Columbia River Project Water Use Plan

Lower Columbia River

Reference: CLBMON #29 (Year 13 – 15)

Lower Columbia River Juvenile Sturgeon Detection Program: 2020 – 2022 Investigations Data Report

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Executive Summary

The population of white sturgeon (*Acipenser transmontanus*) in the Lower Columbia River (LCR), Canada was listed as Endangered under the Species at Risk Act (SARA) in 2006. Despite evidence of limited natural recruitment in the LCR, the level of annual recruitment is considered insufficient to maintain a self-sustaining population and the population was forecast to become functionally extinct by 2044 in the absence of effective recovery measures. Recovery was directly initiated in 2001 through a conservation aquaculture program that released hatchery-origin juveniles as a stopgap measure until recruitment failure could be addressed. It was identified during the development of the Columbia Water Use Plan (WUP) that direct management responses for white sturgeon were limited to non-operational habitat improvements designed to improve spawning success and juvenile survival. However, life history data (e.g., abundance, growth, survival) were lacking, and habitat suitability and availability across larval and juvenile life stages were unknown. Accordingly, larval and juvenile monitoring in the LCR over a longer period was deemed critical to addressing management questions related to recruitment and success of the Conservation Aquaculture Program.

From 2002 – 2022, a total of 109,387 hatchery-origin individuals have been stocked into the LCR, Canada from a conservation aquaculture program. Recent genetic work determined that the number of adults spawning annually in the LCR was more than 10-fold the number spawned to produce progeny released from the Conservation Aquaculture Program. In efforts to increase genetic diversity among stocked juvenile white sturgeon, a streamside incubation facility (SIF) program was implemented in 2014 in order to incorporate naturally produced embryos and larvae collected in the wild into stocking practices. The program was a success, and from 2014 – 2022 wild-origin progeny have been incubated in the SIF and subsequently reared at the Kootenay Trout Hatchery for release as juveniles the following spring. A total of 199 juveniles were released in 2021 (year class 2020) and 2022 (year class 2021).

Early life stage monitoring was conducted in order to determine the distribution of white sturgeon larvae in the LCR and assist in identifying spawning locations and areas of habitat use. In 2020 – 2022, monitoring took place at sites downstream of Arrow Lakes Generating Station (ALH; rkm 0.1), Kinnaird (rkm 13.4 – 18.2) and downstream of the Pend d'Oreille and Columbia River confluence (Waneta; rkm 56.0). Based on developmental stages of captured yolk-sac larvae, spawning was estimated to have occurred in 2020 over a period between June 8 and July 27 at Waneta, July 15 and August 7 at Kinnaird, and July 13 and August 7 at ALH. In 2021, spawning was estimated to have occurred between June 8 and July 26 at Waneta, between July 8 and August 4 at Kinnaird, and between July 6 and August 4 at ALH. In 2022, spawning was estimated to have occurred between June 13 and August 3 at Waneta, between June 28 and August 5 at Kinnaird, and between June 28 and August 5 at ALH. The majority of yolk-sac larvae samples captured in 2020 – 2022 were at an early developmental stage (<40). This suggests some suitable habitat exists for embryo incubation and early larval hiding in until they reach developmental stages where drift would naturally occur.

Juvenile monitoring was conducted in order to estimate survival rate and abundance of the hatchery-origin segment of the white sturgeon population within the LCR. Additionally, data from this program will be used to determine juvenile growth rates, fish condition, age class structure,

reproductive structure, and identify any density dependent responses. This program is coordinated between Canada and the US and takes place in the LCR between the Hugh L. Keenleyside Dam in BC and Gifford in WA. While wild juvenile sturgeon are encountered, captures from 2013 – 2022 have been predominantly hatchery-origin fish with wild juveniles representing <2% of the total catch. Survival analyses completed using juvenile capture data have indicated that survival of hatchery-origin fish has been higher than originally predicted, and is associated with size at release, with fish released at larger body sizes (e.g. >300 g) having the highest survival. Abundance has been estimated at more than 5,000 individuals (BC Hydro 2018). Survival estimates have been used to modify release targets in the LCR, with fish currently reared to a minimum 200 g prior to release to improve survival. Additionally, monitoring results are helping to facilitate discussions around stocking numbers going forward as part of the larger recovery initiative.

Results from this long-term monitoring program will contribute to knowledge regarding larval and juvenile stages to better understand potential causes of recruitment failure and help inform recovery measures moving forward. The state of knowledge pertaining to the various management questions associated with this monitoring project are summarized in Table ES1.

Table ES1. CLBMON #29 Status of Lower Columbia River Juvenile White Sturgeon Monitoring Program Management Questions.

Management Question	Status
What are the relative abundance, survival rates, and distribution locations of larvae and juvenile white sturgeon in the Lower Columbia River under current operating parameters?	Larval Stage: Relative abundance and survival of larval white sturgeon will be difficult to address given limitations related to effectively sampling this life stage. However, data pertaining to timing, locations, and frequency of spawning in the Lower Columbia River (LCR) has been collected. Larvae have been collected near the HLK/ALH spawning area, downstream of Kinnaird, and from the Waneta spawning site downstream into the US portion of the LCR. Larval catch has predominantly consisted of young (stages <40) individuals; however older feeding age larvae (>stage 40; >10 days post hatch) have been collected downstream of HLK/ALH and Waneta. Further, large numbers of later stage larvae (>stage 45) collected on the US side of the LCR suggests that hiding habitat exists from the Canada-US border downstream to Northport, Washington.
	Juvenile Stage: Survival of hatcher-origin juveniles has been higher than originally predicted. This has resulted in a large hatchery population estimated at more than 5,000 individuals in the Canadian section of the LCR. A recent review of white sturgeon capture data has identified high variability in maternal family representation of hatchery-origin juveniles in both the Canadian and US portions of the LCR. While this unequal family representation presents a potential genetic risk to the long-term viability of the white sturgeon population in the LCR, measures undertaken in the US through a harvest fishery have reduced the most abundant year classes. The UCWSRI TWG is working on conservation measures to futher describe and address this issue. One measure has been implemented is the Conservation Aquaculture Program transitioning (2011 in WA and 2015 in BC) entirely to collecting naturally produced embryos and larvae for hatchery rearing - an approach that has demonstrated genetic benefits over broodstock based aquaculture programs. This has also resulted in lower numbers of sturgeon released from the aquaculture program annually.
	Distribution of juveniles has been assessed extensively throughout the LCR, and is restricted primarily to slower moving habitats like eddies and deeper runs. While these habitats are available primarily in the upper

Management Question	Status
	(Robson to Genelle) or lower (Beaver Creek to Waneta) sections of the river, hatchery origin fish are captured throughout the entire LCR.
What are the physical and hydraulic properties of this habitat that define its suitability as juvenile sturgeon habitat?	Juveniles are selecting deeper (>10 m), slow moving (< 1.0 m/s), habitats with smaller substrates (e.g., sand, small gravel). These habitats are widely distributed through the upper reaches (e.g., Robson) and are restricted to eddy habitats downstream of the Kootenay River confluence to the Canada-US border.
How do normal river operations affect larval habitat conditions in the Lower Columbia River?	At the present time more data are required to address this question. Spawning has been identified at several locations but the quantity and quality of spawning habitat is currently unknown. Based on the capture of primarily yolk-sac larvae within a few days of hatch (stages <40), the spawning habitat throughout the LCR was presumed to be poor for hiding after hatch. However, increased drift net effort since 2015 compared to all previous sampling years downstream of the Waneta spawning site indicated that a percentage of larvae hide until feeding age before initiating dispersal downstream. Additionally, older feeding larvae are collected in large numbers on the US side of the LCR suggesting that hiding habitat exists from the Canada-US border downstream to Northport, Washington. A specific Columbia Water Use Plan physical works program (CLBWORKS-27) is currently evaluating habitat conditions for early life stages at the three spawning locations in the LCR. Results are expected to help inform information collected under this monitoring program.
How do normal river operations affect juvenile habitat conditions in the Lower Columbia River during dispersal and on a seasonal basis?	The distribution of juvenile white sturgeon in the LCR is restricted to deeper, slower moving, habitats. These habitats are currently not limited by the operational regime of the river, irrespective of the time of year.

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1 Introduction

The population of white sturgeon (*Acipenser transmontanus*) in the Lower Columbia River (LCR), Canada was listed as Endangered under the Species at Risk Act (SARA) in 2006. In Canada, the LCR is defined as the 57.0 km reach of the Columbia River downstream of Hugh L. Keenleyside Dam (HLK) to the Canada–United States border. An estimated 1,157 adult white sturgeon (95% C.I. 414-1899; Irvine et al. 2007) reside within the Canadian section, with an additional 2,003 individuals (95% C.I. 1093-3223) in the United States between the border and Grand Coulee Dam, WA (Howell and McLellan 2007). This transboundary population is suffering from recruitment failure similar to other populations of white sturgeon residing in the Kootenay (Anders et al. 2002), Nechako (McAdam et al. 2005), and Snake (Jager et al. 2002) rivers. Despite some evidence of limited natural recruitment in the LCR, the level of recruitment annually is considered insufficient to maintain a self-sustaining population and the population was forecast by the Upper Columbia White Sturgeon Recovery Initiative (UCWSRI) to become functionally extinct by 2044 in the absence of effective recovery measures (UCWSRI 2002; UCWSRI 2012).

