Columbia River Project Water Use Plan

Columbia River White Sturgeon Management Plan

Implementation Year 10

Reference: CLBMON-28

Lower Columbia River Adult Sturgeon Population Monitoring

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BC Hydro
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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 five-year population assessment was initiated to estimate survival rates and abundance of the entire transboundary White Sturgeon population. Additionally, data from this program are being used to determine growth, fish condition, age class structuring, and sex ratios. Movement data collected using acoustic telemetry indicated that wild adult sturgeon activity generally occurred during the summer months, likely for feeding or spawning activities. In general, adult White Sturgeon in the LCR are 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 2017, spawning was estimated to have occurred from late-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 2017 occurred June 11 through July 6 at Waneta and July 17 through July 19 at ALH. A single embryo was collected at Kinnaird, with spawning estimated to have occurred on July 10th.

In efforts to increase genetic diversity among stocked juvenile White Sturgeon, increase effective breeding number, and maintain genetic diversity within the population, a Streamside Incubation Facility (SIF) was developed and constructed near the Waneta spawning location for the purpose of incubating naturally produced embryos collected in the LCR. This was based on a 2011-2012 genetic study that determined the number of adults spawning annually in the LCR was more than 10-fold the number that contributed as broodstock in the Conservation Aquaculture Program. Following incubation in the SIF, hatched larvae were transported to the Kootenay Sturgeon Hatchery (KSH) 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 is now the sole provider of juvenile offspring to be stocked in the LCR.

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?	- The most recent abundance estimate for adult White Sturgeon remains at 1,100 in the Canadian section of the lower Columbia River as estimated by Irvine et al. (2007). A five-year systematic stock assessment was conducted from 2013 to 2017 and encompassed the entire Transboundary Reach of the lower Columbia River in Canada and the US. The goals of the stock assessment were to develop population and survival estimates to track recovery targets for this population. At the conclusion of 2017, all ten sessions have been completed and preliminary data analyses have estimated a wild population abundance of 1,071 (629-1,512) individuals. - 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 5,725 (5,022-6,428) 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 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.
How much spawning occurs annually at known spawning locations, and	- Wild spawning has been detected annually at up to 5 locations in the transboundary section of the Columbia River, and while

Management Question	Status
are there other spawning locations unidentified in the lower Columbia River?	confidence around the estimates of the number of spawning days is unknown, it is estimated that multiple spawning days occur annually with embryos surviving to hatch. - 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). - 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 Arrow Lakes Generating Station (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 (2007-2017) 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 Columbia River?	- 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 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. However, while movements have been identified, further data are required to address the interaction (i.e., spawning) of individuals from different sections of the lower Columba River using

Management Question	Status
	the long-term telemetry dataset.
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.

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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), 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. Release criteria developed for these wild origin fish is a minimum of 200 grams in body weight to improve survival following release based on results of recent juvenile survival modeling (BC Hydro 2016b). A total of 63 and 800 wild progeny met the release size criteria and were released the following spring after capture for year classes 2015 and 2016, respectively. In May 2018, 457 wild progeny of 2017 year class were released with additional fish (~150) to be released in the fall once size criteria are met. 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 2017, 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 five-year 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 KSH 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. Assist with directing broodstock acquisition efforts by following movements of fish of known sex or maturity.
2. Provide new information on suspected staging areas, and other suspected spawning sites throughout the LCR that may be used during varying ranges of flows.

3. Provide information on seasonal and annual movements, macro-habitat use, and transboundary interactions.

1.3 Study Area

The study area for the 2017 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; 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.

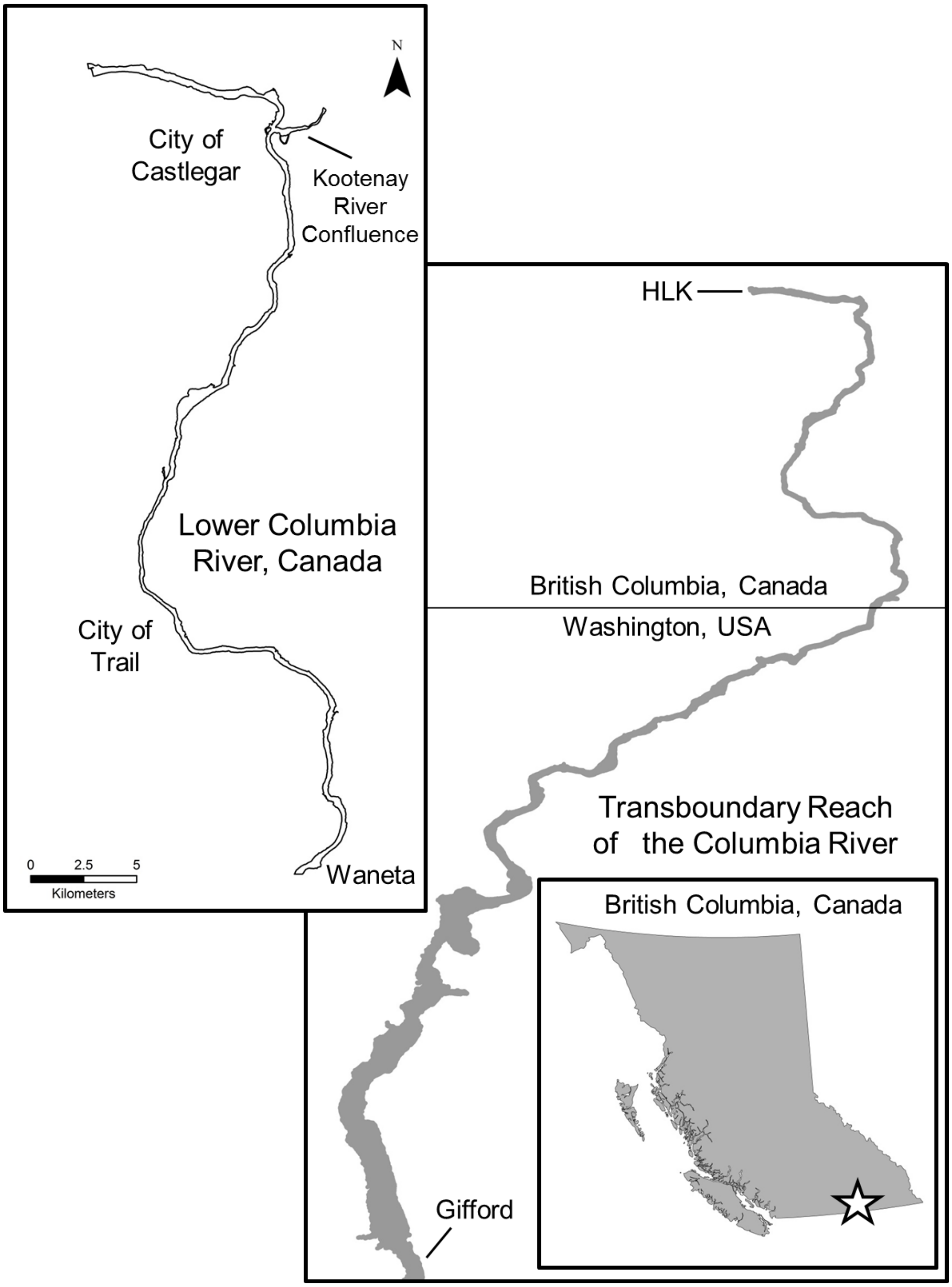

Figure 1. Overview of the study area in the lower Columbia River between Hugh L. Keenleyside Dam (HLK, rkm 0.1) and the Canada/US border (rkm 57.0) in relation to the Transboundary section of the Columbia River.

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 2017, 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 2017 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 12.8 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; Figure 2).

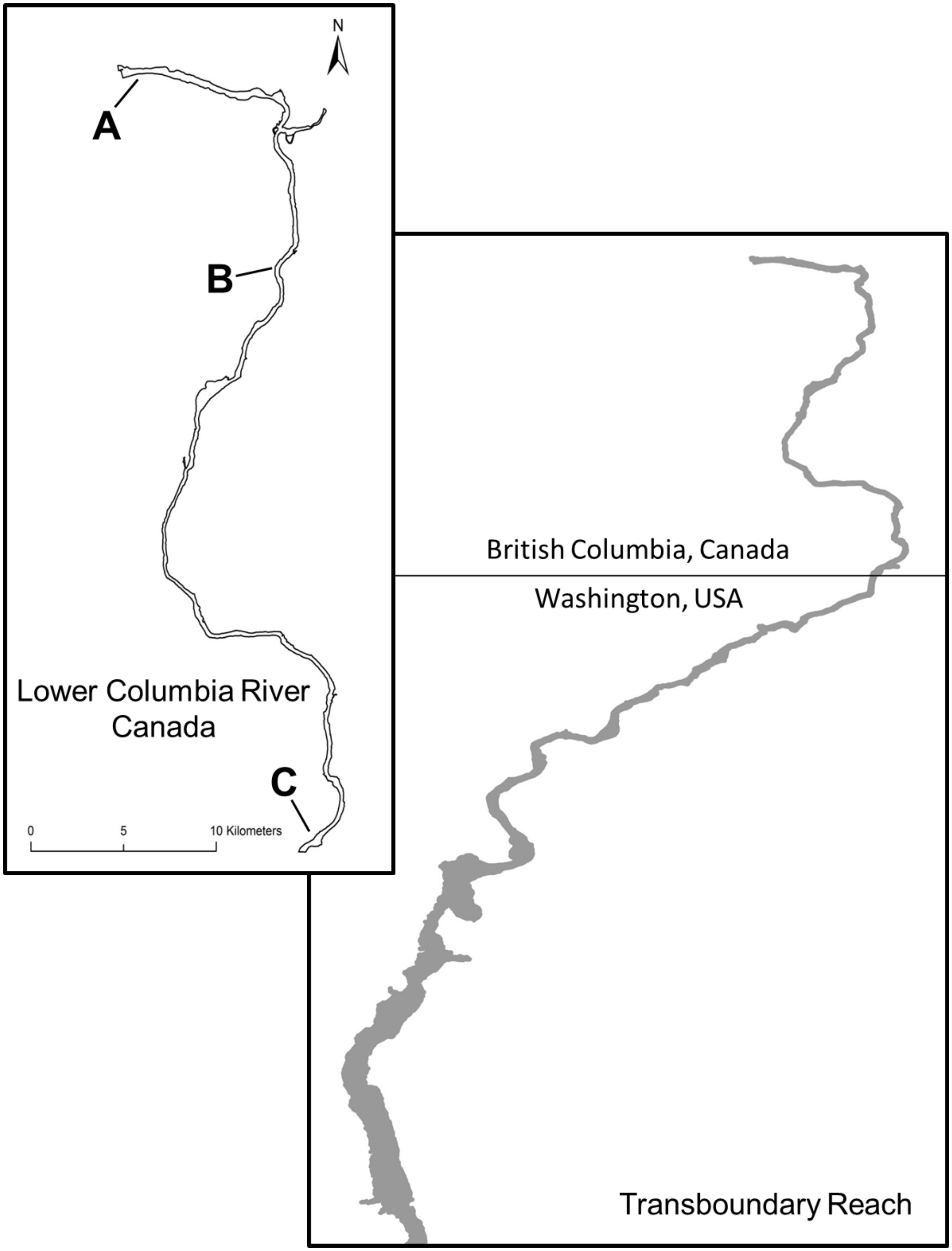

Figure 2. Egg mat and drift net deployment sites of ALH (rkm 0.1; A), Kinnaird (rkm 13.4 to rkm 19.2; B), and Waneta (rkm 56.0; C) in the lower Columbia River in 2016.

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).

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 were deployed at Waneta (n=8) and drift nets were deployed at Waneta (n=6), ALH (n=4), and Kinnaird (n=10; Table 1). The drift net locations at Waneta, ALH, and Kinnaird (rkm 18.2) have been consistent sampling locations since 2007, 2010, and 2009, respectively.

Table 1. Number of drift nets deployed at each spawn-monitoring site in 2017.

Site	rkm	n
Waneta	56	6
ALH	0.1	4
Kinnaird	13.4	3
Kinnaird	14.5	2
Kinnaird	16.9	1
Kinnaird	18.2	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 48 to 120 hour periods. 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 the upstream locations (ALH, rkm 0.1; Kinnaird, rkm 12.8 – 18.2) 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 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. 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 KSH within 7 days of hatch in tanks of ambient river water provided with an oxygen source. Juveniles were reared at the KSH until date of release into the LCR (see FFSBC 2018 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, and was continued for five years, ending in 2017.

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).

