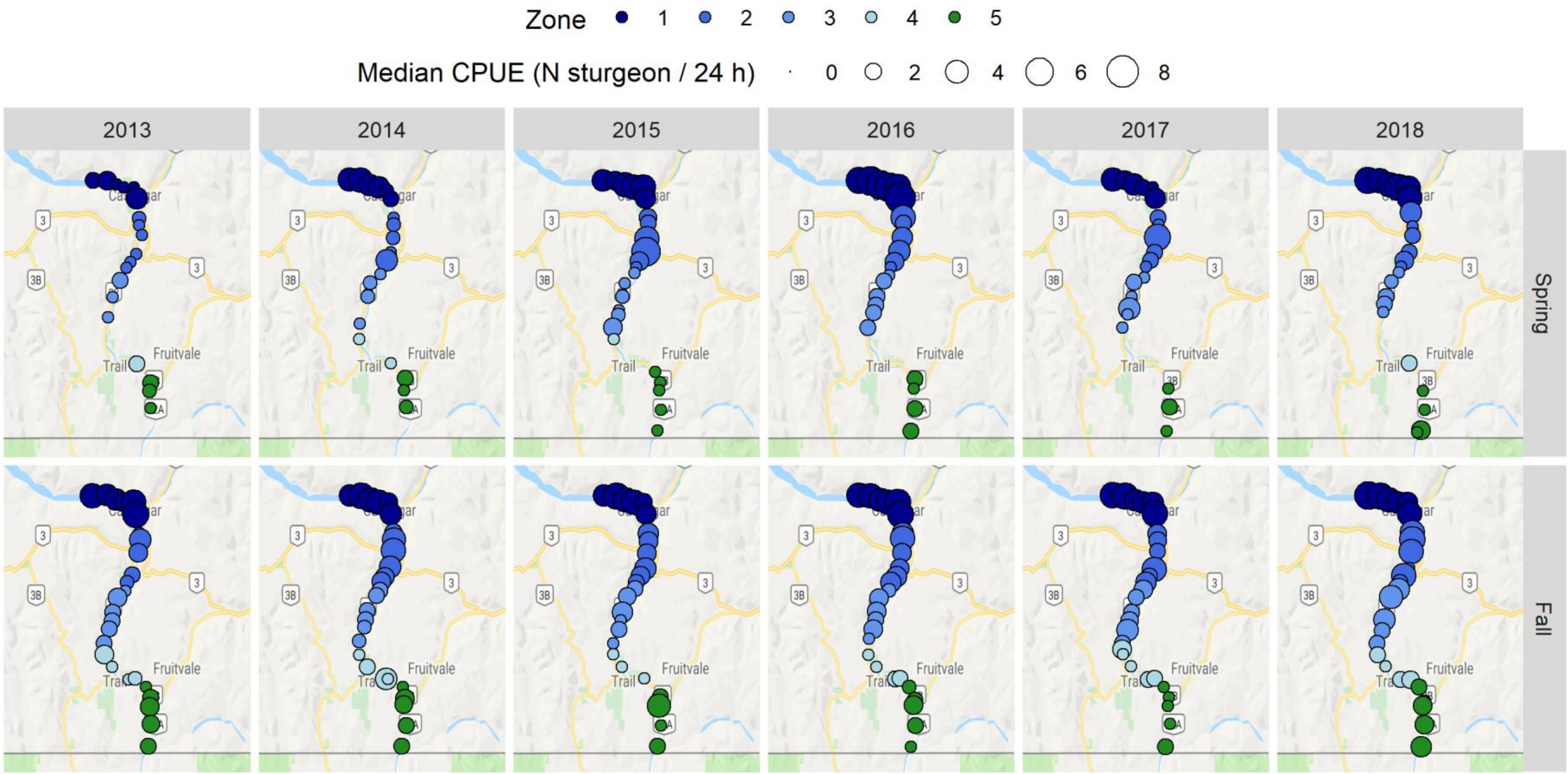
ANNEXE V **Figure 13: Spatial distribution of sampling efforts during the 2013-2018 study.**



ANNEXE W **Figure 14: Boxplot of proportion of positive catch by habitat zone, sampling year, and season. The dashed vertical line represents the US-Canada border.**



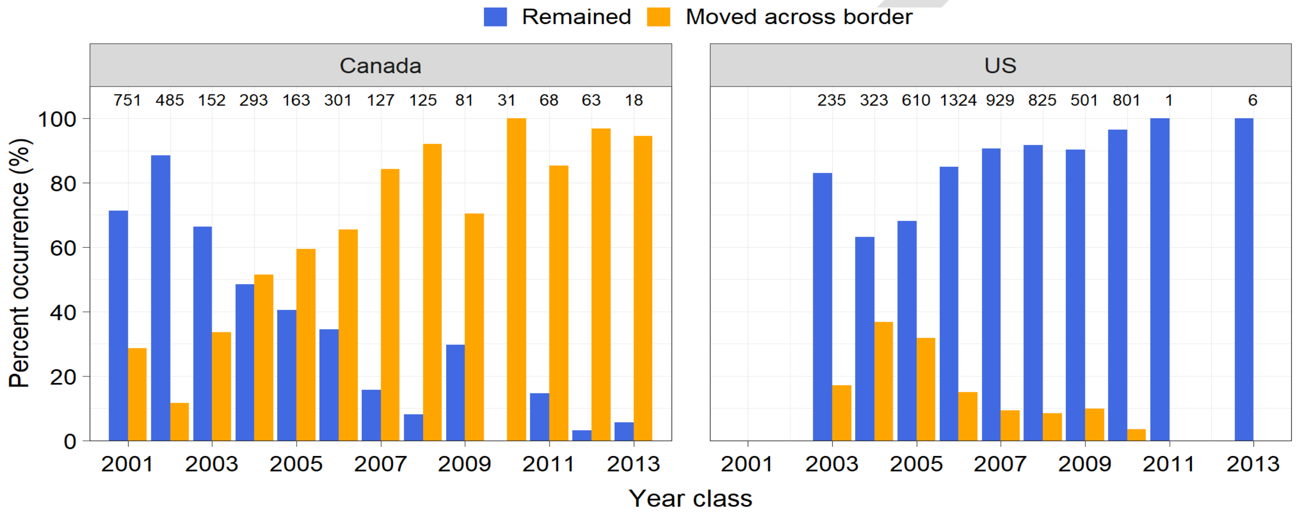
ANNEXE X Figure 15: Spatial distribution of White Sturgeon CPUE in efforts with positive fish catches throughout the transboundary area between 2013 and 2018; point size corresponds to number of median value of CPUE at the sampling point (RKM values rounded to 2 km resolution). Note that this figure does not include efforts with zero captured fish.



ANNEXE Y Figure 16: Spatial distribution of White Sturgeon CPUE in efforts with positive fish catch in the Canadian portion of the transboundary area between 2013 and 2018; point size corresponds to number of median value of CPUE at the sampling point (RKM values rounded to 2 km resolution). Note that this figure does not include efforts with zero captured fish.

Movement Patterns

The movement patterns of hatchery-reared fish that were captured during the 2013-2018 sampling period differed by year-class and country of original release (**Figure 17**; **Table 7**). Hatchery-reared fish that were originally released in Canada had low rates of movement from Canada into the US for the older year-classes (2001-2003), however the rate of movement increased with year-class, with movement rates >70% for 2007-2013 year-classes. In comparison, hatchery fish that were released in the US had higher rates of movement into Canada for the first few year-classes (2003-2006), with movement rates declining to approximately 10% or lower for year-classes 2007-2013.



ANNEXE Z Figure 17: Across-border movement rates (%) between original release and first recapture of hatchery-reared White Sturgeon. Number of captured fish by year-class and country of original release is provided.

DRAFT

ANNEXE AA Table 7: Percentage of hatchery-reared White Sturgeon that remained within country of release or moved across the border after original release. Number of captured fish is provided; the data are shown in Figure 17.

Year-class	Canada			US		
	Number of fish	Moved (%)	Remained (%)	Number of fish	Moved (%)	Remained (%)
2001	751	29	71	---	---	---
2002	485	12	88	---	---	---
2003	152	34	66	235	17	83
2004	293	52	48	323	37	63
2005	163	60	40	610	32	68
2006	301	65	35	1324	15	85
2007	127	84	16	929	9	91
2008	125	92	8	825	8	92
2009	81	70	30	501	10	90
2010	31	100	---	801	3	97
2011	68	85	15	---	---	100
2012	63	97	3	---	---	---

2013	18	94	6	---	---	100

Movement of hatchery-reared fish was also summarized in terms of the habitat zone of the original release and the habitat zone of the first capture during the 2013-2018 sampling program (**Figure 18**). Movement patterns differed between release zones. Fish originally released in habitat zone 1 (most upstream habitat zone in the Canadian portion of the transboundary area) were most often (39%) recaptured in the same zone; however, 48% of those released in zone 1 moved downstream to the US prior to their first recapture, with capture rates up to 12-15% in habitat zones 7, 8, and 9. Of hatchery-reared fish released in habitat zone 3, the majority (45%) were recaptured for the first time in habitat zone 7, indicating high extent of movement across the border. Overall, first recaptures of hatchery-reared fish in Canada were recorded mostly in habitat zone 1, with fewer recaptures in habitat zone 2, and very few recaptures in habitat zones 3-5. This is consistent with the distribution of CPUE values in the Canadian habitat zones (**Figure 15**).

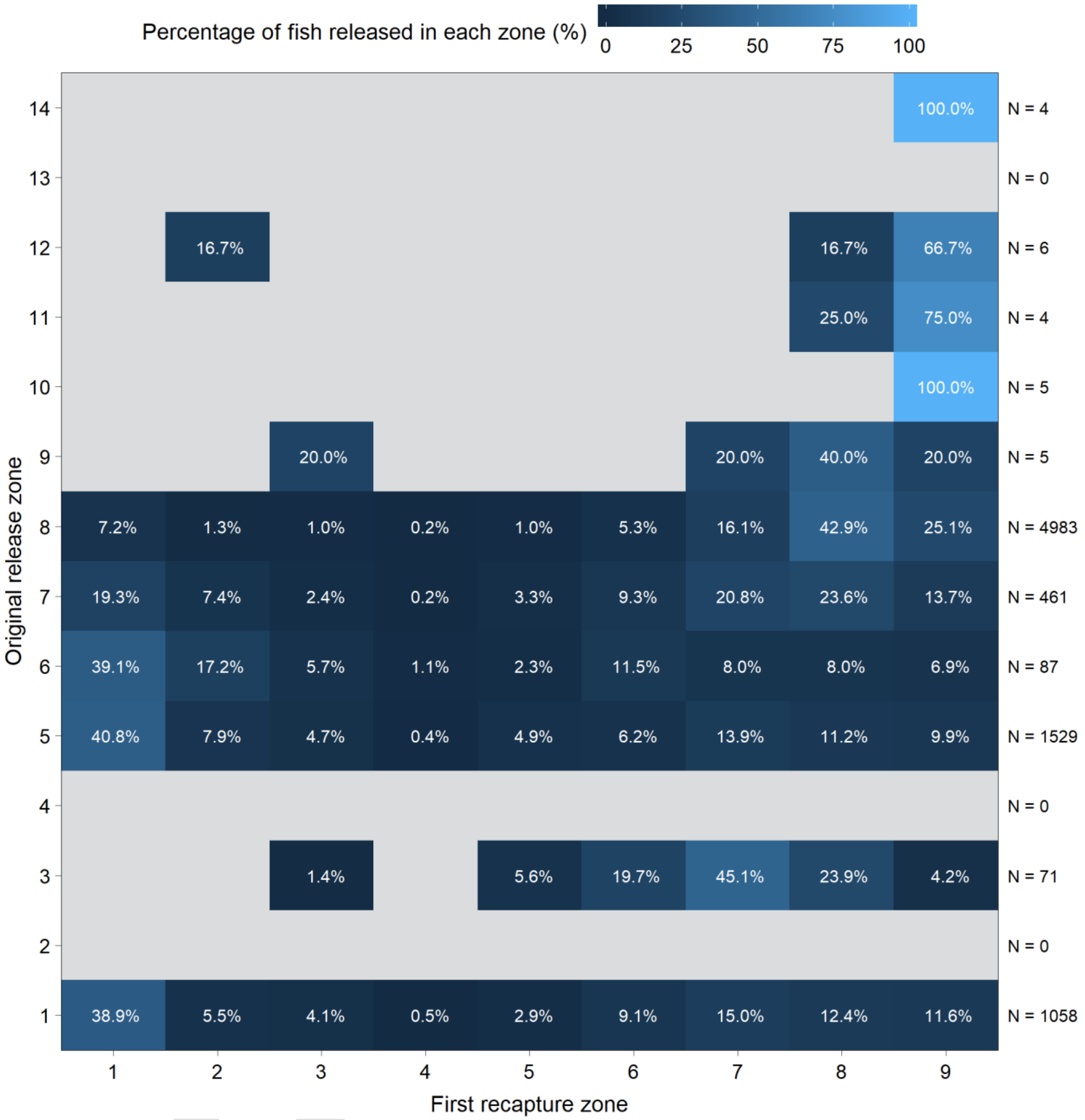
Hatchery-reared fish that were released in either zone 5 or zone 6 (i.e., the zones immediately upstream and downstream of the Canada-US border), were mostly likely (~40%) to be recaptured for the first time in habitat zone 1. In comparison, fish released in habitat zones 7 and 8 (Little Dalles to Rickey Point) were mostly likely to be recaptured for the first time in zone 8 (from Evans to Rickey Point). Since only few fish released in habitat zones 9-14 were recaptured, the patterns of movement between original release and first capture are not very informative; nevertheless, most fish (except for fish released in habitat zone 9) were most likely to be recaptured in the zone of the original release, indicating little movement.

Movement between habitat zones during the 2013-2018 sampling program was limited (**Figure 19**). Generally, fish remained within the zone of the previous capture. Movement to other zones was especially low for fish released in habitat zone 1 (89.9% fish remained within the zone) and in habitat zone 2 (68% of fish remained within the zone). Movement between zones was higher in the US portion of the transboundary area, with only 33-49% of fish remaining within the zone of previous capture. For zones 6, 7, and 8, fish were more likely to travel downstream than upstream; for example, 55.9% of the fish released in habitat zone 7 were recaptured in zones 8-9, whereas only 11.2% of the fish were recaptured in zones 1-6.

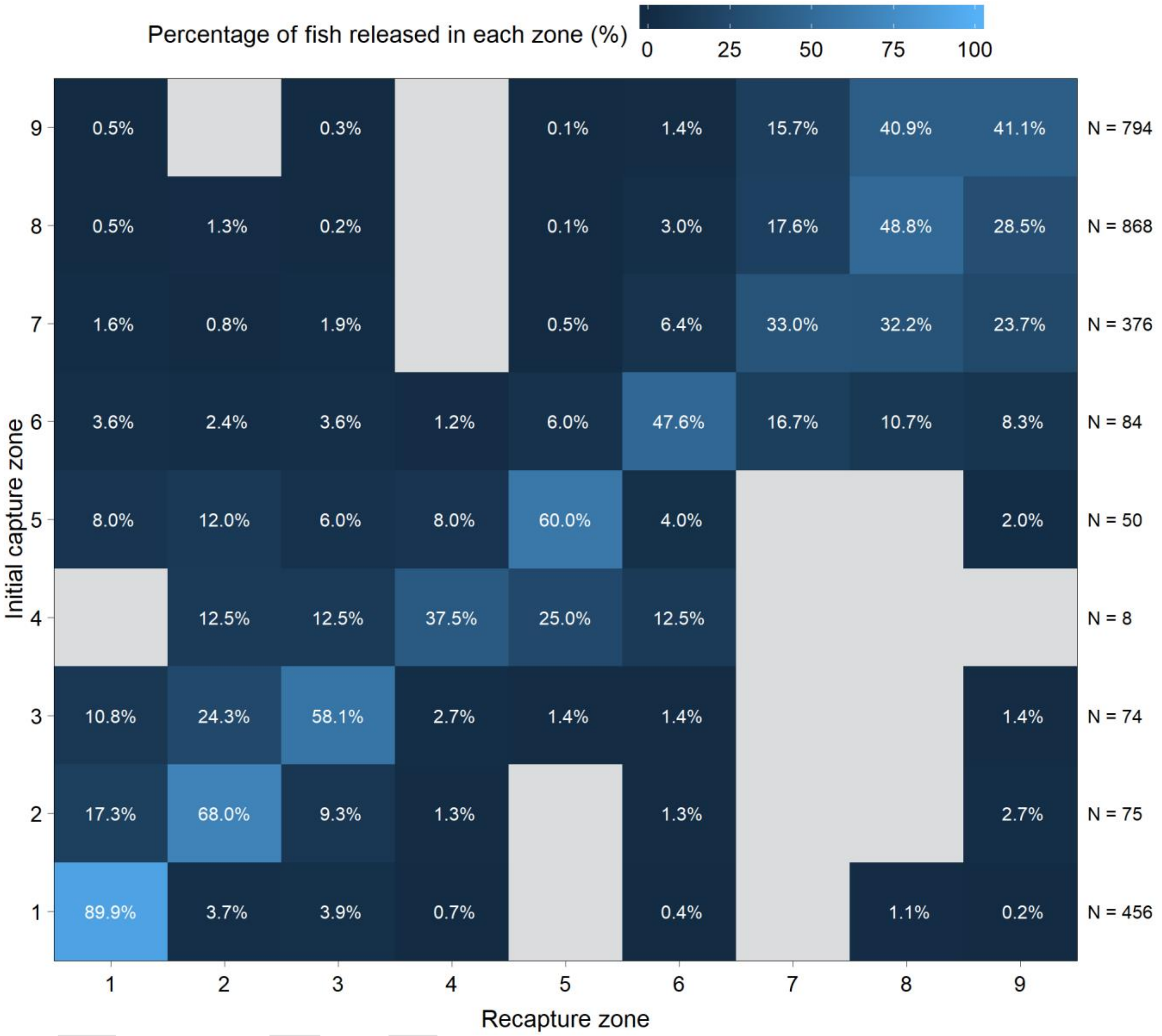
Movements between recaptures differed by country of sampling. In Canada, the vast majority of movements (~90%) was within 10 km from previous capture (**Figure 20**). In the US, small-scale movements (≤10 km) were also the most frequent (i.e., these distances were the mode of the distribution of movement distances), but these only accounted for approximately 30%-40% of recapture cases. No apparent differences were observed between upstream and downstream movements in either country. No consistent pattern in movement distances relative to season of capture or recapture or to time at large (**Figure 21**). Movement within a period of one year from previous capture was variable and did not differ by season within either US or Canada (**Figure 22**).