The Columbia River Water Use Plan (WUP) Consultative Committee (CC; 2005) recommended giving priority to conservation and recovery of white sturgeon. However, in recognition of its high value power generation, the Columbia River was designated to remain a working river. It was identified that direct management responses for white sturgeon were limited to non-operational habitat improvements designed to improve spawning success and juvenile survival. In order to meet this goal, data are required to assess habitat use, suitability, and availability for all life stages of white sturgeon residing in the LCR. These data include life history measures that are indicative of habitat quality including abundance, growth, development, condition, evidence of food availability, and survival rates. Furthermore, providing estimates of successful reproduction (e.g., embryo and larval captures) at both known and suspected spawning locations in the LCR is critical to addressing management questions related to recruitment.

The WUP CC outlined a juvenile sturgeon program that would provide annual monitoring of the relative abundance and distribution of juvenile white sturgeon in the LCR (CC 2005). The supporting rationale indicated monitoring was to provide information on the patterns of habitat use to better understand potential causes of recruitment failure and opportunities for feasible mitigative actions (CC 2005). The rationale assumed that the probable bottleneck affecting juvenile survival could be determined with the release of hatchery-origin juvenile white sturgeon into the system to help identify non-operational changes required for a positive effect on levels of natural recruitment of age 1+ sturgeon. As such, the B.C. Comptroller of Water Rights (CWR) issued a Water License Order directing operations of BC Hydro’s projects on the Columbia River (Mattison 2007). The Order (Schedule F(1)(h)) specifies that the Juvenile Sturgeon Detection Program shall monitor the abundance, distribution, and patterns of habitat use in the LCR in relationship to discharges from HLK.

Identification of critical rearing habitat within the LCR is an important component of recovery to allow for protection or enhancement as recovery moves forward. Monitoring white sturgeon spawning activity helps describe the location of yolk-sac larvae rearing sites. Past studies have documented white sturgeon spawning behavior immediately downstream of Arrow Lakes

Generating Station (ALH, river kilometer (rkm) 0.1; BC Hydro 2013b), downstream of Kinnaird (rkm 13.0 to 19.0; Golder 2009a; BC Hydro 2013b), Pend d'Oreille River confluence (Waneta, rkm 56.0; UCWSRI 2012) and in the vicinity of Northport, WA (Howell and McLellan 2006). At the upstream locations of ALH and Kinnaird, exact locations of egg deposition remains unknown therefore continued monitoring is important to identify location of spawning and yolk-sac larvae rearing habitats.

Outside of annual monitoring programs used to collect information to guide recovery, the sole conservation strategy implemented to date for this population has been restoration through a Conservation Aquaculture program. The objective of this strategy is to supplement the population with hatchery-origin juveniles until adequate levels of natural recruitment can be restored (UCSWRI 2012). Since 2001, an annual broodstock acquisition program has been conducted, with wild mature adults spawned in the hatchery to contribute progeny for stocking in the LCR (BC Hydro 2009). In 2014, it was advised by the Upper Columbia White Sturgeon Recovery Initiative Technical Work Group (UCWSRI TWG) to design a streamside incubation facility (SIF) and implement passive collection techniques (e.g., drift nets) in order to stock naturally produced embryos and larvae (wild-origin progeny) into the LCR. This practice would increase representation of LCR spawning adults and levels of genetic diversity among stocked juvenile white sturgeon (Jay et al. 2014), and has been successful for other sturgeon species (e.g. Lake Sturgeon *Acipenser fulvescens*; Crossman et al. 2011). Developing this SIF program in Canada also aligned with the US portion of the population, as collections of wild-origin yolk-sac larvae serve as the source for the aquaculture program in the US. Results of this program were successful in 2014, and all juvenile white sturgeon stocked annually as of the 2015 year class have been of wild-origin progeny collected through the SIF program (FFSBC 2020).

Hatchery-reared juveniles released as part of the Conservation Aquaculture Program serve as an important learning tool as juvenile age classes are absent in many populations (e.g., see review in Anderson et al. 2022). Determining factors influencing growth and survival of these fish will not only contribute to refining the Conservation Aquaculture Program, but will provide critical insight into the ecology of this species which can be used to guide recovery efforts.

Work that has occurred over the past decade has identified that hatchery-reared juveniles have been successful in surviving after release from the hatchery (Golder 2009b). The survival of hatchery released age-0 juveniles combined with high survival at the older life stages (Golder 2009b; Irvine et al. 2007) suggests that the recruitment bottleneck is likely the result of poor survival during earlier life stages (Gregory and Long 2008; Golder 2009b), which is similar to other systems (Ireland et al. 2002; Gross et al. 2002). As a result, recent monitoring has focused on the potential causes of mortality at the yolk-sac larvae and young-of-year life stages, and to understand underlying mechanisms resulting in recruitment failure.

This report describes the thirteenth (2020), fourteenth (2021), and fifteenth (2022) years of monitoring in the LCR as a component of the WUP under the project: CLBMON-29 Lower Columbia River Juvenile Sturgeon Detection. Specific components are described below.

1.1 Management Questions

Key management uncertainties encountered during development of the WUP related to how operations of HLK may adversely affect habitat suitability and availability for juvenile sturgeon and thus potentially contribute to recruitment failure of white sturgeon in the LCR (Columbia River WUP CC 2005). Fundamental management questions to be addressed through the Juvenile Sturgeon Detection Program include:

1. What are the relative abundance, survival rates, and distribution locations of larval and juvenile white sturgeon in the LCR under current operating parameters?
2. What are the physical and hydraulic properties of this habitat that define its suitability as juvenile sturgeon habitat?
3. How do normal river operations affect larval habitat conditions in the LCR?
4. How do normal river operations affect juvenile habitat conditions in the LCR during dispersal and on a seasonal basis?

1.2 Management Hypothesis

While impoundments and water management at HLK and other dams in the Columbia watershed may be correlated with declines in white sturgeon recruitment in the LCR, the precise mechanisms remain unclear. Early life stages appear to be most adversely affected and spawning site selection and timing may impact mortality rates experienced by these early life stages. The Juvenile Sturgeon Detection Program is designed to provide baseline information that may be used to evaluate recruitment failure hypotheses and can be used in design of future operational or physical mitigative approaches. Additionally, where feasible, the program is experimentally testing of research hypotheses to get at underlying mechanisms behind recruitment failure. This is the established process outlined at the Upper Columbia White Sturgeon Recovery Initiative Technical Working Group, and described in the groups operational plan which available at www.uppercolumbiasturgeon.org.

The following management hypotheses were used to guide the Juvenile Sturgeon Detection Program studies:

H_0: The operations of the Columbia River dams and reservoirs are not contributing to changes in survival among juvenile sturgeon in the lower Columbia reach.

H_1: Columbia River operations (HLK alone or the cumulative operations of dams affecting the LCR reach hydrograph) are affecting larval behaviour, development, growth, and habitat selection, which result in reduced survival of early life stages.

H_2: Columbia River operations (HLK alone or the cumulative operations of dams affecting the lower Columbia reach hydrograph) are affecting juvenile movements, growth, and selection of suitable rearing habitat, which result in reduced survival of juvenile life stages.

H_3: Columbia River operations (HLK alone or the cumulative operations of dams affecting the lower Columbia reach hydrograph) are affecting the suitability and availability of habitat parameters resulting in reduced survival of early life and juvenile stages of White Sturgeon.

1.3 Objectives and Scope

The LCR Juvenile Sturgeon Detection Program in 2020 – 2022 was designed to describe life history aspects of juvenile white sturgeon, as well as provide input to the ongoing consideration of recruitment failure hypotheses, the evaluation of the effects of future management responses, and information to guide conservation culture stocking targets.

As stated in the terms of reference for the work, the objectives of this program will have been met when:

1. The development, condition, drift and movement behaviours, growth, and survival of yolk-sac larvae and juvenile sturgeon are assessed with sufficient consistency to describe annual trends.
2. Early life stage distributions over time, including location and parameters of yolk-sac larvae and juvenile rearing habitats, are adequately defined.
3. Relationships between yolk-sac larvae and juvenile habitat quality and variations in discharge from upstream dams and water levels of Lake Roosevelt reservoir are quantified.
4. Assessment of the effects of current operations and determine feasibility of management responses are completed.

The specific objectives related to the various components of this Juvenile Sturgeon Detection Program are summarized as follows:

1.3.1 Conservation Aquaculture Program

1. Collect naturally produced embryos and larvae for streamside incubation and Kootenay Sturgeon Hatchery (KSH) rearing for stocking purposes.

1.3.2 Larval Assessment

1. Identify timing and frequency of annual spawning days at Waneta, ALH, and Kinnaird sites using drift nets to collect white sturgeon yolk-sac larvae.
2. Identify specific locations of unknown spawning grounds and describe yolk-sac larvae rearing habitat.
3. Assess yolk-sac larvae development, condition, behaviour, and survival.
4. Determine effects of current operations on yolk-sac larvae survival and rearing habitats.

1.3.3 Juvenile Population Assessment

1. Assess juvenile population abundance, age structure, annual survival rates, and population trajectories.
2. Compare new data describing length/weight relationships to monitor growth and conditions of all age classes.
3. Describe reproductive structure of hatchery-origin white sturgeon.

1.3.4 Juvenile Movement Ecology

1. Assess seasonal movement patterns of hatchery-origin white sturgeon at or approaching reproductive maturity.
2. Identify spawning related movements of hatchery-origin white sturgeon to known spawning areas.
3. Determine movements of hatchery-origin white sturgeon between Canada and the US.

2 Methods

The monitoring study design follows the recommendations of the UCWSRI Technical Working Group (TWG) who provided an outline for what they viewed as the components of a LCR juvenile monitoring program (UCWSRI 2006) during the development of the Columbia WUP. Further, it incorporates the guidance of the WUP Fisheries Technical Committee (FTC).

