Columbia River Project Water Use Plan

Lower Columbia River

Reference: CLBMON #28 (Year 15)

Lower Columbia River Adult White Sturgeon Monitoring Program: 2022 Investigations Data Report

Study Period: January 2022 - December 2022

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EXECUTIVE SUMMARY

White Sturgeon (*Acipenser transmontanus*) in the lower Columbia River (LCR), are one of four Canadian 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 conservation and recovery actions. However, given the high value of power generation and flood protection mandated under the Columbia River Treaty, significant physical alterations (e.g. flow augmentation) on the system to address recruitment failure were not deemed feasible and, as such, the system was designated as a working river. As a result, programs were developed that focused on the collection of biological information that could determine the possible mechanisms resulting in recruitment failure and describe the effectiveness of conservation actions. 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) describe the timing and frequency of spawning events.

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

In 2022, spawning was estimated to have occurred from mid-June into late-July in the lower Columbia River. At the Waneta site, the timing and duration of spawning activity was similar to past years, with the majority (75%) of the 12 spawning events 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 2022 occurred June 22 through July 26 at Waneta and a single event was detected in the Kinnaird reach on July 11.

In efforts to increase genetic diversity among stocked juvenile White Sturgeon, increase effective breeding number, and maintain genetic diversity within the population, wild-origin progeny are collected from spawning sites and reared temporarily at a Streamside Incubation Facility (SIF) constructed near the Waneta spawning location. This program was developed as a result of a 2011-2012 genetic study that determined the number of adults spawning annually in the LCR significantly higher than those that contributed as broodstock in the Conservation Aquaculture Program. Following incubation in the SIF, hatched larvae were transported to the conservation hatchery and reared for release in

the following spring. While implemented in 2014 concurrently with the broodstock program (2001-2014), as of 2015, the SIF program was fully adopted with a total of 1095, 76, 800, and 607 wild-origin juvenile white sturgeon released in 2015 through 2018, respectively. Since 2018, the release target has been reduced to a maximum of 200 fish at a minimum size of 200 grams in weight. This target was met for the 2022 year class, with fish released above Castlegar (n=100) and upstream of Waneta (n=100) in spring of 2023.

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

Table ES 1. CLBMON-28 Status of Lower Columbia River Adult White Sturgeon Monitoring Program Objectives, Management Questions, and Hypotheses.

Management Question	Status
What are the abundance trends, population structure and reproductive status of adult White Sturgeon in the lower Columbia River?	- A systematic stock assessment encompassing the entire Transboundary Reach of the lower Columbia River in Canada and the US was initiated in 2013 and has been completed annually. The goals of the stock assessment were to estimate population abundance and survival that can be used to track recovery for this population. At the conclusion of 2018, twelve sessions were completed in Canada and results estimated a wild population abundance of 1,042 (743-1,461) individuals. This is similar to the estimate of 1,100 developed by Irvine et al. (2007) prior to the Columbia WUP program being implemented. The program has continued since 2019 and an open population model incorporating all capture data since the 1990's is being developed to better understand trends in wild and hatchery-origin abundances over the past few decades. - The wild population remains dominated by adult age classes, with limited wild juveniles captured during sampling programs (<1%). Juveniles released from the Conservation Aquaculture Program are surviving and are represented in a large proportion of the adult captures. There are an estimated 5,083 (3,823-6,648) hatchery-origin individuals in Canada from analyses conducted using the stock assessment data up to 2018. 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.

Management Question	Status
	- 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. - Using genetic methods, it was found that 121.5 ± 34.7 adults (mean ± SD) were spawning within the Canadian section of the lower Columbia River within each of two years (2011 and 2012). The sex ratio of the population has been stable at 1 female:1 male since monitoring began. Work to describe the reproductive structure is ongoing.
How much spawning occurs annually at known spawning locations, and are there other spawning locations unidentified in the lower Columbia River?	- Wild spawning has been detected annually at up to 3 locations in the Canadian section of the Columbia River, with the mean number of spawning days ranging from 1.2 at the Arrow Lakes Generating Station (ALH) site to 13.2 at the Waneta site from 2011-2022. Embryos survive to hatch at all locations, though few larvae have been caught at the ALH site up to 2022. - Spawning occurs annually at the Waneta area, with the number of estimated spawning days varying by year. - Spawning has been identified through embryo and larval captures downstream of Hugh Keenleyside Dam and ALH. ALH represents the second known location of egg deposition in the Canadian section of the lower Columbia River and has been incorporated into annual monitoring programs to further describe spawning frequency and duration. - An additional spawning location is used in most years (2007-2019, and 2022) in the vicinity of Kinnaird but the exact location(s) of egg deposition remains unknown.

Management Question	Status
	- 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. An analysis of long-term movements is ongoing to determine the interaction of individuals from different sections of the transboundary reach.
How do existing river operations affect adult movements, habitat preference, spawning site selection, or spawning activity?	- Adults select deep, slow moving sections of the river, which are currently not limited by the existing operating regime of the river. Site fidelity is high for 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. More comprehensive analyses are ongoing to understand long-term trends in movements and habitat use. - 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 the river where they spend the majority of their time.

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1.0 INTRODUCTION

White Sturgeon (*Acipenser transmontanus*) in the lower Columbia River (LCR), are one of four Canadian populations that were listed as endangered under the Species at Risk Act in 2006. The population is undergoing recruitment failure (Hildebrand and Parsley 2013; Fisheries and Oceans 2014) 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. 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. Accordingly, a monitoring program was developed to address these questions and support recovery of the population.

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 under this program, other sites have been located in the Canadian portion of the LCR based on embryo and larval captures and adult movements. Spawning has been identified at the area immediately downstream of Hugh Keenleyside Dam (HLK) and the Arrow Lakes Generating Station (ALH, rkm 0.1; BC Hydro 2013 2015a, 2016) and is known to occur in the vicinity of Kinnaird (rkm 13.0 to 19.0; Golder 2009a, 2009b; BC Hydro 2013, 2015a, 2015b, 2016, 2017, 2018, 2019), though the exact location(s) of egg deposition remains unknown. These results demonstrate that undocumented spawning locations remain in the LCR, and emphasize the importance of continued monitoring to describe adult reproductive ecology, determine mechanisms influencing spawning site selection, and understand underlying mechanisms resulting in recruitment failure.

In 2001, a conservation aquaculture program was initiated to ensure extirpation was avoided through the release of supplemental offspring back into the LCR and to retain the genetic diversity of the wild population. Acquisition of mature wild adults to serve as broodstock for the conservation aquaculture program occurred annually from 2001 – 2014 and was successful in providing 175 individual adults (78 females and 97 males) contributing 105,262 hatchery-reared juvenile sturgeon released in the Canadian portion of the LCR. Based on a study by Jay et al. (2014), it was advised by the Upper Columbia White Sturgeon Recovery Initiative Technical Working Group (UCWSRI TWG) to design a Streamside Incubation Facility (SIF) to incorporate wild offspring into the stocking practices increasing representation of LCR spawning adults and levels of genetic diversity among stocked juvenile White Sturgeon. Alongside the broodstock acquisition program, a pilot SIF program was implemented in 2014 and was successful in releasing 1,095 wild progeny into the LCR the following spring. In 2015, the broodstock program was suspended and all juvenile White Sturgeon stocked as of the 2015 year class have been of wild origin collected through the SIF program. The release strategy for these wild origin fish is a minimum release weight of 200 grams to improve survival following release based on results of juvenile survival modeling (BC Hydro 2016b). A total of 76, 800, and 607 wild progeny were released for year classes 2015, 2016, and 2017. In 2018, release targets were reduced to a maximum of 200 fish and these targets were met in year classes 2018 to 2021. Development of the SIF in Canada also aligned with the US portion of the LCR White Sturgeon population, as collections of wild origin larvae have served as the basis for hatchery releases in the US since 2010.

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

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

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

More specific objectives are provided in section 1.2.

1.1 Management Hypothesis

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

This monitoring program was designed to provide long term information on adult White Sturgeon abundance, biological characteristics exhibited under current operation conditions, and reproductive status. In addition, it was designed to include continued baseline data collection on the remaining wild adults, which will be utilized as a 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 through the use of egg mats and drift nets to collect White Sturgeon embryos and larvae.
2. Provide information on trends in the number of discrete spawning days as a measure of population demographics and reproductive potential.
3. Develop baseline data to assess the effectiveness of future management strategies.
4. Collect naturally produced embryos and larvae for streamside incubation and hatchery rearing to meet objectives of the conservation aquaculture program.

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

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

1.2.3 *Acoustic Tagging and Telemetry*

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

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

1.3 Study Area

The study area for the 2022 monitoring program consisted of the 57 km stretch of the LCR between HLK and the Canada/U.S. Border (downstream of the Pend d'Oreille River confluence) with certain aspects (i.e., stock assessment) extending beyond the international border to Gifford, Washington (Figure 1). The study area also included a small section (~2.5 km) of the Kootenay River below Brilliant Dam extending to its confluence with the LCR. To identify distribution of White Sturgeon for certain components (e.g., population assessment, telemetry), the LCR study area was stratified into 5 equal zones (11.2 km in length; consecutively numbered 1 through 5 from HLK to Canada/Us Border). Specific areas of the LCR sampled under the various components of the program are described below.