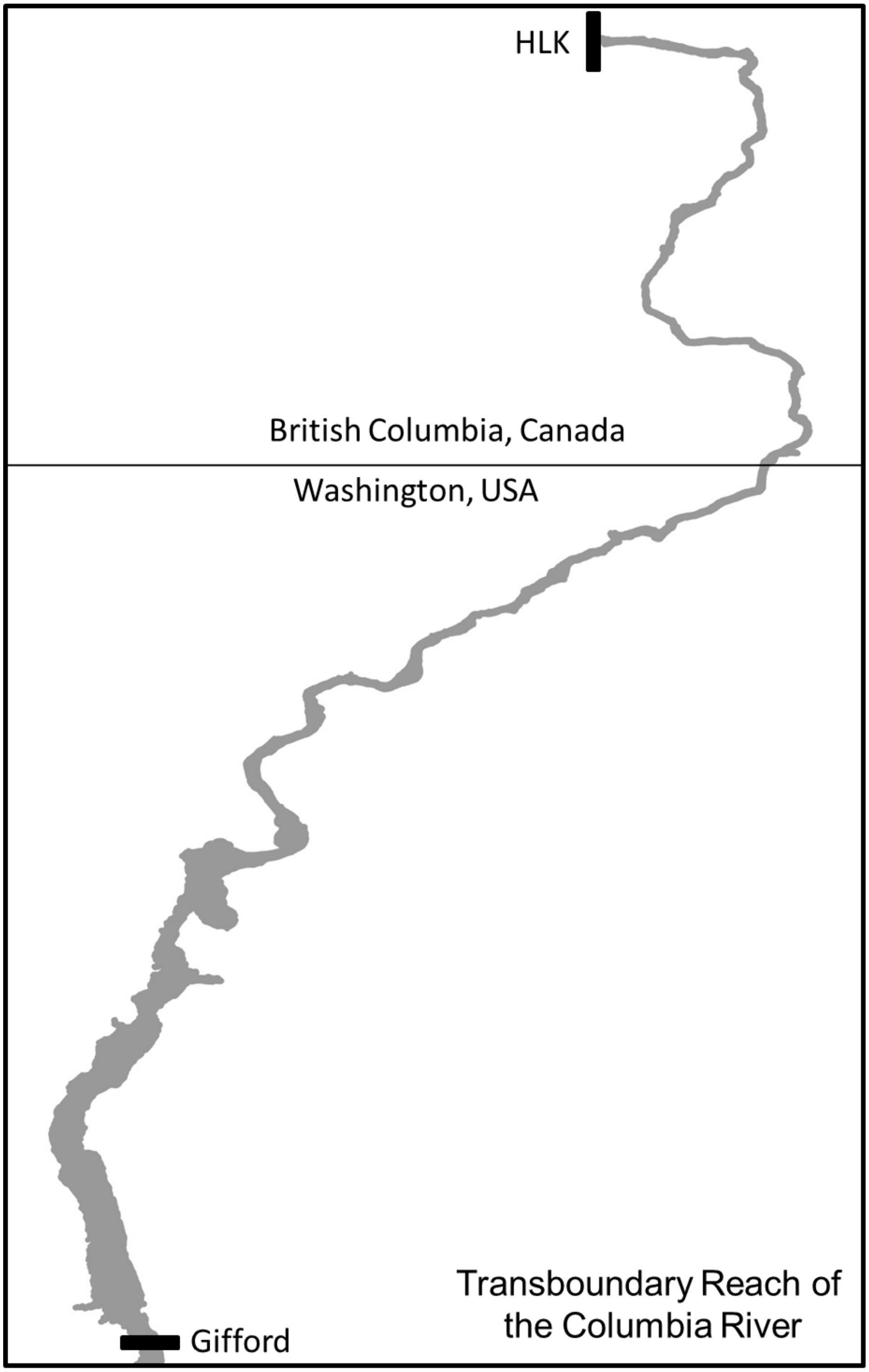

Figure 3. Study area for White Sturgeon stock assessment survey occurring from 2013-2017 in the transboundary reach of the Columbia River. Upstream extent of the study area is Hugh Keenleyside Dam in British Columbia, Canada, and the downstream extent of the study area ends at Gifford, Washington, USA.

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 2nd 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 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. Blood samples were not collected in 2017 as new methods are being developed to provide additional confidence in the measurement of ploidy levels. It is intended that starting in the fall of 2018, blood samples will be collected for ploidy analysis using revised methodology.

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 *Data Analyses*

Adult and juvenile White Sturgeon biological data analyzed in this report include sex ratios, fork length frequencies, 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).

2.3.5 *Mark-recapture analyses*

The 2013-2017 White Sturgeon mark and recapture dataset in the Transboundary Recovery Area of the Columbia River was used to generate preliminary survival, cross-boundary movement probabilities, and population abundance estimates using the programs R v. 3.4.2 (R Core Team 2017) and MARK (White and Burnham 1999) through the package ‘RMark’ (Laake 2013). Population estimates were constructed for wild and hatchery fish released in the US and Canada – by origin (wild / hatchery / combined) and by location (Canada / US / combined). 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. Multiple

Cormack-Jolly-Seber (CJS), POPAN, and multi-state models were examined. The following objectives were addressed:

1) Assessment of survival and recapture

This objective was addressed primarily using CJS models, with survival being allowed to vary by hatchery/wild (variable noted as HW), brood year (as year class for hatchery-reared fish and "Wild" for wild fish), and original country of fish release (Canada / US). Recapture rates were allowed to vary by sampling event, season, multiplicative effects of sampling event and country, and multiplicative effects of season and country. POPAN models also provide estimates of survival and recapture probability and were used for a comparison.

2) Assessment of population abundance in the Canada

This objective was addressed using a set of POPAN models on the Canadian dataset. Super population (for POPAN model estimation) was modeled as a function of hatchery/wild (variable noted as HW) and brood year (equal to year class for hatchery-reared fish and "Wild" for wild fish). The probability of entry (i.e., probability of new animals entering the sampled population) in POPAN model estimation was modeled as a constant, as a function of hatchery/wild, country of release, and an additive function of hatchery / wild and country of release. Due to some data sparsity of hatchery-reared fish from later year classes, all year classes from 2007 and on were aggregated into a single greater than 2007 year class identifier.

3) Assessment of the probability of movement across the Canada-US border

To assess the extent of fish movement across the boundary during the 2013-2017 sampling period, a set of multi-state models was constructed, where the location of fish was retained as part of the recapture history (for example, a fish captured in spring 2013 in Canada and then in fall 2015 in the US is represented as C00U00000). Due to convergence problems, the probability of survival was modeled only as a function of hatchery/wild fish origin. Recapture was allowed to vary with sampling event, country of recapture (stratum), and multiplicative function of sampling season and country of recapture. The probability of movement between the two countries was modeled as a constant, as a function of country of original release, multiplicative function of country of original release and whether the fish was hatchery or wild, a function of country of recapture (stratum), multiplicative function of current location and whether the fish was hatchery or wild, and both additive and multiplicative functions of current location and original country of release.

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. For this analysis, CJS models were not used to provide an estimate of abundance. Once the analyses are finalized in summer 2018, the models will be used to produce abundance estimates for comparison to POPAN abundance estimates. Note that CJS-based abundance estimates are expected to be less precise than the POPAN ones, and should only be used for comparison purposes.

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. 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 Kootenay Sturgeon 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
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 recorded 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.

Detection data from 2016 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).

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) measured from Arrow Reservoir, Kootenay River, Birchbank, and Canada/U.S. International Border for the 2017 study period is presented in Figure 4. 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 6,992.4 (cms) were reached on June 9th, 2017 ahead of with the estimated initial spawning date (Figure 4).

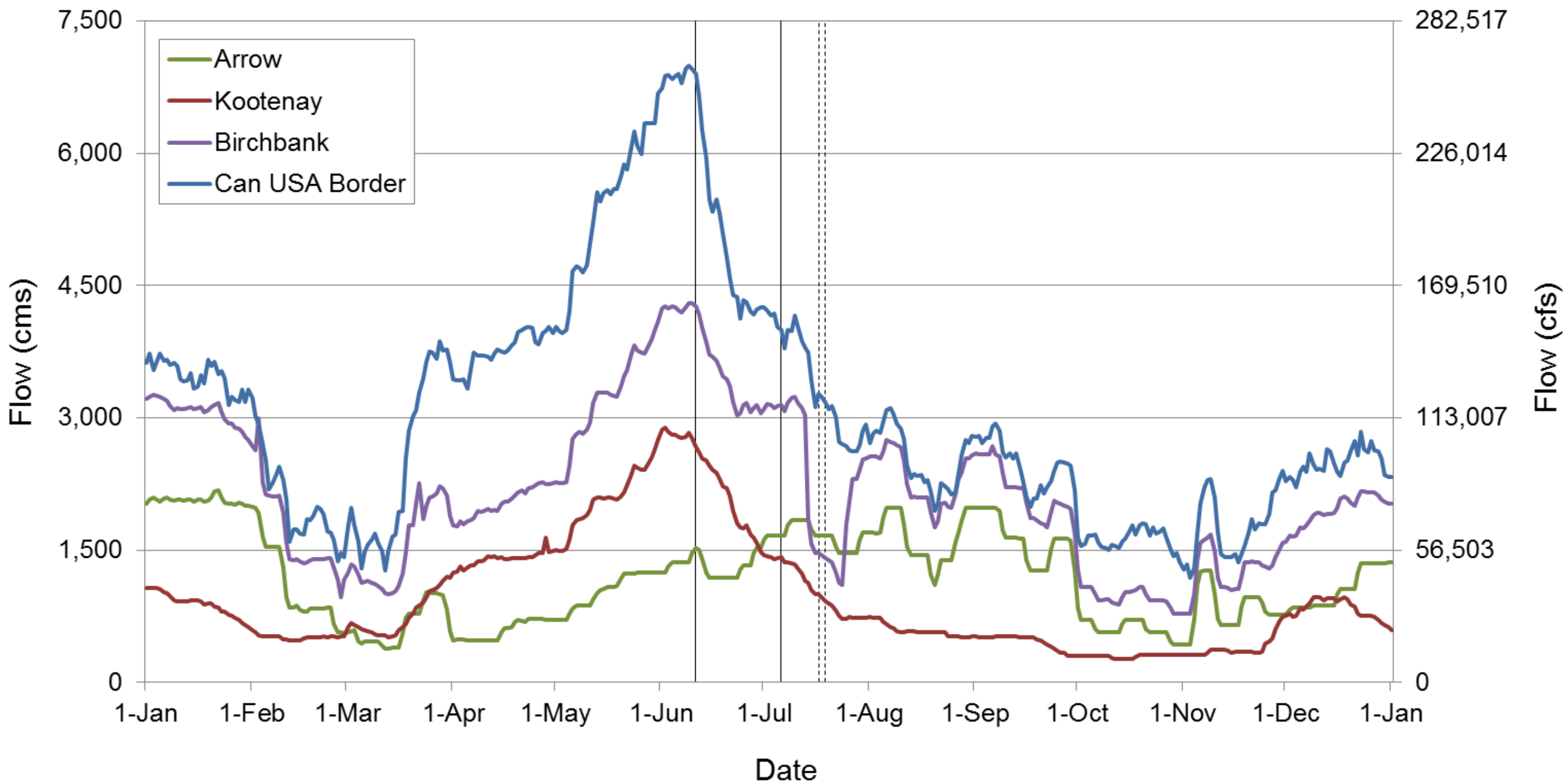

Figure 4. Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada/U.S. International Border on the lower Columbia River from January 01, 2017 – December 31, 2017. The solid and dashed vertical bars represent the first and last estimated spawning dates at Waneta and ALH, respectively. Estimated spawning dates were based on the developmental stage of collected embryos and/or larvae. One embryo was collected at Kinnaird (rkm 13.4 – 18.2) and was estimated to be fertilization on July 10.

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 2017.

Location	Discharge			
	Minimum (cms)	Maximum (cms)	Minimum (cfs)	Maximum (cfs)
Arrow Reservoir	382.16	2,176.25	13,496	76,853
Kootenay River	267.60	2,892.56	9,450	102,150
Birchbank	778.62	4,301.40	27,497	151,903
Border	1,188.75	6,992.40	41,980	246,934

3.1.2 *Water Temperature*

LCR mean daily water temperatures (°C) during 2017 are illustrated in Figure 5. 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 2017. 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).