2.1 Study Area

The study area for the 2020 – 2022 monitoring program encompassed the 57 km stretch of the LCR from HLK to the Canada–US border (Figure 2.1). 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. Specific areas of the LCR sampled under the various components of the program are described below.

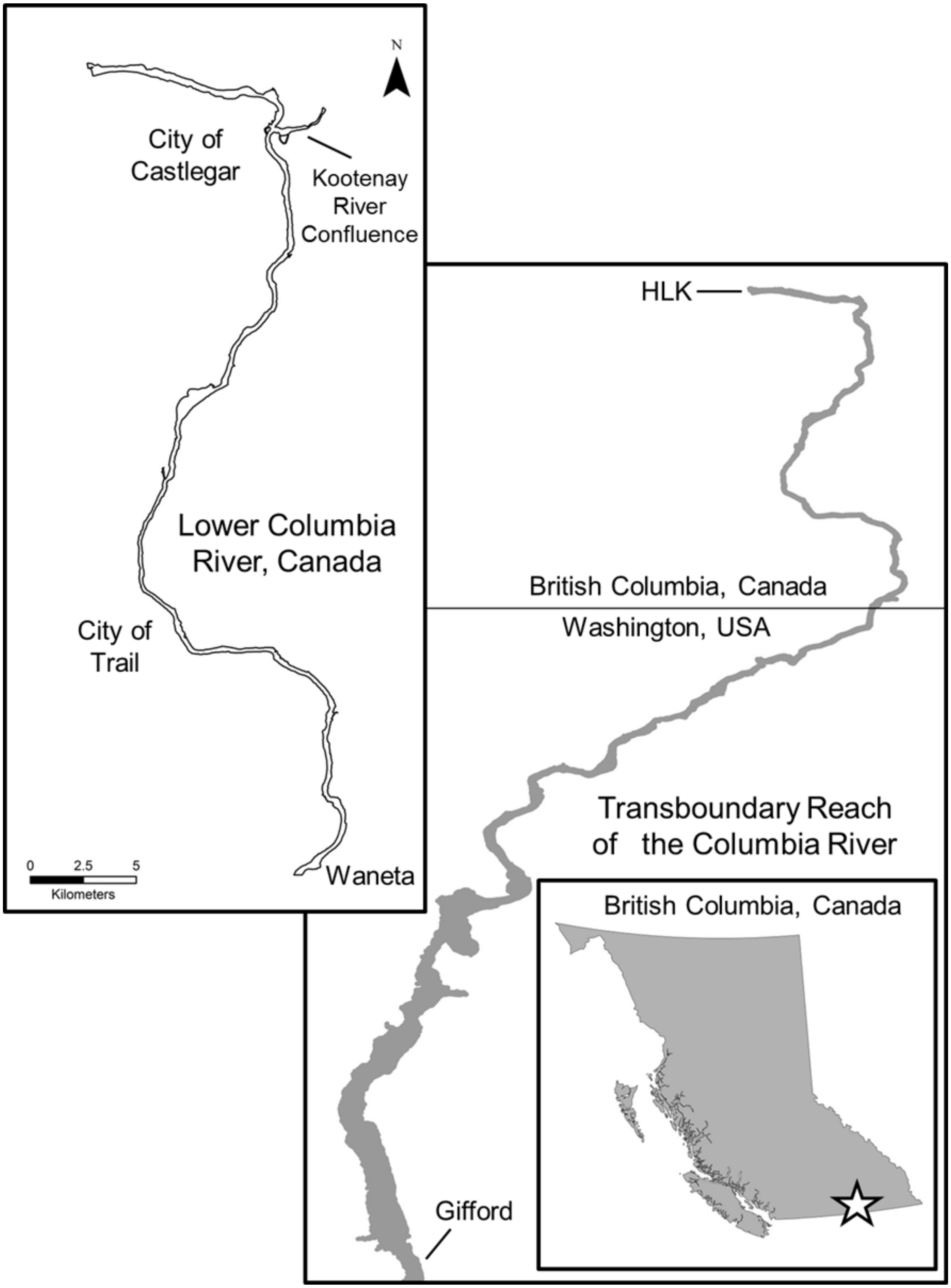

Figure 2.1: Overview of the study area in the lower Columbia River between Hugh L. Keenleyside Dam (HLK; rkm 0.1) and the Canada–US border (rkm 57.0).

2.2 Physical Parameters

2.2.1 Discharge

In 2020 – 2022, discharge records for the LCR at Arrow Reservoir (combined HLK and ALH discharges from Arrow Lakes Reservoir), the Kootenay River (combined discharge from Brilliant Dam and the Brilliant Expansion facility), 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).

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 and discussion sections of this study report.

2.2.2 Water Temperature

For the 2020 – 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), Rivervale (rkm 35.8), and Waneta (rkm 56.0). Water temperatures were recorded hourly at each location using thermographs (Vemco Minilogs, accurate to +0.1°C).

2.3 Larval Assessment

2.3.1 Study Design

Sampling was conducted at several sites to determine the relative abundance and distribution of white sturgeon yolk-sac larvae in the LCR. Sites were selected based on previous monitoring program data collection where white sturgeon have been confirmed to have spawned, or have been suspected to spawn.

Within the Canadian section of the LCR, white sturgeon reproduction occurs from mid-June through August (BC Hydro 2013a, 2013b) at two known spawning sites of Waneta (rkm 56.0) and ALH (rkm 0.1) (Figure 2.2). Waneta sampling is located downstream of the Pend d'Oreille River confluence immediately upstream of the Canada–US border. This site has been monitored for spawning activity since 1993 and is the main area of white sturgeon spawning activity within the LCR, Canada (Hildebrand et al. 1999; Irvine et al. 2007; Golder 2009a). In addition, sampling occurred immediately downstream of ALH tailraces as described by Terraquatic Resource Management (2011). Sampling was also conducted downstream of Kinnaird (rkm 13.4 – rkm 18.2; Figure 2.2) based on previous studies (BC Hydro 2015a, 2015b), however location of exact egg deposition remains unknown.

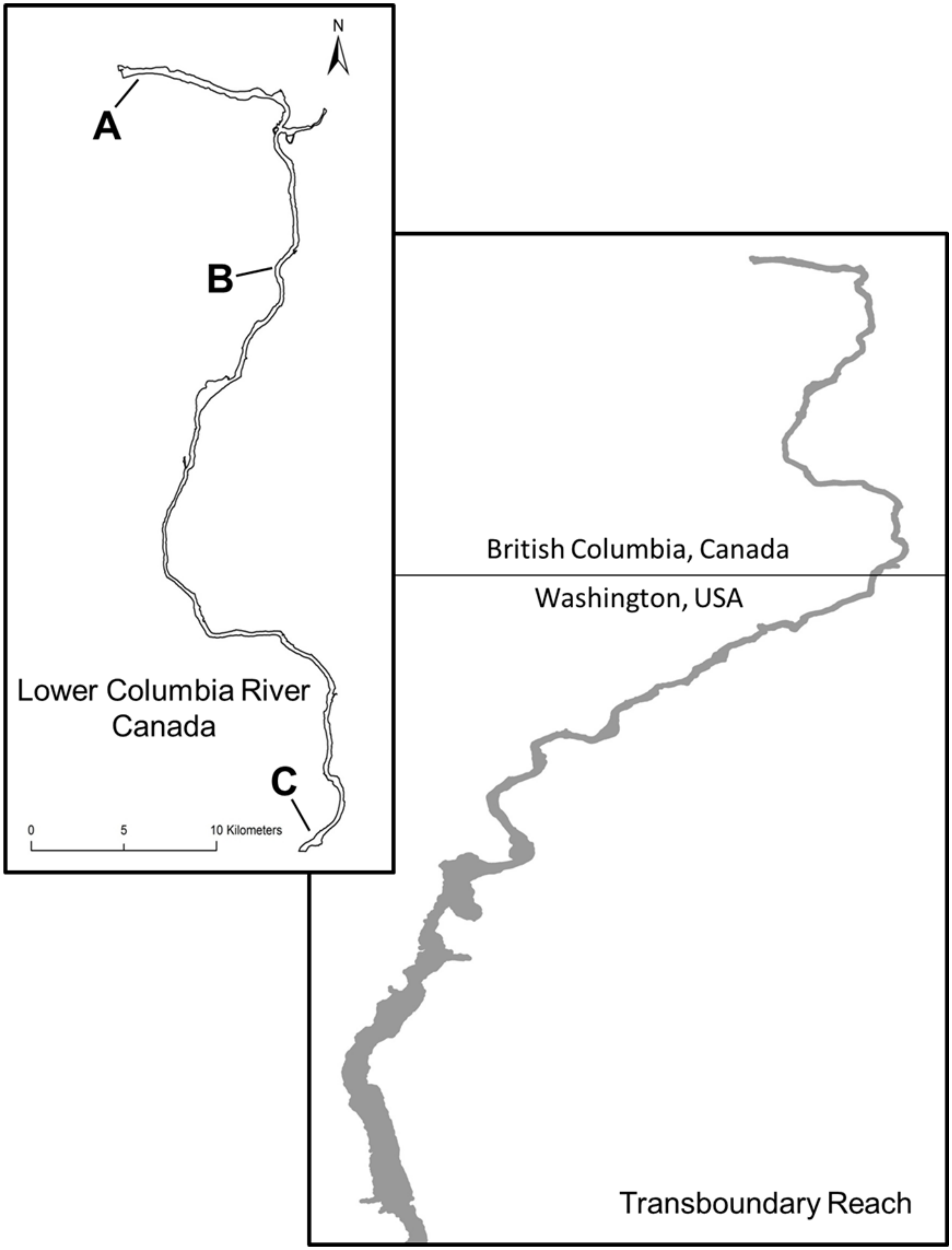

Figure 2.2: Drift net deployment sites in the lower Columbia River including: A) Arrow Lakes Generating Station (rkm 0.1), B) downstream of Kinnaird (rkm 13.4 – rkm 18.2), and C) Waneta (rkm 56.0).