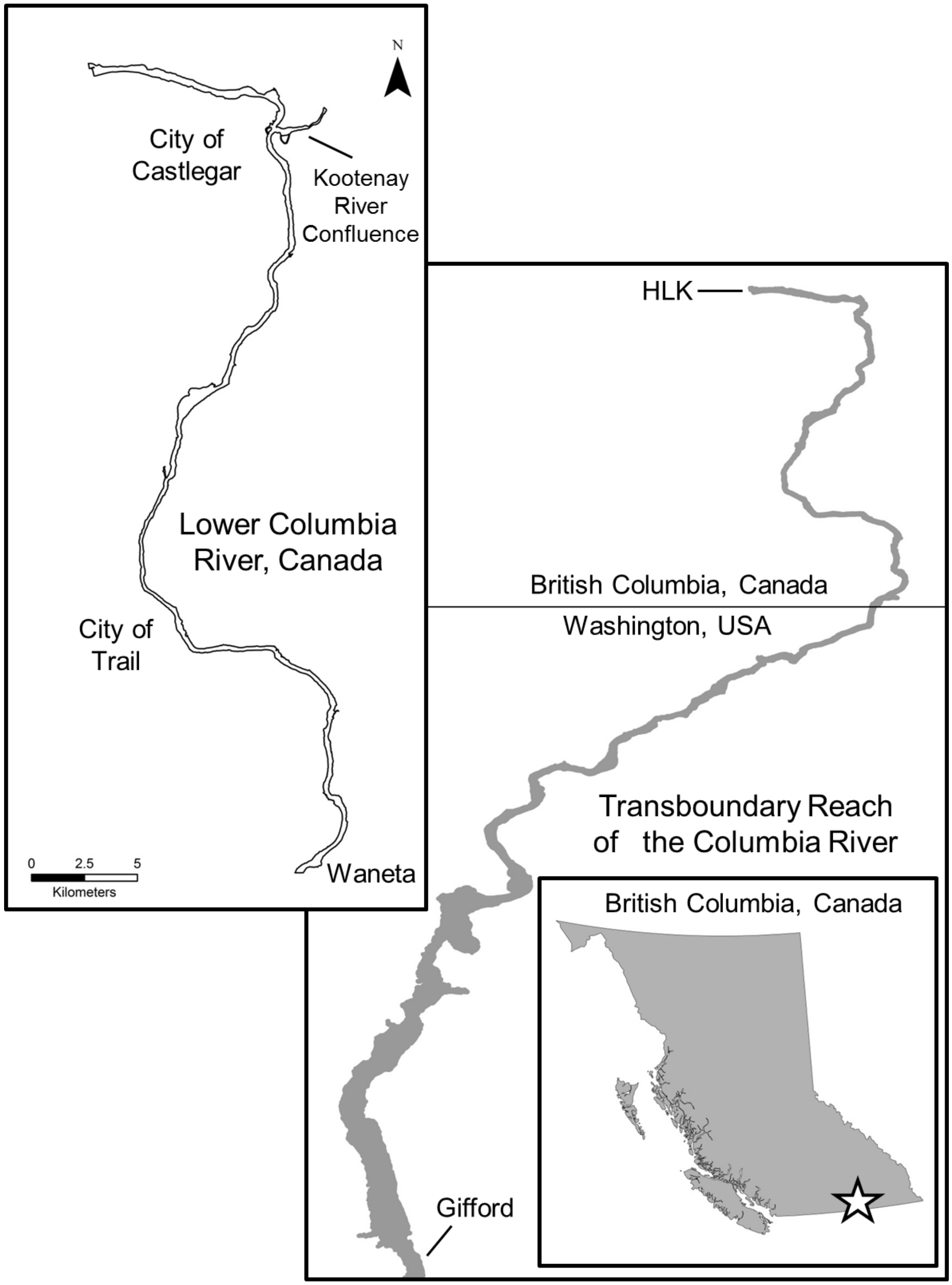

Figure 1. Overview of the study area in the lower Columbia River between Hugh L. Keenleyside Dam (HLK, rkm 0.1) and the Canada–US border (rkm 57.0) in relation to the Transboundary section of the Columbia River.

2.0 METHODOLGY

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

2.1 Physical Parameters

2.1.1 *Discharge*

In 2022, 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 2022 study period, water temperatures were collected at several locations on the LCR including HLK (rkm 0.1), Kootenay River (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), and Waneta (rkm 56.0). Water temperatures were recorded hourly at each location using thermographs (Vemco Minilogs, accurate to ±0.1°C).

2.2 Spawn Monitoring

2.2.1 *Study Design*

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

Monitoring of spawning activity occurred at Waneta (rkm 56.0) located at the Pend d'Oreille River confluence immediately upstream of the Canada/US border (Figure 2). This site has been monitored for spawning activity since 1993 and is designated as the primary White Sturgeon spawning area within the Canadian portion of the LCR (Hildebrand et al. 1999; Irvine et al. 2007; Golder 2009a). Two secondary spawn monitoring sites were located in upstream sections of the LCR at ALH (rkm 0.1) and Kinnaird (rkm 13.4 to rkm 18.2). Spawning has been previously documented immediately downstream of ALH with geographical boundaries described by Terraquatic Resource Management (2011; Figure 2). The extent of sampling downstream of Kinnaird was based on past spawn monitoring surveys and White Sturgeon adult movement studies (BC Hydro 2013, 2015a, 2015b, 2016a, 2017, 2018, 2019, 2020; 2022, Figure 2).

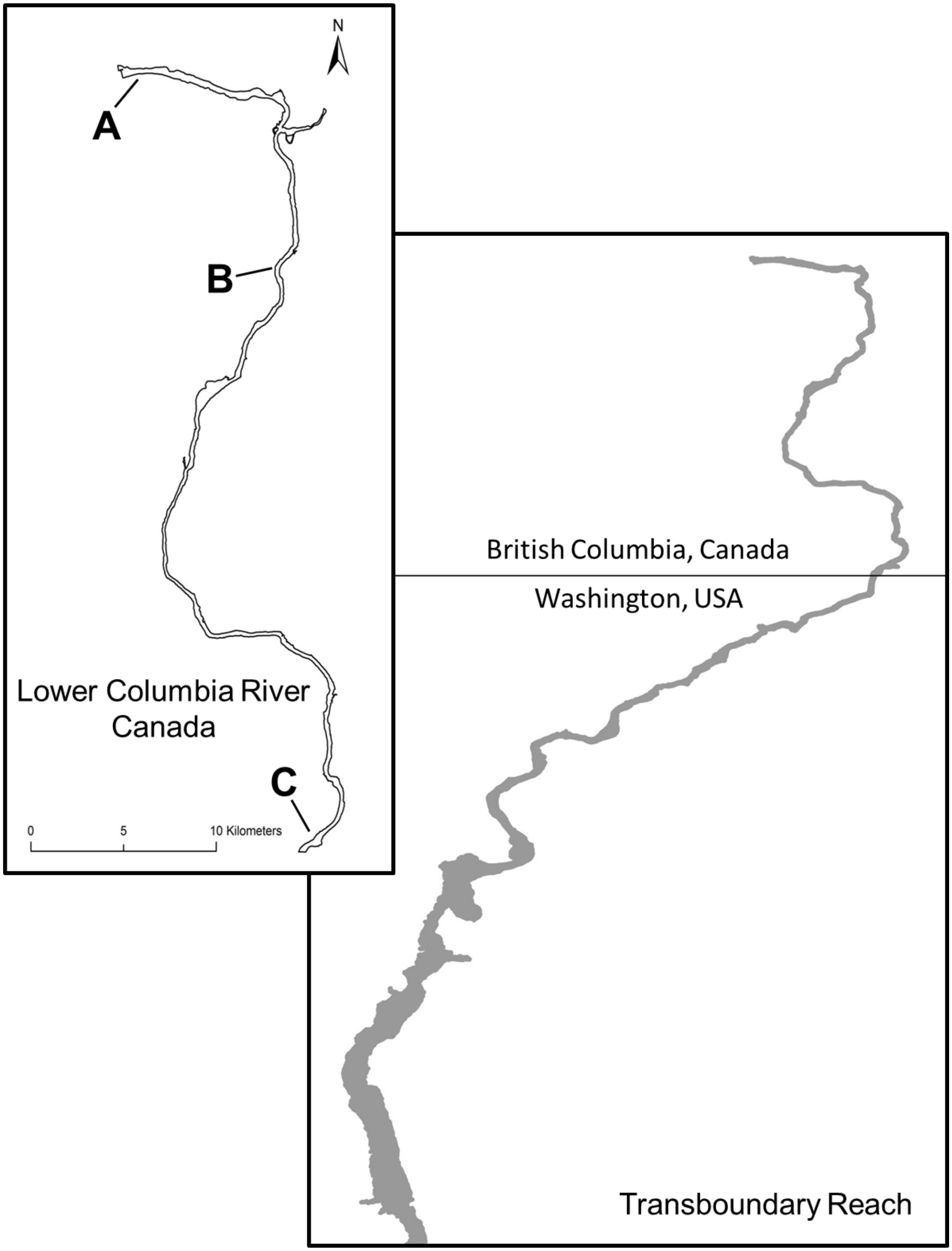

Figure 2. Egg mat and drift net deployment sites of ALH (rkm 0.1; A), Kinnaird (rkm 13.4 to rkm 18.2; B), and Waneta (rkm 56.0; C) in the lower Columbia River in 2022.

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 a key component to the adult spawn monitoring program and has proven successful at documenting spawning activity through the collection of embryos and larvae (BC Hydro 2013, 2015a, 2015b, 2016a, 2017, 2018, 2019, 2020).

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

Table 1. Number of egg mats and drift nets deployed at each spawn-monitoring site in 2022.

		2022	
Site	rkm	Egg Mats	Drift Nets
Waneta	56.0	6	6
ALH	0.1	5	5
Kinnaird	14.5	4	4
Kinnaird	18.2	4	4

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

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

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

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

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

2.2.3 *Embryo and Larval Sampling*

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

2.2.4 *Developmental Staging and Estimation of Fertilization Date*

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

Fertilization date for collected embryos and larvae was estimated by back-calculation from the recorded date and time of capture/preservation based on developmental stage and mean incubation water temperature. The estimated age (hours; embryos, Parsley, U.S. Geological Survey, unpublished; larvae, Jay et al. 2020) was subtracted from the preservation date and time to determine the estimated date and time of fertilization (i.e., spawning date). Calculated fertilization dates provided an estimation of spawning duration for each spawning site. However, the accuracy of embryo developmental staging as a method to delineate spawning days and estimate time of spawning can be affected by individual White Sturgeon spawning behaviour, embryo maturation rates, and more importantly, the fluctuation in daily thermal regimes (Parsley et al. 2010).