Location	RKM	Temperature			Date of Suspected Spawning Threshold (14°C)
		Mean ± SD	Minimum	Maximum	
HLK	0.1	8.56 ± 5.04	1.9	18.7	22-Jun
Kootenay	10.5	9.46 ± 5.84	2.1	20.2	25-Jun
Kinnaird	13.4	9.14 ± 5.34	2.0	19.7	29-Jun
Genelle	26.0	9.03 ± 5.25	1.9	19.4	24-Jun
Rivervale*	35.8	9.18 ± 5.71	1.9	19.5	24-Jun
Waneta*	56.0	12.72 ± 5.22	2.9	20.7	22-Jun

*Data incomplete due to lost or damaged temp loggers

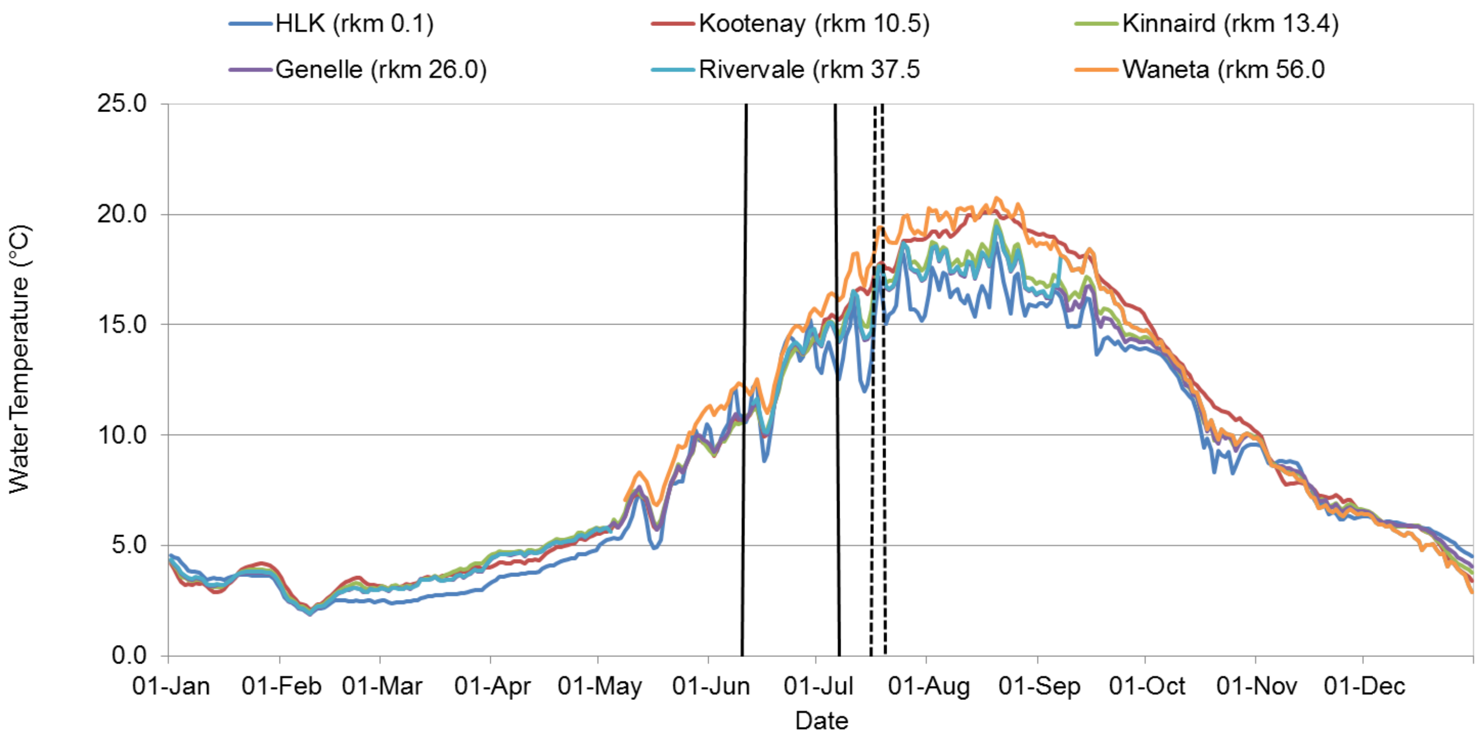

Figure 5. Mean daily water temperature (°C) of the lower Columbia River in 2017. Data was recorded at locations of Hugh L. Keenleyside dam (HLK; rkm 0.1), Kootenay Eddy (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), Rivervale (rkm 35.8) and Waneta (rkm 56.0). Missing data is due to lost or damaged temperature loggers. Vertical solid and dashed lines represent first and last estimated spawning dates at Waneta and ALH, respectively. Estimated spawning duration was based on the developmental stage of collected embryos or larvae. One embryo was collected at Kinnaird (rkm 13.4 – 18.2) and was estimated to be fertilized on July 10.

3.2 Spawn Monitoring

3.2.1 *Embryo and Larval Sampling Effort and Collection*

Downstream Location – Waneta (rkm 56.0)

Egg mats (n=8) and drift nets (n=6) were deployed on May 31 and sampling continued until July 26. Water temperatures ranged from 10.6 to 20.7°C (Figure 5) and water depth (mean ± SD) was 4.3 ± 2.4 m and 5.4 ± 1.6 m for egg mats and drift nets, respectively. Total sampling effort for egg mats and drift nets were 10,3776 hours and 913 hours, respectively (Table 5 and 6). Single set effort was 60.3 ± 20.7 hours and 10.5 ± 8.7 hours for egg mats and drift nets, respectively.

A total of 2,475 embryos (egg mat, n=561; drift net, n=1,914) and 584 larvae (egg mat, n=2; drift net, n=582) were captured at Waneta between the dates of June 14 and July 17 (Table 5 and 6). The largest daily egg mat sample was 225 (embryos, n=225; larvae, n=0) collected on July 3 representing 0.38 of total egg mat sample collection. The largest daily drift net sample was 151 (embryos, n=148; larvae, n=3) collected on July 4 representing 0.06 of total drift net sample collection. Of the total capture, 2,475 embryos were stage and transported with captured larvae (n=31) to the SIF. Hatched larvae (n=1,391) and embryos (n=22) were transported to KSH.

Upstream Location – Kinnaird (rkm 13.4 to rkm 18.2)

Drift nets were deployed at rkm, 13.4 (n=3), rkm 14.5 (n=2), rkm 16.9 (n=1), and rkm 18.2 (n=4) on July 12 and sampling continued until August 2. Water temperatures ranged from 14.6 to 18.9°C (Figure 5) and sampling water depth was 5.0 ± 2.2 m. Total sampling effort for drift nets were 1289 hours (rkm 13.4, 416 h; rkm 14.5, 433 h; rkm 16.9, 78 h; rkm 18.2, 363 h; Table 5 and 6). Mean daily effort was 15.7 ± 10.8 hours.

A total of 1 embryo (rkm 13.4) and 14 larvae (rkm 13.4, n=2; rkm 14.5, n=8; rkm 18.2, n=4; Table 5 and 6) were collected between July 13 and July 27. The embryo was transported to the SIF and all larvae, dead upon capture, were preserved.

Upstream Location – ALH (rkm 0.1)

Drift nets (n=4) were deployed on July 12 and sampling continued until August 3 with water temperatures ranging from 11.7 to 18.4°C (Figure 5). Total drift net sampling effort was 2146 h (Table 5 and 6). Mean daily sampling water depth was 5.2 ± 1.7 m and single set effort was 38.3 ± 22.7 h.

A total of 511 embryos and 159 larvae were collected between July 19 and July 27 (Table 5 and 6). All viable embryos were transferred to the SIF and all dead samples were preserved (larvae, n=159).

Table 5. White Sturgeon embryo and larval (YSL) 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 2017.

Year	Location	Egg Collection Mats			Drift Nets		
		Embryo	YSL	Effort (hrs)	Embryo	YSL	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 Continued. White Sturgeon embryo and larval (YSL) 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 2017.

Year	Location	Egg Collection Mats			Drift Nets		
		Embryo	YSL	Effort (hrs)	Embryo	YSL	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

Table 6. Summary of the total effort, the number of embryos and larvae (YSL) collected, and the estimated number of spawning days from 2008-2017 for the Waneta, Kinnaird, and ALH spawning locations.

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

[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 ranged from newly fertilized embryos to larvae (Table 7).

An estimated 17 discrete spawning days occurred at Waneta based on staged embryos and larvae between the dates of June 11 and July 6 (Table 8). All of these events occurred on the descending limb of the hydrograph. Spawning was estimated to have occurred between July 17 and July 19 at ALH with an estimate of 3 spawning dates (Table 8). One embryo was captured at Kinnaird with an estimated fertilization date of July 10.

Estimated spawning dates at locations of Waneta, Kinnaird, and ALH for sampling years 2011 through 2017 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 of spawning dates at ALH have been late-July to early August.

Table 7. 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 12.8 to rkm 18.2), and Arrow Lakes Generating Station (ALH; rkm 0.1) in 2017. Developmental stages are based on Dettlaff et al. (1993). Due to limited handling of embryos and larvae collected for the Streamside Incubation Facility, 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	1,288	0.44	0	0.00	361	0.58
Yolk Plug	15 - 18	507	0.18	0	0.00	94	0.15
Neurulation - Heart formation - Pre-Hatch	19 - 35	516	0.18	1	0.07	7	0.01
Yolk-Sac Larvae	36 - 45	584	0.20	14	0.93	159	0.26

Table 8. Estimated spawning dates in the lower Columbia River during 2017 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	11-Jun
2	12-Jun
3	13-Jun
4	14-Jun
5	15-Jun
6	21-Jun
7	22-Jun
8	23-Jun
9	28-Jun
10	29-Jun
11	30-Jun
12	01-Jul
13	02-Jul
14	03-Jul
15	04-Jul
16	05-Jul
17	06-Jul
ALH	
1	17-Jul
2	18-Jul
3	19-Jul

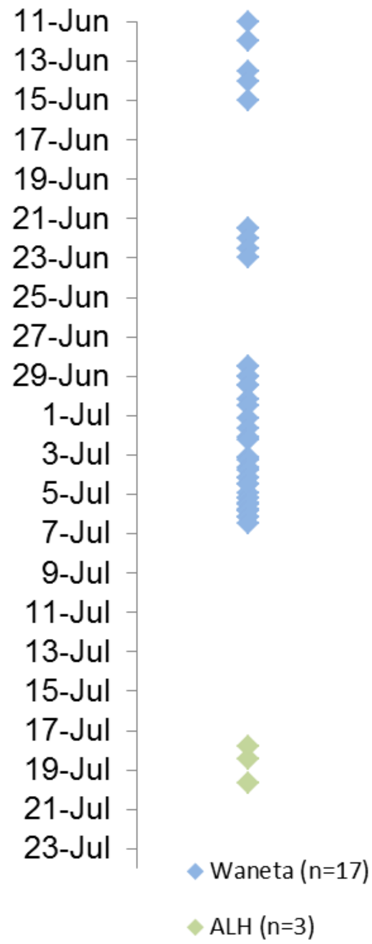

Table 9. Estimated spawning days and duration for White Sturgeon at lower Columbia River spawn monitoring locations of Arrow Lakes Generating Station (ALH; rkm 0.1), Kinnaird (rkm 12.8 to 19.2), and Waneta (rkm 56.0) for years 2011 through 2017. Estimated spawning duration was based on the developmental 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		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
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
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

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).

Embryos (n=2,425) and larvae (n=31) collected at Waneta were transferred to the SIF for incubation (Figure 8). One viable embryo was collected at Kinnaird. A total of 490 embryos and 4 larvae captured at ALH were transferred to the SIF for incubation (Figure 8). Post hatch larvae (n=963) and embryos (n=484) were transported to the KSH. Weekly survival, total survival and total abundance during rearing at KSH are illustrated in Figures 9 and 10. In the spring of 2018, 457 wild progeny from 2017 collections were released into the LCR with the remaining fish to be released in the fall (~150) once target release weight (≥200 g) is met.