2.3.2 Larval Capture

Drift net sampling has been used successfully to capture passively dispersing yolk-sac larvae for many sturgeon species including white sturgeon in the LCR (BC Hydro 2015a), lake sturgeon (*A. fulvescens*; Auer and Baker 2002), and shortnose sturgeon (*A. brevirostrum*; Moser et al. 2000). Drift net sampling has been added to the spawn monitoring program in recent years and has proven to be successful at documenting spawning days and larval dispersal patterns (BC Hydro 2013b).

Spawn monitoring remained consistent with previously established locations of drift net sampling (see Golder 2009a, 2010, 2012, 2013, 2014, and Terraquatic Resource Management 2011 for details). Drift nets were deployed at ALH, Kinnaird, and Waneta (Table 2.1) at the same sampling locations since annual programs were developed in 2010, 2009, and 2007 respectively. Catch per unit effort (CPUE) was calculated for each site across years. The Waneta effort was elevated in 2015 compared to previous years in an attempt to provide embryos and larvae for the SIF and to further describe the timing and frequency of spawning at that location.

Table 2.1: Number of drift nets deployed at each spawning site in 2020 – 2022.

Spawning Site	RKM	2020	2021	2022
ALH	0.1	5	5	5
Kinnaird	14.5	3	4	4
Kinnaird	18.2	2	4	4
Waneta	56.0	10	6	6

Drift net deployment and anchor system specifications were consistent among sampling locations and between sampling years 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 welded vertically across the drift net frame at 15 cm intervals to prohibit adult and juvenile white sturgeon from entering the drift net.

Drift net anchor systems were comprised of two lead steel claw river anchor (30 kg) attached by approximately 6 m of 3/8 galvanized chain. 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 braided rope was attached to the top of the drift net frame to a surface buoy for deployment and retrieval purposes without dislodging the anchor system.

Drift nets were deployed to stand perpendicular to the river bottom and collect drifting 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 19 L buckets 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 trays to improve contrast when searching for white sturgeon larvae. White sturgeon larvae were enumerated by net for each sampling location and session. Deployment and retrieval times, water temperatures (°C), and water depths (m) for each sampling location were recorded.

All live yolk-sac larvae were transported to the SIF (see BC Hydro 2015b). No live samples were sacrificed for preservation as practiced in previous years (BC Hydro 2015a). Dead larval samples collected at all locations were preserved for possible future genetic analyses.

2.3.3 Developmental Staging and Estimation of Fertilization Date

Preserved yolk-sac larvae were randomly examined with respect to date, stage, and site (to reduce observer bias) using a digital compound microscope (Nikon SMZ-745t Stereo Microscope with 10X eyepiece) and assigned a developmental stage. Enumeration of stages corresponded to the yolk-sac larvae classification by Dettlaff et al. (1993), including stages 36 (hatch) through 45 (exogenous feeding). No preserved samples had developed beyond stage 45.

Fertilization dates for collected yolk-sac larvae were estimated by back-calculation from the recorded date and time of preservation based on developmental stage and mean incubation water temperature (Jay et al. 2020). The estimated age 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 developmental staging as a method to delineate spawning days and estimate time of spawning can be affected by individual white sturgeon spawning behaviour, yolk-sac larvae maturation rates, and more importantly, the fluctuation in daily thermal regimes (Parsley et al. 2010).

2.4 Conservation Aquaculture Program

Design of the LCR Streamside Incubation Facility (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 originate. 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 number of eggs to ensure separation was 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, yolk-sac 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 yolk-sac larvae to burrow into interstitial spaces mimicking behaviour documented in the wild (McAdam 2011). To reduce sediment in the incubation jars and tanks, 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 yolk-sac larvae were transported to the KSH within 7 days of hatch in tanks of ambient river water filled with oxygen. Juveniles were reared at the KSH until date of release into the LCR (see FFSBC 2020 for details). Temperature loggers inside the facility recorded air, LCR water, and facility tank water temperatures.

2.5 Juvenile Population Assessment

From 2013 – 2022, a systematic stock assessment program to address uncertainties in the current population abundance and survival estimates was developed between Canadian and US recovery partners. The design of the stock assessment includes two annual surveys, one in the spring and one in the fall. Results presented here include data collected in the Canadian and US sections of the LCR.

Data will be used to estimate population abundance, age class structure, reproductive structure, growth rates, density dependent responses, and survival rates of hatchery released juveniles. Catch records will be analyzed across all years of stock assessment in an effort to provide recommendations to annual conservation aquaculture breeding plans and maximize the genetic diversity available for culture practices.

2.5.1 Study Design

The study area for the stock assessment program started at HLK, Canada, and extended downstream to Gifford, Washington, USA (Figure 2.3). Identifying the distribution of juvenile white sturgeon was an important component to the CLBMON-29 program as previous sampling efforts were limited to specific spatial areas of the LCR (Golder 2006a). Therefore, the LCR study area was stratified into 5 equal zones (11.2 rkm in length), and sampling effort was consistent at 1.6 hooks per hectare of river throughout the entire study area. We used a generalized random-tessellation stratified (GRTS) design developed by Stevens and Olsen (2004) to randomly assign sampling locations spatially balanced within each river zone. 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 2.3: Study area for white sturgeon stock assessment survey occurring from 2013 – 2022 in the Transboundary Reach of the Lower Columbia River. Upstream extent of the study area is Hugh L. Keenleyside Dam in Canada, and the downstream extent of the study area ends at Gifford, Washington, USA.

2.5.2 Juvenile Capture

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

A medium line configuration was the standard used for set lines, similar to that used by the Oregon Department of Fish and Wildlife (ODFW) and the Washington Department of Fish and Wildlife (WDFW) to capture white sturgeon in the United States portion of the Columbia River (Nigro et al. 1988). Medium lines measured 84.0 m in length and consisted of a 0.95 cm diameter nylon mainline with 12 circle halibut hooks attached at 6.0 m intervals. Hooks were attached to the mainline using a 0.95 cm swivel snap and a 0.7 m long ganglion line tied between the swivel and the hook. Four different Halibut hook sizes were used to select for different size classes of white sturgeon. Hook sizes included 14/0, 16.0, 18/0, and 20/0 that 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 pre-selected sampling locations and set configuration was based on the physical parameters (i.e., depths and water flow) of the site. Set line configuration consisted of either deploying the line parallel to the shore in faster flowing water or perpendicular to the shore in slower moving water. This was conducted to ensure that fish were able to orientate themselves into the current and rest on the bottom of the river, minimizing stress. Prior to each set, water depth (m) was measured by an echo sounder, and this information was used to select a float line of appropriate length. Anchors were attached to each end of the mainline and a float line was attached to the back anchor of the mainline. The set line was secured to shore with a shore line of suitable length to ensure that the set line was deployed in water depths greater than 2 m. Set lines were deployed and remained in overnight at each selected site.

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

2.5.3 Fish Handling, Biological Processing, 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 assessed for external markings (removed scutes; see FFSBC 2013 – 2022 for juvenile marking details) and the presence of a PIT tag (400 kHz PIT tags or 134.2 kHz ISO PIT tag; Biosonics Inc.) indicating previous capture. We followed the assumption that juvenile white sturgeon captured without external markings were of wild origin. 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 order to serve as a permanent mark to indicate previous capture.

White sturgeon were measured for fork length (± 0.5 cm) and weight (± 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.

A program to determine the sex and stage of maturation for hatchery-origin white sturgeon was initiated in fall 2015 and continued in the spring and fall of 2016 to address uncertainties related to the proportion of hatchery-origin fish that could initiate spawning with the existing wild adults. A more comprehensive program to determine if hatchery-origin individuals are reaching maturity was developed for the 2017 and 2018 sampling years, building off preliminary results from 2015 and 2016. This program was fully adopted for 2019 forward, focused on hatchery-origin fish >120 cm FL, to ensure reproductive structure is captured as it changes over time.

To determine reproductive status, an endoscopy and biopsy was performed on juvenile sturgeon >120 cm FL. A 1.5 to 2.0 cm long incision was made through the ventral body wall just off the mid-line using a sterile scalpel. An otoscope was inserted into the body cavity to assess the sex and stage of maturation of gonadal tissue based on macroscopic observations (Table 2.2, Figures 2.4 – 2.5). A biopsy tool (Miltex Cup Jaw Biopsy Tool) was then inserted into the body cavity via the otoscope to collect a small (2 mm^3) sample. Each sample was preserved in 10% phosphate buffered formalin. Following endoscopy and biopsy, the incision was closed using a half circle CP-2 reverse cutting-edge needle wedged to a 2-0 monofilament Polydioxanone suture. Sutures were spaced approximately 0.75 cm apart with sufficient slack provided to prevent tissue damage caused by swelling during the healing process. Gonadal tissue was processed histologically by embedding in paraffin, sectioning at 5 µm, and staining by Periodic Acid Schiff stain (PAS; Luna 1968). Slides were examined under a compound scope (5-100x, Leica DM2000), and the germ cells were scored for stage of maturation according to Webb and Van Eenennaam (2015).

Table 2.2: Stage of female and male gonad maturation identified through visual examination. Reproduced from Maskill (2020).