2.2.5 *Streamside Incubation Facility (SIF)*

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

2.3 Population Monitoring, Abundance, and Characteristics

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

2.3.1 *Study Area and Design*

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

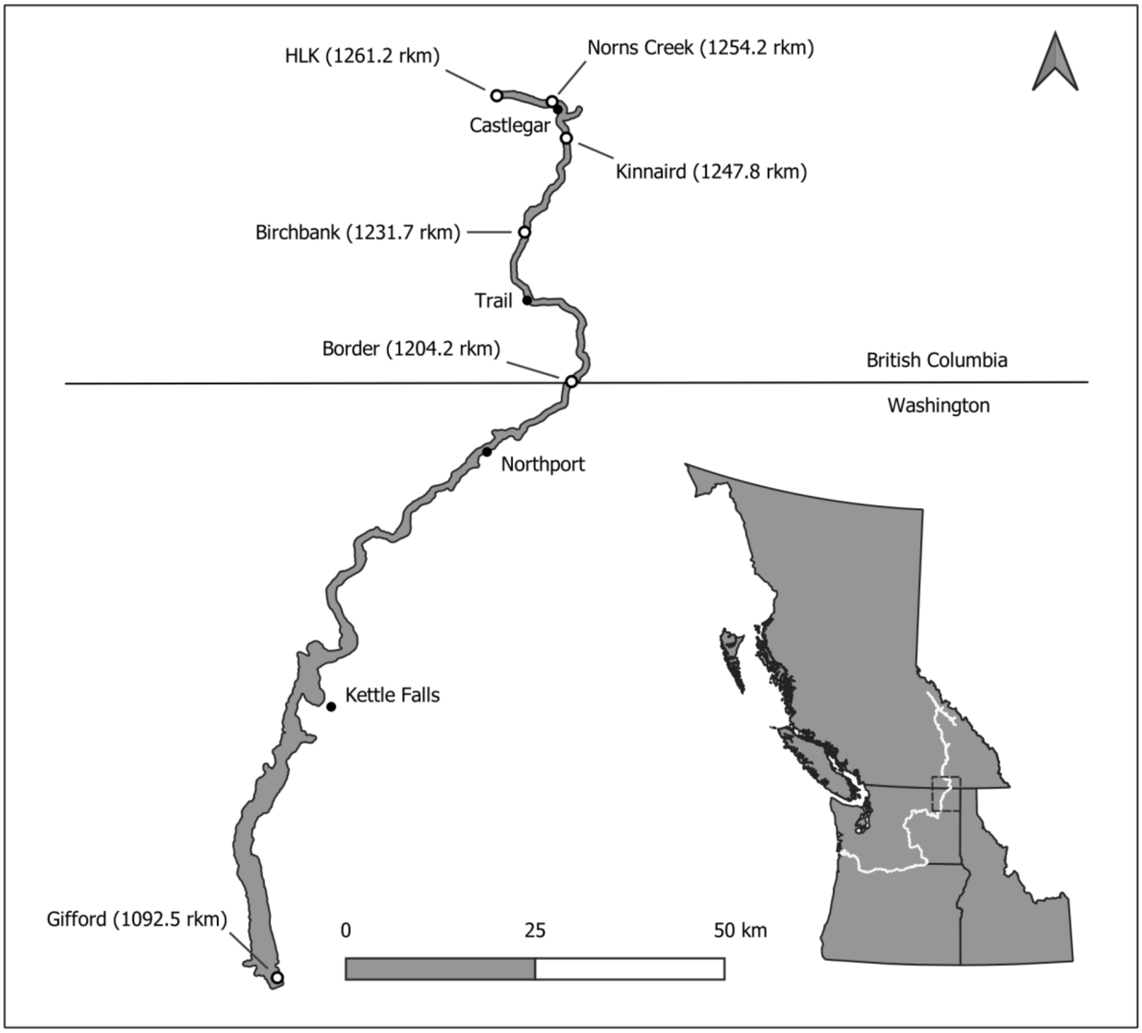

Figure 3. Study area map of the Transboundary Reach of the upper Columbia River. Geographical extent of stock assessment sampling within the study area extends from Gifford, Washington, USA upstream to Hugh L. Keenleyside Dam (HLK) in British Columbia, Canada. Locations where temperature and discharge measurements were collected are highlighted, including Birchbank, and the Canada–US border.

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 (Hildebrand and Parsley 2013). 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 previously in the LCR (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 are 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 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 (smears) were collected from all captured fish in 2014 through 2016 (BC Hydro 2015a, 2016a, 2017), to determine the incidence of 12N fish in the wild as well as hatchery-reared fish stocked in earlier years when ploidy levels were unknown. It was identified that the blood smear method underestimated true rates of autopolyploidy (Andrea Schreier, U.C. Davis, personal communication) and blood samples were not collected in 2017 as new methods were being developed. A subset of fish captured during the fall stock assessment session were sampled in certain years (e.g. 2018) to test ploidy levels using a coulter counter. This will be repeated in future years.

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

2.3.4 *Length, weight and year class characteristics*

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

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

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

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

where L is fork length (FL; cm).

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

More detailed modelling of factors influencing growth rates and condition of wild fish is underway and expected to be complete in 2023.

2.3.5 *Mark-recapture analyses*

The analysis of the coordinated stock assessment program has been ongoing, with results from previous analyses provided in earlier reports (BC Hydro 2020). Moving forward, the stock assessment data will be combined with earlier capture data spanning 1993-2022 to fit an open population model to improve confidence in the estimates of wild survival rates and abundance. Further, an open population model will allow assumptions related to survival relationships developed in earlier analyses (e.g., constant survival through time based on mass-survival relationship and age) to be avoided and allow for hatchery-origin family-specific survival rates and abundance to be estimated. This analysis, expected to be developed in 2023, will provide a more robust understanding of the population before and after hatchery intervention, which is critical given density dependent effects on growth that have been observed in the hatchery segment of the population (Crossman et al. 2023).

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.

Vemco model V16 acoustic tags (operational life of 10 years) were allocated to adult White Sturgeon predicted to spawn within the following 1-3 years (based on sex maturity examinations) in 2009, 2011, and 2013 (BC Hydro 2011, 2013). In 2007 through 2012, all adults collected for broodstock were implanted with an acoustic tag prior to their post spawning release (BC Hydro 2013). In 2013, only one female that was collected for broodstock and did not successfully spawn was implanted with an acoustic tag prior to release in order to monitor post release movements related to spawning. No fish were acoustically tagged in 2014. In June 2015, 4 females expected to spawn in that year were acoustically tagged. In May 2016, 1 male that was expected to spawn was acoustically tagged. One female was tagged in May 2017. No tags were deployed in wild adults in recent years (2018-2021). Total number of White Sturgeon acoustically tagged is provided in Table 2.

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

Year	Wild		Broodstock		Total
	Female	Male	Female	Male	
2007	0	0	5	6	11
2008	0	0	8	7	15
2009	11	8	10	12	41
2010	0	0	9	10	19
2011	4	1	10	11	26
2012	0	0	8	10	18
2013	1	1	1	0	3
2014	0	0	0	0	0
2015	4	0	0	0	4
2016	0	1	0	0	1
2017	1	0	0	0	1
2018	0	0	0	0	0
2019	0	0	0	0	0
2020	0	0	0	0	0
2021	0	0	0	0	0
2022	0	0	0	0	0
Total	21	11	51	56	139

2.4.1 *Acoustic Receiver Array*

We used an array of fixed station remote receivers (Vemco, model VR2 and VR2W) already deployed within the LCR to detect spatial and temporal movements of acoustically tagged White Sturgeon. Since being initially deployed in 2003, the spatial extent of the array encompassing the LCR from HLK (rkm 0.1) southward to the Canada/U.S. International Border (rkm 57.0) remained constant until 2009. In early May of 2010, the array was repositioned to roughly 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 SQL database.

2.4.2 *Telemetry Data Analysis*

Although the acoustic array was originally intended to track the movements of White Sturgeon, multiple research projects involving other fish species are ongoing in the LCR and, as such, user agreements with other agencies and researchers have been developed for the utilization of the telemetry array. For all projects combined, we often record more than 4 million detections annually. Over a period of the last several years, this has resulted in a larger amount of data than anticipated and issues regarding tag collisions increasing the total number of "false" detections occurring in the database. False detections are echoes generated by the system's environment (e.g., bathymetric profile, substrate, narrow river) or pings of multiple tags colliding resulting in detections that were not linked to an active transmitter or does not align with movement data for an active transmitter. The 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. Database solutions are being developed to improve efficiency in data storage and facilitate analyses of the long-term dataset. Detection data from 2009-2017 have been summarized in previous reports (BC Hydro 2020) and a large analysis of all sturgeon detections since 2008 is underway to measure residence time in specific habitats within the LCR and estimate the probability of movement and distance migrated as a function of habitat selection and environmental conditions (discharge and temperatures). Results will help determine the effect of environmental factors and river regulation on habitat use and movements of white sturgeons.

3.0 MONITORING RESULTS

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

3.1 Physical Parameters

3.1.1 *Discharge*

Mean daily discharge (cms; cfs) on the lower Columbia River was measured from Arrow Reservoir, Kootenay River, Birchbank, and Canada–US Border for the 2022 study period and 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 expected to occur annually between June 1 and August 15 based on embryo and larval collections over the past decade. At the Canada–US Border, freshet flows peaked at 7,003 cms on June 26, around the same time as the estimated initial spawning date (Figure 4). Flows exceeded 4,000 cms for 63 days and were above 5,000 cms for 39 days.

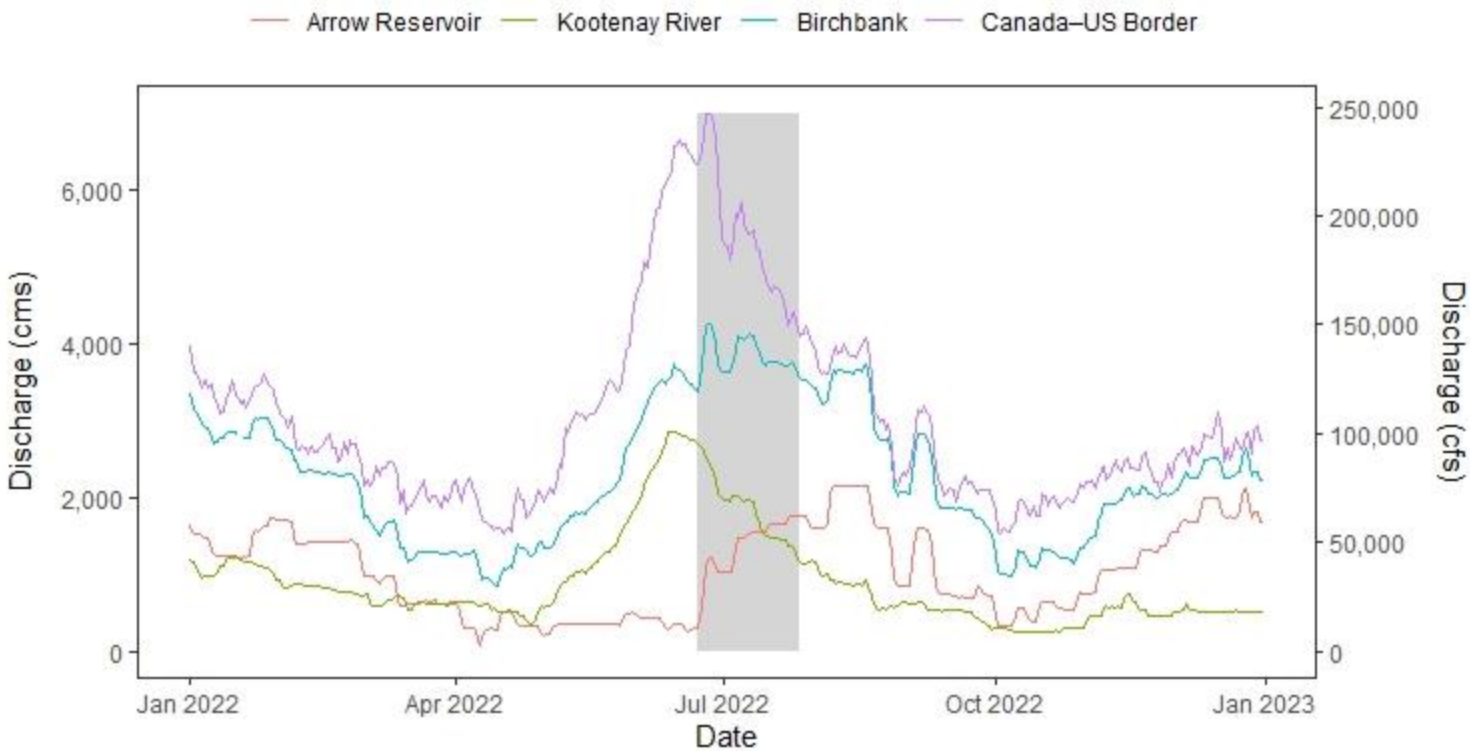

Figure 4. Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada–United States border on the lower Columbia River from January 01, 2022 – December 31, 2022. Shaded areas represent the estimated spawning period. Estimated spawning dates were based on the developmental stage of collected embryos and/or larvae.