As summarized in **Figure 20**, movements of sturgeon in Canada were very localized, with few fish recaptured after moving large distances (**Figure 23**). The majority of recaptures occurred near the HLK Dam. In the US, fish movement was more varied. Fish that crossed the US-Canada border often traveled long distances – i.e., fish that crossed were not necessarily fish that were released in proximity to the border. Only 16 fish moved from the Canadian portion of the transboundary area into the US portion of the transboundary area, out of the total 2,250 unique tags that were captured at least twice during the 2013-2018 study. In comparison, 57 fish moved from the US into the Canadian portion of the transboundary area.

DRAFT

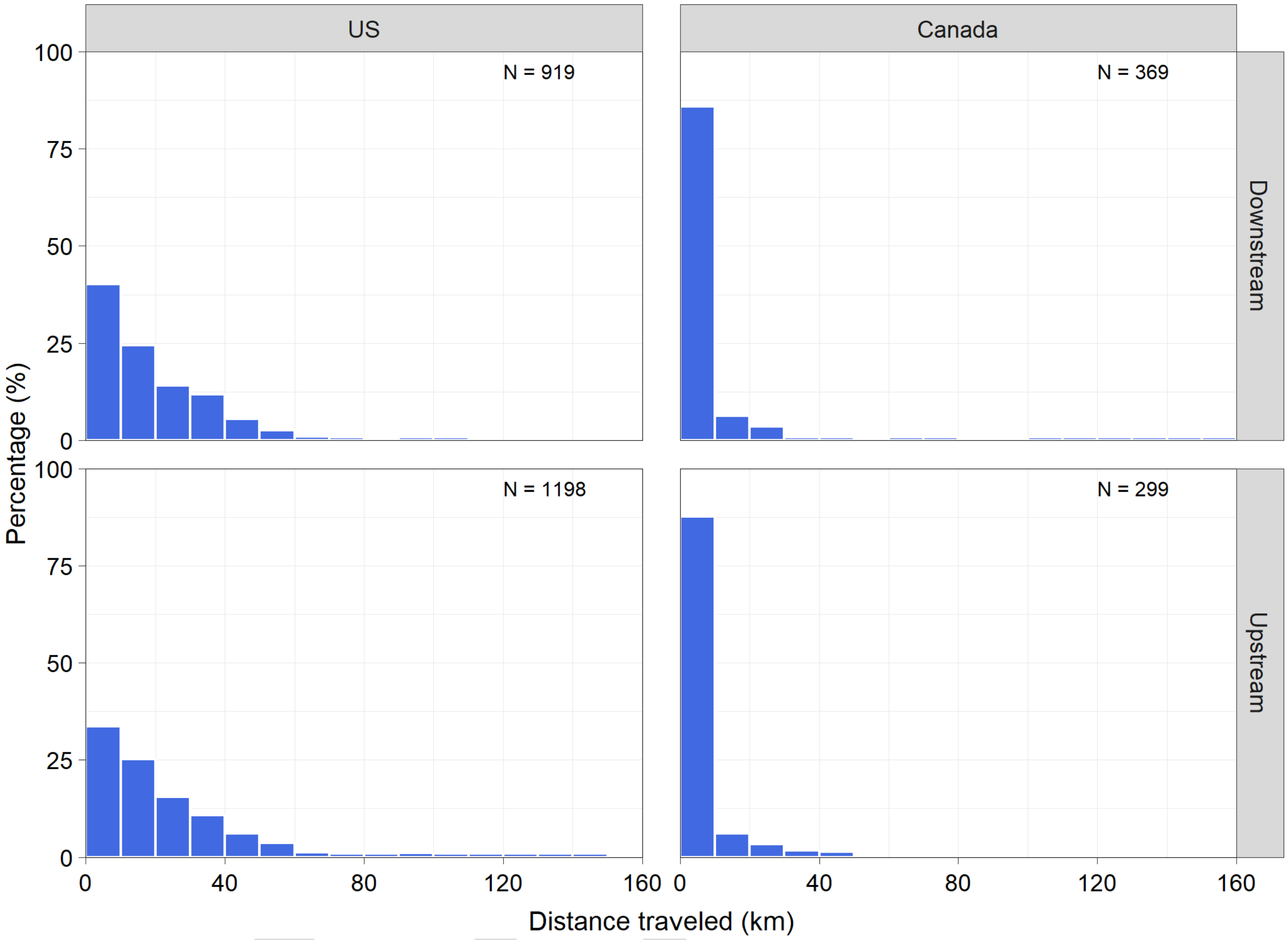


ANNEXE BB **Figure 18: Movement of hatchery-reared White Sturgeon between habitat zones, tabulated by zone of original release and zone of first recapture. Total number of fish captured, by zone of original release, is provided.**



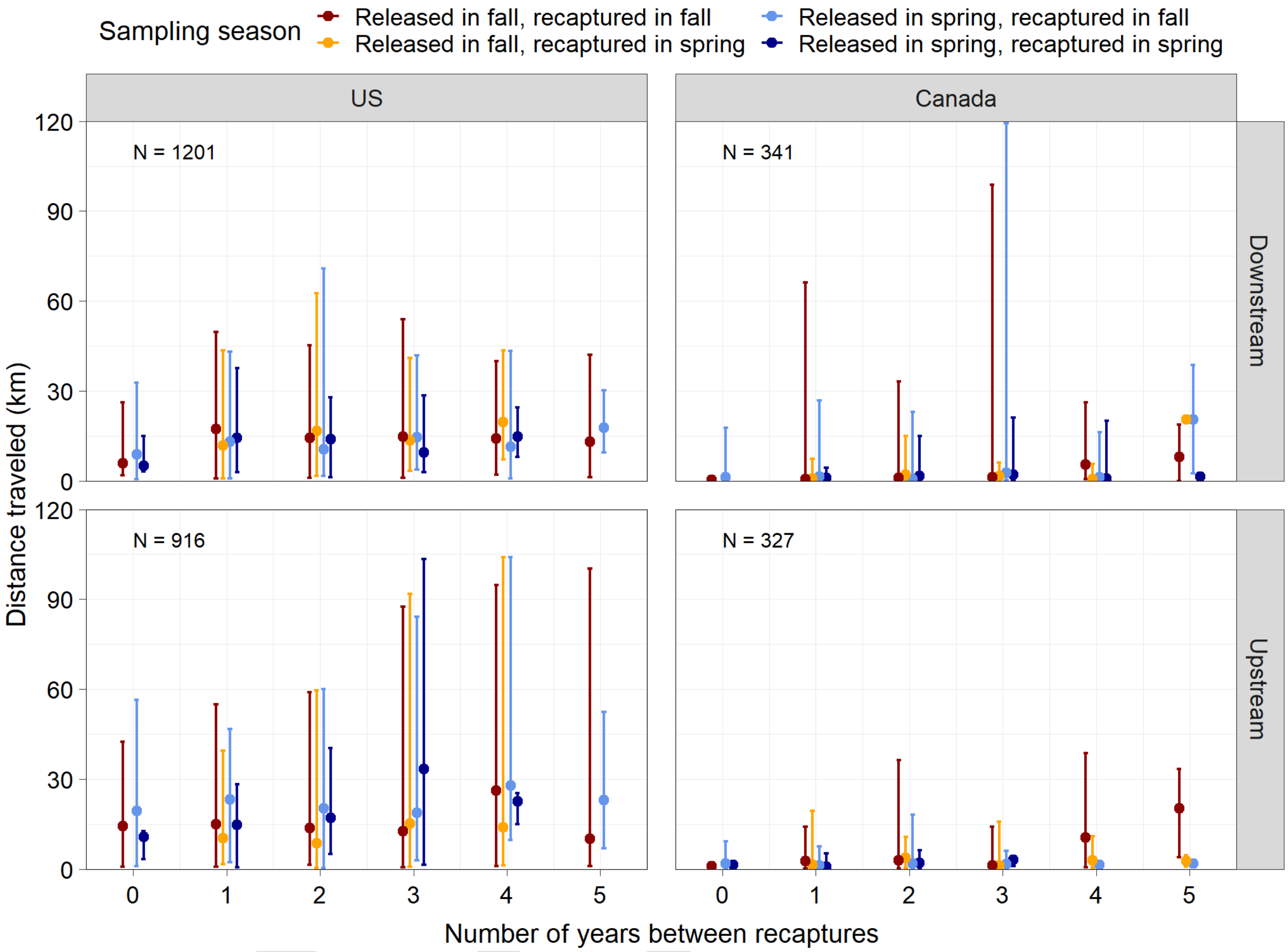
	1	2	3	4	5	6	7	8	9	
9	0.5%		0.3%		0.1%	1.4%	15.7%	40.9%	41.1%	N = 794
8	0.5%	1.3%	0.2%		0.1%	3.0%	17.6%	48.8%	28.5%	N = 868
7	1.6%	0.8%	1.9%		0.5%	6.4%	33.0%	32.2%	23.7%	N = 376
6	3.6%	2.4%	3.6%	1.2%	6.0%	47.6%	16.7%	10.7%	8.3%	N = 84
5	8.0%	12.0%	6.0%	8.0%	60.0%	4.0%			2.0%	N = 50
4		12.5%	12.5%	37.5%	25.0%	12.5%				N = 8
3	10.8%	24.3%	58.1%	2.7%	1.4%	1.4%			1.4%	N = 74
2	17.3%	68.0%	9.3%	1.3%		1.3%			2.7%	N = 75
1	89.9%	3.7%	3.9%	0.7%		0.4%		1.1%	0.2%	N = 456

ANNEXE CC **Figure 19: Movement between habitat zones during the 2013-2018 sampling program, tabulated by zone of last capture and zone of subsequent recapture. Total number of White Sturgeon captured, by zone of last capture, is provided.**



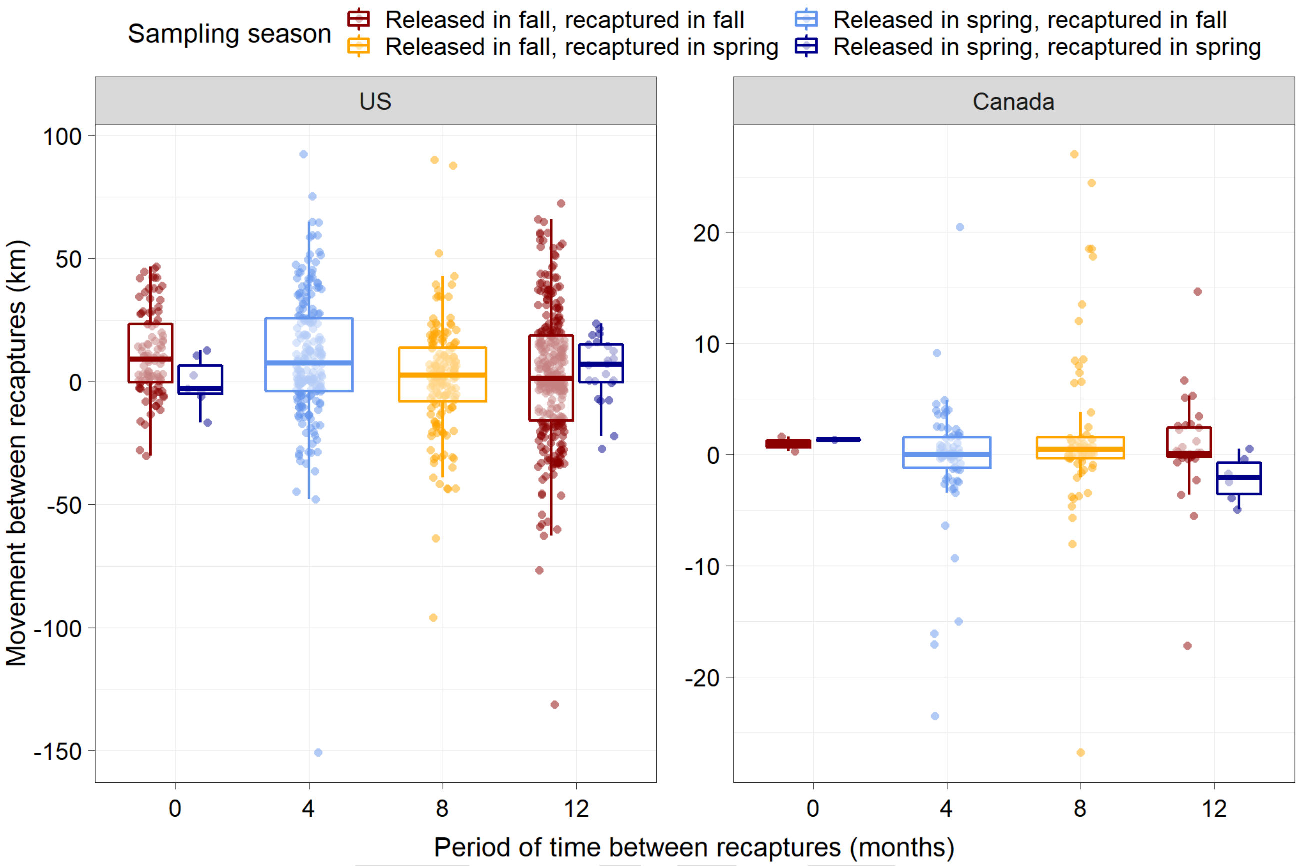
ANNEXE DD **Figure 20: Histogram of movement distance between recapture events, plotted by direction of movement (up- or downstream) and country of the first recapture in each tag's history.**

DRAFT



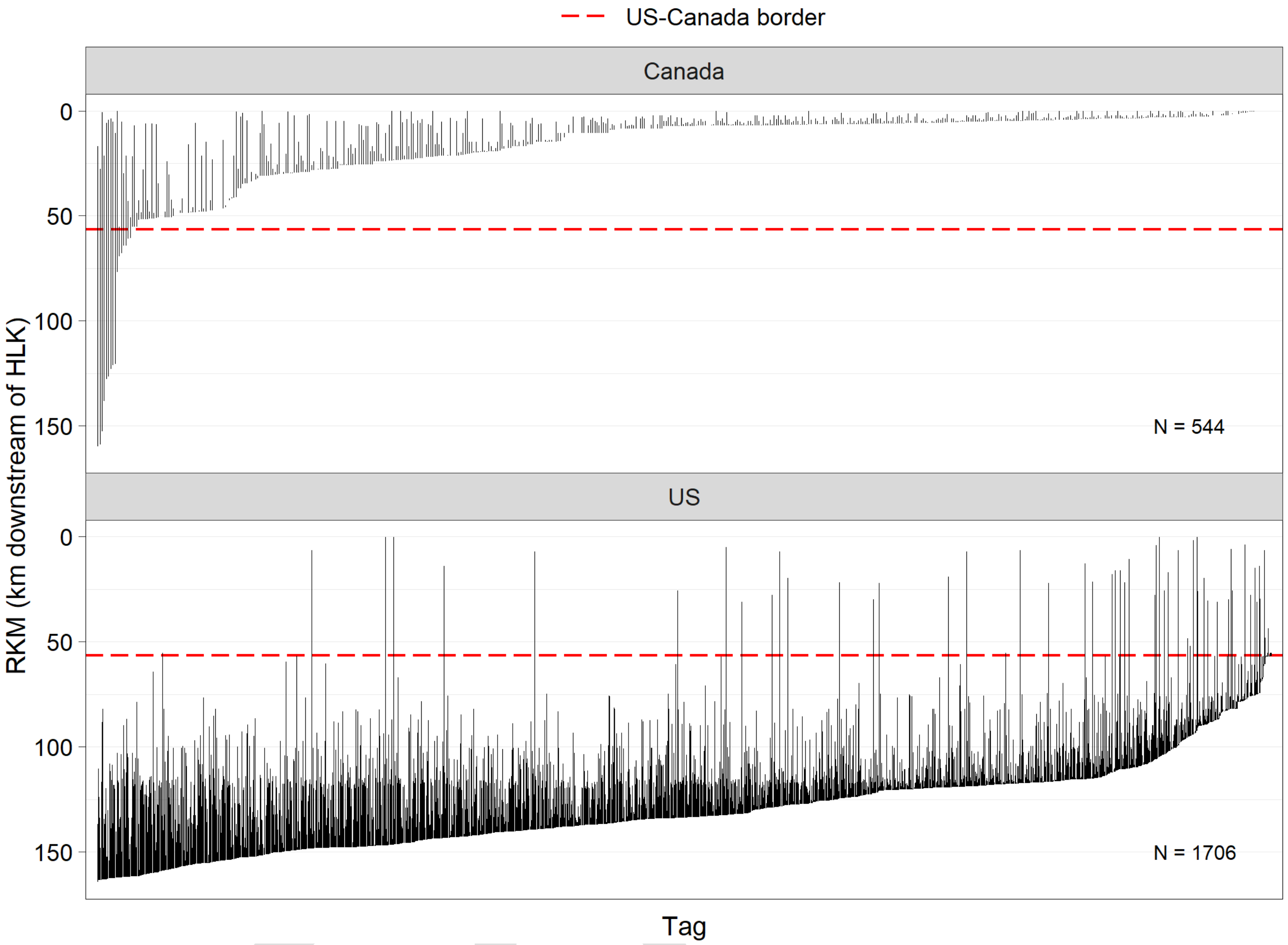
ANNEXE EE **Figure 21: Median values of movement distance between recapture events relative to number of years between capture and recapture events, plotted by season of capture and recapture, direction of movement (up- or downstream), and country of the first recapture in each tag's history.**