Table 10. Mean (± SD), minimum, and maximum air and water temperatures recorded at the location of the Streamside Incubation Facility. 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	22.41 ± 7.84	8.7	40.9
River Intake	14.72 ± 2.04	9.7	19.4
Hatchery Tank 1	15.05 ± 2.06	9.9	19.9
Hatchery Tank 2	15.05 ± 2.02	9.9	19.8

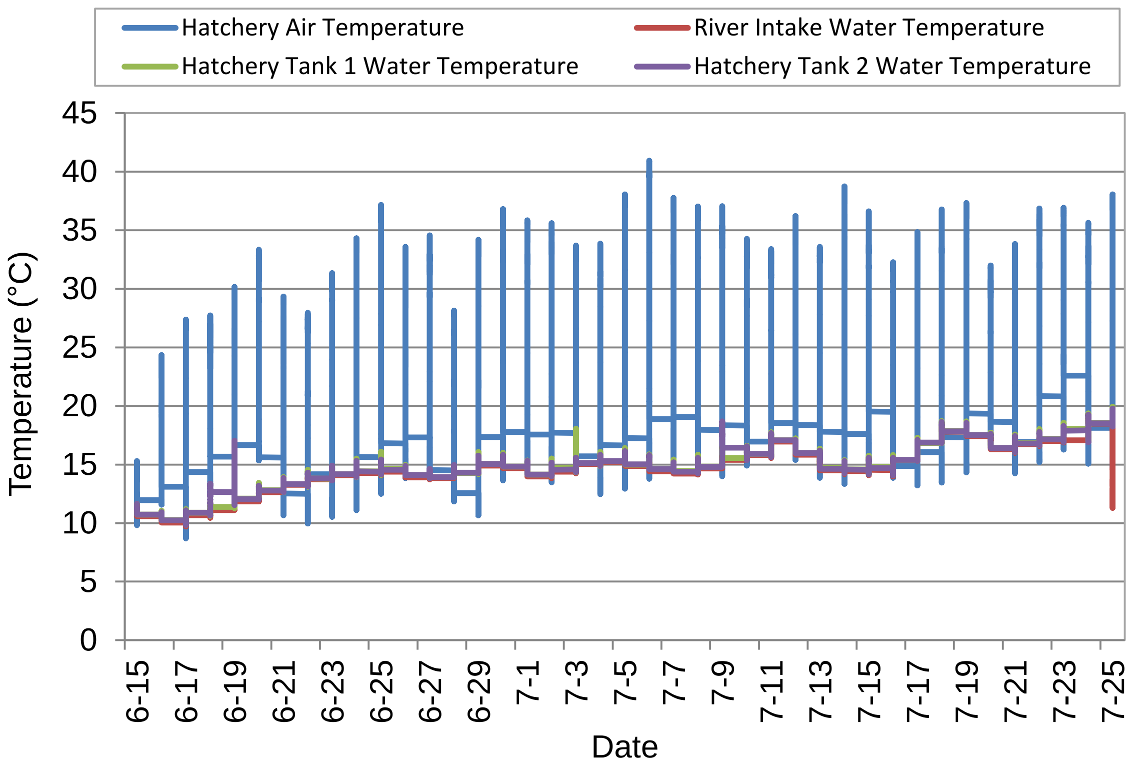

Figure 6. Hourly temperature (°C) recorded at the lower Columbia River (LCR) Streamside Incubation Facility in 2017. Data includes air temperature inside the facility, and water temperatures of the LCR and incubation tanks.

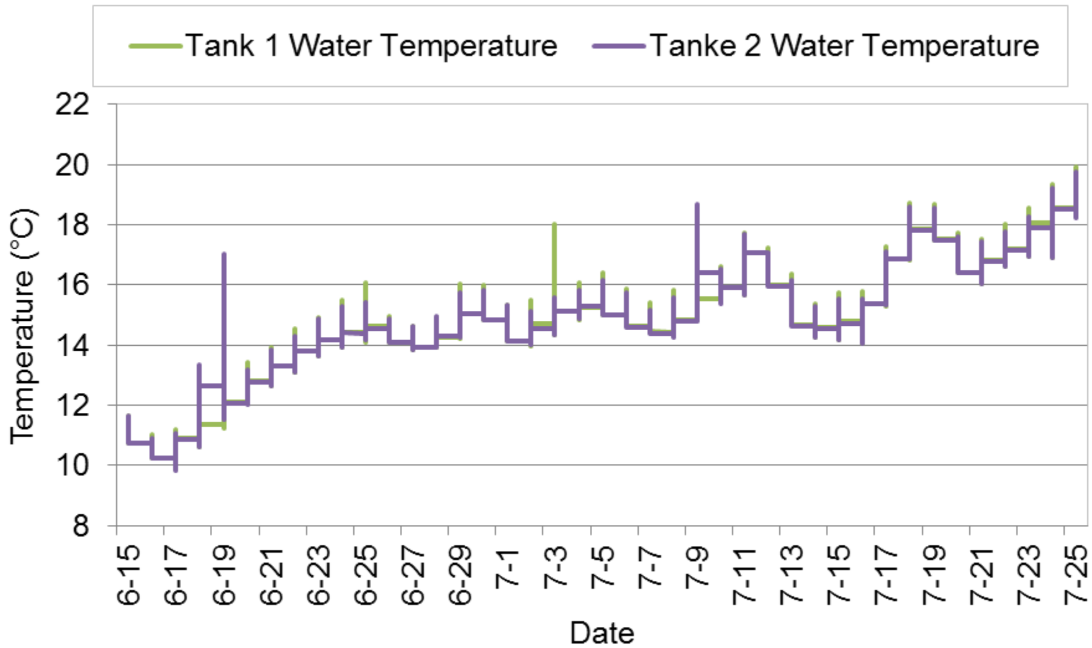

Figure 7. Comparison of hourly temperature (°C) recorded in Tank 1 and Tank 2 of the lower Columbia River Streamside Incubation Facility in 2017.

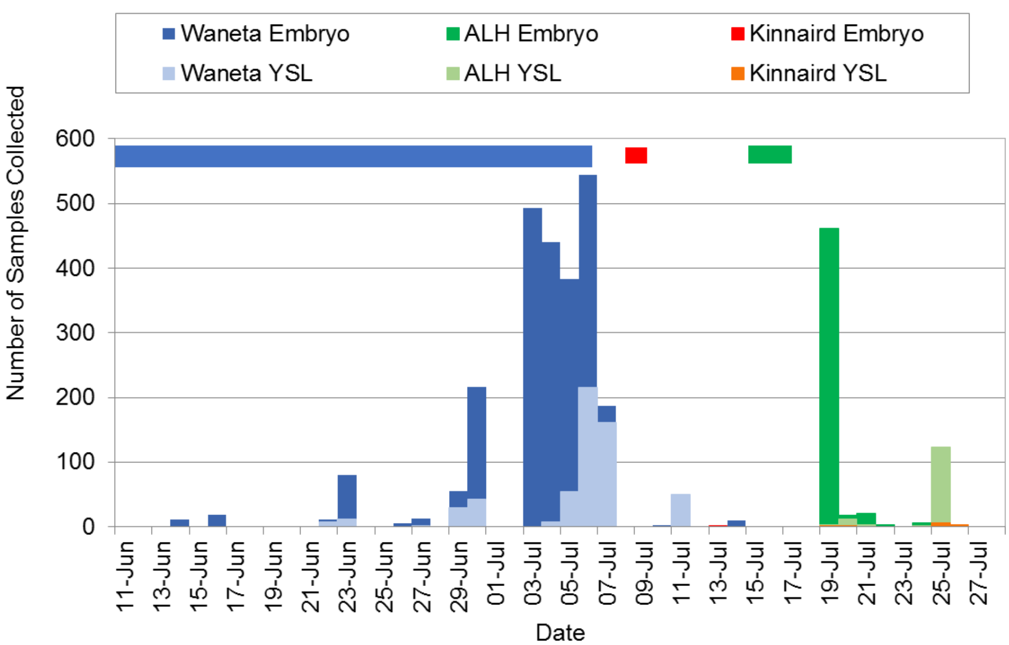

Figure 8. Embryos and larvae (YSL) collected by egg mat and drift net at Waneta, Kinnaird and ALH spawn monitoring sites in the lower Columbia River during the 2017 sampling period (May 31 through August 3). All live embryos and larvae were added to the Streamside Incubation Facility (SIF). Horizontal bars represent duration of estimated spawning based on developmental stages of collected embryos and larvae at Waneta (n=17; blue), Kinnaird (n=1; red) and ALH (n=3; green).

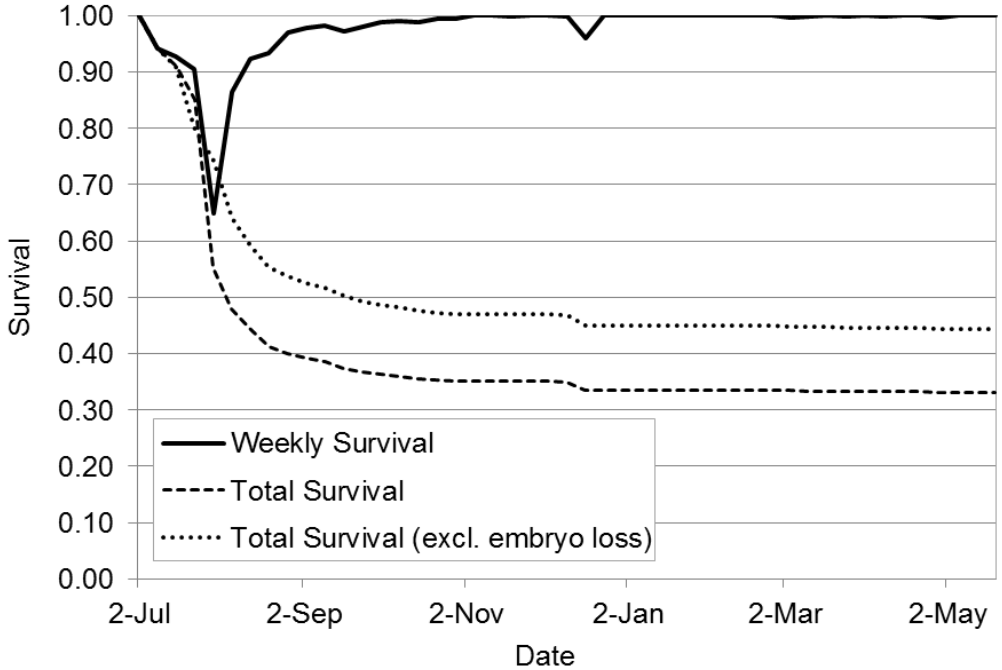

Figure 9. Weekly and total survival of juvenile White Sturgeon at the Kootenay Sturgeon Hatchery (KSH) collected from the lower Columbia River Waneta, Kinnaird and ALH spawn monitoring sites in 2017. The majority of mortalities recorded on July 23 were at the embryo stage.

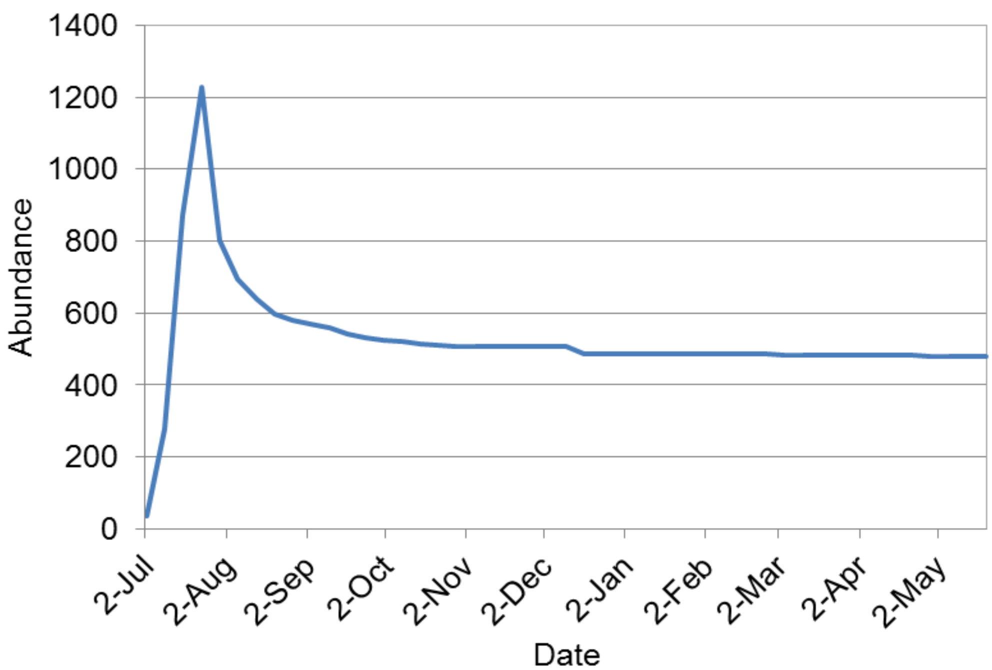

Figure 10. Total abundance of juvenile White Sturgeon of wild origin reared at the Kootenay Sturgeon Hatchery from date of collection (June/July 2017) to release (May 2018). Juveniles were collected as either embryos or larvae in the lower Columbia River (LCR) Waneta, Kinnaird and ALH spawning locations.

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 2017. Results are presented for data collected in the Canadian portion of the LCR.

Within Canada, spring and fall 2017 stock assessments were conducted between the dates of May 8 through May 26 (18 days) and September 19 through October 4 (15 days) with water temperatures (mean ± SD) of 7.4 ± 1.1°C and 14.9 ± 0.9°C (Figure 5), respectively. During the spring and fall assessments, 1,440 hooks were set using 120 lines. Sampling effort for the spring and fall assessments was 2350 h and 2440 h, respectively. Set line deployment during the spring and fall assessments was 19.6 ± 1.9 h and 20.0 ± 3.1 h at water depths of 9.6 ± 3.9 m and 9.4 ± 4.1 m, respectively.