Sex		Stage of Maturation	Description
Female			
	1	Differentiation	Ovarian groove starts to develop into small, very thing ovigerous ribbon containing clusters of oogonia
	2	Pre-vitellogenic	Obvious ovigerous folds with small translucent oocytes
	3	Early vitellogenic	Ovigerous folds contain small white oocytes
	4	Mid-vitellogenic	Eggs in the ovary are seen as larger spheres, white to cream to yellowish in colour
	5	Late vitellogenic	Grey to black ovarian follicles are visible
	6	Post vitellogenic	Fully grown, black ovarian follicles
	7	Oocyte Maturation/Ovulation	Eggs are freely flowing from vent
	8	Post-ovulatory	Ovaries contain postovulatory follicles and the next generation of oocytes are present (stage 2 or 3)
	9	Atretic	Oocytes are soft, crush easily, and have a marbled appearance
Male			
	1	Differentiation	Testicular tissue is a thin white thread (<1 mm)
	2	Pre-meiotic	Testicular tissue is a thicker white thread (1 to 4 mm)
	3	Onset of meiosis	Testis have whitish colour and turgid texture ranging from 0.5 to 2 cm
	4	Meiotic	Gonad is primarily testicular tissue (2 to 3 cm) with much less adipose tissue
	5	Mature	Large milky-white testis (3 to 8 cm) with no adipose tissue
	6	Spermiation	Release of milt
	7	Post-spermiation	Classification requires histological methods

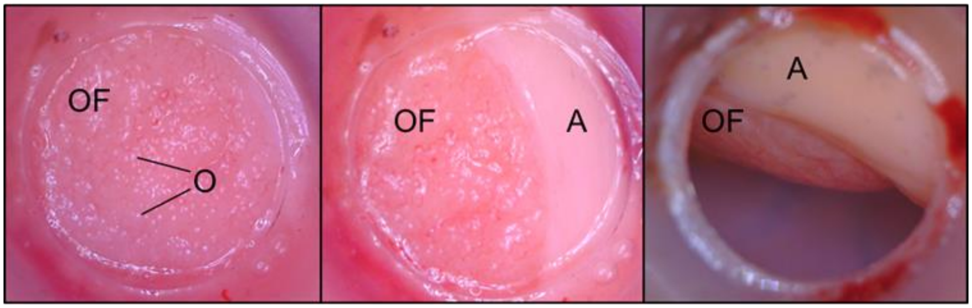

Figure 2.4: Endoscopic images of adipose tissue (A), ovigerous folds (OF), and small translucent oocytes (O) in pre-vitellogenic female juvenile white sturgeon. Reproduced from Maskill (2020).

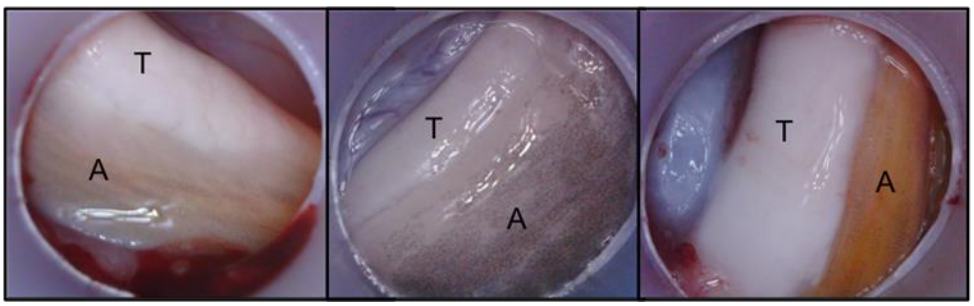

Figure 2.5: Endoscopic images of testicular tissue (T) and adipose tissue (A) in male juvenile white sturgeon. Stage of maturity cannot be determined through visual examination. Reproduced from Maskill (2020).

Blood samples were also collected from fish >120 cm FL to help assign reproductive status through measurement of plasma sex steroids (Webb et al. 2018). Blood was collected 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 were extracted from plasma for analysis by radioimmunoassay (RIA) at the Bozeman Fish Technology Center, Bozeman, MT, USA.

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; Schreier et al. 2021). This has raised concerns within the LCR White Sturgeon Conservation Aquaculture Program, as the hatchery reared offspring reproductive success and effects on the wild population are unknown. Due to these recent discoveries, blood samples were collected from all captured fish in 2014 – 2016 (BC Hydro 2015a, 2016a, 2017), to determine the incidence of 12N fish in the wild as well as hatchery-reared fish stocked in earlier years when ploidy levels were unknown. Blood samples were not collected in 2017 as new methods were being developed to provide additional confidence in the measurement of ploidy levels. Starting in 2018, ploidy sampling was conducted on a subset of fish annually to describe proportions of individuals with higher ploidy levels.

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.

2.5.4 Data Analysis

Catch Per Unit Effort

Catch per unit effort (CPUE) was calculated as total white sturgeon captures per effort hour. Proportion of total capture was calculated by means of brood year class and sampling zone. Spatial distribution of juvenile white sturgeon in the LCR was assessed qualitatively by visual examination of capture locations and quantitatively by comparison of CPUE among sampling zones within each year.

Fork Length, Weight, and Relative Weight

Biological data collected and analyzed in this report included fork length (FL; cm), weight (kg), and relative weight (W_r). Relative weight is a measure of fish plumpness allowing comparison between fish of different lengths, inherent changes in body forms, and populations (Wege and Anderson 1978). Relative weight was 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). We determined W_r for captured juveniles according to the white sturgeon standard weight-length equation developed by Beamesderfer (1993):

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

where W_s is standardized weight and L is fork length (FL; cm).

Growth

Growth rate was analyzed using von Bertalanffy growth rate models, similar to those developed in Korman et al. (2021), and used the long-term mark-recapture dataset (2002 – 2018) of hatchery-origin white sturgeon in the LCR to evaluate the influence of environmental (temperature, discharge, habitat), biological (maternal family, age, year class), and ecological (e.g. competition) factors on growth and predict length-at-age relationships. Full methods are provided in Crossman et al. (2023).

Survival and Abundance

Simple deterministic models were developed for a long-term mark-recapture dataset (2002 – 2018) of hatchery-origin white sturgeon in the LCR to evaluate the influence of biological (maternal family, age, year class) and environmental (habitat) factors on abundance and biomass over time. Abundance after age 2 was calculated based on a constant annual survival rate of 0.943. Full methods are provided in Crossman et al. (2023).

2.6 Juvenile Movement Ecology

Hidden Markov models and generalized linear mixed models were developed for a short-term acoustic telemetry dataset (2019 – 2020) of hatchery-origin white sturgeon in the LCR to investigate how movement behaviour varied spatially (between habitats and countries), temporally (between seasons), and by biological factors (age, size, sex) and river regulation (water temperature, discharge). Full methods are provided in Jetter (2022).

3 Results

3.1 Physical Parameters

3.1.1 Discharge

Mean daily discharge (cms) measured from Arrow Reservoir, Kootenay River, Birchbank, and Canada–United States border for the 2020 – 2022 study period is presented in Figure 3.1. Minimum and maximum discharge (cms) for each location is given in Table 3.1.

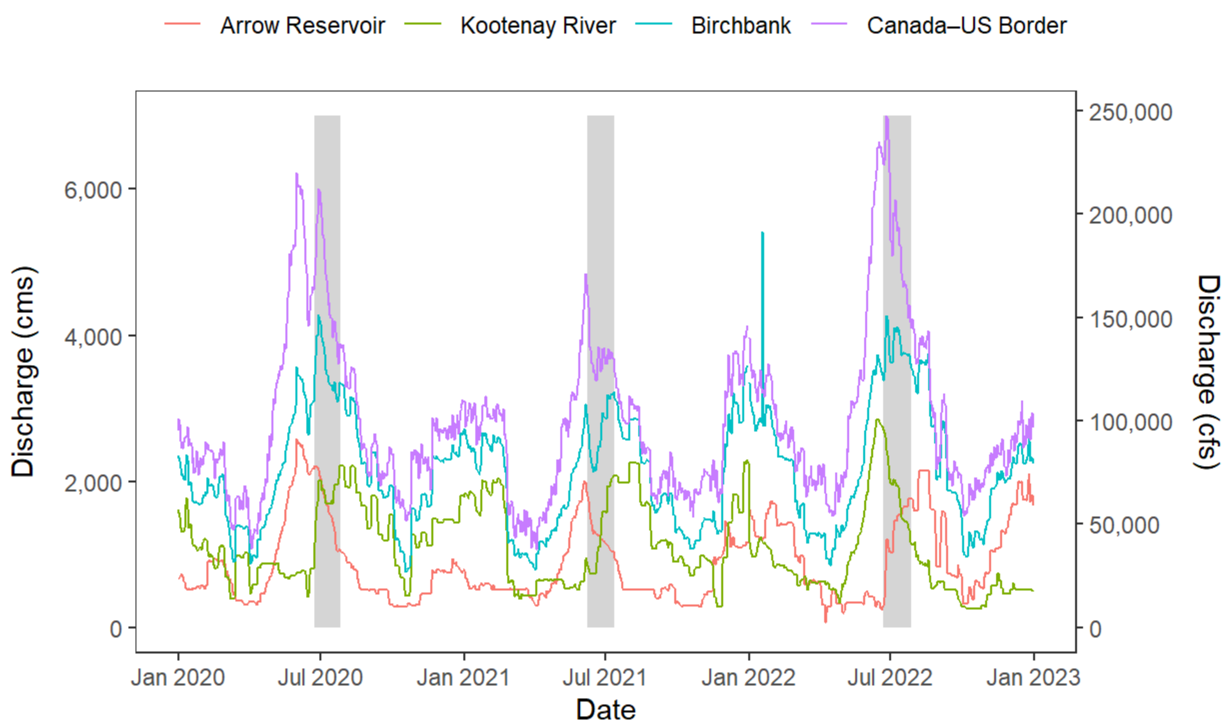

Figure 3.1: Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada–United States border on the Lower Columbia River from January 01, 2020 – December 31, 2022. Shaded areas represent the estimated spawning period across years. Estimated spawning dates were based on the developmental stage of collected embryos and/or larvae.