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 2022.

		Discharge			
Year	Location	Min (cms)	Max (cms)	Min (cfs)	Max (cfs)
2022	Arrow	61	2,149	2,154	75,891
	Kootenay	256	2,864	9,041	101,141
	Birchbank	847	4,267	29,912	150,688
	Border	1,526	7,003	53,890	247,309

3.1.2 *Water Temperature*

LCR mean daily water temperatures (°C) and estimated spawning period during 2022 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 (ºC) recorded within the lower Columbia River during 2022. 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).

		Water Temperature (°C)			Date of Suspected Spawning Threshold (14°C)
Year	Location	Mean	Min	Max	
2022	HLK	7.9 ± 5.5	2.2	18.5	June 24
	Kootenay	9.5 ± 5.9	1.8	20.7	July 12
	Kinnaird	9.1 ± 5.4	2.5	19.1	July 12
	Genelle	9.2 ± 5.6	2.4	18.8	July 11
	Rivervale	9.0 ± 5.3	2.4	18.8	July 3
	Waneta	9.6 ± 6.4	1.8	21.4	June 28

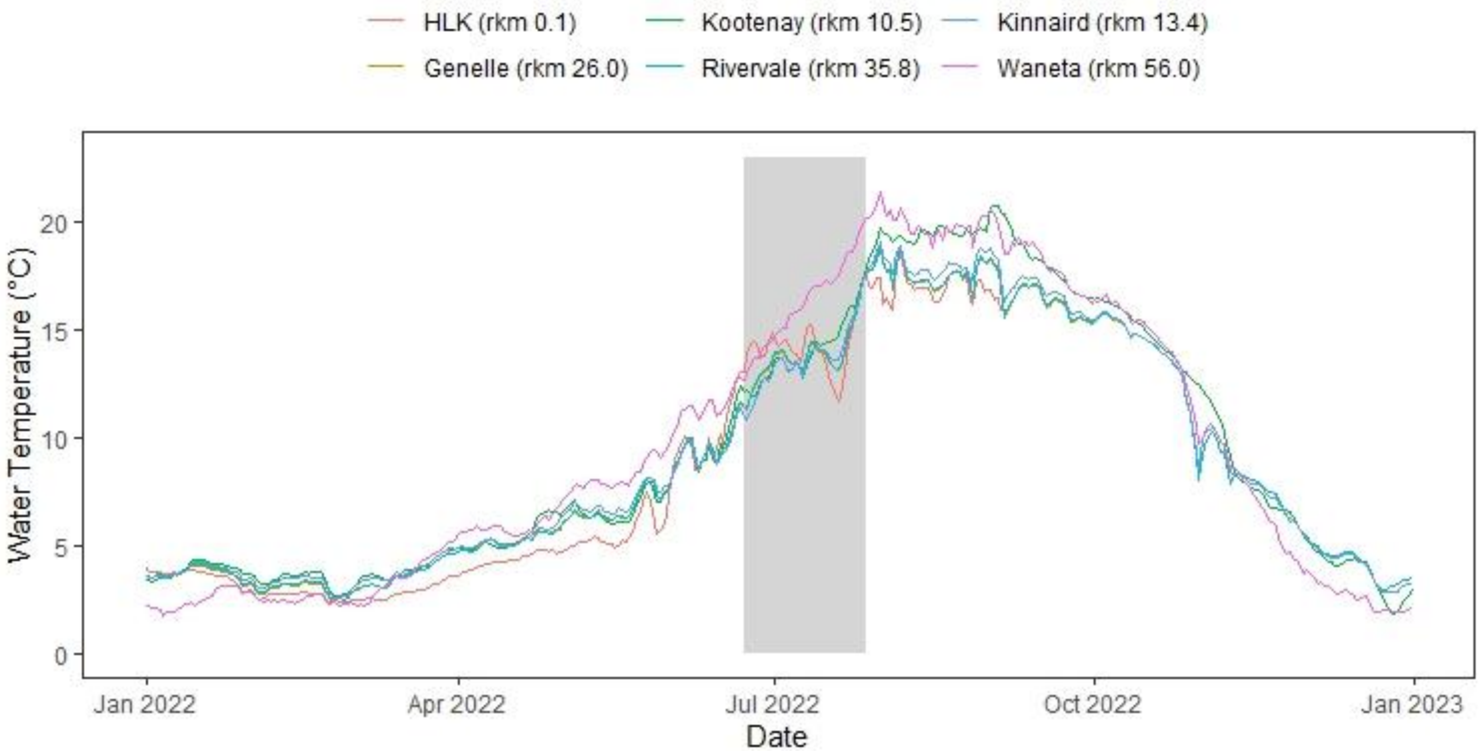

Figure 5. Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada–United States border on the lower Columbia River from January 01, 2022 – December 31, 2022. Shaded areas represent the estimated spawning period. Estimated spawning dates were based on the developmental stage of collected embryos and/or larvae.

3.2 Spawn Monitoring

3.2.1 *Embryo and Larval Sampling Effort and Collection*

Downstream Location – Waneta (rkm 56.0)

Sampling effort alternated between egg mats and drift nets using the same anchoring systems for each sampling method. Six anchoring systems were deployed starting on June 13 and egg mat/drift net sampling continued until August 3. During the sampling period, water temperatures ranged from 11.0 to 22.5°C (Figure 5) and water depth (mean ± SD) was 5.5 ± 1.5 m. Total sampling effort for egg mats and drift nets was 5,360 hours and 268 hours, respectively (Table 5). Single set effort (mean ± SD) was 59.6 ± 48.4 and 3.0 ± 2.5 hours, respectively.

A total of 1,173 embryos (egg mat, n=229; drift net, n=944) and 67 larvae (egg mat, n=0; drift net, n=67) were captured at Waneta between the dates of June 22 and July 27 (Table 5). The largest daily egg mat sample was 55 (embryos, n=55; larvae, n=0) collected on June 28 representing 0.24 of total egg mat sample collection. The largest daily drift net sample was 405 (embryos, n=405; larvae, n=0) collected on June 28 representing 0.43 of total drift net sample collection.

Upstream Location – Kinnaird (rkm 13.4 to rkm 18.2)

Four anchoring systems were deployed at both rkm 14.5 and rkm 18.2 starting on June 28 and sampling continued until August 5. During the sampling period, water temperatures ranged from 12.5 to 18.8°C (Figure 5) and sampling water depth was 4.6 ± 1.3 m. Total egg mat sampling effort was 4,222 hours and mean single set effort was 74.1 ± 44.4 hours (Table 5). Total sampling effort for drift nets was 1,432 hours and mean single set effort was 14.5 ± 10.4. A total of one embryo (egg mat, n=0; drift net, n=1) was captured at Kinnaird on July 11 (Table 5).

Upstream Location – ALH (rkm 0.1)

Five anchoring systems were deployed on June 28 and sampling continued until August 5. During the sampling period, water temperatures ranged from 11.0 to 18.3°C (Figure 5) and water depth was 5.9 ± 1.3. Total egg mat sampling effort was 2,567 hours (Table 5) and mean single set effort was 91.7 ± 35.2 hours. Total drift net sampling effort was 1,140 hours and single set effort was 19.3 ± 8.7 hours. No embryos or larvae were captured at ALH sites.

Table 5. White Sturgeon embryo and larvae collection and sampling effort for monitoring locations in the lower Columbia River including Waneta (rkm 56.0), downstream of Kinnaird (rkm 12.8, rkm 13.4, rkm 14.5, rkm 15.0, rkm 15.6, rkm 16.9, rkm 17.3, rkm 18.2, rkm 19.2), Kootenay (rkm 10.5), downstream Arrow Lakes Generating Station (ALH; rkm 6.0), ALH (rkm 0.1) and Hugh L. Keenleyside dam (HLK; rkm 0.1) for years 2008 – 2022.

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

Year	Location	Egg Mats			Drift Nets		
		Embryo	Larvae	Effort (hrs)	Embryo	Larvae	Effort (hrs)
2015	Waneta	245	1	22,016	8	55	275
	rkm 13.4	-	-	-	0	0	533
	rkm 14.5	-	-	-	0	1	272
	rkm 16.9	-	-	-	0	4	186
	rkm 17.3	-	-	-	0	1	187
	rkm 18.2	-	-	-	0	2	1,767
	rkm 19.2	-	-	-	0	0	91
	ALH	-	-	-	0	1	1,373
2016	Waneta	1270	4	13,831	5203	955	965
	rkm 12.8	-	-	-	0	0	901
	rkm 13.4	-	-	-	0	0	118
	rkm 14.5	-	-	-	0	3	381
	rkm 16.9	-	-	-	0	5	121
	rkm 17.3	-	-	-	0	1	122
	rkm 18.2	-	-	-	0	8	990
	ALH	-	-	-	0	0	1006
2017	Waneta	561	2	10,377	1,914	582	913
	rkm 13.4	-	-	-	1	2	416
	rkm 14.5	-	-	-	0	8	433
	rkm 16.9	-	-	-	0	0	78
	rkm 18.2	-	-	-	0	4	363
	ALH	-	-	-	511	159	2,146
2018	Waneta	455	17	6,456	9,515	570	1,258
	rkm 13.4	-	-	-	0	2	1,071
	rkm 14.5	-	-	-	0	1	707
	rkm 18.2	-	-	-	0	1	979
	ALH	-	-	-	3	14	2,290
2019	Waneta	105	2	8,738	721	127	437
	rkm 14.5	0	0	836	1	0	1,335
	rkm 18.2	-	-	-	0	6	131
	ALH	0	0	2,860	3	6	1,311
2020	Waneta	817	1	5,560	6,170	148	769
	rkm 14.5	0	0	613	0	0	534
	rkm 18.2	-	-	-	0	0	100
	ALH	0	0	1,083	3	0	1,113
2021	Waneta	861	1	6,617	2,378	53	286
	rkm 14.5	0	0	1,443	0	0	856
	rkm 18.2	-	-	-	0	0	100
	ALH	0	0	2,267	0	0	1,385

Year	Location	Egg Mats			Drift Nets		
		Embryo	Larvae	Effort (hrs)	Embryo	Larvae	Effort (hrs)
2022	Waneta	229	0	5,360	944	67	268
	rkm 14.5	0	0	1,913	1	0	876
	rkm 18.2	0	0	2,308	0	0	556
	ALH	0	0	2,567	0	0	1,140

3.2.2 *Developmental Staging and Estimated Spawning Dates*

Embryos and larvae were assigned a developmental stage based on Dettlaff et al. (1993) to calculate an estimated date of fertilization. Stages were generalized compared to previous sampling years (BC Hydro 2015a) to reduce handling of collected embryos and larvae. Samples collected in years 2012 to 2022 ranged from newly fertilized embryos to larvae (Tables 6 and 7).

Based on staged embryos and yolk-sac larvae, an estimated 12 discrete spawning days occurred at Waneta and one at Kinnaird in 2022 (Table 8). All of these events occurred on the descending limb of the hydrograph. No spawning was detected at ALH in 2022.