DRAFT



ANNEXE FF **Figure 22: Movement distance (km) of White Sturgeon recaptured within a year (365 days) from previous capture event.**

DRAFT



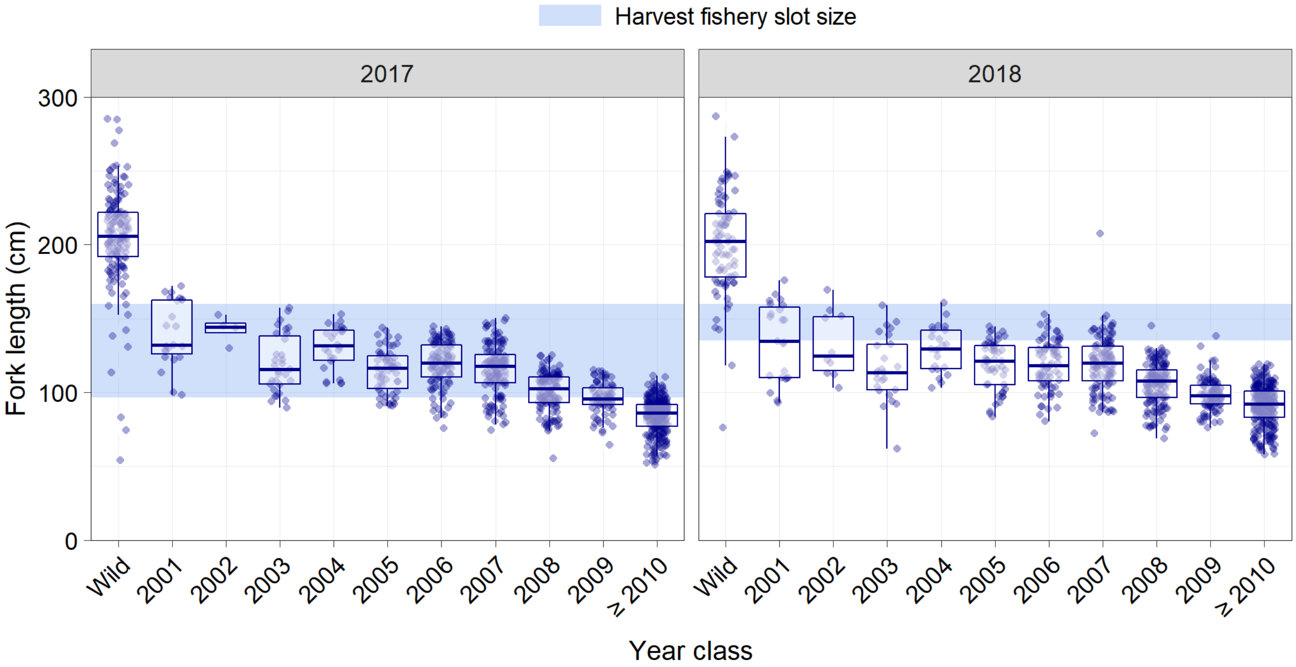
ANNEXE GG **Figure 23: Ranges of RKM values recorded for every recaptured White Sturgeon, plotted by country of first capture event. Each segment represents a single fish tag; tags are sorted by minimum RKM value within each of the two countries.**

DRAFT

Modeling

Survival, Recapture, and Population Abundance- US

The defined slot size for harvest fishery in the US changed between summer 2017 and summer 2018, resulting in a change of exposure of the different year-classes to fishery (**Figure 24**). In summer 2017, the slot size was wide, ranging from 38 in to 63 in (96.5-160 cm), which affected the majority of hatchery-reared year-classes. In summer 2018, the slot size was altered to range between 53 in and 63 in (135-160 cm), reducing the exposure of many year-classes. For the mark-recapture modeling done in this report, it was stipulated that at least 25% of the fish from each year-class captured in the stock assessment in that year had to fall within the slot size to be considered “vulnerable to fishery” in the model. This included year-classes 2001-2009 in 2017 and year-classes 2001 and 2004 in 2018.



ANNEXE HH **Figure 24: Extent of exposure of White Sturgeon captured in the US to fishery, as defined by the slot size in both 2017 and 2018 fishing seasons.**

DRAFT

Out of the set of CJS models constructed for mark-recapture data collected in the US, the model with the best support (as indicated by QAICc) estimated survival as an additive function of year-class and whether a harvest fishery was taking place, and recapture probability as a function of sampling event and year-class (**Table 8**). Out of the set of POPAN models constructed for mark-recapture data collected in the US, the model with the best support (as indicated by QAICc) estimated survival as a function of whether a harvest fishery was taking place, recapture probability as a multiplicative function of year-class and sampling occasion, and super population as a function of year-class (Table 9). The probability of entry for this model was a constant of zero, i.e., no recruitment.

ANNEXE II **Table 8: Comparisons of the converged CJS models developed for White Sturgeon in the US portion of the transboundary area of the Upper Columbia River between 2013 and 2018. Models are arranged in order of QAICc. The specifications of survival (Phi) and recapture rates (p) are indicated for each model, as well as the number of model parameters (npar), and QAICc statistics**

Phi	p	npar	QAICc	ΔQAICc	QAICc weight
Year-class + Fishery	Year-class + Occasion	29	12641.1	0.0	0.62
Year-class + Fishery	Year-class * Occasion	98	12644.6	3.5	0.11
Year-class	Year-class * Occasion	95	12644.6	3.5	0.11
Year-class * Fishery	Year-class + Occasion	38	12644.8	3.7	0.10
Fishery	Year-class * Occasion	89	12645.8	4.7	0.06
Year-class	Year-class + Occasion	28	12648.9	7.8	0.01
Year-class * Fishery	Year-class * Occasion	107	12656.4	15.3	0.00
Occasion	Year-class + Occasion	26	12663.3	22.2	0.00
Fishery	Year-class + Occasion	20	12671.0	29.9	0.00
Occasion	Year-class * Occasion	95	12682.5	41.4	0.00
Fishery	Year-class * Occasion[1]	88	12690.4	49.3	0.00
Year-class + Fishery	Year-class * Occasion[1]	97	12691.6	50.5	0.00
Year-class	Year-class * Occasion[1]	96	12693.1	52.1	0.00
Occasion	Year-class * Occasion[1]	94	12696.7	55.6	0.00
Year-class * Fishery	Year-class * Occasion[1]	106	12699.8	58.7	0.00
Occasion	Year-class * Season	30	12702.5	61.4	0.00
Year-class + Fishery	Year-class * Season	33	12732.8	91.7	0.00
Year-class	Occasion	18	12738.3	97.2	0.00
Year-class + Fishery	Occasion	19	12738.7	97.6	0.00
Year-class	Year-class * Season	32	12739.6	98.5	0.00
Occasion	Occasion	16	12748.9	107.8	0.00
Fishery	Occasion	10	12752.1	111.0	0.00
Year-class * Fishery	Year-class * Season	42	12759.4	118.3	0.00
Fishery	Year-class * Season	24	12759.9	118.8	0.00
Occasion	Season	10	12790.0	148.9	0.00
Year-class * Fishery	Occasion	11	12792.5	151.4	0.00
Year-class * Fishery	Season	22	12820.3	179.2	0.00
Year-class + Fishery	Season	13	12840.0	198.9	0.00
Year-class	Season	12	12842.1	201.0	0.00
Fishery	Season	4	12850.7	209.6	0.00
Occasion	Constant	9	13014.8	373.7	0.00
Year-class + Fishery	Constant	12	13050.3	409.2	0.00
Year-class	Constant	11	13050.5	409.4	0.00
Fishery	Constant	3	13063.5	422.4	0.00
Year-class * Fishery	Constant	8	13132.8	491.8	0.00

Notes: [1] = to assist parameter estimation and based on preliminary analysis, recapture rates were forced to be the same between the two spring sampling efforts within each year-class, and the same between the two spring sampling efforts and the first fall sampling for year-classes 2002, 2009, and ≥2010).

DRAFT

ANNEXE JJ **Table 9: Comparisons of the converged POPAN models developed for White Sturgeon in the US portion of the transboundary area of the Upper Columbia River between 2013 and 2018. Models are arranged in order of QAICc. The specifications of survival (Phi), recapture rates (p), probability of entry (pent), and super-population (N) are indicated for each model, as well as the number of model parameters (npar), and QAICc statistics**

Phi	p	pent	N	npar	QAICc	ΔQAICc	QAICc weight
Fishery	Year-class * Occasion	Constant (zero)	Year-class	112	13360.1	0.0	0.58
Fishery	Year-class * Occasion^{1}	Year-class * Occasion^{2}	Year-class	117	13361.0	0.9	0.38
Occasion	Year-class * Occasion	Constant (zero)	Year-class	118	13365.2	5.1	0.05
Year-class + Fishery	Year-class * Occasion	Constant (zero)	Year-class	122	13372.9	12.8	0
Year-class * Fishery	Year-class * Occasion	Constant (zero)	Year-class	132	13380.9	20.8	0
Year-class	Year-class * Occasion^{1}	Year-class * Occasion^{2}	Year-class	146	13406.9	46.8	0
Occasion	Year-class * Occasion^{1}	Year-class * Occasion^{2}	Year-class	143	13412.4	52.3	0
Year-class + Fishery	Year-class + Occasion	Year-class * Occasion^{2}	Year-class	55	13504.5	144.4	0
Year-class	Year-class + Occasion	Year-class * Occasion^{2}	Year-class	66	13536.3	176.2	0
Year-class * Fishery	Year-class + Occasion	Year-class * Occasion^{2}	Year-class	60	13605.7	245.6	0.0
Year-class + Fishery	Year-class * Occasion^{1}	Year-class * Occasion^{2}	Year-class	147	13618.3	258.2	0.0
Fishery	Year-class + Occasion	Year-class * Occasion^{2}	Year-class	57	13655.7	295.5	0.0
Occasion	Year-class + Occasion	Year-class * Occasion^{2}	Year-class	63	13664.4	304.2	0.0
Occasion	Year-class * Season	Year-class * Occasion^{2}	Year-class	53	13667.3	307.2	0.0
Year-class	Occasion	Year-class * Occasion^{2}	Year-class	47	13693.4	333.2	0.0
Year-class + Fishery	Year-class * Season	Year-class * Occasion^{2}	Year-class	54	13720.0	359.9	0.0
Year-class * Fishery	Occasion	Year-class * Occasion^{2}	Year-class	53	13725.4	365.3	0.0
Year-class	Year-class * Season	Year-class * Occasion^{2}	Year-class	69	13746.8	386.7	0.0
Occasion	Occasion	Year-class * Occasion^{2}	Year-class	44	13781.6	421.4	0.0
Fishery	Occasion	Year-class * Occasion^{2}	Year-class	33	13801.5	441.4	0.0
Fishery	Year-class * Season	Year-class * Occasion^{2}	Year-class	43	13836.5	476.4	0.0
Year-class * Fishery	Year-class * Occasion^{1}	Year-class * Occasion^{2}	Year-class	157	13986.7	626.5	0.0
Year-class + Fishery	Season	Year-class * Occasion^{2}	Year-class	39	14023.4	663.3	0.0
Occasion	Season	Year-class * Occasion^{2}	Year-class	36	14078.5	718.4	0.0
Year-class + Fishery	Year-class + Occasion	Constant (zero)	Year-class	40	14088.0	727.9	0.0
Year-class	Season	Year-class * Occasion^{2}	Year-class	48	14101.5	741.4	0.0
Fishery	Season	Year-class * Occasion^{2}	Year-class	31	14116.4	756.2	0.0
Year-class	Year-class * Season	Constant (zero)	Year-class	44	14232.8	872.7	0.0
Year-class + Fishery	Year-class * Season	Constant (zero)	Year-class	42	14245.8	885.7	0.0
Year-class * Fishery	Year-class * Season	Constant (zero)	Year-class	53	14409.8	1049.7	0.0
Year-class	Occasion	Constant (zero)	Year-class	31	14534.6	1174.5	0.0
Year-class + Fishery	Occasion	Constant (zero)	Year-class	32	14577.0	1216.8	0.0
Year-class * Fishery	Year-class + Occasion	Constant (zero)	Year-class	46	14626.9	1266.8	0.0
Occasion	Year-class * Season	Constant (zero)	Year-class	41	14658.9	1298.8	0.0
Occasion	Year-class + Occasion	Constant (zero)	Year-class	35	14667.3	1307.2	0.0
Fishery	Year-class * Season	Constant (zero)	Year-class	35	14695.5	1335.4	0.0
Fishery	Year-class + Occasion	Constant (zero)	Year-class	32	14807.9	1447.8	0.0
Year-class * Fishery	Occasion	Constant (zero)	Year-class	35	14920.6	1560.5	0.0
Year-class	Season	Constant (zero)	Year-class	24	14973.0	1612.9	0.0

DRAFT

Phi	p	pent	N	npar	QAICc	ΔQAICc	QAICc weight
Year-class + Fishery	Season	Constant (zero)	Year-class	23	15036.5	1676.3	0.0
Occasion	Constant	Year-class * Occasion[2]	Year-class	45	15137.3	1777.2	0.0
Fishery	Occasion	Constant (zero)	Year-class	22	15172.6	1812.5	0.0
Year-class	Constant	Year-class * Occasion[2]	Year-class	44	15174.3	1814.2	0.0
Year-class + Fishery	Constant	Year-class * Occasion[2]	Year-class	47	15210.0	1849.9	0.0
Year-class * Fishery	Constant	Year-class * Occasion[2]	Year-class	41	15277.3	1917.2	0.0
Fishery	Constant	Year-class * Occasion[2]	Year-class	39	15279.6	1919.5	0.0
Year-class * Fishery	Season	Constant (zero)	Year-class	28	15296.3	1936.2	0.0
Occasion	Occasion	Constant (zero)	Year-class	28	15319.4	1959.3	0.0
Occasion	Season	Constant (zero)	Year-class	21	15529.3	2169.1	0.0
Fishery	Season	Constant (zero)	Year-class	15	15550.4	2190.3	0.0
Year-class	Constant	Constant (zero)	Year-class	23	16745.7	3385.6	0.0
Year-class + Fishery	Constant	Constant (zero)	Year-class	23	16799.5	3439.3	0.0
Fishery	Constant	Constant (zero)	Year-class	14	16973.9	3613.8	0.0
Occasion	Constant	Constant (zero)	Year-class	13	17039.5	3679.4	0.0
Year-class * Fishery	Constant	Constant (zero)	Year-class	23	17058.3	3698.2	0.0

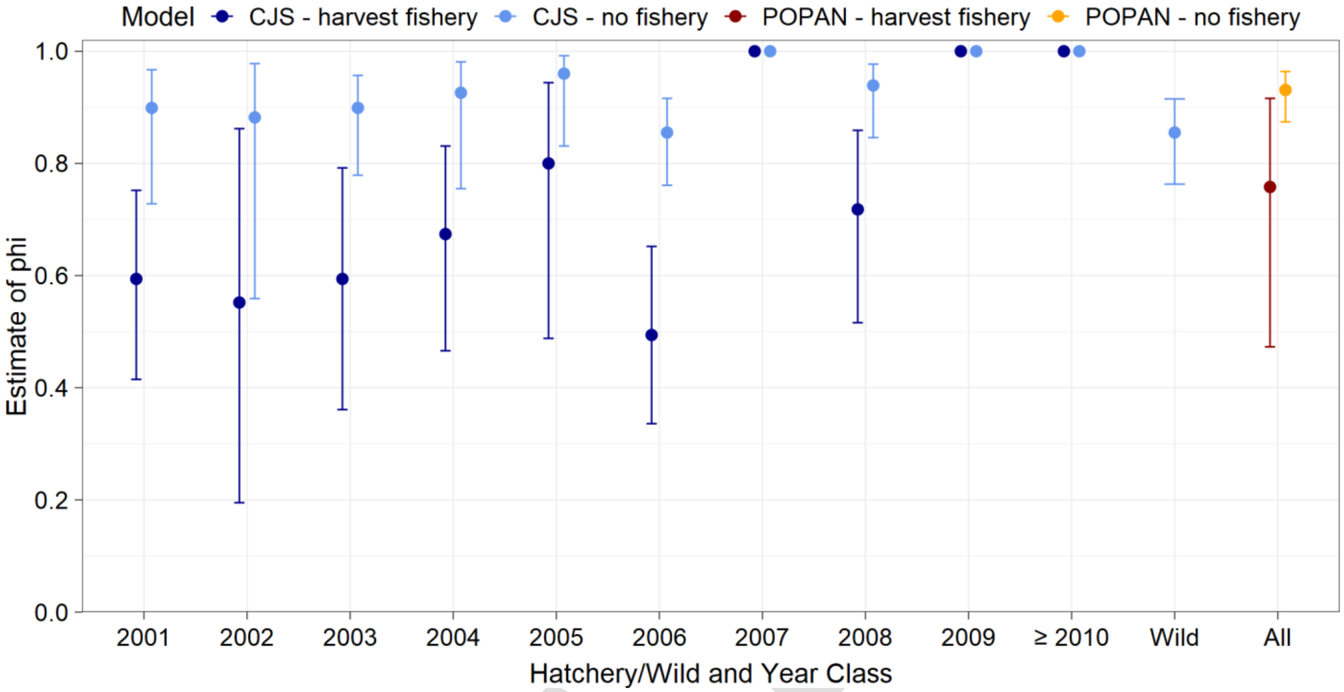
Notes: [1] = recapture rates for the first and third occasion were set to be the same for the 2008, 2009, and ≥ 2010 year-classes, to make the first population size identifiable, per the limitations of the POPAN model specification

[2] = pent set to zero for year-classes 2001-2007 and wild fish, and allowed to vary by sampling occasion for 2008 and ≥ 2009 year-classes

The survival estimates based on CJS models indicated that when no harvest fishery was taking place, survival ranged between 0.855 (for wild fish and year-class 2006) and 1.00 (year-classes 2007, 2009, and ≥2010; **Figure 25** and **Table 10**). Uncertainty in estimates (as the difference between upper and lower 95% confidence limits) was generally low, ranging between 10% and 48% of the mean (for POPAN estimates and year-class 2002, respectively). When a harvest fishery took place, mean survival estimates decreased and ranged between 0.494 (year-class 2006) and 1.00 (year-classes 2007 and 2009). For these estimates, uncertainty was high, ranging between 48% of the mean (year-class 2008) and 121% of the mean (year-class 2002). Survival estimates from the POPAN model were generally comparable to the CJS survival estimates.