Table 3.1: Minimum and maximum discharge (cms) at four locations on the Lower Columbia River between 2020 – 2022.

		Discharge (cms)		Discharge (cfs)	
Year	Location	Min	Max	Min	Max
2020					
	Arrow Reservoir	282	2,580	9,959	91,112
	Kootenay River	390	2,212	13,773	78,116
	Birchbank	761	4,286	26,874	151,359
	Canada–US Border	1,074	6,225	37,928	219,834
2021					
	Arrow Reservoir	289	2,007	10,206	70,877
	Kootenay River	292	2,292	10,312	80,941
	Birchbank	787	3,589	27,793	126,744
	Canada–US Border	1,070	4,837	37,787	170,817
2022					
	Arrow Reservoir	61	2,149	2,154	75,891
	Kootenay River	256	2,864	9,041	101,141
	Birchbank	847	5,425	29,912	191,582
	Canada–US Border	1,526	7,003	53,890	247,309

3.1.2 Water Temperature

Mean daily water temperatures (°C) in the LCR during 2020 – 2022 are illustrated in Figure 3.2. 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 3.2. 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.

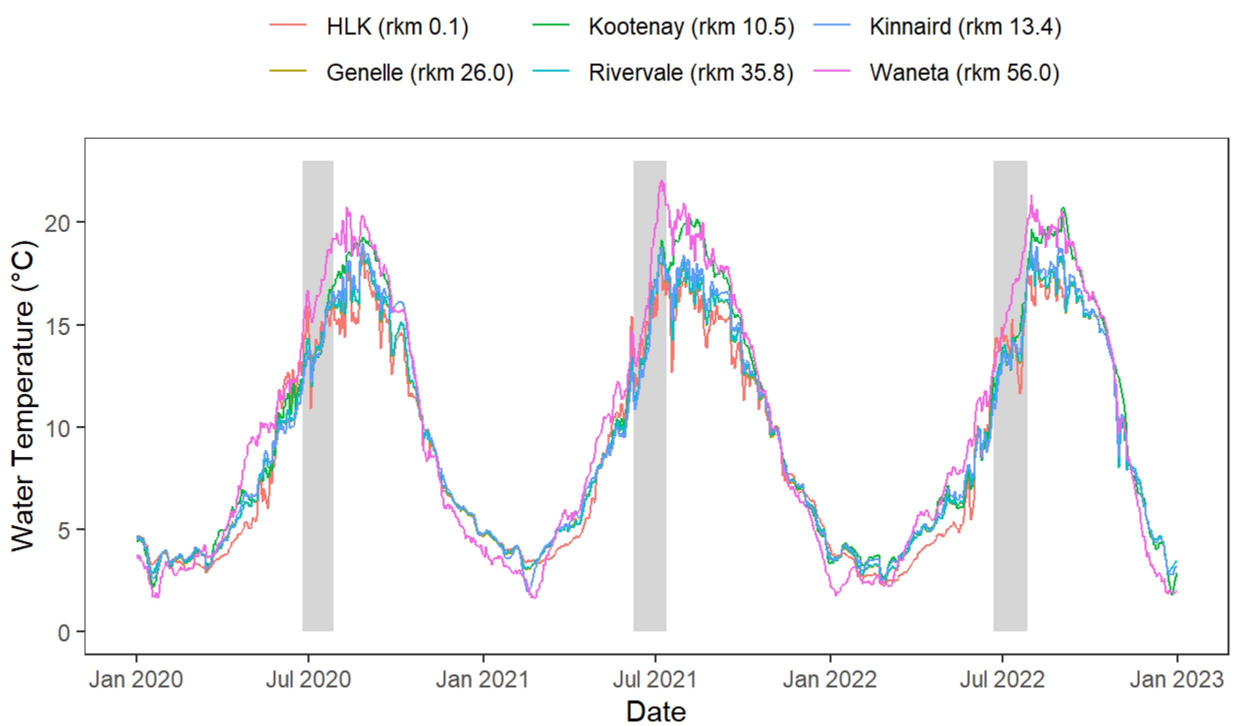

Figure 3.2: Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada–United States border on the Lower Columbia River from January 01, 2020 – December 31, 2022. Shaded areas represent the estimated spawning period across years. Estimated spawning dates were based on the developmental stage of collected embryos and/or larvae.

Table 3.2: Annual mean (± SD), minimum, and maximum water temperatures (°C) recorded within the Lower Columbia River between 2020 – 2022. Data was recorded at locations of 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)			
Year	Location	Mean ± SD	Min	Max	Date of Suspected Spawning Threshold (14°C)
2020					
	HLK	9.0 ± 4.9	2.9	18.7	June 25
	Kootenay	9.6 ± 5.3	2.2	19.3	July 15
	Kinnaird	9.3 ± 5.1	2.6	19.0	July 14
	Genelle	9.2 ± 4.9	2.8	18.9	June 28
	Rivervale	9.2 ± 4.9	2.9	19.0	June 28
	Waneta	10.0 ± 6.0	1.6	20.8	June 23
2021					
	HLK	9.5 ± 4.8	3.3	18.2	June 4
	Kootenay	10.2 ± 5.6	2.0	20.3	June 21
	Kinnaird	9.8 ± 5.1	2.0	18.8	June 24
	Genelle	9.7 ± 4.9	3.0	18.6	June 21
	Rivervale	9.7 ± 4.9	3.1	18.7	June 21
	Waneta	10.5 ± 6.2	1.6	22.1	June 4
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

3.2 Larval Assessment

3.2.1 Sampling Effort and Capture

Waneta (rkm 56.0)

In 2020, drift nets (n=10) were deployed on June 8 and sampling continued until July 27. During the sampling period, water temperatures ranged from 11.2 to 20.2°C and water depth (mean ± SD) was 5.1 ± 1.6 m. Total sampling effort was 6,329 hours and single set effort (mean ± SD) was 19.1 ± 24.2 hours (Table 3.3). A total of 78 larvae were captured at Waneta between the dates of June 30 and July 27 (Table 3.3). Live larvae (n=9) were transported to the SIF and later to KSH for rearing purposes while the remaining larvae were preserved.

In 2021, drift nets (n=6) were deployed on June 8 and sampling continued until July 26. During the sampling period, water temperatures ranged from 13.0 to 23.3°C and water depth (mean ± SD) was 4.5 ± 1.0 m. Total sampling effort was 6,902 hours and single set effort (mean ± SD) was 25.5 ± 29.0 hours (Table 3.3). A total of 54 larvae were captured at Waneta between the dates of June 15 and July 7 (Table 3.3). Live larvae (n=8) were transported to the SIF and later to KSH for rearing purposes while the remaining larvae were preserved.

In 2022, drift nets (n=6) were deployed on June 13 and sampling continued until August 3. During the sampling period, water temperatures ranged from 11.0 to 22.5°C and water depth (mean ± SD) was 5.5 ± 1.5 m. Total sampling effort was 5,629 hours and single set effort (mean ± SD) was 31.3 ± 44.4 hours (Table 3.3). A total of 67 larvae were captured at Waneta between the dates of June 30 and July 18 (Table 3.3). Live larvae (n=8) were transported to the SIF and later to KSH for rearing purposes while the remaining larvae were preserved.

Kinnaird (rkm 13.4 – 18.2)

In 2020, drift nets (n=5) were deployed on July 15 and sampling continued until August 7. During the sampling period, water temperatures ranged from 14.8 to 17.9°C and water depth (mean ± SD) was 4.7 ± 1.1 m. Total sampling effort was 1,248 hours and single set effort (mean ± SD) was 17.1 ± 24.1 hours (Table 3.3). No larvae were captured at Kinnaird in 2020.

In 2021, drift nets (n=8) were deployed on July 8 and sampling continued until August 4. During the sampling period, water temperatures ranged from 14.1 to 18.6°C and water depth (mean ± SD) was 4.8 ± 1.4 m. Total sampling effort was 2,398 hours and single set effort (mean ± SD) was 26.6 ± 35.0 hours (Table 3.3). No larvae were captured at Kinnaird in 2021.

In 2022, drift nets (n=8) were deployed on June 28 and sampling continued until August 5. During the sampling period, water temperatures ranged from 12.5 to 18.8°C and water depth (mean ± SD) was 4.6 ± 1.3 m. Total sampling effort was 5,654 hours and single set effort (mean ± SD) was 36.2 ± 40.1 hours (Table 3.3). No larvae were captured at Kinnaird in 2022.

ALH (rkm 0.1)

In 2020, drift nets (n=5) were deployed on July 13 and sampling continued until August 7. During the sampling period, water temperatures ranged from 13.8 to 17.5°C and water depth (mean ± SD) was 6.0 ± 1.9 m. Total sampling effort was 2,197 hours and single set effort (mean ± SD) was 20.3 ± 23.8 hours (Table 3.3). No larvae were captured at ALH in 2020.

In 2021, drift nets (n=5) were deployed on July 6 and sampling continued until August 4. During the sampling period, water temperatures ranged from 12.5 to 19.1°C and water depth (mean ± SD) was 5.2 ± 1.6 m. Total sampling effort was 3,364 hours and single set effort (mean ± SD) was 36.2 ± 31.4 hours (Table 3.3). No larvae were captured at ALH in 2021.