Estimated spawning dates at locations of Waneta, Kinnaird, and ALH for sampling years 2011 through 2022 are provided in Table 9. Spawning has generally been estimated to occur at Waneta in mid-June to late July and at Kinnaird in early to late July. Estimated spawning dates at ALH have been early July to early August.

Table 6. Proportion of White Sturgeon embryos and larvae collected across different developmental stages from lower Columbia River spawn monitoring locations of Waneta (rkm 56.0), Kinnaird (rkm 13.4 to rkm 18.2), and Arrow Lakes Generating Station (ALH; rkm 0.1) in 2022. Developmental stages are based on Dettlaff et al. (1993). To limit the handling of embryos and larvae, developmental stages were generalized compared to previous collection years (BC Hydro 2015).

Developmental Category	Stage	Waneta		Kinnaird		ALH	
		n	*Prop.*	*n*	*Prop.*	*n*	*Prop.*
Cleavage - Gastrulation	1 - 14	710	0.73	1	1.00	0	-
Yolk Plug	15 - 18	76	0.08	0	0.00	0	-
Neurulation - Heart formation - Pre-Hatch	19 - 35	115	0.12	0	0.00	0	-
Yolk-Sac Larvae	36 - 45	67	0.07	0	0.00	0	-

Table 7. Proportion of White Sturgeon embryos and larvae collected across different developmental stages from lower Columbia River spawning locations of Waneta (rkm 56.0), Kinnaird (rkm 12.8 to 18.2), and Arrow Lakes Generating Station (ALH); rkm 0.1) in years 2012 – 2022.

Developmental Category	Stage	Waneta		Kinnaird		ALH	
		n	*Prop.*	*n*	*Prop.*	*n*	*Prop.*
Cleavage - Gastrulation	1 - 14	23,217	0.70	4	0.05	361	0.57
Yolk Plug	15 - 18	4,312	0.13	1	0.01	94	0.15
Neurulation - Heart formation - Pre-Hatch	19 - 35	3,029	0.09	1	0.01	14	0.02
Yolk-Sac Larvae	36 - 45	2,554	0.08	66	0.92	166	0.26

Table 8. Estimated spawning dates at the Waneta (rkm 56.0) and Kinnaird (rkm 13.4 to rkm 18.2) spawning locations in the lower Columbia River in 2022. Dates are determined through back calculation from date of capture based on developmental stage of eggs and larvae.

Spawning Event	Location: Waneta	Location: Kinnaird
1	June 22	July 11
2	June 23	
3	June 25	
4	June 27	
5	June 28	
6	July 4	
7	July 6	
8	July 7	
9	July 11	
10	July 12	
11	July 15	
12	July 26	

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 – 2022. Estimated spawning duration was based on the developmental stage of collected embryos or larvae. Yearly data was excluded due to reasons of poor condition of samples collected inhibiting assignment of developmental stage or no samples were collected. Minimum and maximum mean daily water temperatures were calculated during the period spawning occurred.

Location	Year	Number of Estimated Spawning Days	Duration		Daily Mean Water Temperature (°C)	
			Start	End	Minimum	Maximum
ALH	2011	5	01-Aug	05-Aug	14.8	16.1
	2017	3	17-Jul	19-Jul	12.4	17.4
	2018	3	04-Jul	07-Jul	13.7	15.3
	2019	2	23-Jul	24-Jul	15.0	15.1
Kinnaird	2013	2	23-Jul	27-Jul	16.8	18.1
	2014	3	14-Jul	22-Jul	16.5	17.8
	2015	4	02-Jul	09-Jul	16.7	19.0
	2016	6	03-Jul	30-Jul	13.0	19.2
	2017	1	10-Jul	10-Jul	15.6	16.0
	2018	4	5-Jul	13-Jul	14.9	16.6
	2019	4	24-Jun	23-Jul	14.0	16.5
	2022	1	11-Jul	11-Jul	13.3	14.1
Waneta	2011	19	30-Jun	03-Aug	11.8	18.1
	2012	18	28-Jun	22-Jul	13.0	16.0
	2013	12	18-Jun	18-Jul	12.8	19.9
	2014	5	21-Jun	15-Jul	11.3	18.7
	2015	6	11-Jun	21-Jun	n/a	n/a
	2016	13	03-Jun	25-Jun	12.2	19.4
	2017	17	11-Jun	6-Jul	13.3	16.6
	2018	21	12-Jun	15-Jul	11.9	18.0
	2019	14	12-Jun	30-Jul	15.1	20.0
	2020	11	23-Jun	27-Jul	14.7	19.5
	2021	9	8-Jun	9-Jul	13.0	23.3
	2022	12	22-Jun	26-Jul	12.7	19.8

3.2.3 *Streamside Incubation Facility*

Daily air and water temperatures recorded at the streamside facility are illustrated in Figure 6. Mean (± SD), minimum, and maximum air and water temperatures are provided in Table 10 for 2022. Despite elevated air temperatures in the SIF, water temperatures recorded from the LCR and facility tanks were similar (Figures 6).

Live embryos (n=914) and larvae (n=8) collected at Waneta were transferred to the SIF for incubation. One live embryo was collected at Kinnaird and transferred to the SIF. No live embryos or larvae were collected at ALH. Following incubation, larvae originating from Waneta (n=530) were transported to the conservation hatchery. Abundance and survival for sampling years 2014 through 2022 are provided in Tables 11 and 12, respectively. In the summer of 2023, 200 wild progeny from 2022 collections were released into the LCR with the remaining fish to be released in the Middle Columbia River.

Table 10. Mean (± SD), minimum, and maximum air and water temperatures recorded at the location of the Streamside Incubation Facility (SIF) in 2022. Temperature loggers were stationed to record SIF inside air, lower Columbia River (LCR) water intake, and SIF trough water temperatures (°C).

		Temperature (°C)		
Year	Source	Mean ±SD	Minimum	Maximum
2022	SIF Air	21.9 ± 8.5	8.1	43.5
	River Intake	14.1 ± 2.4	8.8	19.2
	SIF Trough	14.4 ± 2.5	8.9	19.7

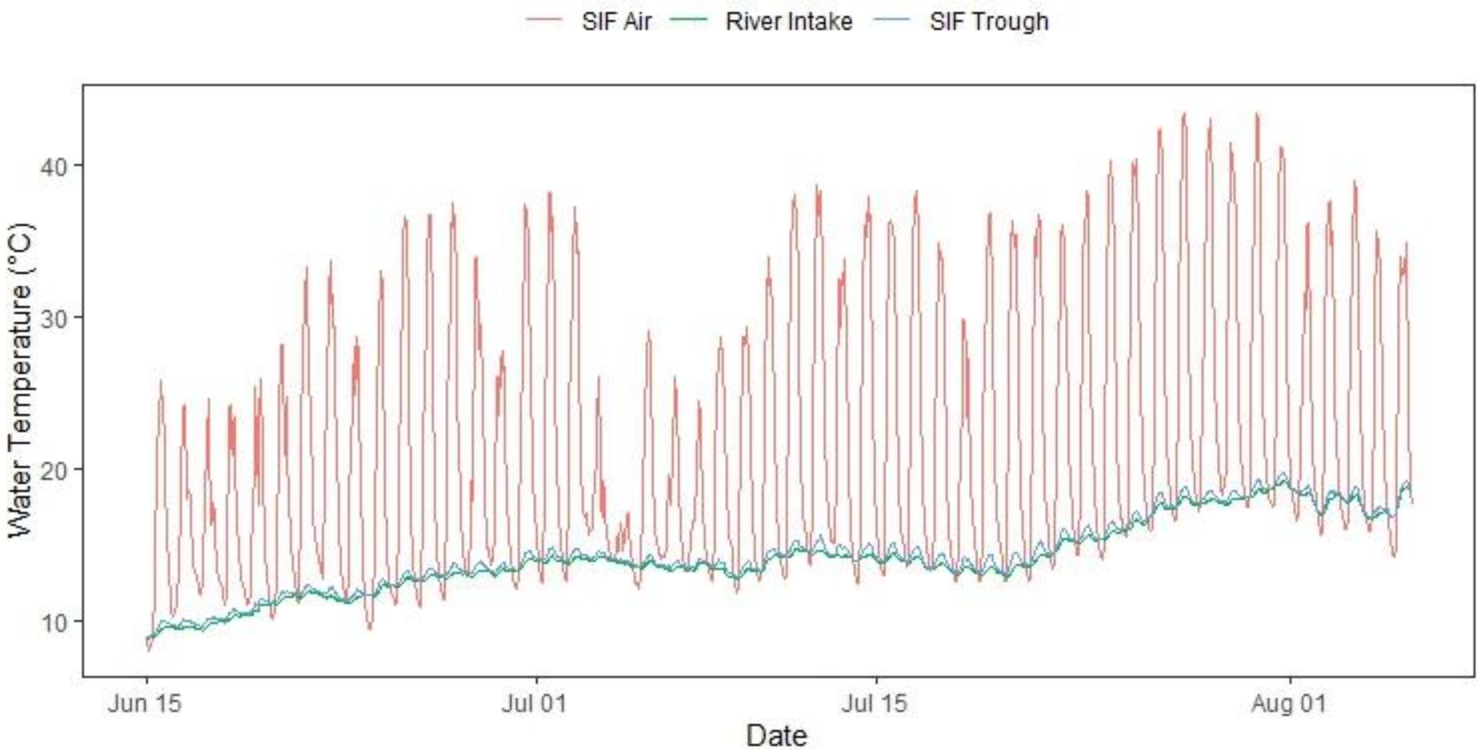

Figure 6. Hourly temperature (°C) recorded at the lower Columbia River (LCR) Streamside Incubation Facility in 2022. Data includes air temperature inside the facility, and water temperatures of the LCR and incubation tanks.

Table 11. Numbers of embryos and larvae collected, incubated at the streamside incubation facility (SIF), and transferred to the hatchery from 3 spawning locations in the lower Columbia River, 2014 – 2022.

		Total Collected		Total Transferred to SIF		Total Transferred to the Hatchery		Total at time of release
Year	Location	Embryos	Larvae	Embryos	Larvae	Embryos	Larvae	
2022	Waneta	1,173	67	914	8	0	530	311*
	Kinnaird	1	0	1	0	0	0	0
	ALH	0	0	0	0	0	0	0
2021	Waneta	3,239	54	1,337	8	0	726	420*
	Kinnaird	0	0	0	0	0	0	0
	ALH	0	0	0	0	0	0	0
2020	Waneta	6,987	149	3,626	80	0	1,248	571*
	Kinnaird	0	0	0	0	0	0	0
	ALH	3	0	0	0	0	0	0
2019	Waneta	826	129	645	33	0	423	280*
	Kinnaird	1	0	1	0	0	1	1
	ALH	3	6	3	1	0	0	0
2018	Waneta	11,197	587	9,970	76	0	2,119	1,068*
	Kinnaird	0	4	0	0	0	0	0
	ALH	5	14	3	2	0	5	4
2017	Waneta	2,475	584	2,475	31	22	1,391	828
	Kinnaird	1	14	0	0	0	0	0
	ALH	511	159	1	0	507	0	55
2016	Waneta	6,473	959	6,473	286	0	2,245	1,224
	Kinnaird	0	17	0	3	0	2	1
	ALH	0	0	0	0	0	0	0
2015	Waneta	253	56	216	5	132	56	63
	Kinnaird	0	8	0	0	0	0	0
	ALH	0	1	0	0	0	0	0
2014	Waneta	5,762	67	5,176	17	0	1,951	1,108
	Kinnaird	6	13	3	0	0	2	0
	ALH	0	0	0	0	0	0	0

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

Table 12. Annual survival (all sites and events combined) in both the streamside Incubation Facility (SIF) and in the conservation hatchery, 2014 – 2022.