Estimated recapture probabilities were very similar between CJS and POPAN models, generally with high values in fall 2013 and fall 2014, and low values in spring 2014 and spring 2015 (**Figure 26**). Recapture probabilities were similar between fall 2015 and fall 2018. Recapture probabilities of the youngest year-classes (2009 and ≥2010) slowly increased over time, reflecting the recruitment of the youngest year-classes to gear, as observed by the increased captures of year-classes 2009 and younger (**Table 3**). Recapture values in spring samples were considerably lower than those of fall samples, especially in 2014.

DRAFT

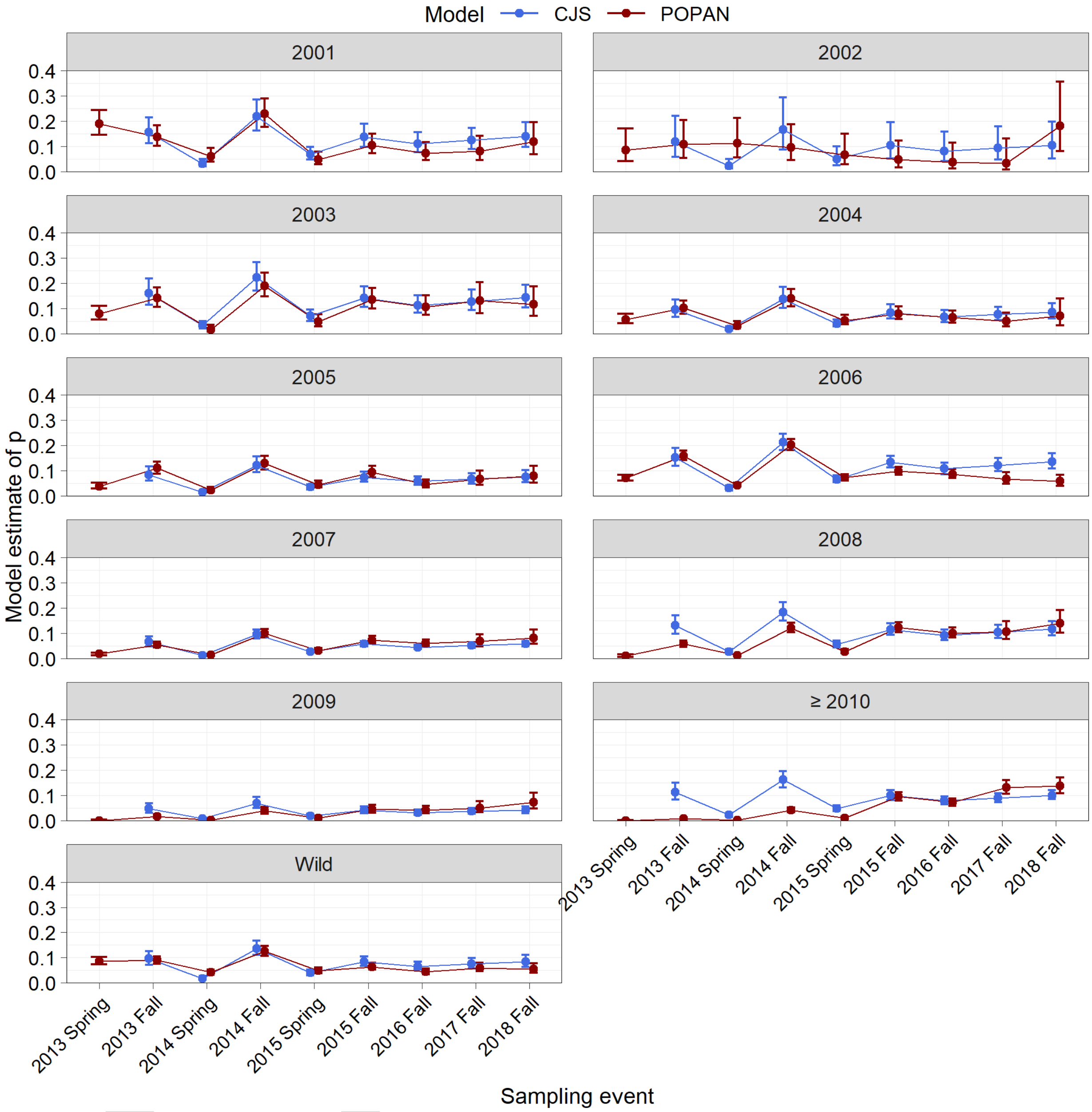


ANNEXE KK Figure 25: Comparison of survival (phi) estimates across CJS and POPAN models for White Sturgeon mark-recapture in the US portion of the transboundary area.

ANNEXE LL Table 10: Estimated survival probabilities from CJS and POPAN models for the US portion of the transboundary area (values shown in Figure 25).

Year-class	Model	Harvest fishery			No harvest fishery		
		Estimate	LCL	UCL	Estimate	LCL	UCL
2001	CJS	0.594	0.415	0.752	0.899	0.728	0.967
2002		0.552	0.195	0.862	0.882	0.559	0.978
2003		0.594	0.361	0.792	0.899	0.779	0.957
2004		0.674	0.466	0.831	0.926	0.755	0.981
2005		0.800	0.488	0.944	0.960	0.831	0.992
2006		0.494	0.336	0.652	0.855	0.761	0.916
2007		1.000	1.000	1.000	1.000	1.000	1.000
2008		0.718	0.516	0.859	0.939	0.846	0.977
2009		1.000	1.000	1.000	1.000	1.000	1.000
≥ 2010		---	---	---	1.000	1.000	1.000
Wild		---	---	---	0.855	0.763	0.915
All	POPAN	0.758	0.473	0.916	0.931	0.874	0.964

DRAFT



ANNEXE MM **Figure 26: Comparison of recapture (p) estimates for CJS and POPAN models – for the US portion of the transboundary area.**

ANNEXE NN **Table 11: Estimated population abundance of White Sturgeon (means with 95% confidence intervals) from CJS and POPAN models for the US portion of the transboundary area (values shown in Figure 25).**

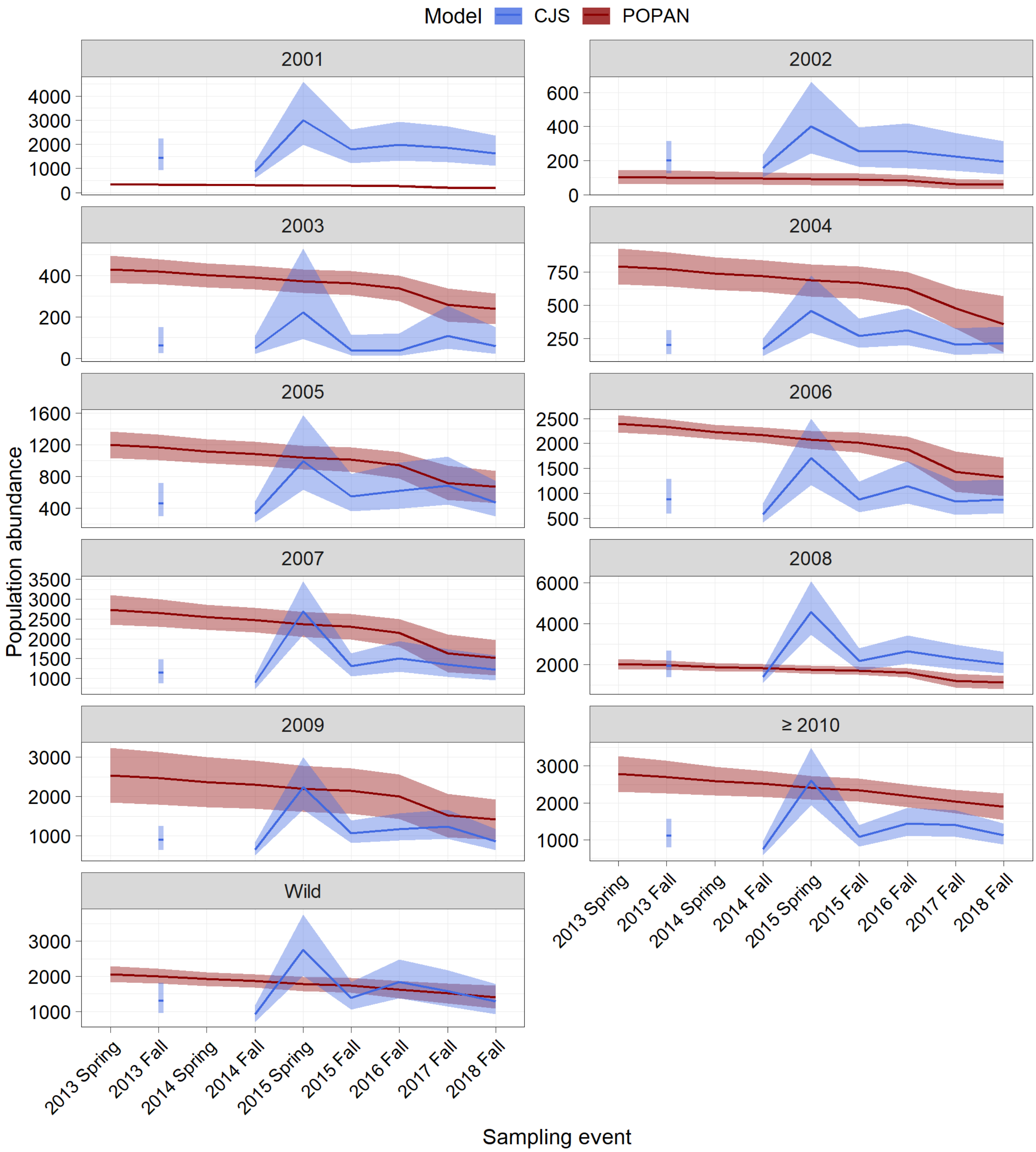
Model	Year	Season	Year-class									Total
			2001-2002	2003	2004	2005	2006	2007	2008	≥2009	Wild	
CJS	2013	Fall	1433 (916 - 2242)	200 (127 - 315)	60 (24 - 150)	200 (128 - 313)	459 (293 - 718)	874 (593 - 1288)	1135 (869 - 1483)	1910 (1368 - 2668)	895 (644 - 1244)	1120 (802 - 1564)
	2014	Fall	886 (600 - 1308)	157 (104 - 236)	48 (21 - 112)	171 (117 - 248)	327 (219 - 488)	581 (419 - 805)	891 (734 - 1082)	1394 (1090 - 1782)	655 (509 - 844)	755 (586 - 973)
	2014	Spring	9996 (6158 - 16226)	922 (528 - 1611)	395 (153 - 1017)	1229 (738 - 2046)	2824 (1699 - 4695)	4909 (3131 - 7694)	6164 (4319 - 8799)	11374 (7686 - 16831)	5106 (3418 - 7628)	5964 (3979 - 8941)
	2015	Fall	1787 (1223 - 2611)	255 (163 - 396)	39 (13 - 112)	268 (179 - 401)	546 (357 - 833)	874 (617 - 1239)	1311 (1052 - 1633)	2181 (1701 - 2795)	1066 (818 - 1389)	1080 (829 - 1408)
	2015	Spring	3005 (1973 - 4578)	400 (242 - 662)	223 (93 - 530)	459 (291 - 724)	997 (630 - 1579)	1706 (1166 - 2496)	2690 (2098 - 3450)	4580 (3458 - 6068)	2238 (1666 - 3006)	2604 (1943 - 3489)
	2016	Fall	1978 (1336 - 2928)	255 (156 - 419)	37 (11 - 119)	309 (201 - 477)	618 (391 - 975)	1147 (799 - 1648)	1506 (1170 - 1937)	2652 (2052 - 3427)	1179 (885 - 1570)	1442 (1109 - 1877)
	2017	Fall	1860 (1263 - 2739)	225 (139 - 364)	108 (46 - 255)	203 (126 - 325)	686 (447 - 1053)	839 (567 - 1242)	1343 (1036 - 1741)	2296 (1768 - 2981)	1240 (920 - 1670)	1399 (1086 - 1803)
	2018	Fall	1619 (1106 - 2370)	194 (120 - 315)	58 (22 - 150)	216 (138 - 338)	469 (297 - 739)	877 (600 - 1282)	1223 (943 - 1586)	2032 (1576 - 2620)	864 (636 - 1173)	1127 (882 - 1439)
POPAN	2013	Fall	335 (288 - 381)	102 (63 - 142)	418 (357 - 479)	773 (644 - 902)	1167 (1006 - 1328)	2327 (2170 - 2483)	2654 (2305 - 3002)	1963 (1739 - 2188)	2468 (1799 - 3136)	2703 (2264 - 3142)
	2013	Spring	344 (296 - 393)	105 (65 - 146)	430 (366 - 494)	795 (660 - 930)	1201 (1030 - 1371)	2393 (2215 - 2571)	2730 (2354 - 3105)	2020 (1772 - 2267)	2538 (1841 - 3236)	2780 (2297 - 3263)
	2014	Fall	312 (267 - 357)	95 (59 - 132)	389 (333 - 446)	720 (599 - 841)	1087 (938 - 1237)	2168 (2015 - 2320)	2472 (2159 - 2786)	1829 (1636 - 2023)	2299 (1686 - 2911)	2518 (2165 - 2871)
	2014	Spring	321 (276 - 366)	98 (60 - 136)	401 (343 - 458)	741 (618 - 863)	1119 (966 - 1271)	2230 (2084 - 2375)	2543 (2221 - 2865)	1882 (1680 - 2083)	2365 (1733 - 2997)	2590 (2208 - 2973)
	2015	Fall	291 (243 - 338)	89 (54 - 124)	363 (305 - 421)	671 (549 - 792)	1013 (858 - 1167)	2019 (1821 - 2217)	2303 (1984 - 2621)	1704 (1506 - 1902)	2141 (1563 - 2719)	2345 (2038 - 2653)
	2015	Spring	298 (252 - 344)	91 (56 - 127)	372 (315 - 429)	688 (567 - 809)	1039 (888 - 1190)	2072 (1893 - 2250)	2363 (2050 - 2676)	1748 (1555 - 1941)	2197 (1609 - 2785)	2406 (2088 - 2725)
	2016	Fall	271 (219 - 322)	83 (49 - 116)	338 (276 - 400)	625 (498 - 753)	945 (777 - 1112)	1883 (1627 - 2138)	2147 (1799 - 2496)	1589 (1364 - 1813)	1997 (1436 - 2558)	2187 (1887 - 2488)
	2017	Fall	206 (143 - 270)	63 (33 - 93)	257 (178 - 336)	476 (323 - 628)	719 (501 - 936)	1432 (1028 - 1837)	1634 (1155 - 2113)	1209 (871 - 1546)	1519 (969 - 2070)	2039 (1718 - 2360)
	2018	Fall	192 (131 - 252)	59 (31 - 87)	239 (165 - 314)	359 (146 - 572)	668 (463 - 873)	1332 (949 - 1715)	1520 (1071 - 1969)	1124 (809 - 1440)	1413 (901 - 1925)	1897 (1541 - 2253)