In 2022, drift nets (n=5) 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 and water depth (mean ± SD) was 5.9 ± 1.3 m. Total sampling effort was 3,707 hours and single set effort (mean ± SD) was 42.6 ± 40.0 hours (Table 3.3). No larvae were captured at ALH in 2022.

Table 3.3: White sturgeon embryo and larval collection and sampling effort at Lower Columbia River monitoring locations of Waneta (rkm 56.0), Kinnaird (rkm 12.8 – 19.2), Kootenay (rkm 10.5), downstream ALH (rkm 6.0), and ALH (rkm 0.1), and HLK (rkm 0.1) for years 2008 – 2022.

Year	Location	Embryos	Larvae	Effort (hrs)	CPUE
2008					
	rkm 18.2	0	1	164	0.01
	Waneta	494	220	72	9.92
2009					
	rkm 6.0	0	0	3,091	0.00
	rkm 18.2	0	5	976	0.01
	Waneta	77	39	90	1.29
2010					
	rkm 18.2	1	8	2,104	0.00
	Waneta	888	89	113	8.65
	ALH	30	115	2,084	0.07
2011					
	rkm 18.2	2	33	1,413	0.02
	rkm 14.5	0	0	154	0.00
	rkm 10.5	0	0	993	0.00
	Waneta	234	15	50	4.98
	HLK	0	0	461	0.00
	ALH	183	308	2,538	0.19
2012					

Year	Location	Embryos	Larvae	Effort (hrs)	CPUE
	rkm 18.2	0	0	197	0.00
	Waneta	134	15	48	3.10
	ALH	6	0	2,979	0.00
2013					
	rkm 18.2	0	4	363	0.01
	rkm 14.5	0	1	154	0.01
	ALH	0	0	680	0.00
2014					
	rkm 18.2	5	8	1,514	0.01
	rkm 17.3	0	1	128	0.01
	rkm 16.9	0	2	43	0.05
	rkm 15.6	0	0	77	0.00
	rkm 15.0	0	0	106	0.00
	rkm 14.5	1	2	670	0.00
	Waneta	33	62	43	2.21
	ALH	0	0	857	0.00
2015					
	rkm 19.2	0	0	91	0.00
	rkm 18.2	0	2	1,767	0.00
	rkm 17.3	0	1	187	0.01
	rkm 16.9	0	4	186	0.02
	rkm 14.5	0	1	272	0.00
	rkm 13.4	0	0	805	0.00
	Waneta	8	55	275	0.23
	ALH	0	1	1,373	0.00
2016					
	rkm 18.2	0	8	990	0.01
	rkm 17.3	0	1	122	0.01
	rkm 16.9	0	5	121	0.04
	rkm 14.5	0	3	381	0.01
	rkm 13.4	0	0	118	0.00
	rkm 12.8	0	0	901	0.00
	Waneta	5,203	955	965	6.38
	ALH	0	0	1,006	0.00
2017					
	rkm 18.2	0	4	363	0.01
	rkm 16.9	0	0	78	0.00

Year	Location	Embryos	Larvae	Effort (hrs)	CPUE
	rkm 14.5	0	8	433	0.02
	rkm 13.4	1	2	416	0.01
	Waneta	1,914	582	913	2.73
	ALH	511	159	2,146	0.31
2018					
	rkm 18.2	0	1	979	0.00
	rkm 14.5	0	1	707	0.00
	rkm 13.4	0	2	1,071	0.00
	Waneta	9,515	579	1,258	8.02
	ALH	3	14	2,290	0.01
2019					
	rkm 18.2	0	6	131	0.05
	rkm 14.5	1	0	1,335	0.00
	Waneta	721	127	437	1.94
	ALH	3	6	1,311	0.01
2020					
	rkm 18.2	0	0	101	0.00
	rkm 14.5	0	0	1,147	0.00
	Waneta	6,986	78	6,329	1.12
	ALH	3	0	2,197	0.00
2021					
	rkm 18.2	0	0	99	0.00
	rkm 14.5	0	0	2,299	0.00
	Waneta	3,239	54	6,902	0.48
	ALH	0	0	3,364	0.00
2022					
	rkm 18.2	0	0	2,864	0.00
	rkm 14.5	1	0	2,790	0.00
	Waneta	1,173	67	5,629	0.22
	ALH	0	0	3,707	0.00

3.2.2 Developmental Staging and Estimated Spawning Dates

All preserved larvae in good condition were assigned a developmental stage based on Dettlaff et al. (1993) to calculate an estimated date of fertilization. The majority of yolk-sac larvae samples captured in 2020 – 2022 were at an early developmental stage (<40; Table 3.4).

In 2020, spawning was estimated to have occurred at Waneta on 14 days between the dates of June 24 and July 27. There was no evidence of spawning at the ALH and Kinnaird sites.

In 2021, spawning was estimated to have occurred at Waneta on 11 days between the dates of June 8 and July 9. There was no evidence of spawning at the ALH and Kinnaird sites.

In 2022, spawning was estimated to have occurred at Waneta on 17 days between the dates of June 22 and July 26. A total of 1 spawning day was estimated at the Kinnaird site on July 11. There was no evidence of spawning at the ALH site.

Table 3.4: Developmental stages of white sturgeon larvae collected at ALH, Kinnaird, and Waneta spawning sites in the Canadian section of the Lower Columbia River between 2020 – 2022.

		Developmental Stage								
Year	Location	36	37	38	39	40	41	42	43	44
2020										
	ALH	0	0	0	0	0	0	0	0	0
	Kinnaird	0	0	0	0	0	0	0	0	0
	Waneta	69	0	0	0	0	0	0	0	0
2021										
	ALH	0	0	0	0	0	0	0	0	0
	Kinnaird	0	0	0	0	0	0	0	0	0
	Waneta	46	0	0	0	0	0	0	0	0
2022										
	ALH	0	0	0	0	0	0	0	0	0
	Kinnaird	0	0	0	0	0	0	0	0	0
	Waneta	58	0	0	1	0	0	0	0	0

3.3 Conservation Aquaculture Program

The Conservation Aquaculture Program has released a total of 149,262 juvenile white sturgeon from 2002 – 2022 (Table 3.5). A total of 199 wild-origin juveniles were released in to the LCR in fall of 2021 and 2022 (year classes 2020 and 2021). Additional fish (716) were released into Arrow Lakes Reservoir. Fork length (mean ± SD) of wild-origin juveniles released in 2021 and 2022 was 34.8 ± 2.3 cm and 32.8 ± 1.5 cm, respectively (Figure 3.3). Weight of juveniles released in 2021 and 2022 was 296.7 ± 59.7 g and 229.5 ± 25.8 g, respectively (Figure 3.4).

Table 3.5: Numbers of hatchery (H) and wild (W) origin juvenile white sturgeon released into the Transboundary Reach of the Lower Columbia River from 2002 – 2022. Wild-origin represents progeny collected in the wild as embryos or larvae and reared in the hatchery. Release numbers are presented by release year, release country, and indicated whether they occurred in the spring or fall.

		Canada		USA		
Release Year	Year Class - Origin	Spring	Fall	Spring	Fall	Total
2002	2001-H	8,671				8,671
2003	2002-H	11,803				11,803
2004	2003-H	9,695		1,881		11,576
2005	2004-H	12,748		3,755		16,503
2005	2005-H		5,039			5,039
2006	2005-H	10,828		4,351		15,179
2006	2006-H		4,042			4,042
2007	2006-H	8,123		3,422		11,545
2007	2007-H		4,029			4,029
2008	2007-H	6,448		3,821		10,269
2009	2008-H	4,141		3,537		7,678
2010	2009-H	3,947		3,873		7,820
2010	2010-W				522	522
2011	2010-H	4,010		3,869		7,879
2011	2011-W				3,586	3,586
2012	2011-H	4,000				4,000
2012	2012-W				302	302
2013	2012-H	4,037				4,037
2014	2013-W				656	656
2014	2013-H	1,800				1,800
2015	2014-H	2,800				2,800
2015	2014-W	1,095		2,833		3,928
2016	2015-W	76		2,333		2,409
2017	2016-W	800		1,134		1,934
2018	2017-W	457				457
2019	2018-W	200				200
2020	2019-W	200				200
2021	2020-W	199				199
2022	2021-W	199				199
Total		96,277	13,110	34,809	5,066	149,262

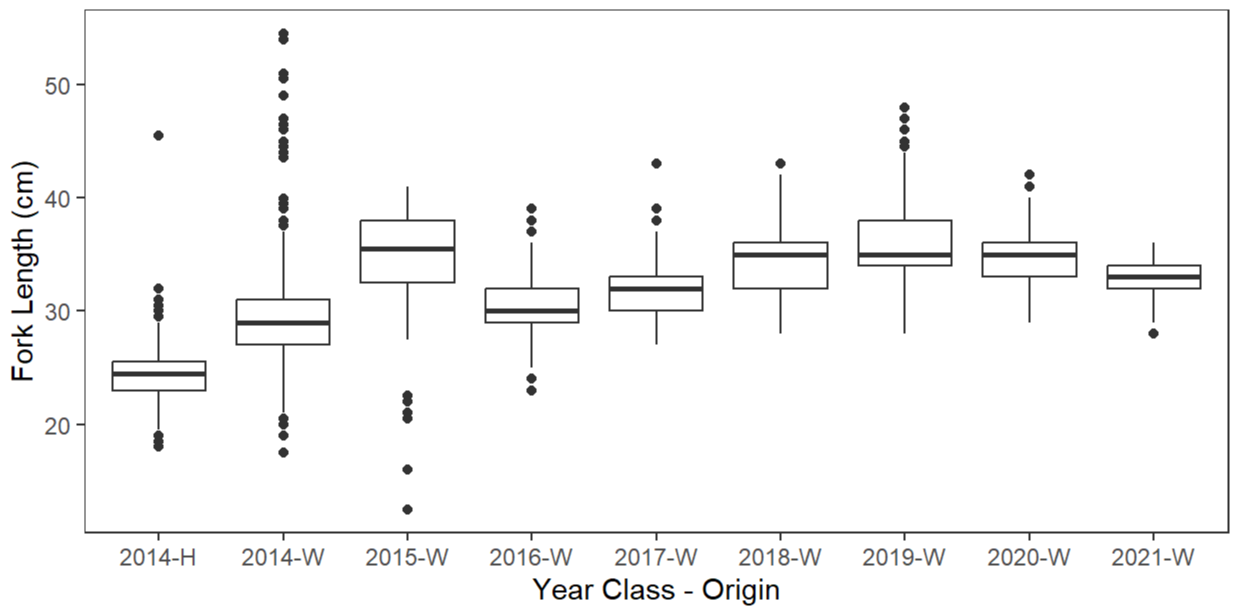

Figure 3.3: Fork length (cm) at release in Canada (approximately 9 months of age) of 2014 – 2021 year class juvenile white sturgeon of hatchery (H) and wild (W) origins.