Year	Survival in SIF	Survival in hatchery
2022	0.57	0.58
2021	0.54	0.58
2020	0.41	0.43
2019	0.61	0.70
2018	0.21	0.53
2017	0.55	0.42
2016	0.33	0.55
2015	0.25	0.44
2014	0.38	0.56

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

Spring and fall 2022 stock assessments in the Canadian section of the LCR were conducted between the dates of May 17 – June 3 (17 days) and September 26 – October 13 (17 days) with water temperatures (mean ± SD) of 7.6 ± 1.0 °C and 14.5 ± 0.5 °C, respectively. During the spring and fall assessments, 1,332 hooks were set using 111 lines. Sampling effort for the spring and fall assessments was 2,430 hours and 2,321 hours, respectively. Set line deployment (mean ± SD) during the spring and fall assessments was 21.9 ± 2.4 hours and 20.9 ± 2.9 hours at water depths of 10.6 ± 4.8 m and 10.3 ± 4.9 m, respectively.

Within Canada, total White Sturgeon captures of 2022 was 210 and 369 (CPUE of 0.086 and 0.159) during the spring and fall stock assessments, respectively (Tables 13 and 14). Across all sampling years (2013 – 2022), number of captures was highest in sampling zone 1 (82 to 319 captures; CPUE 0.088 to 0.336) and lowest in sampling zone 4 (1 to 31 captures; CPUE 0.003 to 0.075; sampling zones represent 11.2 km increments; consecutively numbered 1 through 5 from HLK to Canada–US Border). A total of 6,384 captures have occurred over the nine sampling years (2013 – 2022) within the Canadian section of the LCR (Table 13). Of the total Canadian captures, 268 individuals were not previously handled during any White Sturgeon monitoring (new fish; Table 13). Hook sizes used for sampling remain effective at targeting both hatchery and wild fish >50 cm FL, with larger hook sizes catching marginally larger fish (Figure 7). Size 20-0 hooks were most effective for capturing wild adults and the larger hatchery-origin (>125 cm FL) sturgeon (Figure 7).

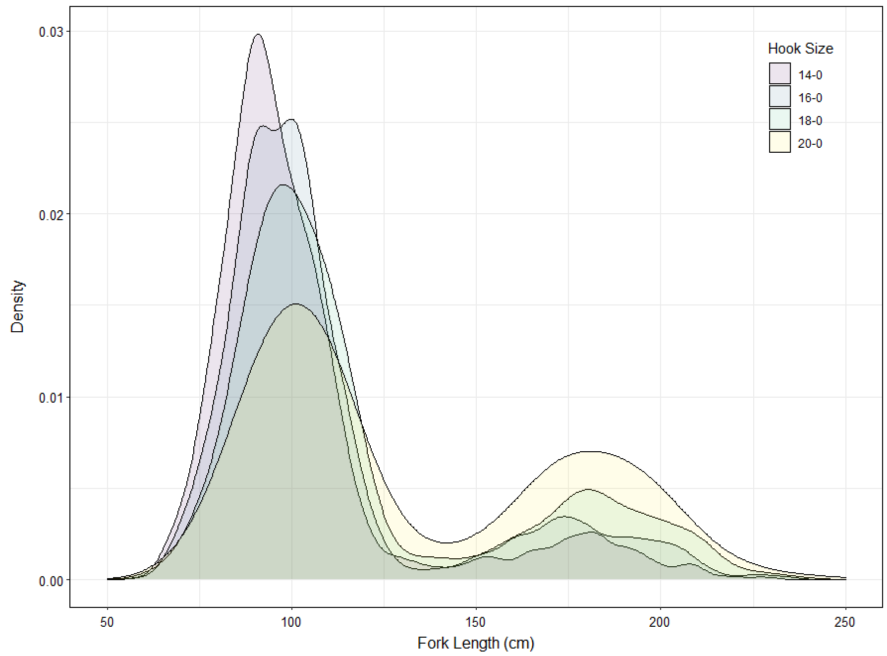

Figure 7. Fork length of white sturgeon captured using four different hook sizes used on setlines deployed during stock assessment surveys from 2013 – 2021. Hook sizes were balanced on each setline, with 3 hooks of each size category.

Table 13. Total number of White Sturgeon captured during the 2013 – 2022 spring and fall stock assessments in the lower Columbia River, Canada. Unmarked fish were considered new captures (i.e., not previously handled by researchers; does not include hatchery origin fish).

Year	Survey	Total	Wild	Hatchery Origin	New Fish	Water Temp (°C)
2013	Spring	117	80	37	23	6.1 ± 0.8
2013	Fall	250	93	157	29	15.9 ± 0.6
2014	Spring	194	93	101	21	7.5 ± 0.7
2014	Fall	358	83	275	35	15.7 ± 0.7
2015	Spring	295	78	217	15	8.9 ± 0.5
2015	Fall	360	74	286	20	13.7 ± 0.3
2016	Spring	426	74	352	8	8.9 ± 0.5
2016	Fall	370	90	280	15	13.7 ± 0.9
2017	Spring	175	34	141	8	7.4 ± 1.1
2017	Fall	396	60	336	16	14.9 ± 0.9
2018	Spring	328	40	288	4	10.5 ± 1.1
2018	Fall	423	87	336	14	14.6 ± 0.7
2019	Spring	341	63	278	15	10.5 ± 1.5
2019	Fall	436	71	365	14	15.0 ± 2.1
2020	Spring	273	40	233	9	8.6 ± 0.8
2020	Fall	358	47	310	3	16.4 ± 0.9
2021	Spring	383	33	350	6	10.8 ± 1.2
2021	Fall	322	30	292	4	13.4 ± 1.0
2022	Spring	210	29	177	4	7.6 ± 1.0
2022	Fall	369	42	322	5	14.5 ± 0.5
Total		6,384	1,241	5,133	268	-

Table 14. Total number of White Sturgeon captured and catch per unit effort (CPUE) by sampling zone for the 2013 – 2022 spring and fall stock assessments in the lower Columbia River, Canada.

	Total Capture (CPUE)											
	1		2		3		4		5		LCR	
2013 Spring	82	(0.088)	13	(0.023)	7	(0.012)	2	(0.044)	13	(0.027)	117	(0.039)
2013 Fall	117	(0.203)	42	(0.090)	37	(0.073)	16	(0.048)	38	(0.083)	250	(0.106)
2014 Spring	148	(0.176)	29	(0.058)	8	(0.021)	2	(0.006)	7	(0.017)	194	(0.079)
2014 Fall	222	(0.227)	55	(0.138)	33	(0.078)	13	(0.050)	35	(0.079)	358	(0.143)
2015 Spring	227	(0.223)	44	(0.113)	13	(0.025)	5	(0.015)	6	(0.014)	295	(0.109)
2015 Fall	220	(0.229)	43	(0.165)	50	(0.106)	10	(0.030)	37	(0.088)	360	(0.147)
2016 Spring	319	(0.336)	57	(0.152)	25	(0.053)	2	(0.009)	23	(0.065)	426	(0.179)
2016 Fall	202	(0.230)	62	(0.170)	62	(0.118)	10	(0.043)	34	(0.085)	370	(0.154)
2017 Spring	133	(0.143)	22	(0.060)	13	(0.031)	1	(0.003)	6	(0.019)	175	(0.074)
2017 Fall	237	(0.230)	53	(0.164)	58	(0.116)	15	(0.074)	33	(0.087)	396	(0.162)
2018 Spring	253	(0.270)	36	(0.110)	23	(0.047)	2	(0.008)	14	(0.039)	328	(0.100)
2018 Fall	235	(0.247)	39	(0.174)	102	(0.177)	18	(0.075)	29	(0.075)	423	(0.178)
2019 Spring	229	(0.268)	30	(0.104)	31	(0.071	23	(0.051)	28	(0.053)	341	(0.133)
2019 Fall	208	(0.227)	65	(0.201)	80	(0.176)	31	(0.159)	31	(0.159)	52	(0.130)
2020 Spring	196	(0.217)	28	(0.083)	35	(0.070)	4	(0.025)	10	(0.022)	273	(0.116)
2020 Fall	176	(0.198)	56	(0.175)	69	(0.142)	14	(0.074)	43	(0.098)	358	(0.154)
2021 Spring	254	(0.262)	43	(0.110)	48	(0.104)	8	(0.045)	30	(0.070)	383	(0.157)
2021 Fall	191	(0.198)	49	(0.135)	54	(0.127)	8	(0.049)	20	(0.050)	322	(0.139)

	Total Capture (CPUE)											
	1		2		3		4		5		LCR	
2022 Spring	139	(0.140)	34	(0.111)	22	(0.062)	6	(0.015)	9	(0.024)	210	(0.086)
2022 Fall	186	(0.218)	78	(0.196)	42	(0.133)	29	(0.083)	34	(0.085)	369	(0.159)

3.3.2 *Mark-Recapture Analyses*

Results from earlier mark-recapture analyses are presented in earlier reports (BC Hydro 2020). An open population model that integrates mark-recapture data over the past 30 years is in development to describe demographics over that period, which includes the period before and after supplementation of hatchery fish was initiated. Results will be reported in future years.

3.3.3 *Fork Length, Weight, and Relative Weight*

Fork length (cm; mean ± SD), weight (kg; mean ± SD), and relative weight (W_r; mean ± SD) of all White Sturgeon collected within Canada between 2013 – 2022 are reported in Tables 15, 16, and 17. Results for the 2022 spring and fall stock assessments are similar to previous years of stock assessments conducted within the Canadian section of the LCR.

The weight-length relationship for White Sturgeon captured in 2022 is shown in Figure 8.