DRAFT

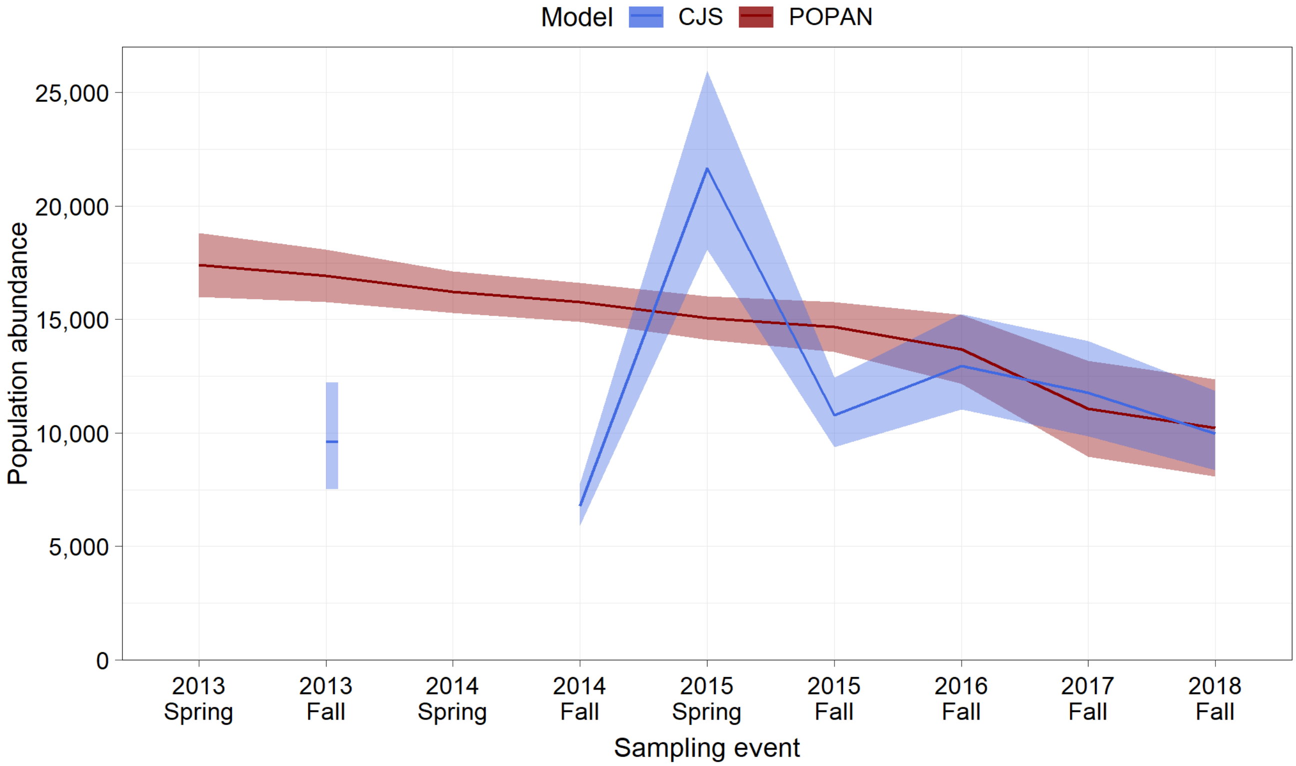
Population abundance estimates from CJS models fluctuated strongly up to and including spring 2015 (**Table 11** and **Figure 27**). Starting in fall 2015, year-class population abundance estimates became more stable. Overall, most estimated population abundances declined (7%-24%) between fall 2015 and fall 2018, although the timing and extent of decline depended on year-class, and population estimates of year classes 2003, 2006, and ≥2010 remained stable (i.e., change of 0%) or increased by 4%-49%. The extremely high abundance values estimated from CJS models for spring 2014 were a result of the very low recapture probability for this sampling event (**Figure 26**). POPAN-based estimates of year-class abundance generally indicated a decrease in population abundance between spring 2013 and fall 2018 (**Table 11** and **Figure 27**), with a faster decline in years when a harvest fishery took place. In fall 2018, estimated populations abundances by year-class ranged between 46% of the estimated abundance in fall 2013 (for year-class 2004) to 70% of the abundance in spring 2013 (for wild fish and year-class ≥2010).

Combined across all year-classes, and with the exception of spring 2014 and spring 2015, CJS abundance estimates indicated a stable population, with a total of 9,594 fish in fall 2013 (95% CIs of 7,526 – 12,231 fish) and a total of 9,959 fish in fall 2018 (95% CIs of 8,369 – 11,581). In contrast, POPAN estimates decreased from 17,400 fish in spring 2013 (95% CIs of 15,995 – 18,804 fish) to 10,211 fish (95% CIs of 8,069 – 12,353) in fall 2018, which is a 41% reduction in the mean abundance estimate. Note that CJS-based abundance estimates are expected to be less precise than the POPAN estimates and should only be used for comparison purposes.

DRAFT



ANNEXE OO **Figure 27: Population abundance estimates by year-class based on CJS and POPAN models of White Sturgeon in the US portion of the transboundary area. CJS estimates for spring 2014 are not shown due to excessive uncertainty, but are detailed in Table 11.**



ANNEXE PP **Figure 28: Total population abundance estimates based on CJS and POPAN models of White Sturgeon in the US portion of the transboundary area. CJS estimates for spring 2014 are not included due to excessive uncertainty, but are detailed in Table 11.**

DRAFT

Survival, Recapture, and Population Abundance – Canada

Out of the set of CJS models constructed for mark-recapture data collected in the Canadian portion of the transboundary area, the model with the best support (as indicated by QAICc) estimated survival as a constant, and recapture probability as a function of year-class and sampling occasion (Out of the set of CJS models constructed for mark-recapture data collected in the Canadian portion of the transboundary area, the model with the best support (as indicated by QAICc) estimated survival as a constant, and recapture probability as a function of time and age (Table 15). Wild fish were assumed to be the same age as the 2001 year class in the model because their true age was unknown. Out of the set of POPAN models constructed for mark-recapture data collected in the US, the model with the best support (as indicated by QAICc) estimated survival as a function of year class, recapture probability as a multiplicative function of time and age, probability of entry as a function of age, and super population as a function of year class (Table 16).

Table). Out of the set of POPAN models constructed for mark-recapture data collected in the US, the model with the best support (as indicated by QAICc) also estimated survival as a constant and recapture probability as a multiplicative function of year-class and sampling occasion, with no recruitment, and super population as a function of year-class (

DRAFT

Table).

ANNEXE QQ **Table 12: Comparisons of the converged CJS models developed for White Sturgeon in the Canadian portion of the transboundary area of the Upper Columbia River between 2013 and 2018. Models are arranged in order of QAICc. The specifications of survival (Phi) and recapture rates (p) are indicated for each model, as well as the number of model parameters (npar), and QAICc statistics**

Phi	p	npar	QAICc	ΔQAICc	QAICc weight
Constant	Year-class + Sampling occasion	21	7106.9	0.0	0.96
Year-class	Year-class + Sampling occasion	30	7113.5	6.6	0.04
Sampling occasion	Year-class + Sampling occasion	31	7122.2	15.4	0.00
Year-class	Sampling occasion	21	7130.9	24.0	0.00
Constant	Year-class + Season	12	7132.4	25.6	0.00
Sampling occasion	Year-class + Season	22	7138.4	31.6	0.00
Constant	Year-class * Season	21	7138.6	31.8	0.00
Year-class	Year-class + Season	21	7139.7	32.8	0.00
Sampling occasion	Year-class * Season	31	7144.5	37.6	0.00
Year-class	Year-class * Season	30	7145.9	39.0	0.00
Year-class	Constant	11	7156.0	49.1	0.00
Year-class	Season	12	7157.5	50.7	0.00
Constant	Sampling occasion	12	7172.8	66.0	0.00
Constant	Year-class * Sampling occasion	108	7176.8	70.0	0.00
Sampling occasion	Sampling occasion	22	7188.6	81.7	0.00
Year-class	Year-class * Sampling occasion	120	7190.8	83.9	0.00
Sampling occasion	Year-class * Sampling occasion	118	7193.8	86.9	0.00
Constant	Constant	2	7199.7	92.9	0.00
Sampling occasion	Constant	12	7200.7	93.9	0.00
Constant	Season	3	7201.3	94.5	0.00
Sampling occasion	Season	13	7202.6	95.8	0.00

DRAFT

ANNEXE RR Table 13: Comparisons of the converged POPAN models developed for White Sturgeon in the Canadian portion of the transboundary area of the Upper Columbia River between 2013 and 2018. Models are arranged in order of QAICc. The specifications of survival (Phi), recapture rates (p), probability of entry (pent), and superpopulation (N) are indicated for each model, as well as the number of model parameters (npar), and QAICc statistics

Phi	p	pent	N	npar	QAICc	ΔQAICc	QAICc weight
Constant	Year-class * Occasion[1]	Constant (zero)	Year-class	137	8066.1	0.0	1.00
Year-class	Year-class * Occasion[1]	Constant (zero)		149	8085.5	19.3	0.00
Occasion	Year-class * Occasion[1]	Constant (zero)		150	8090.0	23.9	0.00
Occasion	Year-class * Occasion[2]	Year-class * Occasion[3]		159	8096.4	30.3	0.00
Year-class	Year-class * Occasion[2]	Year-class * Occasion[3]		163	8101.2	35.0	0.00
Year-class	Year-class + Occasion[2]	Year-class * Occasion[3]		64	8295.3	229.1	0.00
Year-class	Year-class + Occasion	Constant (zero)		41	8374.3	308.1	0.00
Constant	Year-class + Occasion[2]	Year-class * Occasion[3]		43	8451.7	385.6	0.00
Occasion	Year-class + Occasion[2]	Year-class * Occasion[3]		65	8482.8	416.7	0.00
Constant	Year-class * Occasion[2]	Year-class * Occasion[3]		154	8536.0	469.8	0.00
Year-class	Occasion[2]	Year-class * Occasion[3]		55	8547.6	481.5	0.00
Occasion	Year-class + Occasion	Constant (zero)		42	8572.5	506.4	0.00
Occasion	Occasion[2]	Year-class * Occasion[3]		47	8641.5	575.4	0.00
Year-class	Occasion	Constant (zero)		32	8671.8	605.7	0.00
Constant	Occasion	Constant (zero)		23	8786.8	720.6	0.00
Occasion	Occasion	Constant (zero)		33	8805.7	739.6	0.00
Constant	Year-class + Season	Year-class * Occasion[3]		30	8812.8	746.6	0.00
Constant	Year-class * Season	Year-class * Occasion[3]		42	8827.0	760.9	0.00
Year-class	Year-class + Season	Year-class * Occasion[3]		46	8852.9	786.8	0.00
Occasion	Year-class + Season	Year-class * Occasion[3]		55	8863.5	797.3	0.00
Year-class	Year-class * Season	Constant (zero)		40	8922.3	856.2	0.00
Constant	Year-class * Season	Constant (zero)		31	8949.6	883.5	0.00
Constant	Year-class + Season	Constant (zero)		22	9009.3	943.2	0.00
Occasion	Season	Year-class * Occasion[3]		46	9009.8	943.7	0.00
Occasion	Year-class + Season	Constant (zero)		32	9029.6	963.5	0.00
Occasion	Constant	Year-class * Occasion[3]		27	9134.6	1068.5	0.00
Constant	Year-class + Occasion	Constant (zero)		30	9175.3	1109.1	0.00
Constant	Season	Constant (zero)		13	9197.8	1131.7	0.00
Year-class	Season	Constant (zero)		22	9201.0	1134.9	0.00
Occasion	Season	Constant (zero)		23	9218.0	1151.9	0.00
Constant	Season	Year-class * Occasion[3]		23	9282.7	1216.5	0.00
Constant	Constant	Constant (zero)		12	9330.4	1264.3	0.00
Constant	Constant	Year-class * Occasion[3]		20	9939.3	1873.2	0.00

Notes: [1] = to assist parameter estimation and based on preliminary analysis, recapture rates were forced to be the same between the first and third sampling efforts for year-classes 2007, 2008, and ≥2009.

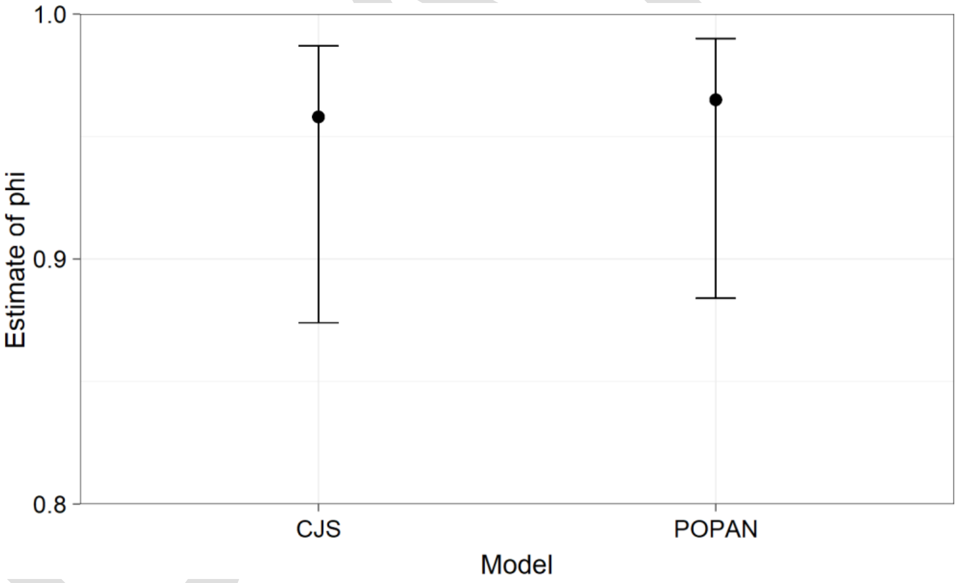
DRAFT

[2] = recapture rates for the first and third occasion were set to be the same for the 2008 and ≥ 2009 year-classes, to make the first population size identifiable, per the limitations of the POPAN model specification

[3] = pent set to zero for year-classes 2001-2007 and wild fish, and allowed to vary by sampling occasion for 2008 and ≥ 2009 year-classes

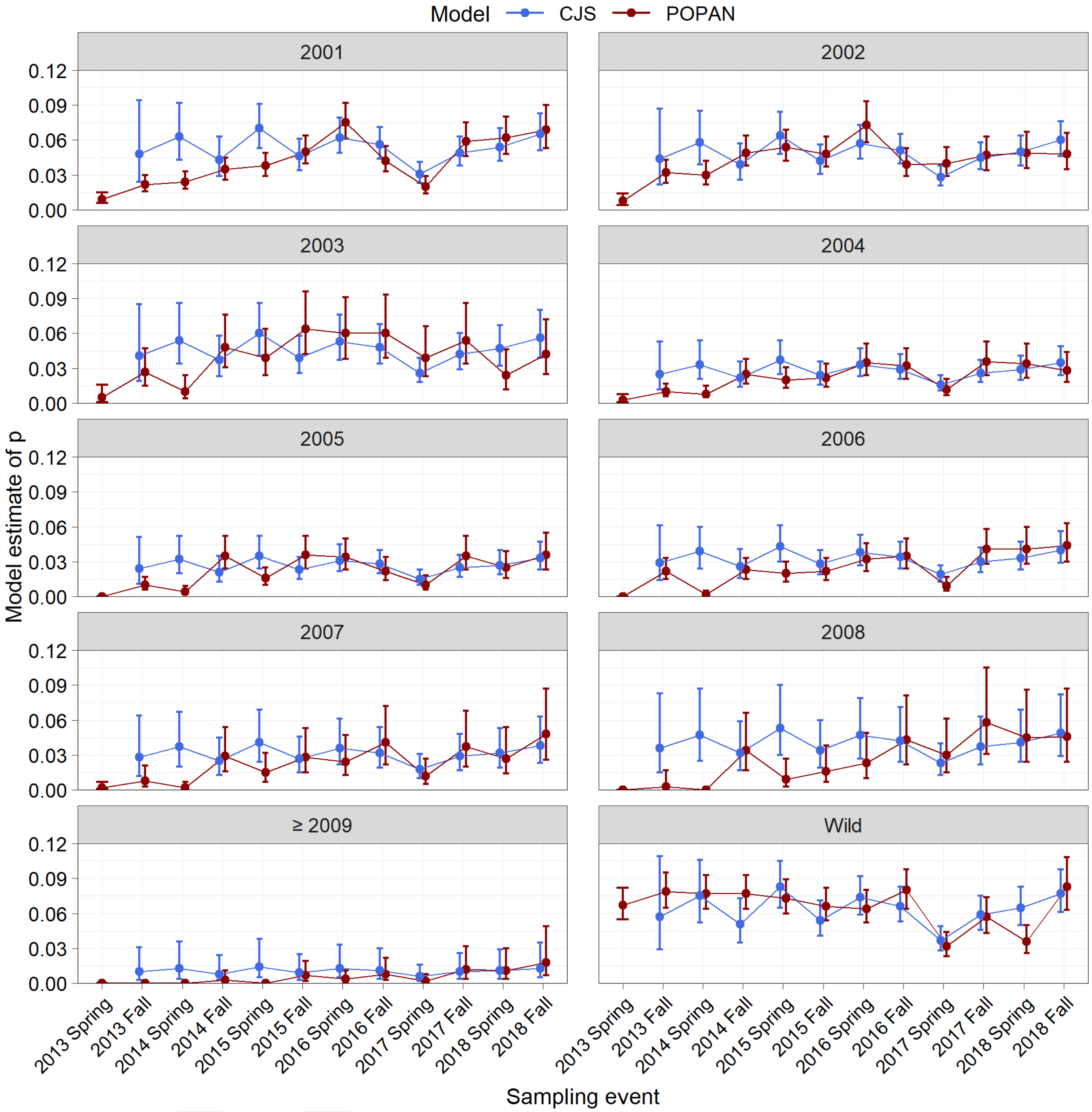
The estimated survival values based on CJS models were high (0.958), with a 95% confidence interval spanning between 0.874 and 0.987 (**Figure**). Survival estimates from the POPAN model were similar, with a mean estimate of 0.965 and a 95% confidence interval that spanned between 0.884 and 0.990.