Within Canada, total White Sturgeon captures of 2017 was 175 and 396 for a CPUE of 0.074 and 0.162 during the spring and fall stock assessments, respectively (Table 11 and 12). Across all sampling years (2013-2017), number of captures (82 to 319) and CPUE (0.088 to 0.336) was highest in sampling zone 1 and lowest in sampling zone 4 (number of captures, 2 to 16; CPUE, 0.004 to 0.048; sampling zones represent 11.2 km increments; consecutively numbered 1 through 5 from HLK to Canada/Us Border). A total of 2,941 captures have occurred over the five sampling years (2013 – 2017) within the Canadian portion of the LCR, of which, 424 were recaptured fish (Table 11). Of the total Canadian captures, 190 individuals were not previously handled during any White Sturgeon monitoring (new fish; Table 11).

Table 11. Total number of White Sturgeon captured during the 2013 through 2017 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 released juveniles). Recaptured fish were those handled more than once within each sampling period and the total recaptures includes fish captured across multiple sampling periods.

Year	Survey	Total	Adult	Juvenile	New Fish[a]	Recaptured Fish[b]	Water Temp (°C)[a]
2013	Spring	117	80	37	23	1	6.1 ± 0.8
2013	Fall	250	93	157	29	0	15.9 ± 0.6
2014	Spring	194	93	101	21	0	7.5 ± 0.7
2014	Fall	358	83	275	35	0	15.7 ± 0.7
2015	Spring	295	78	217	15	0	8.9 ± 0.5
2015	Fall	360	74	286	20	2	13.7 ± 0.3
2016	Spring	426	74	352	8	0	8.9 ± 0.5
2016	Fall	370	90	280	15	0	13.7 ± 0.9
2017	Spring	175	34	141	8	0	7.4 ± 1.1
2017	Fall	396	60	336	16	0	14.9 ± 0.9
Total	ALL	2941	759	2182	190	424	-

[a]Individuals that have not been handled over all White Sturgeon monitors
[b]Fish recaptured within a sampling period (e.g., 2013 spring stock assessment) and location (e.g., Canada)

Table 12. Total number of White Sturgeon captured and catch per unit effort (CPUE) by sampling zone for the 2013 through 2017spring 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)

3.3.2 *Mark-Recapture Analyses*

Preliminary estimates for recapture, survival, and abundance are reported; however, they should be treated with caution as they are based on an initial analysis of the 2013-2017 dataset and additional revisions to the dataset and statistical models being used are required. A substantial number of fish have been captured over the 5 year period, with fall captures higher compared to spring captures (Figure 11). The capture data from the Transboundary Reach and from within Canadian efforts are presented in Tables 13 and 14, respectively.

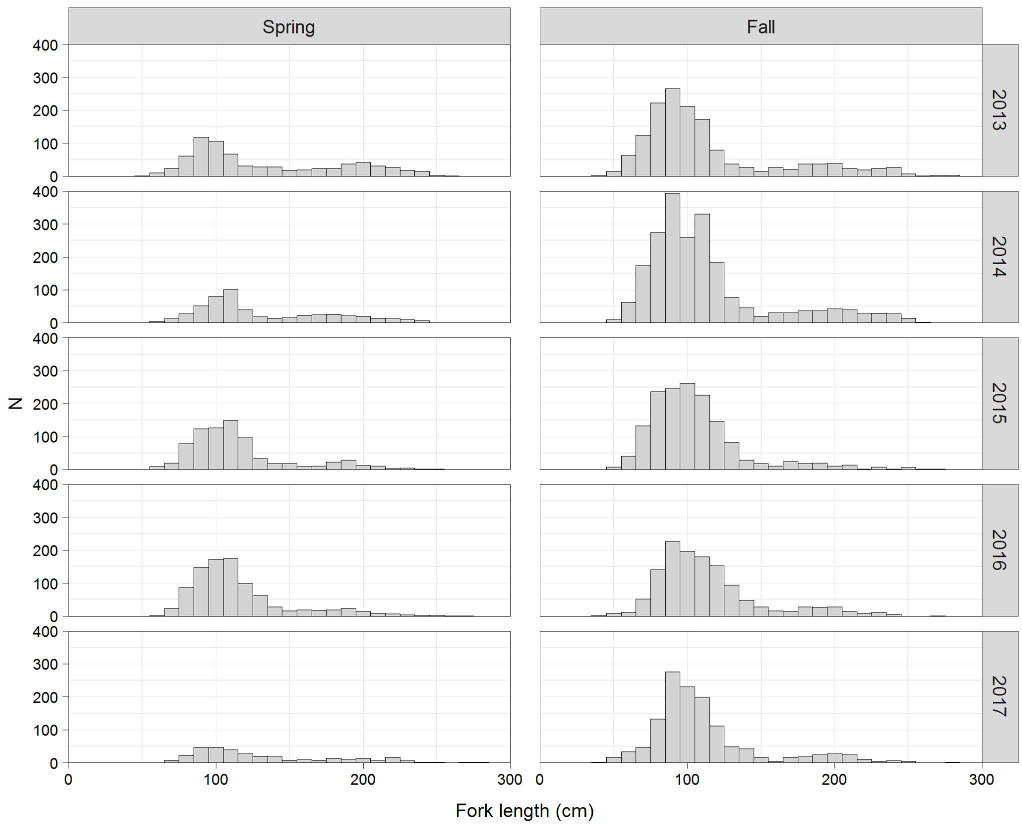

Figure 11. Length frequency plot of captured sturgeon by stock assessment sampling event, 2013-2017. Captures represent sampling conducted through the entire Transboundary Reach.

Table 13. Number of sturgeon marked and recaptured in each sampling event in the Transboundary Reach.

Hatchery/ Wild	Sampling event	N individuals		N Recaptured									
		Total	New[1]	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017
Hatchery	2013 spring	474	474	0	56	11	76	23	46	31	37	7	17
	2013 fall	1204	1147	0	0	18	130	47	77	61	58	13	61
	2014 spring	352	322	0	0	0	36	10	27	20	30	4	10
	2014 fall	1789	1541	0	0	0	0	64	117	53	90	21	64
	2015 spring	658	510	0	0	0	0	0	43	20	32	15	31
	2015 fall	1409	1093	0	0	0	0	0	0	41	62	7	58
	2016 spring	818	587	0	0	0	0	0	0	0	9	2	14
	2016 fall	1135	807	0	0	0	0	0	0	0	0	3	4
	2017 spring	235	162	0	0	0	0	0	0	0	0	0	12
	2017 fall	1130	850	0	0	0	0	0	0	0	0	0	0
Wild	2013 spring	262	262	0	19	15	40	13	12	11	14	7	13
	2013 fall	278	259	0	0	12	20	8	7	6	14	10	6
	2014 spring	173	146	0	0	0	15	8	6	10	3	5	8
	2014 fall	326	251	0	0	0	0	8	9	7	6	6	11
	2015 spring	119	82	0	0	0	0	0	2	4	7	2	5
	2015 fall	123	87	0	0	0	0	0	0	4	6	3	7
	2016 spring	123	81	0	0	0	0	0	0	0	6	1	4
	2016 fall	156	100	0	0	0	0	0	0	0	0	3	8
	2017 spring	84	47	0	0	0	0	0	0	0	0	0	2
	2017 fall	149	85	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).

Table 14. Number of sturgeon marked and recaptured in each sampling event, Canada only.

Hatchery/ Wild	Sampling event	N individuals		N Recaptured									
		Total	New[1]	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017
Hatchery	2013 spring	31	31	0	1	1	1	1	2	3	0	2	1
	2013 fall	152	151	0	0	1	3	10	5	8	9	3	8
	2014 spring	99	97	0	0	0	3	3	2	5	7	3	4
	2014 fall	264	256	0	0	0	0	8	10	9	7	3	5
	2015 spring	209	186	0	0	0	0	0	7	8	5	12	9
	2015 fall	279	251	0	0	0	0	0	0	14	7	5	10
	2016 spring	352	303	0	0	0	0	0	0	0	8	2	13
	2016 fall	279	234	0	0	0	0	0	0	0	0	3	4
	2017 spring	140	106	0	0	0	0	0	0	0	0	0	5
	2017 fall	330	270	0	0	0	0	0	0	0	0	0	0
Wild	2013 spring	85	85	0	5	10	5	9	5	6	6	4	4
	2013 fall	97	92	0	0	9	4	7	4	4	9	2	0
	2014 spring	92	73	0	0	0	4	7	3	9	2	3	2
	2014 fall	92	79	0	0	0	0	7	4	2	3	1	5
	2015 spring	86	56	0	0	0	0	0	1	3	7	1	4
	2015 fall	77	60	0	0	0	0	0	0	2	4	3	2
	2016 spring	73	47	0	0	0	0	0	0	0	4	1	3
	2016 fall	89	54	0	0	0	0	0	0	0	0	1	3
	2017 spring	35	19	0	0	0	0	0	0	0	0	0	0
	2017 fall	61	38	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).

1) Assessment of survival and recapture

We report results of models developed using the entire transboundary reach dataset. The suite of converged CJS models developed to estimate survival and recapture rates for White Sturgeon in the Transboundary Reach of the Upper Columbia River between 2013 and 2017 are presented in Table 15. While largely used for abundance estimates, POPAN models also estimates survival and recapture and are presented in Table 16. Survival was function of year class (Table 17), and was high overall but varied by year class and wild fish (Figure 12). It is likely that the low survival estimated for the 2009 year class is due to low recruitment to gear (due to young ages/small sizes); this survival is therefore expected to increase with additional sampling in the future. Estimated recapture rates were lower in the spring than in the fall for US-released fish, especially so for hatchery-reared sturgeon (Figure 13). Based on both POPAN and CJS models, spring recapture rates in the US increased from 2013 until (and including) 2016, then decreased in 2017. Note that analysis of data collected both across the Transboundary Reach and in US only indicated a strong difference between hatchery-reared and wild fish. For hatchery-reared fish in the US, fall sampling had significantly higher recapture probabilities, while wild fish usually (except for 2014) had comparable recapture rates between the seasons, or only slightly higher fall recapture probabilities. In samples from Canada, seasonal effects on recapture rates of hatchery fish differed by year (significantly higher fall recapture rates in 2013, 2014, and 2017, but not 2015 or 2016). In wild fish collected in Canada, recapture rates were generally highly uncertain, with no significant differences between.

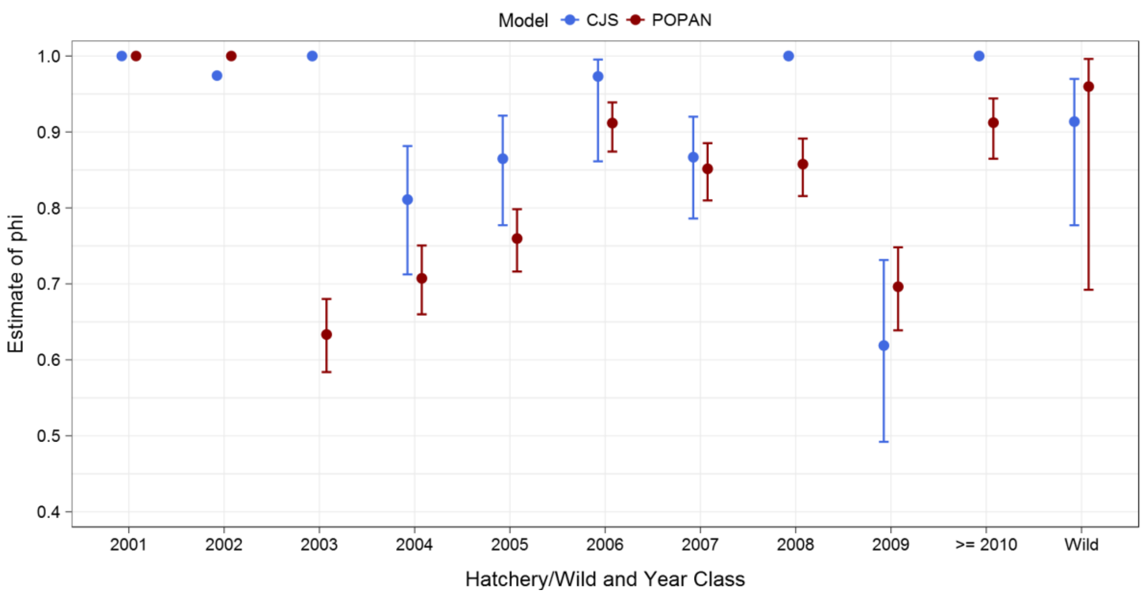

Figure 12. Comparison of model-averaged survival estimates across CJS and POPAN models.