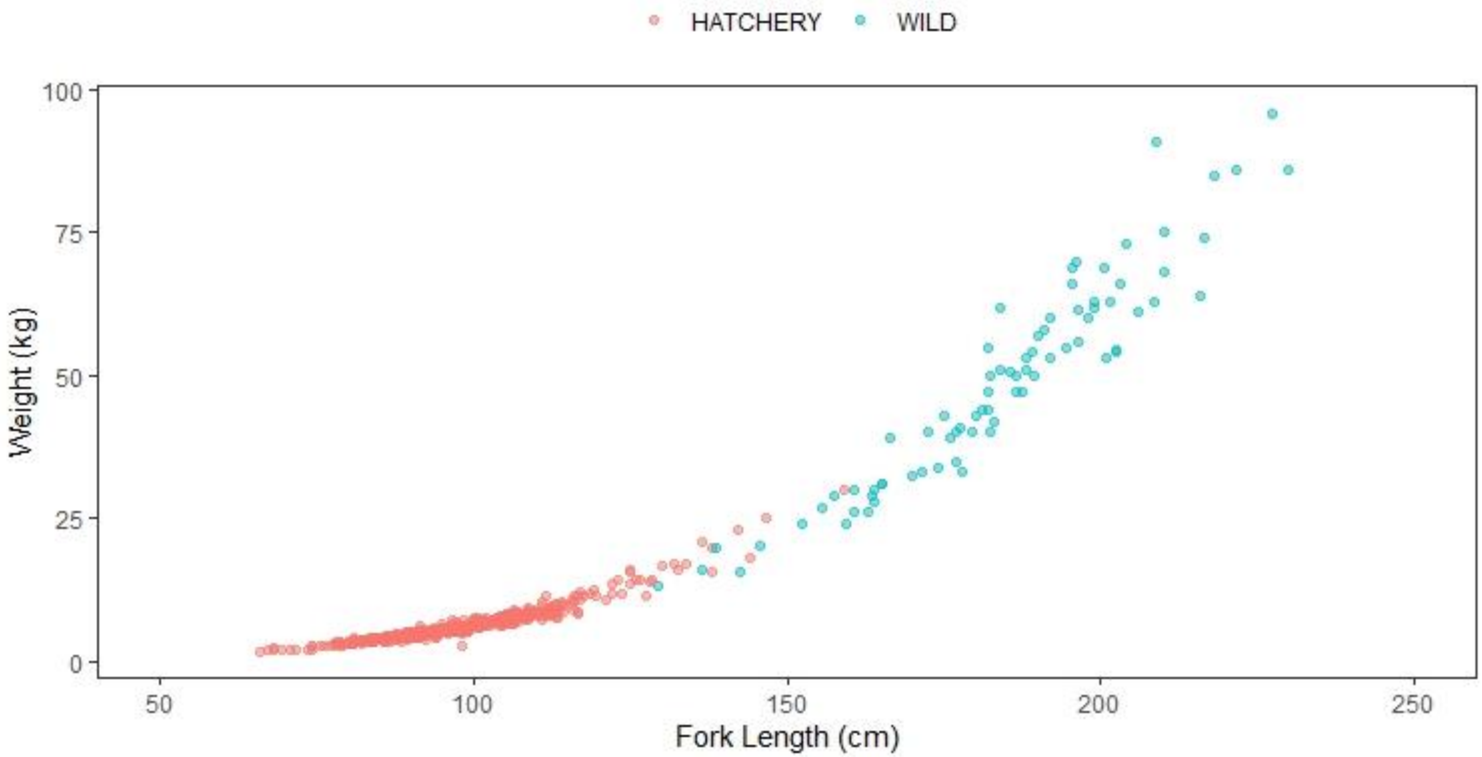

Figure 8. Weight-length relationship of wild and hatchery origin white sturgeon captured in the 2022 spring and fall stock assessments in the lower Columbia River, Canada.

Table 15. Fork length (cm; mean ± SD) for wild and hatchery origin White Sturgeon captured during the transboundary stock assessments (2013 – 2022). Data presented here includes fish captured in Canada. Sampling efforts extended from Hugh L. Keenleyside Dam in Castlegar British Columbia, Canada, to the Canada–US Border. For USA data see BC Hydro (2016a).

Year	Survey	Wild	Hatchery Origin	All Captures
2013	Spring	184.3 ± 19.0	102.3 ± 14.7	160.4 ± 41.5
2013	Fall	182.3 ± 17.8	93.4 ± 16.5	126.5 ± 46.3
2014	Spring	179.4 ± 17.2	103.8 ± 13.0	140.1 ± 40.8
2014	Fall	182.0 ± 18.3	97.1 ± 15.5	116.8 ± 39.4
2015	Spring	184.1 ± 16.5	99.6 ± 14.5	122.0 ± 40.2
2015	Fall	182.1 ± 18.0	98.2 ± 13.6	115.5 ± 37.0
2016	Spring	177.2 ± 19.9	98.6 ± 11.4	112.2 ± 32.6
2016	Fall	182.6 ± 27.5	95.8 ± 13.1	116.8 ± 40.5
2017	Spring	180.4 ± 21.5	98.3 ± 14.2	114.2 ± 36.2
2017	Fall	183.5 ± 18.6	97.8 ± 12.6	110.8 ± 33.7
2018	Spring	177.5 ± 23.5	98.1 ± 12.7	107.8 ± 29.8
2018	Fall	179.6 ± 23.3	99.2 ± 13.7	115.8 ± 36.4
2019	Spring	184.4 ± 23.7	98.4 ± 13.1	114.3 ± 36.9
2019	Fall	182.9 ± 22.7	97.6 ± 13.4	111.5 ± 35.1
2020	Spring	175.3 ± 30.4	97.2 ± 12.5	108.7 ± 32.1
2020	Fall	187.9 ± 21.1	95.7 ± 13.6	107.8 ± 34.5
2021	Spring	171.5 ± 30.7	98.2 ± 13.7	104.3 ± 25.7
2021	Fall	176.6 ± 22.1	95.0 ± 14.1	102.6 ± 28.1
2022	Spring	177.9 ± 19.1	99.1 ± 12.0	111.5 ± 31.6
2022	Fall	184.6 ± 28.9	96.6 ± 13.3	107.8 ± 33.5

Table 16. Weight (kg; mean ± SD) for wild and hatchery origin White Sturgeon capture during the transboundary stock assessments (2013 – 2022). Data presented here includes fish captured in Canada. Sampling efforts extended from Hugh L. Keenleyside Dam in Castlegar British Columbia, Canada, to the Canada–US Border. For USA data see BC Hydro (2016a).

Year	Survey	Wild	Hatchery Origin	All Captures
2013	Spring	53.6 ± 16.2	7.7 ± 4.2	40.2 ± 25.1
2013	Fall	48.2 ± 16.9	5.8 ± 3.6	21.6 ± 23.2
2014	Spring	43.7 ± 13.9	7.7 ± 3.1	25.0 ± 20.5
2014	Fall	47.4 ± 17.7	6.3 ± 3.5	15.9 ± 19.6
2015	Spring	48.1 ± 14.0	7.0 ± 3.9	17.9 ± 19.8
2015	Fall	44.3 ± 15.5	6.4 ± 2.9	14.2 ± 17.1
2016	Spring	41.2 ± 15.3	6.5 ± 2.4	12.6 ± 14.8
2016	Fall	46.4 ± 16.5	6.0 ± 2.6	15.8 ± 19.3
2017	Spring	45.0 ± 18.5	6.4 ± 3.0	13.9 ± 17.5
2017	Fall	48.4 ± 16.2	6.3 ± 2.9	12.6 ± 16.3
2018	Spring	45.2 ± 16.9	6.2 ± 2.9	10.9 ± 14.31
2018	Fall	45.1 ± 17.8	6.4 ± 3.1	14.4 ± 17.8
2019	Spring	50.3 ± 20.1	6.4 ± 3.1	14.5 ± 19.3
2019	Fall	48.1 ± 17.4	6.1 ± 2.9	12.9 ± 17.2
2020	Spring	42.1 ± 19.7	6.1 ± 2.7	11.4 ± 15.0
2020	Fall	47.9 ± 17.3	5.8 ± 3.0	11.4 ± 15.8
2021	Spring	41.3 ± 22.0	6.3 ± 3.4	9.3 ± 12.0
2021	Fall	41.4 ±17.6	5.7 ± 2.7	9.0 ± 11.9
2022	Spring	43.6 ± 15.8	6.7 ± 2.9	12.5 ± 15.1
2022	Fall	50.9 ± 21.6	6.0 ± 3.3	11.8 ± 17.1

Table 17. Relative weight (W_r; mean ± SD) for wild and hatchery origin White Sturgeon collected during the transboundary stock assessments (2013 – 2022). Data presented here includes fish captured in Canada. Sampling efforts extended from Hugh L. Keenleyside Dam in Castlegar British Columbia, Canada, to the Canada–US Border. For USA data see BC Hydro (2016a).

Year	Survey	Wild	Hatchery Origin	All Captures
2013	Spring	91.3 ± 9.6	83.1 ± 9.6	88.9 ± 10.3
2013	Fall	84.0 ± 8.5	81.4 ± 8.7	82.4 ± 8.7
2014	Spring	80.8 ± 7.4	82.2 ± 7.2	81.5 ± 7.3
2014	Fall	83.0 ± 12.6	80.3 ± 7.4	80.9 ± 8.9
2015	Spring	82.1 ± 8.9	83.0 ± 7.8	82.7 ± 8.1
2015	Fall	77.5 ± 8.0	80.3 ± 7.4	79.7 ± 7.6
2016	Spring	78.0 ± 7.9	82.6 ± 12.1	81.8 ± 11.5
2016	Fall	79.6 ± 12.1	81.2 ± 9.4	80.8 ± 10.1
2017	Spring	79.2 ± 7.4	80.6 ± 9.6	80.3 ± 9.5
2017	Fall	81.8 ± 13.6	80.1 ± 9.4	80.3 ± 10.1
2018	Spring	82.2 ± 20.2	78.1 ± 13.0	78.6 ± 7.2
2018	Fall	81.0 ± 8.9	77.8 ± 10.5	78.5 ± 7.9
2019	Spring	82.3 ± 8.2	80.1 ± 7.1	80.5 ± 7.4
2019	Fall	81.2 ± 9.0	77.8 ± 6.9	78.3 ± 7.3
2020	Spring	77.6 ± 8.9	80.2 ± 7.1	79.8 ± 7.4
2020	Fall	75.1 ± 8.9	79.0 ± 8.4	78.5 ± 8.5
2021	Spring	81.8 ± 23.7	78.8 ± 6.6	79.0 ± 9.3
2021	Fall	77.4 ± 8.3	78.6 ± 9.7	78.5 ± 9.6
2022	Spring	81.5 ± 8.8	81.4 ± 7.5	81.4 ± 7.7
2022	Fall	80.7 ± 9.6	79.3 ± 7.2	79.4 ± 7.5

3.4 Acoustic Tagging and Telemetry

A large-scale analysis of the telemetry data is being conducted that incorporates 2008-2021 and results of this work are not yet available. Results will be updated in 2022 when complete. Results from 2008-2017 are presented in previous reports (e.g., BC Hydro 2020).

4.0 DISCUSSION

The primary objectives of this monitoring program were to describe adult White Sturgeon life history, biological, and population characteristics. Through the fifteenth year of this work, we have been successful in quantifying fish abundance and condition, estimating timing and duration of spawning, identifying environmental spawning cues, and describing spawning-related movements and habitat use of adult White Sturgeon in the LCR. With over a decade of data collection complete, more comprehensive analyses are underway to evaluate program objectives and inform remaining uncertainties. Further, this program was initially responsible for the collection of sexually mature White Sturgeon to use as broodstock but results have led to rearing naturally produced offspring collected from the wild for the Conservation Aquaculture Program. Data collection will continue in the following years to build on the estimates of population abundance and survival presented in this report. These results are actively being used in discussions around recovery planning going forward. Outstanding issues identified by the WUP Fisheries Technical Committee (FTC) during the creation of the Columbia Water Use Plan, as provided in the Terms of Reference for this program, are described and addressed in Table 18.