Estimated recapture probabilities were often similar between CJS and POPAN models (**Figure**). In both models, recapture probabilities differed between year-classes and fluctuated between sampling events. Multiple year-classes had low recapture probabilities in spring 2013 (all except wild fish), spring 2017 (year-classes 2001, 2004-2007, and ≥2009). While POPAN recapture probabilities for the youngest year-classes (2007, 2008, and ≥2009) were essentially zero in the earlier sampling events, they were considerably higher in CJS estimates. In all sampling events, both models estimated a lower recapture probability for the youngest year-classes, which reflects their recruitment to gear, as observed by the increased captures over time of year-classes 2009 and younger (**Table 3**). Although in the US portion of the transboundary area recapture probabilities in the spring were consistently lower than those in the fall, no consistent seasonal trends were observed for recapture probabilities in the Canadian portion of the transboundary area.



ANNEXE SS Figure 29: Comparison of survival (phi) estimates across CJS and POPAN models of sturgeon mark-recapture in the Canadian portion of the transboundary area.

DRAFT



ANNEXE TT **Figure 30: Comparison of recapture probability (p) estimates for CJS and POPAN models – for the Canadian portion of the transboundary area.**

ANNEXE UU **Table 14: Estimated population abundance of White Sturgeon (means with 95% confidence interval) from CJS and POPAN models for the Canadian portion of the transboundary area (values shown in Figure 25).**

Model	Year	Season	Year-class										Total
			2001	2002	2003	2004	2005	2006	2007	2008	>2009	Wild	
CJS	2013	Fall	1437 (711 - 2906)	1508 (740 - 3074)	267 (109 - 653)	1267 (572 - 2809)	1531 (694 - 3379)	959 (433 - 2123)	395 (151 - 1035)	194 (69 - 551)	1462 (445 - 4801)	1436 (728 - 2829)	10456 (5244 - 20850)
	2014	Spring	888 (564 - 1399)	834 (520 - 1336)	258 (132 - 505)	688 (374 - 1266)	656 (352 - 1225)	881 (509 - 1526)	380 (177 - 815)	147 (60 - 363)	863 (287 - 2595)	882 (578 - 1346)	6479 (4308 - 9746)
	2014	Fall	1408 (894 - 2216)	1030 (631 - 1681)	383 (195 - 754)	1073 (585 - 1969)	1589 (894 - 2823)	928 (514 - 1676)	608 (285 - 1298)	282 (120 - 663)	945 (301 - 2968)	1497 (982 - 2281)	9742 (6527 - 14541)
	2015	Spring	847 (591 - 1214)	723 (490 - 1066)	234 (126 - 431)	702 (415 - 1188)	761 (451 - 1286)	795 (493 - 1282)	269 (127 - 574)	228 (108 - 482)	636 (213 - 1902)	933 (676 - 1288)	6129 (4605 - 8159)
	2015	Fall	1136 (770 - 1677)	959 (630 - 1460)	459 (255 - 824)	1040 (603 - 1793)	1173 (685 - 2010)	971 (578 - 1631)	377 (171 - 828)	292 (132 - 646)	988 (328 - 2977)	1212 (848 - 1730)	8606 (6289 - 11778)
	2016	Spring	821 (575 - 1174)	847 (585 - 1226)	300 (168 - 536)	730 (431 - 1234)	571 (323 - 1012)	868 (543 - 1389)	221 (97 - 500)	214 (99 - 465)	718 (241 - 2136)	855 (616 - 1186)	6144 (4682 - 8064)
	2016	Fall	825 (573 - 1187)	865 (594 - 1261)	251 (132 - 474)	883 (529 - 1475)	1100 (672 - 1801)	852 (526 - 1381)	277 (126 - 612)	239 (110 - 519)	1072 (374 - 3075)	921 (663 - 1280)	7285 (5497 - 9654)
	2017	Spring	1685 (1143 - 2486)	1353 (883 - 2074)	606 (330 - 1112)	1430 (821 - 2489)	1494 (856 - 2607)	1395 (827 - 2354)	619 (287 - 1336)	217 (82 - 573)	1648 (556 - 4887)	1629 (1123 - 2362)	12076 (8774 - 16619)
	2017	Fall	1076 (752 - 1538)	868 (584 - 1291)	213 (105 - 433)	887 (520 - 1513)	967 (569 - 1643)	1000 (617 - 1622)	349 (161 - 756)	135 (52 - 351)	1219 (425 - 3500)	1041 (740 - 1463)	7755 (5776 - 10412)
	2018	Spring	993 (696 - 1419)	887 (604 - 1305)	343 (191 - 616)	767 (447 - 1317)	947 (563 - 1593)	814 (495 - 1339)	190 (77 - 464)	122 (47 - 317)	1192 (420 - 3385)	913 (646 - 1292)	7169 (5317 - 9667)
	2018	Fall	873 (620 - 1229)	604 (405 - 901)	321 (183 - 561)	808 (490 - 1335)	693 (408 - 1178)	775 (483 - 1243)	367 (181 - 741)	183 (83 - 403)	681 (230 - 2013)	969 (704 - 1334)	6274 (4836 - 8139)
POPAN	2013	Spring	1494 (1252 - 1736)	1158 (967 - 1349)	413 (300 - 526)	1242 (873 - 1612)	1249 (872 - 1627)	1356 (991 - 1721)	503 (276 - 729)	343 (180 - 507)	2129 (82 - 4177)	1266 (1139 - 1393)	11154 (8697 - 13612)
	2013	Fall	1472 (1250 - 1693)	1141 (964 - 1318)	407 (298 - 515)	1224 (867 - 1580)	1231 (866 - 1595)	1336 (985 - 1687)	495 (274 - 716)	338 (179 - 497)	2097 (87 - 4108)	1247 (1135 - 1359)	10987 (8661 - 13313)
	2014	Spring	1438 (1242 - 1634)	1115 (954 - 1275)	397 (294 - 501)	1196 (855 - 1536)	1202 (854 - 1550)	1305 (972 - 1637)	484 (270 - 698)	331 (177 - 484)	2049 (92 - 4006)	1218 (1120 - 1317)	10734 (8574 - 12894)
	2014	Fall	1419 (1233 - 1604)	1100 (946 - 1254)	392 (291 - 493)	1180 (847 - 1512)	1186 (846 - 1526)	1288 (964 - 1612)	477 (267 - 688)	326 (176 - 476)	2022 (95 - 3950)	1202 (1106 - 1298)	10592 (8506 - 12678)
	2015	Spring	1387 (1213 - 1561)	1075 (928 - 1223)	383 (285 - 482)	1153 (831 - 1476)	1160 (830 - 1489)	1259 (946 - 1572)	467 (262 - 671)	319 (173 - 464)	1977 (97 - 3857)	1175 (1074 - 1277)	10355 (8359 - 12352)
	2015	Fall	1367 (1196 - 1539)	1060 (913 - 1207)	378 (281 - 475)	1137 (819 - 1455)	1143 (818 - 1468)	1241 (932 - 1549)	460 (258 - 662)	314 (171 - 457)	1949 (97 - 3800)	1159 (1049 - 1268)	10207 (8244 - 12170)
	2016	Spring	1337 (1163 - 1512)	1037 (886 - 1188)	370 (274 - 466)	1112 (799 - 1425)	1118 (798 - 1438)	1214 (909 - 1518)	450 (252 - 648)	307 (168 - 447)	1906 (97 - 3715)	1133 (1006 - 1260)	9984 (8039 - 11929)
	2016	Fall	1319 (1139 - 1499)	1023 (867 - 1178)	365 (269 - 461)	1097 (785 - 1409)	1103 (784 - 1421)	1197 (893 - 1501)	444 (248 - 640)	303 (165 - 441)	1880 (96 - 3664)	1118 (978 - 1257)	9848 (7895 - 11801)
	2017	Spring	1289 (1096 - 1482)	999 (833 - 1166)	356 (260 - 453)	1072 (760 - 1384)	1078 (759 - 1396)	1170 (864 - 1476)	434 (240 - 627)	296 (161 - 432)	1837 (92 - 3582)	1092 (931 - 1254)	9624 (7629 - 11620)
	2017	Fall	1273 (1070 - 1476)	987 (813 - 1160)	352 (254 - 449)	1058 (745 - 1372)	1064 (745 - 1384)	1155 (847 - 1464)	428 (236 - 620)	293 (158 - 427)	1814 (90 - 3538)	1079 (904 - 1253)	9504 (7472 - 11535)
	2018	Spring	1243 (1020 - 1466)	963 (775 - 1152)	344 (244 - 443)	1033 (716 - 1351)	1039 (716 - 1362)	1128 (813 - 1443)	418 (227 - 609)	286 (153 - 418)	1771 (84 - 3458)	1053 (855 - 1252)	9278 (7157 - 11398)
	2018	Fall	1228 (994 - 1462)	952 (755 - 1149)	339 (239 - 440)	1021 (701 - 1342)	1027 (701 - 1353)	1115 (795 - 1434)	413 (223 - 603)	282 (150 - 414)	1750 (81 - 3419)	1041 (830 - 1251)	9168 (6996 - 11341)

DRAFT

Population abundance estimates from CJS models fluctuated between sampling events (**Table** and **Figure 31**). For all year-classes except for 2003, CJS population abundance estimated for fall 2018 was lower than the mean estimate from fall 2013, with values ranging from 40% from the initial estimate (year-class 2002) to 94% of the initial estimate (year-class 2008). Only year-class 2003 had an estimated increase in abundance (20% relative to initial estimate). Overall, estimated CJS population abundances remained stable or declined throughout the 2013-2018 study, although the extent of change depended on year-class.

POPAN-based estimates of year-class abundance decreased between spring 2013 and fall 2018 (**Table** and **Figure 31**). Since the data did not support a model that included a recruitment parameter for the younger year-classes (

DRAFT

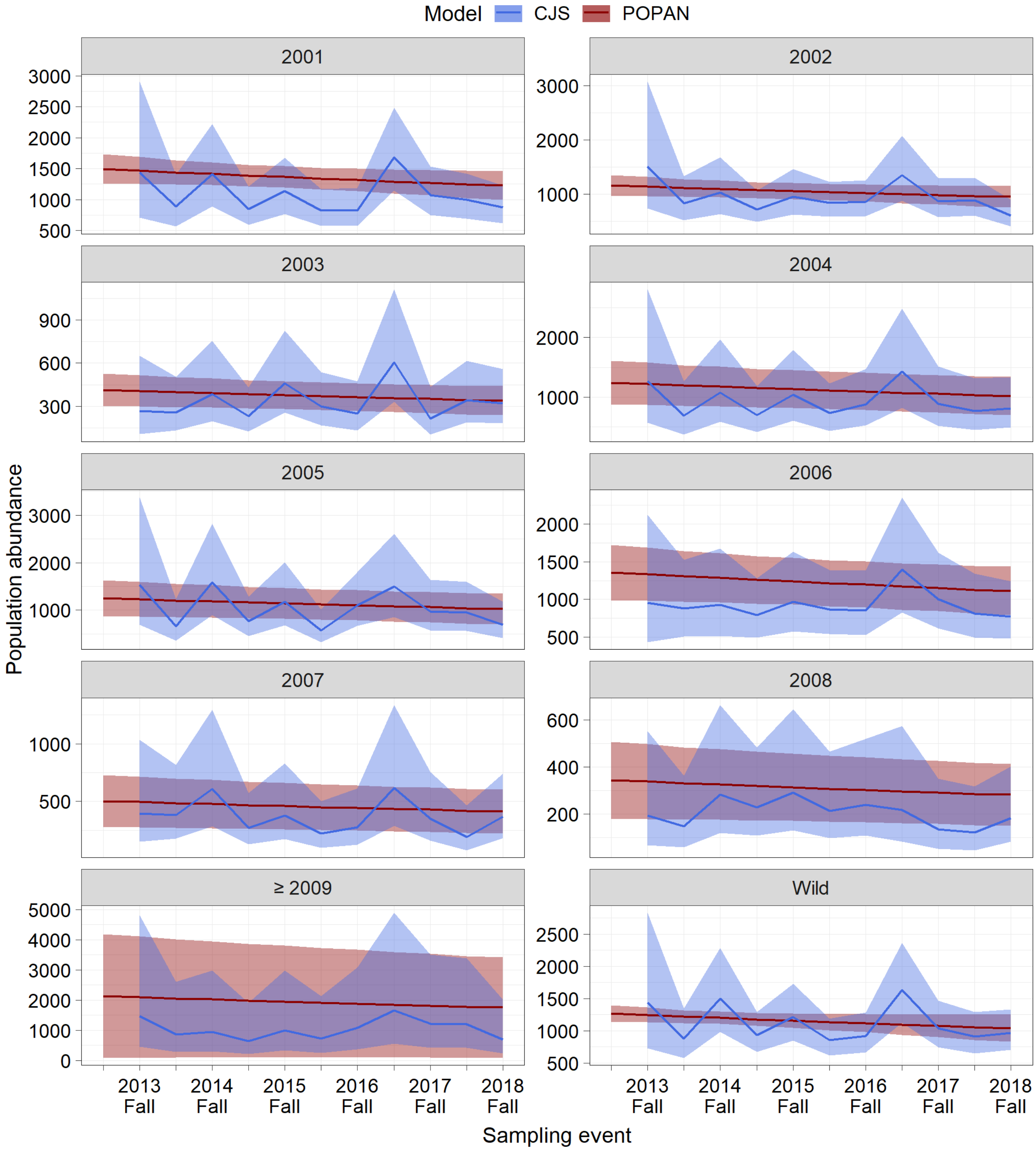
Table), the decrease in population abundances was estimated for all year-classes. In fall 2018, estimated population abundances by year-class were 82% of the estimate for spring 2013 for all year-classes (**Table**), since the top model, selected for interpretation, represented survival as a simple constant value (

DRAFT

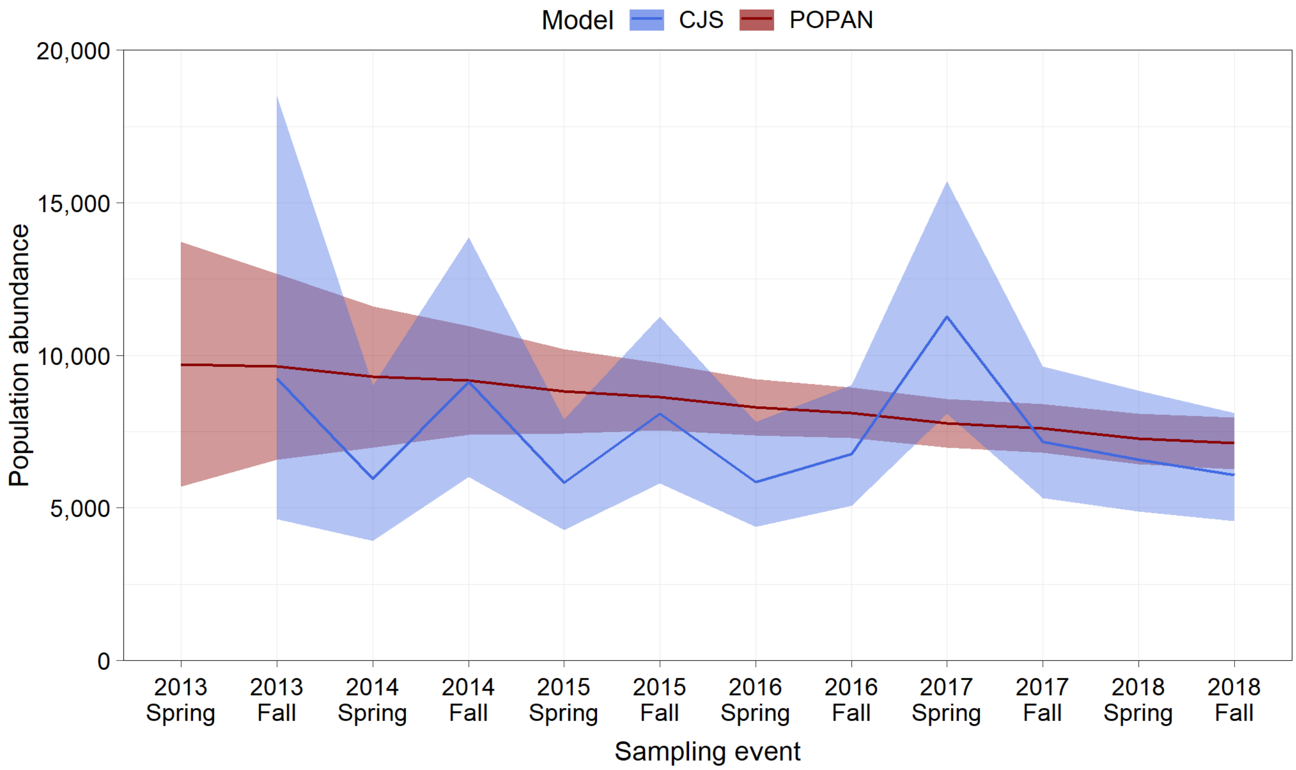
Table).

Combined across all year-classes, CJS abundance estimates indicated a stable or slightly decreasing population abundance, as abundances generally fluctuated between sampling events but did not exhibit a strong directional trend over time. Mean abundance was estimated to be 10,456 fish in fall 2013 (95% CI of 5,244 – 20,850 fish) and a total of 6,274 fish in fall 2018 (95% CI of 4,836 – 8,139). The mean abundance estimate in fall 2018 (6,274 fish) represents a decrease of 40% relative to the abundance estimated in fall 2013, or a 4% decrease relative to the abundance estimated in spring 2014. In contrast, POPAN estimates consistently decreased from 11,154 fish in spring 2013 (95% CIs of 8,697 – 13,612 fish) to 9,168 fish (95% CIs of 6,996 – 11,341 fish) in fall 2018, which is a 18% reduction in the mean abundance estimate.