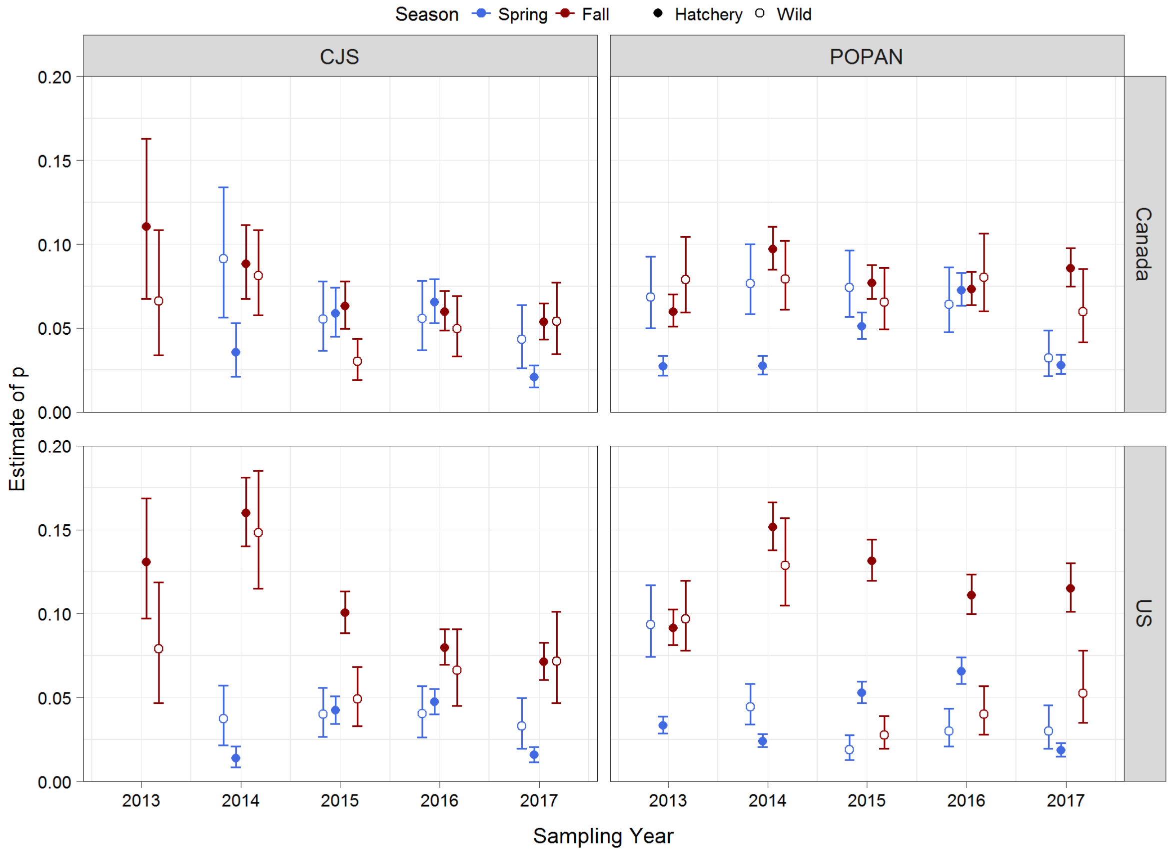

Figure 13. Comparison of model-averaged recapture estimates across CJS and POPAN models.

Table 15. Comparisons of the converged CJS models developed for White Sturgeon in the Transboundary Reach of the Lower Columbia River between 2013 and 2017. 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. 25 models were developed but only the top 15 are presented.

Phi	p	npar	QAICc	ΔQAICc	QAICc weight
~ YearClass	~HW * time + Country * time	37	15,493	0	1
~ YearClass	~Country * time	28	15,528	35	0
~1	~HW * time + Country * time	28	15,543	50	0
~ HW	~HW * time + Country * time	29	15,543	50	0
~ YearClass	~HW * time	28	15,550	57	0
~ HW	~Country * time	20	15,578	85	0
~1	~Country * time	19	15,582	89	0
~ YearClass	~Country + time	20	15,585	92	0
~ YearClass	~time	19	15,592	99	0
~1	~HW * time	19	15,595	102	0
~ HW	~HW * time	20	15,595	102	0
~ HW	~Country + time	12	15,634	141	0
~ HW	~time	11	15,637	144	0
~1	~Country + time	11	15,638	145	0
~1	~time	10	15,642	149	0

Table 16. Comparisons of the converged POPAN models developed for White Sturgeon in the Transboundary Reach of the Lower Columbia River between 2013 and 2017. Models are arranged in order of QAICc. The specification of survival (Phi), recapture (p), probability of entry (pent), and super population (N) values 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	~HW * Country * time	~HW	~HW * Country	57	18,812	0	0.8
~ YearClass	~HW * Country * time	~HW [1]	~Country	54	18,814	2	0.2
~ YearClass	~HW * Country * time	~HW [1]	~1	53	18,956	144	0
~ YearClass	~HW * Country * time	~HW [1]	~HW	54	18,958	146	0
~ YearClass	~Country * time	~HW [1]	~HW * Country	36	19,153	341	0
~ YearClass	~Country * time	~HW	~HW * Country	37	19,154	342	0
~ YearClass	~Country * time	~HW [1]	~Country	34	19,312	500	0
~ YearClass	~Country * time	~HW [1]	~HW	34	19,453	641	0
~ YearClass	~Country * time	~HW [1]	~1	33	19,507	696	0
~ Country	~Country * time	~HW [1]	~HW * Country	27	19,734	922	0
~ HW	~Country * time	~HW [1]	~Country	25	19,816	1,004	0
~ Country	~Country * time	~HW [1]	~Country	25	19,817	1,005	0
~ Country	~Country * time	~HW [1]	~HW	25	19,997	1,185	0
~ HW	~Country * time	~HW [1]	~1	24	20,030	1,219	0
~ Country	~Country * time	~HW [1]	~1	24	20,037	1,226	0

[1] = the probability of entry of wild fish was fixed at a value of 0

Table 17. Estimated survival probabilities from model-averaged CJS and POPAN models (values shown in Figure 12).

Year class	CJS			POPAN		
	estimate	LCL	UCL	estimate	LCL	UCL
2001	1.000	1.000	1.000	1.000	1.000	1.000
2002	0.974	0.974	0.974	1.000	1.000	1.000
2003	1.000	1.000	1.000	0.633	0.584	0.680
2004	0.811	0.712	0.881	0.707	0.660	0.751
2005	0.865	0.777	0.921	0.760	0.716	0.798
2006	0.973	0.861	0.995	0.912	0.874	0.939
2007	0.867	0.786	0.920	0.852	0.810	0.885
2008	1.000	1.000	1.000	0.858	0.816	0.891
2009	0.619	0.492	0.731	0.696	0.639	0.748
>= 2010	1.000	1.000	1.000	0.912	0.865	0.944
Wild	0.914	0.777	0.970	0.960	0.692	0.996

2) Assessment of population abundance in the Canada

While an objective is to estimate population abundance for the entire Transboundary Reach, we are only reporting preliminary estimates made using the Canadian capture data, 2013-2017. The larger Transboundary dataset will be finalized and analyses completed later in 2018. For the Canadian abundance estimate, the POPAN models were constructed using only Canadian capture data (Table 18). The POPAN abundance estimates suggested an overall stable population of both wild and hatchery-origin sturgeon (Table 19; Figure 14). Due to some data sparsity of hatchery-reared fish from later year classes, all year classes from 2007 and on were aggregated into a single greater than 2007 year class identifier for the POPAN models.

Table 18. Comparisons of the converged POPAN models developed for White Sturgeon in the Canadian portion of the Upper Columbia River between 2013 and 2017. Models are arranged in order of QAICc. The specification of survival, recapture, probability of entry, and super population values 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	~HW * time	~HW	~1	31	4,151	0	0.6
~ YearClass	~HW * time	~HW	~HW	32	4,151	1	0.4
~ YearClass	~time	~Season + HW	~1	22	4,183	33	0.0
~ YearClass	~time	~HW	~HW	22	4,208	57	0.0

Table 19. Estimated population abundances from model-averaged POPAN models of US samples (values shown in Figure 14).

Sampling year	Season	Hatchery			Wild		
		Estimate	LCL	UCL	Estimate	LCL	UCL
2013	Spring	4,915	2,993	6,836	1,101	697	1,506
2013	Fall	5,051	3,412	6,689	1,109	758	1,460
2014	Spring	4,985	3,635	6,335	1,086	771	1,401
2014	Fall	5,176	4,045	6,307	1,098	810	1,387
2015	Spring	5,132	4,203	6,061	1,076	777	1,374
2015	Fall	5,324	4,544	6,105	1,086	784	1,389
2016	Spring	5,303	4,626	5,980	1,065	723	1,407
2016	Fall	5,534	4,899	6,170	1,081	719	1,442
2017	Spring	5,505	4,866	6,144	1,057	643	1,470
2017	Fall	5,725	5,022	6,428	1,071	629	1,512

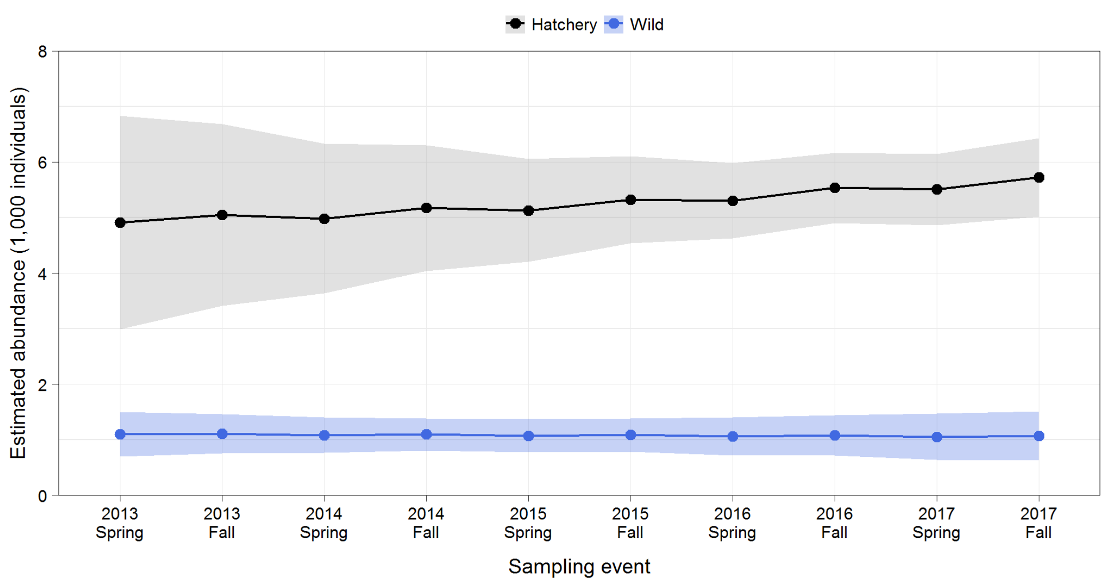

Figure 14. Hatchery-reared and wild sturgeon abundance estimates, based on samples only from Canada. Ribbons are 95% confidence intervals.

3) <u>Assessment of the probability of movement across the Canada-US border</u>
To assess the extent of fish movement across the boundary during the 2013-2017 sampling period, a set of multi-state models was constructed (Table 20). Following release from the hatchery at 9 months of age, there is an initial distribution where a portion of individuals released in each country disperse across the border and then subsequently remain. Following this initial redistribution shown in Figure 15, the estimated movement probabilities were

very low, ranging from 0.006 to 0.014 (Table 21), during the 5 years stock assessment was conducted. Hatchery fish originally released in Canada but captured in the US had the highest probability of moving across the border (back to Canada; estimate of 0.014; Figure 16). The remaining three categories – a) hatchery fish released in Canada and captured in Canada, b) hatchery fish released in the US and captured in the US, and c) hatchery fish released in the US and captured in Canada – all had similar, lower probability of moving across the border (estimate of 0.006-0.007). However, the 95% confidence intervals for movement probabilities overlapped across all modeled categories, suggesting no significant differences in movement probabilities based on hatchery / wild origins, country of original release, and country of capture.

Table 20. Comparisons of the converged multi-state models developed for White Sturgeon in the Transboundary Reach of the Lower Columbia River between 2013 and 2017. Models are arranged in order of QAICc. The specifications of survival (S), recapture (p), and probability of movement between countries (psi) are indicated for each model, as well as the number of model parameters (npar), and QAICc statistics.