Table 18. 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 analysis has identified >100 adults spawning annually in the Canadian portion of the Columbia River (Jay et al. 2014), with additional adults spawning at two locations downstream. There are now 5 known spawning sites in the transboundary section of the Columbia River. Additional genetic work is underway as of 2022 to confirm contributions of wild adults to spawning events (2014-2021). Results from this work are expected in 2024 and will be important as collections of wild embryos and larvae serve as the basis for the conservation aquaculture program.

FTC Outstanding Issue	Current Status
Changes in movement and spawning behaviour in response to management responses (relative to the baseline established through this monitoring program) may reveal that additional spawning sites (and sub populations) exist in the LCR.	Additional spawning sites have been identified through analysis of adult movements (e.g., ALH spawning area in 2010) and through the collection of larvae downstream from suspected locations (e.g., Kinnaird 2007 to current). Currently, known spawning sites in Canada are being monitored annually and spawning related movements are evaluated in order to identify any further locations. Ongoing analyses using long-term telemetry data are being conducted to further address this question. Importantly, spawning substrate restoration at the ALH spawning site was completed in April 2023. This monitoring program will be integral in determining the effectiveness of that enhanced habitat.
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 the stock assessment program, with a revised population estimate provided earlier reports (BC Hydro 2020). An open population model to better describe changes to population demographics is being developed, with results expected for the next report.
Of equal importance to the maintenance of the remaining White Sturgeon population; are there sufficient adults to continue the Conservation Aquaculture Program?	Based on both previous genetic studies and the success in collecting wild-origin progeny, sufficient breeding adults remain to support a conservation aquaculture program. In the short-term, the aquaculture program will use embryos and larvae collected from wild spawning events 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. Hatchery-origin sturgeon are beginning to reach sexual maturity (males) and will start to contribute to spawning events in the wild. Accordingly, understanding the genetic integrity of the aquaculture program to date remains a key objective.

FTC Outstanding Issue	Current Status
	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. Results from Crossman and Korman (2022) show progeny from all hatchery family groups have been captured in post-release monitoring efforts.

4.1 Streamside Incubation Facility

A key component of the recovery program for LCR White Sturgeon has been a conservation aquaculture program to supplement the existing wild population through the release of hatchery-reared juvenile White Sturgeon (Hildebrand and Parsley 2013; see review in Anderson et al. 2022). 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 (see Crossman et al. 2023) and objective 1 is considered by the UCWSRI to have largely to be met. 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 supported by results from other species where similar streamside programs show improvements for genetic diversity of supplemental offspring compared to more traditional hatchery practices of spawning adults (e.g., lake sturgeon, Crossman et al. 2011). For the Upper Columbia population, results of genetic work by Jay et al. (2014) supported piloting the transition to a wild-origin program. 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. Collections of embryos and larvae were low in 2015, which was one of the driest and warmest years since regulation of the Columbia River began. While a larger number of embryos and larvae were not available in 2015 at the Canadian spawning sites, it should be noted that a significant number of wild feeding age larvae were collected downstream of Northport in the US and were raised for release into Lake Roosevelt. The last several years' collections were all successful with 800 and 607 wild-origin juveniles released in 2016 and 2017, respectively, and 200 released each year from 2018 to 2022. While annual variability in numbers of embryos and larvae collected for conservation aquaculture was initially expected as part of this revised plan, release strategies have been adjusted to reflect higher than anticipated survival following release. With a maximum of 200 fish produced for release, the wild-origin progeny collection approach has been further focused on ensuring all spawning events and spawning locations are represented in progeny released. Importantly, sampling effort needs to be consistent and balanced across the entire spawning distribution to maximize genetic diversity. Genetic diversity goals are being validated through ongoing genetic work that is expected to be complete in 2024. Post-release survival of wild-origin progeny is still being evaluated through the juvenile monitoring program but the revised minimum size at release targets (200 grams) is expected to have improved survival following release. Survival within the streamside facility is variable and depends on a number of factors including the developmental stage of embryos collected in the river (e.g., handling stress), the timing of the spawning event (later warmer events tend to have lower survival), and the number of embryos captured in drift nets, as embryos can clump and stick together when caught in large numbers reducing survival. Survival from the time larvae are transferred to the time of stocking has generally been good, with over 50% survival to date for most years. Further refinements to methods during incubation at the SIF near Waneta and while at the conservation hatchery will be explored to improve survival further.

4.2 Spawn Monitoring

For White Sturgeon throughout their range, it is generally thought that the spawning period is protracted and occurs in the late spring and early summer months (May to July) with specific timing dependent on environmental cues (e.g., temperature, flows; Parsley and Beckman 1994). Peak flows on the Columbia River in 2019 and 2021 were slightly below average. However in 2022, flows exceeded 200 kcfs for 22 days, which is considered high. Compared to other years with freshet flows >200 kcfs, 2022 peak freshet was in late-June and spawning had already started as temperatures reached 14ºC prior to the peak. While the period over which spawning occurs at the two upstream locations can be up to a month in duration (e.g., 27 days at Kinnaird in 2016), it is generally much shorter compared to Waneta and has only ever been observed over a few days at ALH (e.g., 3 days in 2018 and 2 in 2019). While no spawning was detected in 2020 and 2021 at Kinnaird or ALH, a single spawning event was detected at Kinnaird in 2022. It is unknown if the intermittent use of these spawning areas by presumably smaller numbers of adults will change as additional hatchery-origin spawners reach maturity and begin contributing as documented in the sex and stage of maturity program under CLBMON-29 (BC Hydro 2019). Tracking annual use through continued spawn monitoring will be important to identifying a change in spawning frequency over time and help monitor effectiveness of a restoration program that was completed at the ALH site in 2023 under the CLBWORKS-27 Lower Columbia White Sturgeon Habitat Restoration program. Given the variability in the start and duration of spawning activity at Kinnaird and ALH, monitoring is required for approximately 6–8 weeks from mid-June to early August to ensure if spawning occurs it is detected.

Table 19. Estimated number of annual spawning events at the Waneta Spawning area from 2001 – 2022 in relation to peak flows on the lower Columbia River. Grey highlighted rows represent years where flows exceeded 200 cfs at the international border on the lower Columbia River.

Year	Peak discharge (cfs)	Peak freshet date	Estimated number of spawning events	% of Spawning events Occurring after peak freshet or on the descending limb of the hydrograph
1997*	302,452	6-June	N/A	N/A
2001	114,651	26-May	7	100
2002	230,412	30-June	9	56
2003	150,526	5-June	9	100
2004	135,089	14-June	9	100
2005	166,521	10-June	12	100
2006	227,250	25-May	N/A	N/A
2007	185,984	9-June	10	100
2008	216,651	4-June	17	100
2009	173,948	2-June	15	100
2010	181,245	21-June	18	63
2011	267,000	14-June	8	88
2012	280,400	28-June	18	100
2013	202,000	1-July	12	100
2014	221,000	28-May	5	100
2015	155,382	3-June	6	100
2016	157,083	29-May	13	100
2017	246,934	9-June	17	100
2018	282,365	28-May	21	100
2019	136,799	18-May	14	100
2020	219,818	1-Jun	11	100
2021	170,802	5-Jun	9	100
2022	247,309	26-Jun	12	75

* Monitoring of White Sturgeon spawning at Waneta was not conducted

Despite considerable effort and spatial distribution of sampling gear, few dispersing larvae were collected within the vicinity of Kinnaird and the exact location of the spawning area remains unknown. Up to 2019, 12 consecutive years of detecting spawning activity had occurred in the Kinnaird area and increased telemetry work in that area was intended to refine the location of spawning within the 8 km reach. However, no spawning was detected in either 2020 or 2021. In particular, 2021 was a hot dry year and spawning may have happened much earlier compared to previous years. In 2022, a single event was detected earlier in July, suggesting that sampling should begin by early July and continue into August, with eggs mats deployed by late June in drier warmer years like 2015 and 2021. Determining capture efficiency of both embryo and larval samples between gear types is important when identifying exact spawning locations of unknown areas. Egg mats have been consistently used at Waneta for the collection of

White Sturgeon embryos since the spawning location was first described in 1993 (Hildebrand and Parsley 2013). At the upstream locations (ALH and Kinnaird), the use of drift nets has been more effective in collecting embryos or larvae. For spawning areas where the exact geographical location is uncertain, drift nets are more effective as they can represent all areas upstream of the sampling location. Though egg mats are effective when the main areas of egg deposition have been identified, drift nets should be used primarily when attempting to assign a general location where spawning may be occurring. To address the objectives of this program as it relates to describing new spawning areas, it is recommended that use of egg mats be restricted to Waneta, and that drift nets are the primary technique used in areas where spawning locations are uncertain (e.g., Kinnaird).

4.3 Population Monitoring, Abundance, and Characteristics

Prior to 2013, the broodstock program served as the primary 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 and ensure the work was standardized into the US portion of the 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, 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 2013-2021. Additional years of data combined with historical capture information prior to the WUP program will provide more robust estimates of abundance that include both wild and hatchery-origin sturgeon which can be used in recovery planning. Additional years of stock assessment surveys have been recommended by the UCWSRI TWG as part of the recovery program to improve confidence in the estimates being produced. Results from updated population abundance and survival modelling are expected early in 2024.

4.4 Acoustic Tagging and Telemetry

The long-term telemetry dataset collected as part of this program is being analyzed now that 10 years of data have been collected. This work, through collaboration with the University of Northern BC and other recovery team partners is ongoing. General results to date have found that White Sturgeon in the LCR tend to select deep, slow-moving sections of the river which do not appear to be limited under the current operating regime. Adult movements are low and have been similar across all years evaluated with activity generally occurring during the summer months for assumed foraging or spawning. Adult male and female White Sturgeon spent 64 and 63% of their time at a single location, respectively. When movements were evaluated at a larger reach scale (11.2 rkm increments), residency to those areas increased to 88% and 87% for males and females, respectively (BC Hydro 2020). White Sturgeon residing in the Middle

(Kinnaird to Genelle) and Lower sections (Trail to Waneta) of the LCR were observed migrating within the respective section of residency for suspected spawning related movements. This behavior is similar to observations made in previous years where suspected spawning related movements revealed that resident adults within the Upper river section tend to migrate to adjacent downstream spawning areas (Middle section). A small portion of adults monitored in this study exhibited putative spawning migrations to adjoining river areas indicating mixing of adults throughout the river.

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

5.0 RECOMMENDATIONS

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 6–8 week monitoring period from late June through early August is recommended to ensure spawning is detected.

2. Drift nets maximize catch per unit effort of embryos and larvae from locations upstream of the sampling equipment and should continue to be used as the primary collection method in areas where the exact geographical boundary of the spawning location remains unknown (e.g., in the vicinity of Kinnaird).

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

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

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

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

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

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

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

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

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

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