DRAFT



ANNEXE VV **Figure 31: Population abundance estimates of White Sturgeon by year-class based on CJS and POPAN models in the Canadian portion of the transboundary area. Estimates are detailed in Table .**



ANNEXE WW Figure 32: Total population abundance estimates of White Sturgeon based on CJS and POPAN models in the Canadian portion of the transboundary area. Estimates but are detailed in Table .

Analysis of Sensitivity to Sampling Design

The analysis of sensitivity to sampling design resulted in 12 sets of models, with a set for each combination of country (US or Canada), model type (CJS and POPAN), and scenario (only fall sampling, sampling every other year but both seasons, and sampling every other year and only in the fall). For each model set, the best model was selected for interpretation (**Table 15**). In the US, the effect of a harvest fishery was estimated in both CJS and POPAN models of the full data set, but only in the CJS model of fall-sampled data. Some of the models of reduced data sets resulted in a simplified structure, e.g., constant recapture rates in the best-fitting CJS models of data sampled every other year and only in the fall.

DRAFT

DRAFT

ANNEXE XX **Table 15: Top CJS and POPAN models developed during analysis of sensitivity to sampling design. The specifications of survival (Phi), recapture rates (p), probability of entry (pent), and superpopulation (N) are indicated for each model, as applicable, as well as the number of model parameters (npar), and QAICc statistics (estimated within each set of models; however, only top model is shown for each set of models).**

Country	Sampling design	Model	Phi	p	pent	N	npar	QAICc	ΔQAICc	QAICc weight
US	Full data set	CJS	Year-class + Fishery	Year-class + Occasion	---	---	29	12641.1	0	0.61
		POPAN	Fishery	Year-class * Occasion	Constant (zero)	Year-class	112	13360.1	0	0.58
	Only fall samples	CJS	Year-class + Fishery	Year-class + Occasion	---	---	26	8420.1	0	0.55
		POPAN	Constant	Year-class * Occasion	Constant (zero)	Year-class	78	8961.8	0	0.48
	Sample every other year, fall and spring sampling	CJS	Year-class	Year-class + Occasion	---	---	25	4874.2	0	0.66
		POPAN	Occasion	Year-class * Occasion	Constant (zero)	Year-class	64	5187.4	0	0.96
	Sample every other year, only fall sampling	CJS	Year-class	Constant	---	---	12	2178.2	0	0.33
		POPAN	Constant	Year-class * Occasion	Constant (zero)	Year-class	45	2495.8	0	0.50
Canada	Full data set	CJS	Constant	Year-class + Occasion	---	---	21	7106.9	0	0.96
		POPAN	Constant	Year-class * Occasion	Constant (zero)	Year-class	137	8066.12	0	1.00
	Only fall samples	CJS	Constant	Year-class + Occasion	---	---	15	1954.6	0	0.97
		POPAN	Constant	Year-class * Occasion	Constant (zero)	Year-class	71	2446.7	0	1.00
	Sample every other year, fall and spring sampling	CJS	Year-class	Occasion	---	---	15	2495.3	0	0.78
		POPAN	Constant	Year-class * Occasion	Constant (zero)	Year-class	57	3107.06	0	1.00
	Sample every other year, only fall sampling	CJS	Year-class	Constant	---	---	9	651.6	0	0.43
		POPAN	Year-class	Year-class + Occasion	Constant (zero)	Year-class	26	1046.4	0	1.00

Notes: [1] = to assist parameter estimation and based on preliminary analysis, recapture rates were forced to be the same between the first and third sampling efforts for year-classes 2007, 2008, and ≥2009.

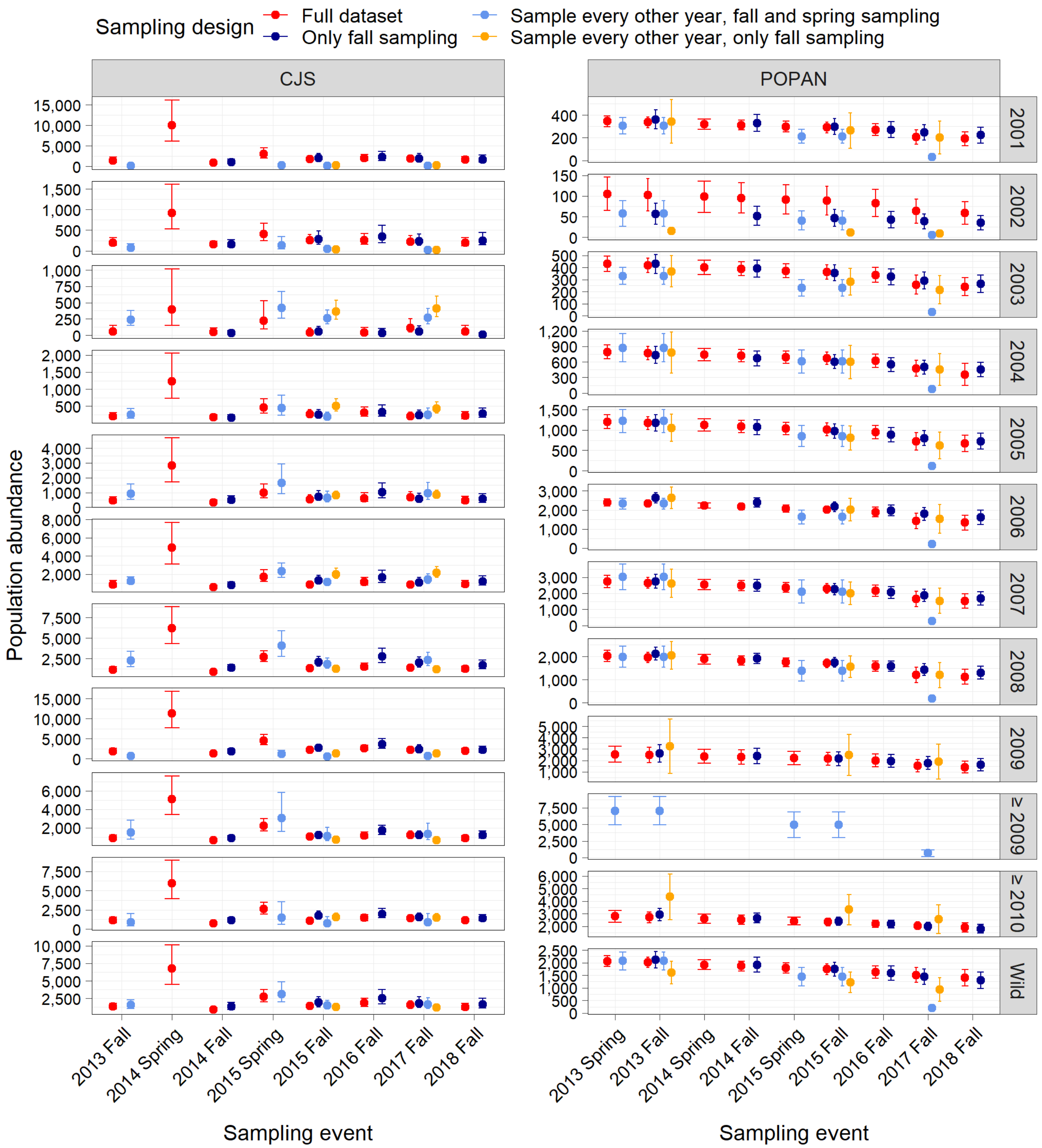
In the US, the effect of removing spring samples from the data resulted in similar or slightly higher abundances when compared to the original estimates for both CJS and POPAN models, whether examined by year-class (**Figure 33**) or all data combined (**Figure 34**). The scenario of sampling only every other year but using both spring and fall data resulted in some decreased abundances (e.g., for year-classes 2001, 2002, 2009, and ≥2010 for CJS models and all year-classes in 2015 and 2017 POPAN estimates). This scenario resulted in a substantial decrease in abundances estimated in fall 2017, considerably underestimating the year-class and total abundance. On the other hand, a sampling design where data were collected every other year but only in the fall resulted in mean estimates that were overall similar to the estimates of the original analysis, in both CJS and POPAN models, and for both year-class-specific and total abundances. However, this scenario resulted in an increase uncertainty around the mean estimates relative to the abundance uncertainty estimated from the full data set, ranging from an increase of 23% (CJS model, fall of 2017) to an increase of 230% (POPAN model, fall of 2013).

Overall, in the US, reduction of effort from a twice-annual sampling to a single annual sampling did not substantially affect mean abundance estimates or the uncertainty around the estimates. Reduction of effort to sampling every other year, but including both seasons, resulted in a strong negative bias of the resulting abundance estimates, considerably changing the mean estimates, while also increasing the uncertainty around the means. In comparison, sampling every other year and in fall did not consistently bias mean abundance estimates, but inflated the uncertainty relative to the uncertainty of the original estimates.

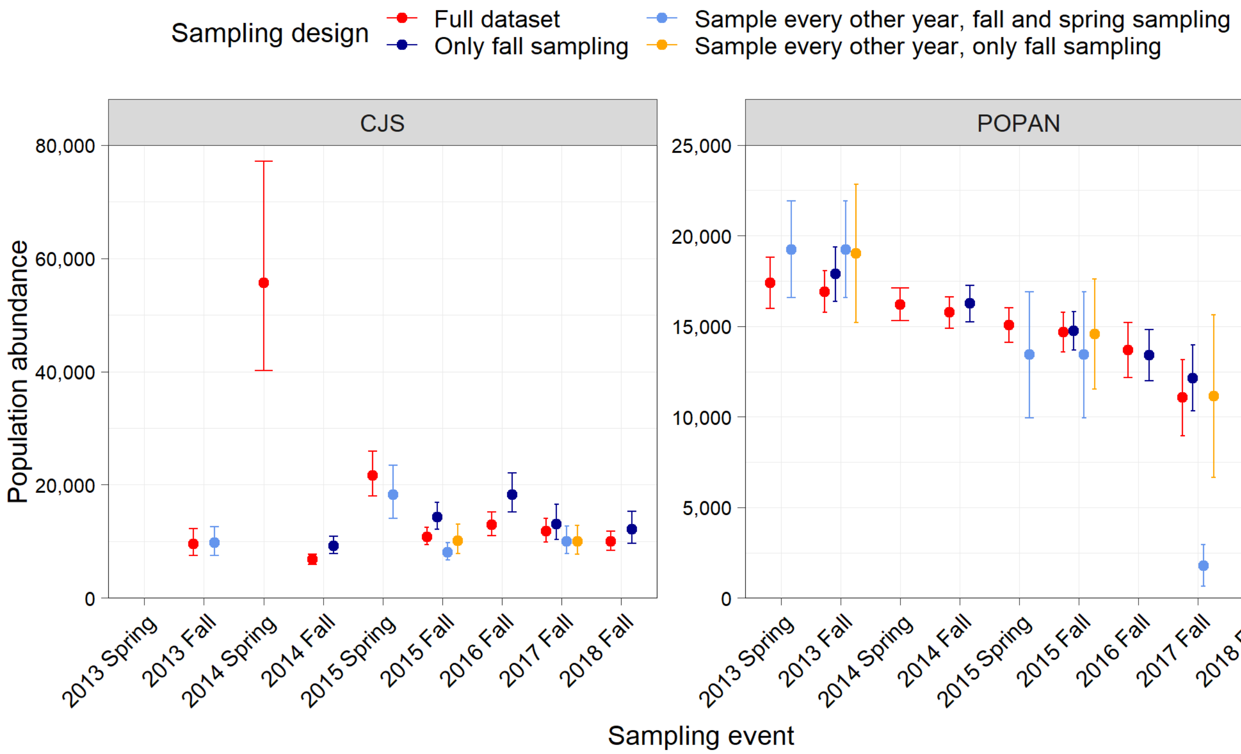
In the Canadian portion of the transboundary area, the effect of removing spring samples from the data resulted in an increase in both mean and uncertainty of abundance estimates based on both CJS and POPAN models (**Figure 35**, **Figure 36**), although a few cases of reduced estimates were also recorded, e.g., year-class 2005 in fall 2016 (**Figure 35**). Overall, the fall-only sampling resulted in higher abundance estimates that were also much more uncertain, with uncertainty increases relative to the original estimates ranging from 119% (CJS model, fall 2018) to 269% (CJS model, fall 2014). The sampling design where data were collected only every other year, but included both fall and spring collections, resulted in considerably lower abundance estimates for both CJS and POPAN models. In POPAN models, the top model for this sampling design estimated mean survival at essentially 1.0. While abundance was approximately 25% lower than mean values estimated from the full dataset, the perfect survival resulted in no decrease in abundance estimates over time, which is not likely, and differs from the estimates based on the full data set. In comparison, a sampling design where data were collected every year but only in the fall resulted in a faster rate of decline than that of the original model (for POPAN model) and in considerably lower CJS-based abundance estimates.

Overall, in the Canadian portion of the transboundary area, reduction of effort from a twice-annually sampling to any of the three examined scenarios resulted in substantial changes to mean values (as in the two scenarios where sampling is only performed every other year) or in considerable inflation of the uncertainty around the estimates (as in fall-only sampling designs, whether annual or every other year). Removal of spring samples resulted in a positive bias of mean estimates and a large increase in uncertainty, whereas sampling every other year, but in both spring and fall, resulted in a strong negative bias in mean estimates of abundance.

DRAFT

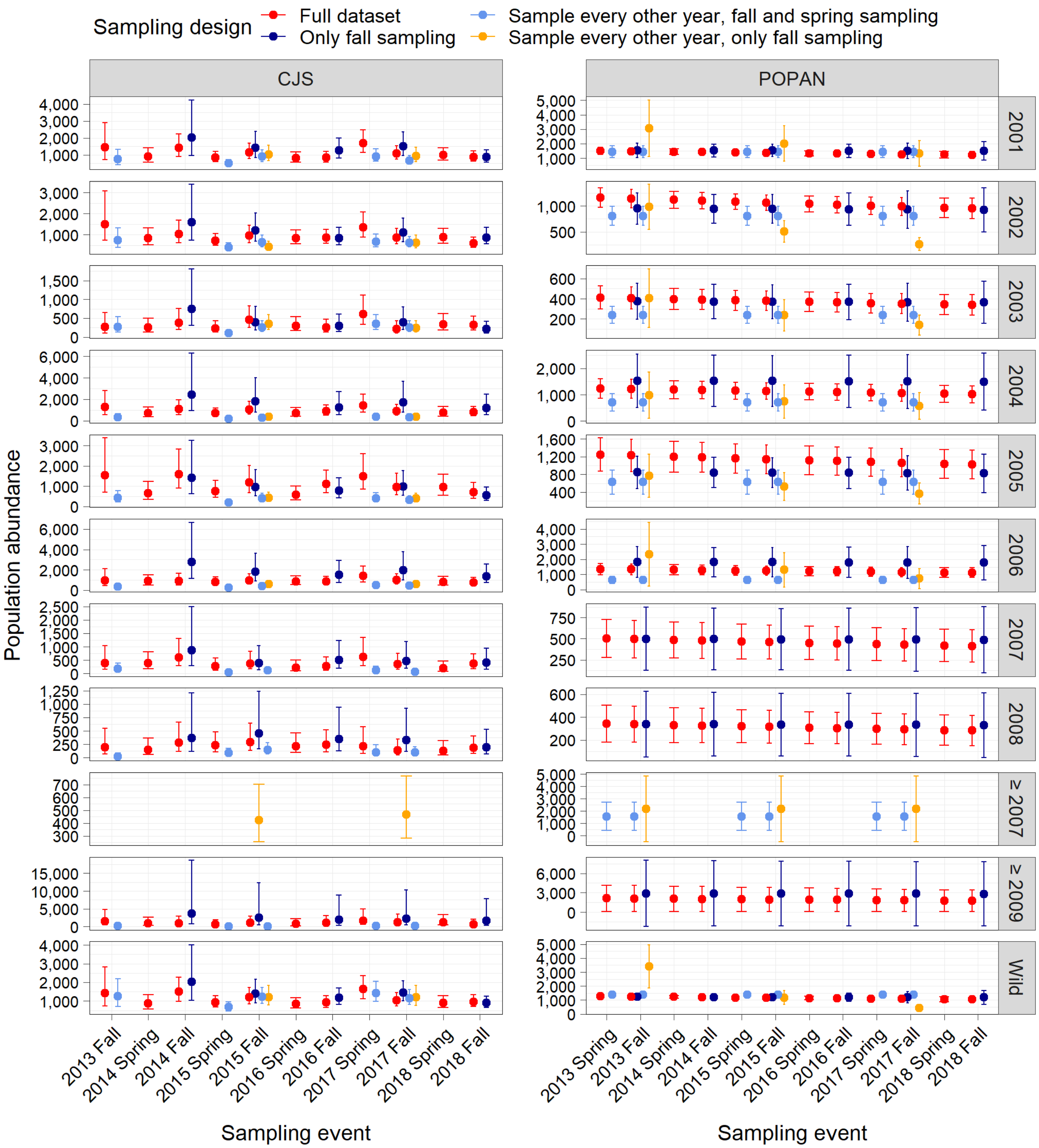


ANNEXE YY **Figure 33: Population abundance estimates of White Sturgeon in the US, by year-class and sampling design, based on CJS and POPAN models in the US portion of the transboundary area. Models used to derive the estimates are detailed in Table 15.**