S	p	psi	npar	QAICc	ΔQAICc	QAICc weight
~ HW	~ time	~ReleaseCountry + stratum	14	12,853	0	0.32
~ HW	~ time	~ReleaseCountry * stratum	15	12,854	0	0.26
~ HW	~ time	~1	12	12,855	2	0.13
~ HW	~ time	~ReleaseCountry	13	12,855	2	0.11
~ HW	~ time	~HW	13	12,856	3	0.08
~ HW	~ time	~ stratum	13	12,857	4	0.05
~ HW	~ time	~ReleaseCountry * HW	15	12,858	5	0.03
~ HW	~ time	~HW * stratum	15	12,859	6	0.02
~ HW	~stratum * Season	~ReleaseCountry + stratum	9	13,126	273	0
~ HW	~stratum * Season	~ReleaseCountry * stratum	10	13,127	273	0
~ HW	~stratum * Season	~1	7	13,129	276	0
~ HW	~stratum * Season	~ stratum	8	13,130	277	0
~ HW	~stratum * Season	~HW	8	13,130	277	0
~ HW	~stratum * Season	~ReleaseCountry	8	13,130	277	0
~ HW	~stratum * Season	~HW * stratum	10	13,132	279	0
~ HW	~stratum * Season	~ReleaseCountry * HW	10	13,133	279	0
~ HW	~stratum	~ReleaseCountry + stratum	7	13,532	678	0
~ HW	~stratum	~ReleaseCountry * stratum	8	13,532	679	0
~ HW	~stratum	~1	5	13,534	681	0
~ HW	~stratum	~ReleaseCountry	6	13,534	681	0
~ HW	~stratum	~HW	6	13,535	682	0
~ HW	~stratum	~ stratum	6	13,535	682	0
~ HW	~stratum	~ReleaseCountry * HW	8	13,537	684	0
~ HW	~stratum	~HW * stratum	8	13,537	684	0
~ HW	~stratum	~ReleaseCountry + stratum	7	13,532	678	0
~ HW	~stratum	~ReleaseCountry * stratum	8	13,532	679	0

Note: stratum designates the country where the fish was captured

Table 21. Estimated probability of movement between countries from model-averaged multi-state models (values shown in Figure 16).

Hatchery / wild	Country of original release	Country of capture					
		Canada			US		
		Estimate	LCL	UCL	Estimate	LCL	UCL
Hatchery	Canada	0.007	0.004	0.015	0.014	0.006	0.037
Hatchery	US	0.007	0.001	0.042	0.007	0.004	0.011
Wild	Canada	0.007	0.003	0.015	0.014	0.005	0.039
Wild	US	0.006	0.001	0.044	0.006	0.004	0.011

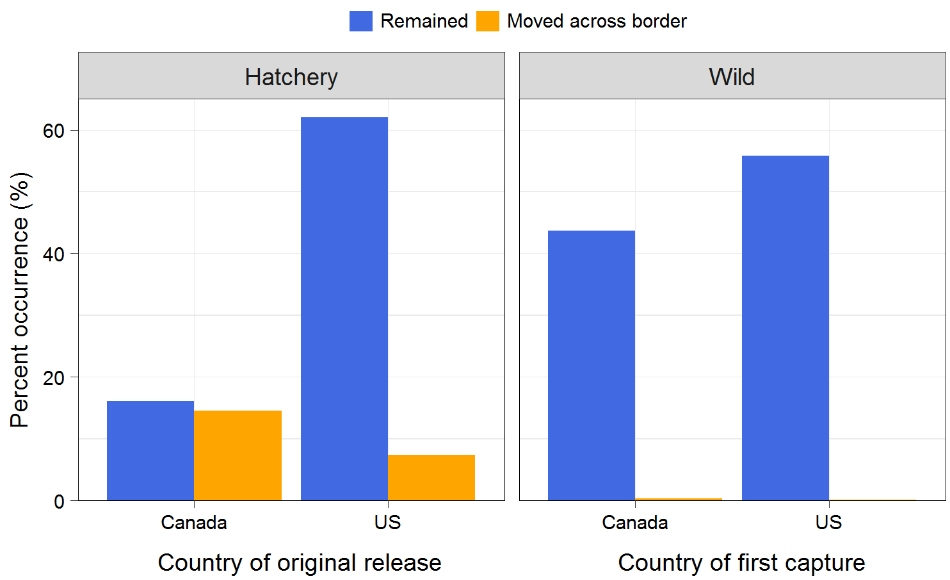

Figure 15. Summary of sturgeon movement across the US-Canada border from original release (prior to 2013 for all hatchery-reared fish). Percentages are calculated from a total of hatchery or wild fish.

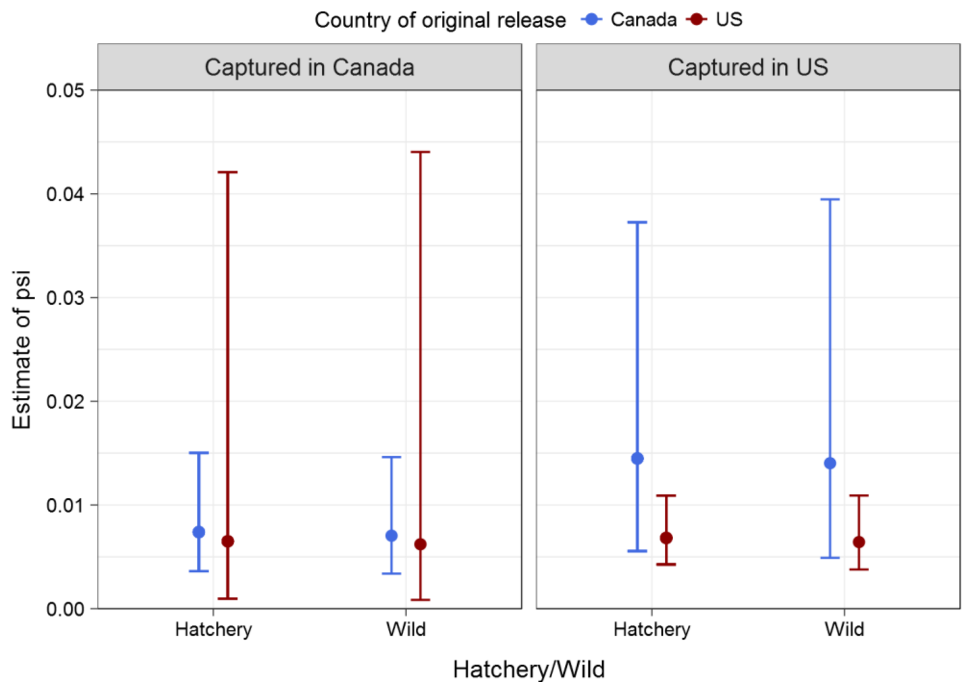

Figure 16. Estimates of the probability of movement between countries, detailed by hatchery/wild, country of original release (colour), and location of capture (panels). The probability of movement shown on the US-capture panel represents the probability of movement to Canada, and vice versa. Error bars are 95% confidence intervals.

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 2017 stock assessments (n=571) was 114.2 ± 36.2 cm and 110.8 ± 33.7 cm, respectively (Table 22). Fork length of juveniles captured during the spring and fall was 98.3 ± 14.2 cm and 97.8 ± 12.6 cm, respectively. Fork length for adults captured in the spring and fall was 180.4 ± 21.5 cm and 183.5 ± 18.6 cm, respectively. These results are similar to the juvenile (97.6 ± 53.8 cm) and adult (181.0 ± 97.6 ± 53.8 cm) fork length recorded over all stock assessments conducted within the Canadian portion of the LCR (2013-2017).

Weight of juveniles captured within Canada during the spring and fall was 6.4 ± 3.0 kg and 6.3 ± 2.9 kg, respectively. Adult weight was 45.0 ± 18.5 kg and 48.4 ± 16.2 kg for spring and fall captures, respectively. These results were similar to those recorded over the entire study (2013-2017; adult, 46.2 ± 16.9 kg; juvenile, 6.3 ± 2.8 kg; Table 23).

Relative weight (W_r) for all White Sturgeon captured within Canada over the period of the stock assessment (2013 – 2017) was 81.4 ± 8.7 (Table 24). Relative weight for adults captured in 2017 (spring, 79.2 ± 9.0; fall, 80.5 ± 13.6) was lower than the W_r calculated for adults captured over the entire study (81.8 ± 12.7). Relative weight for juveniles captured in 2017 (spring, 80.1 ± 9.6; fall, 80.4 ± 10.0) was similar to the W_r for juveniles captured over the entire study (81.2 ± 10.2).

Table 22. Fork length (cm; mean ± SD) for adult and juvenile White Sturgeon captured during the transboundary stock assessments (2013-2017). 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	Adult	Juvenile	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
All Captures		181.0 ± 55.1	97.6 ± 53.8	119.6 ± 39.8

Table 23. Weight (kg; mean ± SD) for adult and juvenile White Sturgeon capture during the transboundary stock assessments (2013-2017). 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	Adult	Juvenile	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
All Captures		46.2 ± 16.9	6.3 ± 2.8	16.9 ± 19.7

Table 24. Relative weight (W_r; mean ± SD) for adult and juvenile White Sturgeon collected during the transboundary stock assessments (2013-2017). 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	Adult	Juvenile	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
All Captures		81.9 ± 12.7	81.2 ± 10.1	81.4 ± 8.2

3.3.4 *Fork Length Frequency*

Total captures within Canada were predominately of juvenile fish (<150 cm) of hatchery origins (n=2153; Figure 17). Grouping FL 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 25). Wild fish were predominantly larger in fork length (170 to 200 cm).

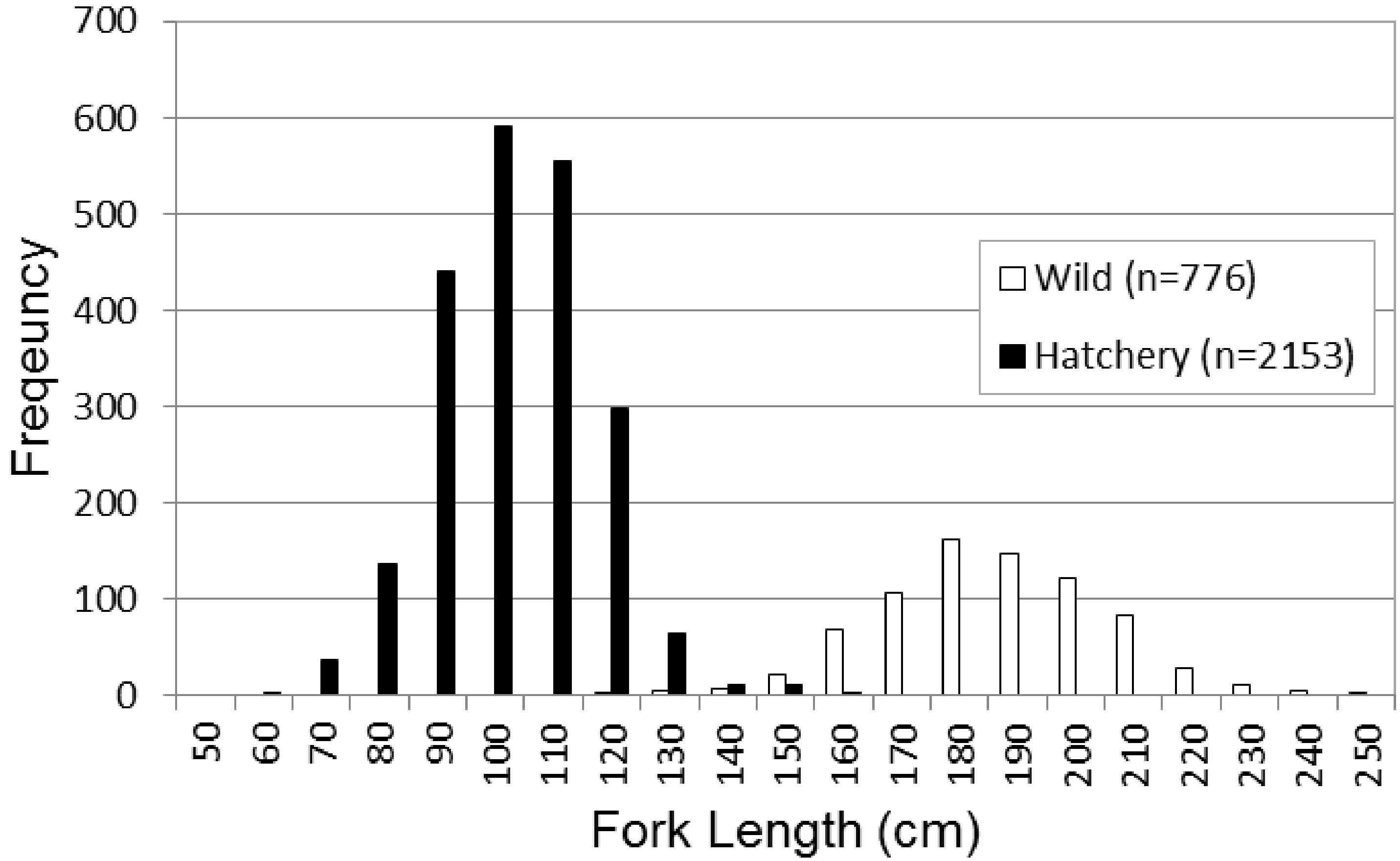

Figure 17. Fork length frequency of hatchery (median 97.5 cm) and wild (median 181 cm) origin White Sturgeon captured in the lower Columbia River during Canadian stock assessments, 2013-2017.