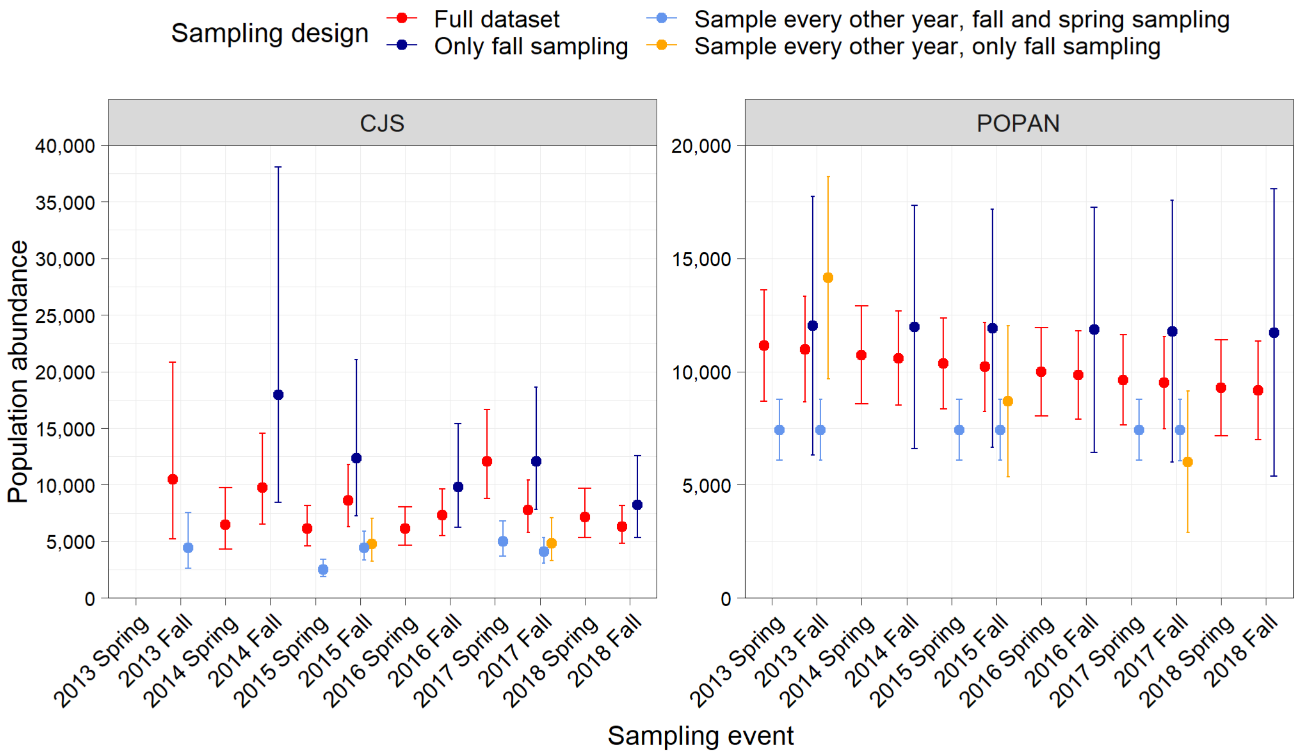


ANNEXE ZZ **Figure 34: Total population abundance estimates of White Sturgeon, by sampling design, based on CJS and POPAN models in the US portion of the transboundary area.**

DRAFT



ANNEXE AAA **Figure 35: Population abundance estimates of White Sturgeon, by year-class and sampling design, based on CJS and POPAN models in the Canadian portion of the transboundary area. Models used to derive the estimates are detailed in Table 15.**



ANNEXE BBB Figure 36: Total population abundance estimates of White Sturgeon, by sampling design, based on CJS and POPAN models of White Sturgeon in the Canadian portion of the transboundary area.

DRAFT

DISCUSSION

Length, Weight, and Growth

The growth of hatchery-released White Sturgeon differed significantly based on country of original release and country of residency. Fish that were released in Canada and moved into the US portion of the transboundary area exhibited the fastest growth, whereas fish that were released in the US and moved into the Canadian portion of the transboundary area exhibited the slowest growth. These results indicate a strong effect of environment, since fish released in the same location grew very differently in different areas; this may be due to temperature differences, hydrological differences, or food availability. In addition, the results suggest an effect of stock genetics, since fish captured in the same location (either Canada or the US) grew differently based on their original country of release, and therefore the genetic makeup of the brood fish. Specifically, fish released in the US grew faster than fish released in Canada.

The condition (weight-at-length) of hatchery-reared fish at original release did not always correspond with the condition of fish at recapture. While year-class 2006 had above-average condition at both original release and at recapture, year-classes 2012 and 2013 had average or high condition at original release, but decreased condition relative to the average at recapture. These differences in growth between year-classes may be the result of stock genetics or of food availability. With the removal of fish from the system via culling and a harvest fishery, it will be possible to examine whether growth patterns of the remaining fish change.

Fish growth decreased with age, as expected by the von Bertlanffy model. Growth between subsequent recaptures was highest in the summer (i.e., capture in the spring and recapture in the fall) and generally lower in the winter (i.e., capture in the fall and recapture in the spring). Fish that were originally released in Canada and remained in Canada generally had lower body weight at previous capture than fish that moved to the US, as expected based on the reduced length-at-age of the fish that remained in Canada.

Fish culling (Canada and US) and fishery harvest (in the US only) affected the distribution of year-classes observed in each sampling event. The 2006 year-class, which was the most dominant in the 2013-2014 sampling events (and had the fastest growth, as weight-at-length values), decreased in abundance and by 2017, it became only the fourth largest year-class in the US. The effect of culling and fishery on the survival and growth of the remaining sturgeon is not yet known, and will be examined after more data are collected.

Spatial Distribution

1.1.1 Spatial Distribution of White Sturgeon

In the Canadian portion of the transboundary area, sturgeon were generally concentrated in the vicinity of the HLK Dam (habitat zone 1). The proportion of positive catch near the HLK Dam was usually >75%, whereas the values decreased with distance from the Dam, up to habitat zone 5 (immediately upstream of the US-Canada border). In the US portion of the transboundary area, positive catch was often higher in the upstream zones than further downstream, except during spring sampling in 2013 to 2015. Similar to the proportion of positive catch, the CPUE values of efforts with positive catch were higher in habitat zone 1 of the Canadian portion of the transboundary area and in habitat zones 7 and 8 in the US portion of the transboundary area.

The uneven distribution of fish across the transboundary area underlines the importance of a spatially-balanced, consistent sampling design. The low recapture probability estimated for spring 2017 based on the analysis of 2013-2017 data (Golder 2018) was likely driven by the lack of sampling in habitat zones 6 and 7, since zone 7 had high positive catch values in spring 2015 and spring 2016, as well as high CPUE in efforts with positive catch.

1.1.2 Spatial Mark-Recapture Analysis

Mark-recapture estimates of abundance can be biased in certain situations, such as when animals differ in their exposure to the capture method (i.e., some animals are closer and therefore more likely to be captured) or the spatial extent of the target population is poorly defined (Efford and Fewster 2013). Spatially-explicit mark-capture methods that account for the spatial distribution of animals and capture devices produce less biased estimates of density in some situations. We reviewed spatially-explicit mark-recapture methods to determine whether they could improve abundance estimates of the transboundary White Sturgeon population compared to conventional, non-spatial mark-recapture.

DRAFT

Most spatially-explicit mark-recapture methods are area-based and account for the location of capture devices and animals in two dimensions (e.g. the R package ‘secr’; Efford 2019). A recent R package, ‘linearsecr’ allows for spatially-explicit mark-recapture in linear habitats and is suitable for animals in rivers or other habitats where expressing density in terms of animals per km is appropriate (Efford 2017). Both the area-based and linear mark-recapture methods rely on typical assumptions for closed populations, with no additions or losses (births/deaths, immigration/emigration). Both the linear and area-based spatially-explicit mark-recapture methods for closed populations are based on the robust design (Pollock 1982), where there are multiple sampling “occasions” (e.g., weekly or daily sampling) within each sampling “session” (e.g., each year or season). Methods for spatially-explicit mark-recapture for open populations, which allow for losses/additions of animals between occasions, have recently been developed in the R package ‘openCR’ (Efford 2019b). This software allows for Cormack-Jolly-Seber (CJS) or Jolly-Seber-Schwarz-Arnason (JSSA) open population models that do not require more than one sampling occasion per session.

The study area for the transboundary White Sturgeon population is riverine and could be considered linear, although certain sections of the river in Lake Roosevelt Reservoir may be suitable for area-based methods. Annual mark-recapture sampling includes only one sampling occasion per session. Therefore, the White Sturgeon data are not suitable for current software for linear or area-based spatial mark-recapture methods based on the robust design. Spatially explicit methods for open populations such as the ‘openCR’ package would allow a spatial CJS model for the White Sturgeon data, but the spatial component would be area-based, not linear. To our knowledge, methods for spatially-explicit mark-recapture in linear habitats for open populations have not been developed. Other limitations of the ‘openCR’ package are that it is very recently developed, the utility of spatial CJS method is somewhat questionable (Efford 2019b), and there is little guidance or documentation available for the software. For these reasons, spatially-explicit mark-recapture models are not recommended at the present time for the transboundary White Sturgeon data set.

Movement Patterns

Hatchery-reared fish that were originally released in Canada in the early years of stocking (year-classes 2001-2003) were more likely to remain within Canada than hatchery fish that were released in later years (year-classes 2007-2013). Conversely, hatchery fish that were released in the US in the earlier years (year-classes 2004-2005) moved into Canada more often than fish released in later years. Following original release, fish moved across multiple habitat zones, populating mainly habitat zones 1 (near the HLK Dam) and zones 7 and 8 in the US, consistent with the observed high proportion of positive catch and CPUE values in these three areas. While movement between original release of hatchery-reared fish and subsequent recapture was high, movement between recaptures during the 2013-2018 sampling program was low, especially in the Canadian portion of the transboundary area. In the US, fish moved between habitat zones 6, 7, and 8, although they were more likely to move downstream than upstream. Distance traveled between subsequent recaptures did not have apparent patterns with time between recaptures, season of capture or recapture, or direction (downstream or upstream).

DRAFT

With the onset of harvest fishery in the US in summer 2017, it was of concern that fish from the Canadian portion of the transboundary area would move into the US and be harvested. The movement patterns recorded during the 2013-2018 suggest very minimal movement from the Canadian portion of the transboundary area into the US. Only 16 fish out of 2,250 unique tags captured at least twice during the 2013-2018 study period moved from Canada to the US (compared to 57 fish that moved in the opposite direction). Therefore, it is not likely that the harvest fishery in the US will affect White Sturgeon that did not migrate into the US prior to this study. However, this pertains only to fish of year-classes 2001-2013 that have been released in the area up to 2014. During the 2002-2014 releases of hatchery-reared fish, fish that were released in Canada in later years were very likely to move across the border. Therefore, any new releases of hatchery-reared fish should take into account possible high movement rates, with subsequent harvest in the US.

Survival, Recapture, and Abundance Estimates – US

The harvest fishery in Lake Roosevelt, which began in summer 2016, reduced estimated survival for the relevant year-classes (as defined based on sampled fish lengths and fishery slot size). Fish recruitment to the sampling gear resulted in younger year-classes having recapture probabilities that were low in the early sampling years but increased in the later portion of the sampling period. In 2017 and 2018, as intermediate-size fish were removed in the fishery and younger fish recruited to gear, the recapture of younger year classes was estimated to be higher than that of some of the older year-classes.

As in previous assessments (Golder 2018), spring recapture rates were considerably lower than those estimated for the fall. Since spring 2016 and 2017 data were removed from analysis, it was not assessed whether the pattern continued in these years.

Population abundance based on CJS models was relatively stable throughout the 2013-2018 study, whereas population estimates based on POPAN models decreased consistently throughout the 2013-2018 period, resulting in a mean abundance estimate that was 41% lower relative to the mean abundance estimated in the beginning of the study period. Note that CJS-based abundance estimates are expected to be less precise than the POPAN estimates and should only be used for comparison purposes.

DRAFT

Survival, Recapture, and Abundance Estimates – Canada

Fish recruitment to the sampling gear resulted in recapture probabilities that depended on year-class and sampling event, with low recapture of younger fish in all sampling years, but an increase in recapture rates of younger year-classes in the later portion of the sampling period. No consistent difference in spring and fall recapture probabilities was identified, as opposed to the lower recapture probability in the spring that was observed in the US portion of the transboundary area.

Population abundance based on CJS models fluctuated between sampling events throughout the 2013-2018 sampling program, but did not suggest a strong, long-term increasing or decreasing trend. For example, mean abundance estimates for fall 2018 were 40% lower than mean estimates for fall 2013, but 2% higher than mean estimates for spring 2015. Population abundance estimates based on POPAN models decreased consistently throughout the 2013-2018 sampling, with mean estimates in fall 2018 decreasing by approximately 27% relative to either spring or fall 2013 estimates. Note that CJS-based abundance estimates are expected to be less precise than the POPAN estimates and should only be used for comparison purposes.

Sensitivity to Sampling Design

In the US, the analysis using fall-only sampling resulted in no substantial change to mean abundance estimates. Further reduction of the effort, to sample only in the fall of every other year did not affect mean abundance estimates, but inflated the uncertainty around the estimates. Of the three sampling scenarios examined, sampling every other year but including both spring and fall collections resulted in the largest change to estimates of abundance relative to the original values estimated based on the full 2013-2018 data set.

In contrast, in the Canadian portion of the transboundary area, all three of the reduced effort scenarios resulted in considerable changes to mean values or uncertainty around them. This sensitivity is likely due to the difference in sample sizes collected in the US and Canada. In the cleaned data set used for analysis in this report, the US data set had a total of 8,262 fish, of which only 1,482 (18%) were collected in the spring. On the other hand, the data set of fish sampled in Canada only had 3,668 records, of which 1,529 fish (42%) were sampled in the spring. Therefore, even the removal of spring sessions in Canada resulted in a large decrease in sample size, and therefore a large change in estimated abundance values relative to the original population abundance.

The sensitivity analysis performed here used the combined 2013-2018 data set, which was repeatedly reduced to mimic data collected under the three sampling scenarios. However, reduction of effort would be performed in the future, and any data collected under a lower effort scenario would be analyzed together with the combined 2013-2018 data. This is expected to decrease the extent of change of sampling design on both means and uncertainty estimates of population abundance, if survival and recapture estimates in best-supported models share information between sampling years (e.g., models where survival is constant or only depends on year-class).

Overall, in the US, it is estimated that the omission of spring sampling from future data collection efforts will not severely affect resulting abundance estimates. Even a larger decrease in sampling effort, with data collected only in the fall of every other year, is not expected to strongly affect mean abundance estimates, although it will likely increase uncertainty. In Canada, the reduction of effort, whether to spring-only sampling or to every other year sampling, will have a larger effect on population abundance estimation than in the US.

RECOMMENDATIONS

Based on the current study, the following recommendations are made:

1) Data management – it is recommended that the full collected data set be imported into a single database. This would help resolve inconsistencies in data collection between BC

DRAFT

Hydro, CCT, and STOI. It would also assist with data cleaning, future data access, and subsequent additions to the database.

Sampling consistency – the spatial balance of the samples over time is required to correctly model recapture probabilities. Inconsistent samples (such as in the US in spring 2016 and 2017) prevent the use of the collected data in the models. It is recommended that consistent sampling is adhered to throughout future sampling events.

Growth analysis – the removal of fish due to culling and harvest fishery may result in changes to growth patterns of the remaining White Sturgeon, if density dependence occurred prior to fish removal. It is recommended to assess whether growth patterns differed before and after culling efforts and harvest fishery.

Sampling design – a reduction in effort had a strong effect on mean values of population abundance and the uncertainty associated with them, especially in the Canadian portion of the transboundary area. Considering this finding and the interest in reducing effort while maintaining the ability to detect changes to the population, it is recommended that survival values of interest be identified (e.g., reduction of 10%, 20%, and 30% of survival) and a simulation analysis be performed to estimate the magnitude of change in population abundances as a result of survival reduction, under the different sampling scenarios.

CLOSURE

We trust that the information contained in this report meets your present requirements. Please contact us if you have any questions or concerns regarding the above

Golder Associates Ltd.

Sima Usvyatsov
ANNEXE CCC
Biologist

David Roscoe, MSc, RPBio
Biological Scientist Fisheries

Reviewed by:

Shawn Redden, RPBio
Associate, Senior Fisheries Biologist

SU/DR/SR/cmc

DRAFT

https://golderassociates.sharepoint.com/sites/10649g/6 deliverables/1773569-006-r-reva/1773569-006-r-reva-mark-recap 30sep_19.docx

DRAFT

REFERENCES

Efford, M.G., and Fewster, R.M. 2013. Estimating population size by spatially explicit capture–recapture. Oikos 122: 918-928.

Efford, M.G. 2017. secrlinear: Spatially Explicit Capture--Recapture for Linear Habitats. R package version 1.1.1. https://CRAN.R-project.org/package=secrlinear

Efford, M. G. 2019a. secr: Spatially explicit capture-recapture models. R package version 3.2.0. https://CRAN.R-project.org/package=secr

Efford, M.G. 2019b. openCR: Open population capture-recapture models. R package version 1.3.4. https://CRAN.R-project.org/package=openCR

Kahle, D., and Wickham H. 2013. ggmap: Spatial Visualization with ggplot2. The R Journal 5: 144-161. URL http://journal.r-project.org/archive/2013-1/kahle-wickham.pdf

Laake, J.L. 2013. RMark: An R interface for analysis of capture-recapture data with MARK. AFSC Processed Rep 2013-01, 25p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Pollock, K.H. 1982. A capture–recapture design robust to unequal probability of capture. Journal of Wildlife Management 46: 757–760.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Austria. URL http://www.R-project.org/.

White, G.C., and Burnham, K.P. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46(Suppl.): 120–138.

Wickham H. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

DRAFT