Table 25. Proportion of fork length frequency of White Sturgeon captured in the lower Columbia River during the 2013-2017 Canadian stock assessments. The three predominant fork length bins (10cm) are highlighted bold for comparison.

FL (cm)	Hatchery	Wild	Canada
>50	0.000	0.000	0.000
50-59	0.001	0.000	0.001
60-69	0.017	0.000	0.013
70-79	0.064	0.000	0.047
80-89	**0.205**	0.000	**0.151**
90-99	**0.275**	0.000	**0.202**
100-09	**0.258**	0.000	**0.190**
110-119	0.138	0.001	0.102
120-129	0.030	0.006	0.024
130-139	0.006	0.010	0.007
140-49	0.005	0.028	0.011
150-159	0.000	0.089	0.024
160-169	0.000	0.139	0.037
170-179	0.000	**0.210**	0.056
180-189	0.000	**0.189**	0.050
190-199	0.000	**0.157**	0.042
200-209	0.000	0.107	0.028
210-219	0.000	0.037	0.010
220-229	0.000	0.015	0.004
230-239	0.000	0.008	0.002
240-249	0.000	0.001	0.000
250+	0.000	0.000	0.000

3.4 Acoustic Tagging and Telemetry

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 18).

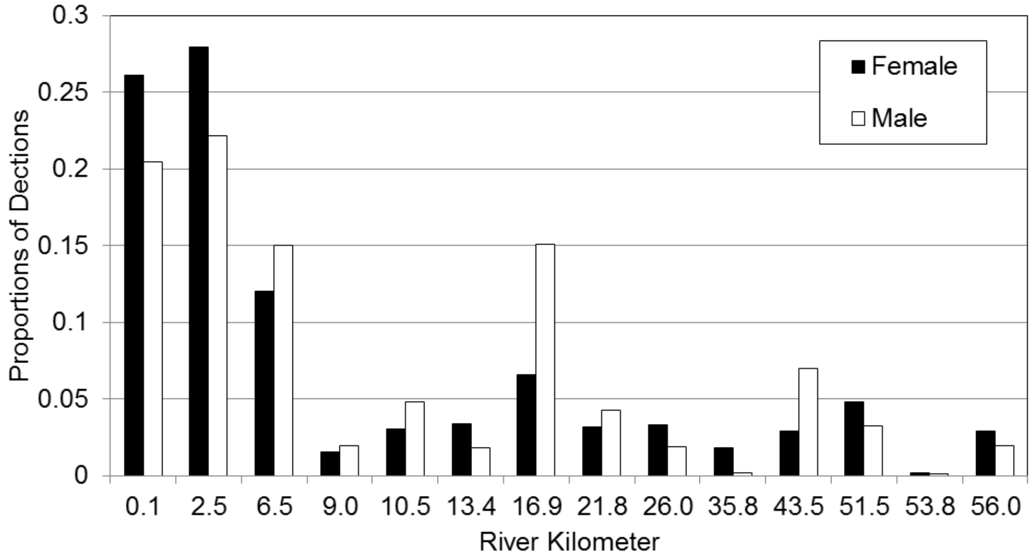

Figure 18. The proportion of detection days by river kilometer of female (n = 52) and male (n = 48) adult White Sturgeon implanted with acoustic transmitters in the lower Columbia River, 2008-2017.

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 26). 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 26).

Table 26. 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 27; Figure 19). 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.

Table 27. 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**

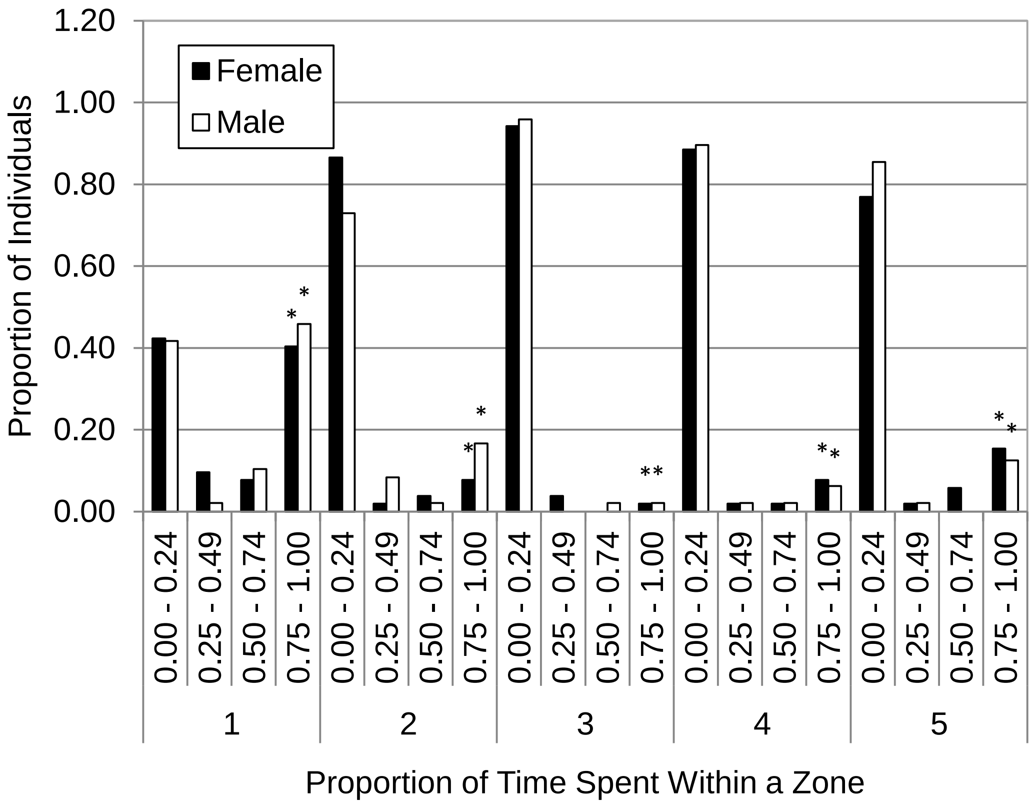

Figure 19. The proportion of acoustically tagged male (n=48) and female (n=52) adult White Sturgeon detected within each sampling zone of the lower Columbia River, Canada, in 2008 through 2017. Individuals were assigned to one of four categories representing the proportion of their detections recorded 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.

In 2017, 11 adults (5 males, 6 females; Figure 20) 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 28). 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 29). 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 29).

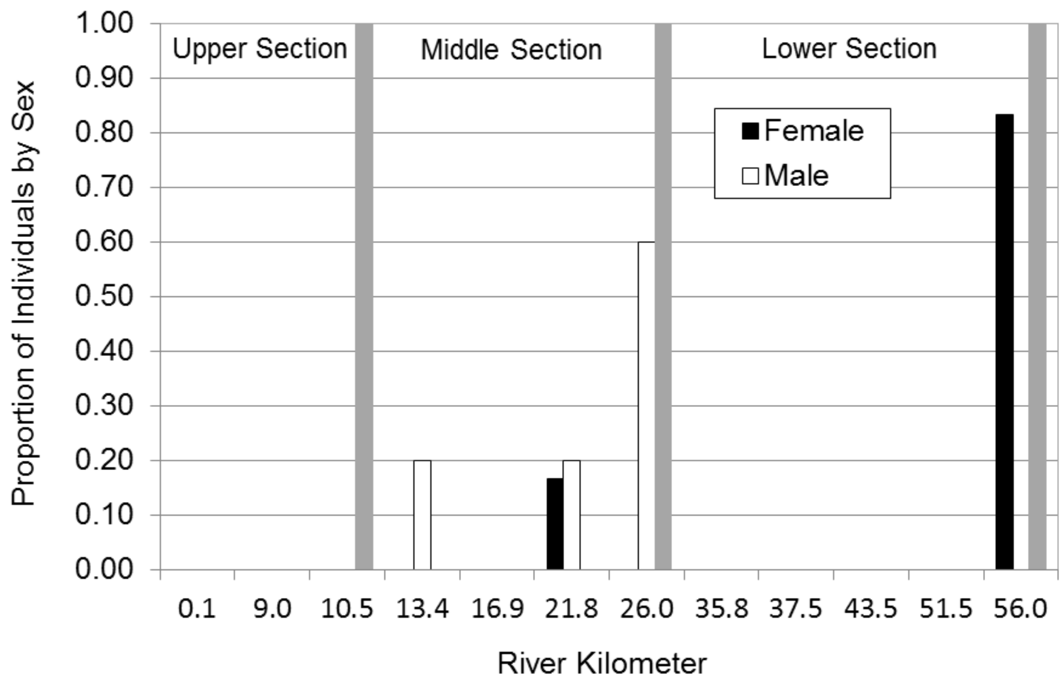

Figure 20. Proportion of detections by river kilometer (rkm) of acoustically tagged female (n=6) and male (n=5) White Sturgeon identified for suspected spawn related movements in the lower Columbia River (LCR) in 2017. The LCR was divided into three sections including: Upper (HLK [rkm 0.1] to Kootenay River Confluence [rkm 10.5]), Middle (downstream Kootenay River Confluence to Birchbank [rkm 29]), and Lower (downstream Birchbank to Waneta [rkm 56.0]).

Table 28. 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 29. 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 tenth 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. Further, this program was responsible for the collection of sexually mature White Sturgeon to use as broodstock and 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 30.

Table 30. 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 should be considered 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.
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.	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 of 1,071 (629-1,512) individuals. .
Of equal importance to the maintenance of the remaining White Sturgeon population;	Based on both previous genetic studies and the success in collecting wild-origin progeny, sufficient breeding adults remain to support a

FTC Outstanding Issue	Current Status
are there sufficient adults to continue the Conservation Aquaculture Program?	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 years since regulation of the Columbia River began. While a larger numbers 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 two years collections, 2016 and 2017, were successful with both wild-origin embryos (n=484; from ALH) and larvae (n=963) transferred to the KSH for rearing in 2017. This annual variability in numbers of embryos and larvae collected for conservation aquaculture was expected as part of this revised plan and reflects results from 2008-present which are included in Table 5. While numbers of juveniles released at 9 months of age may be low in certain years like 2015, revised minimum size at release targets (200 grams) will help improve survival following release. At KSH, survival from the time larvae are transferred to the time of stocking has also been good, with over 60% survival for the 4 years implemented to date. Further refinements to methods during incubation at the SIF near Waneta and while at KSH 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 2015, spawning was estimated to have only occurred for 10 days in June at Waneta. However, in 2016 and 2017 spawning was detected at Waneta over 22 and 26 days, respectively, which is similar to past years (e.g. 2010-2012). 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 several days at ALH (e.g. 3 days in 2017). The timing of spawning activity for both locations is similar to past years, with the majority of estimated spawning days occurring on the descending limb of the hydrograph and at water temperatures at or above 14ºC. Spawning was detected in 2017 downstream of ALH, through the collections of both embryos and larvae. While spawning was detected at ALH in 2015, it was only through the collection of a single larvae and prior to that the last time spawning was detected at the ALH site was 2012. It is unknown if the intermittent use of this spawning area (5 of 8 years monitoring has occurred) will change as additional hatchery-origin spawners reach maturity and begin contributing. 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.

Dispersing larvae were collected within the vicinity of Kinnaird; however, exact location of the spawning area remains unknown despite a decade of consistent use of the area. 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 (Table 5). 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 2013-2017. The initial estimates include both hatchery and wild origin and it should be noted that the total population abundance estimates presented in this report are based on initial analyses and as such, should be interpreted with caution. As the final 5-year stock assessment data are analyzed later in 2018, 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. As presented in this report, results from an analysis evaluating the importance of both spring and fall sessions to the overall population abundance estimates found that a single fall session is adequate moving forward.

4.4 Acoustic Tagging and Telemetry

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 a decade of movement data is scheduled starting in 2018 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. Only a single fall session will be implemented for the 2019 stock assessment program and beyond but additional sessions may be useful to address other questions around movement and habitat use.

    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.

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