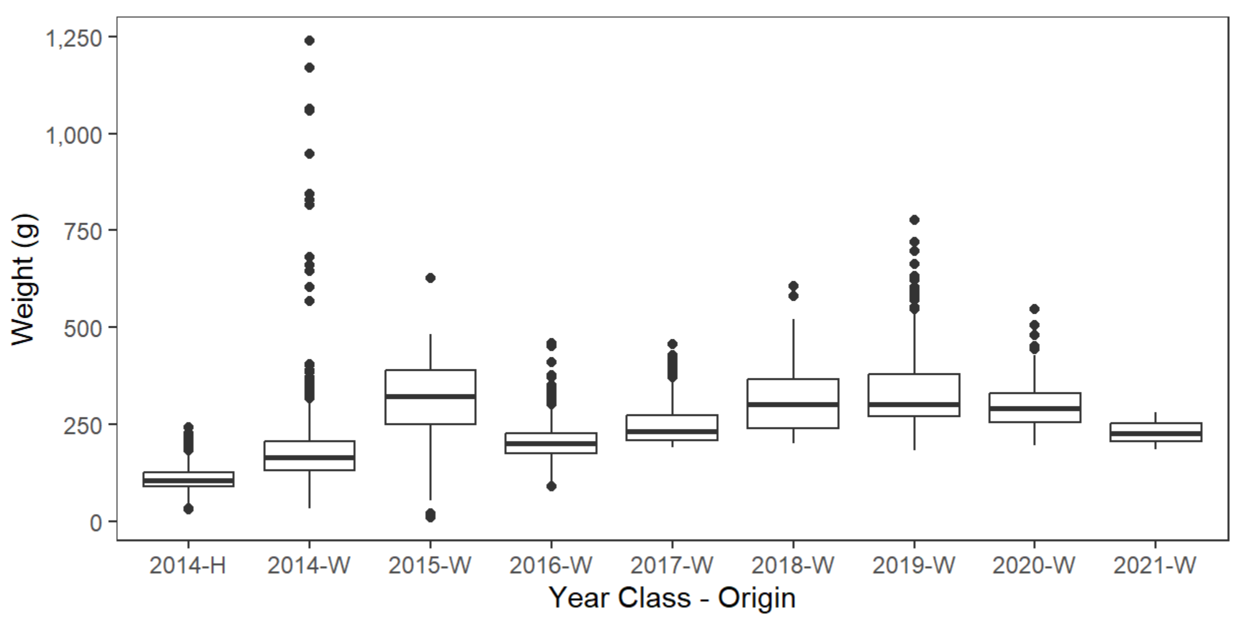

Figure 3.4: Weight (g) at release in Canada (approximately 9 months of age) of 2014 – 2021 year class juvenile white sturgeon of hatchery (H) and wild (W) origins.

3.4 Juvenile Population Assessment

3.4.1 Sampling Effort and Capture

Spring and fall 2020 stock assessments in the Canadian section of the LCR were conducted between the dates of May 18 – May 29 (11 days) and September 13 – September 24 (11 days) with water temperatures (mean ± SD) of 9.1 ± 1.1 °C and 15.7 ± 0.7 °C, respectively. During the spring and fall assessments, 1,380 hooks were set using 115 lines. Sampling effort for the spring and fall assessments was 2,351 hours and 2,328 hours, respectively. Set line deployment (mean ± SD) during the spring and fall assessments was 20.4 ± 1.3 hours and 20.2 ± 2.0 hours at water depths of 11.1 ± 4.7 m and 10.5 ± 4.9 m, respectively.

Spring and fall 2021 stock assessments in the Canadian section of the LCR were conducted between the dates of May 16 – June 3 (18 days) and September 26 – October 8 (12 days) with water temperatures (mean ± SD) of 10.8 ± 1.3 °C and 13.2 ± 0.9 °C, respectively. During the spring and fall assessments, 1,380 hooks and 1,320 hooks were set using 115 lines and 110 lines, respectively. Sampling effort for the spring and fall assessments was 2,437 hours and 2,321 hours, respectively. Set line deployment (mean ± SD) during the spring and fall assessments was 21.2 ± 2.5 hours and 21.1 ± 2.2 hours at water depths of 10.4 ± 4.6 m and 10.8 ± 4.7 m, respectively.

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 hatchery-origin white sturgeon captured during the 2020 spring and fall stock assessments were 233 and 311, respectively (Table 3.6). In 2021, 351 and 292 hatchery-origin white sturgeon were captured during the spring and fall stock assessments, respectively. In 2022, 177 and 322 hatchery-origin white sturgeon were captured during the spring and fall stock assessments, respectively. Individuals less than 150 cm fork length with no PIT tag administered by the hatchery or lateral scutes removed were considered wild fish as a product of natural reproduction and of unknown age.

Within Canada, total capture by year class in 2020 – 2022 is provided in Figure 3.5. Since stock assessments were initiated in 2013, the 2001 and 2002 year classes have represented the largest number of total capture. Catch per unit effort during the 2020 – 2022 stock assessments shows juveniles being captured most frequently in sampling zone 1 and least frequently in sampling zone 4 (Figure 3.6).

Table 3.6: Total hatchery-origin white sturgeon captured during the 2013 – 2022 stock assessments in the Canadian section of the Lower Columbia River. Individuals less than 150 cm fork length with no PIT tag administered by the hatchery or lateral scutes removed were considered wild juvenile fish as a product of natural reproduction and of unknown age.

Year	Season	Hatchery	Wild	Total
2013	Spring	31	6	37
2013	Fall	152	5	157
2014	Spring	99	2	101
2014	Fall	263	12	275
2015	Spring	209	8	217
2015	Fall	281	5	286
2016	Spring	347	5	352
2016	Fall	275	5	280
2017	Spring	140	1	141
2017	Fall	334	2	336
2018	Spring	288	2	290
2018	Fall	336	9	345
2019	Spring	278	3	281
2019	Fall	365	4	369
2020	Spring	233	5	238
2020	Fall	311	1	312
2021	Spring	351	7	358
2021	Fall	292	2	294
2022	Spring	177	2	179
2022	Fall	322	5	327
Total		5,084	91	5,175

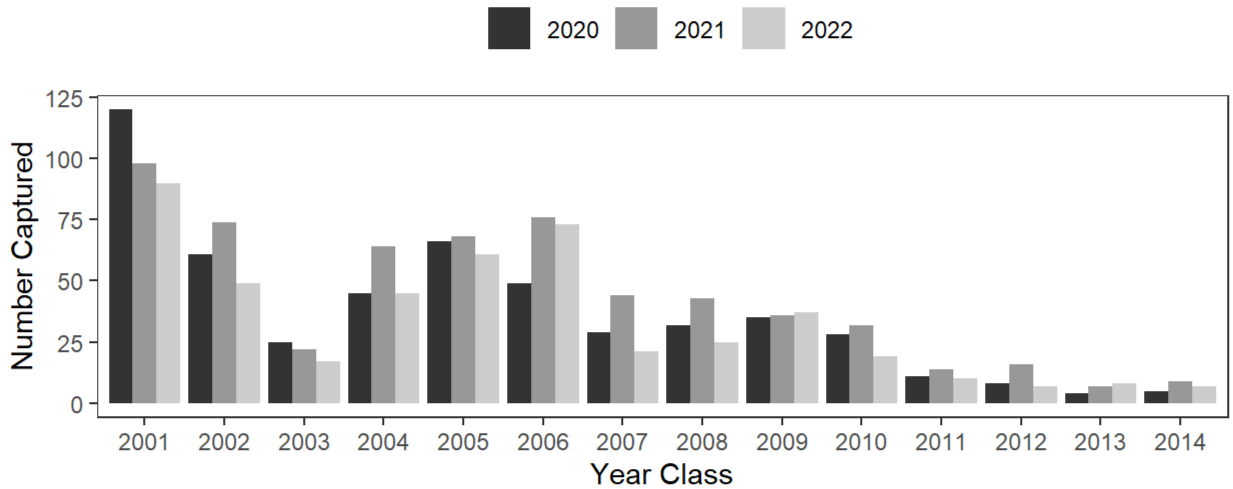

Figure 3.5: The total number of hatchery-origin white sturgeon captured within the Canadian section of the Lower Columbia River during the 2020 – 2022 stock assessments by year class.

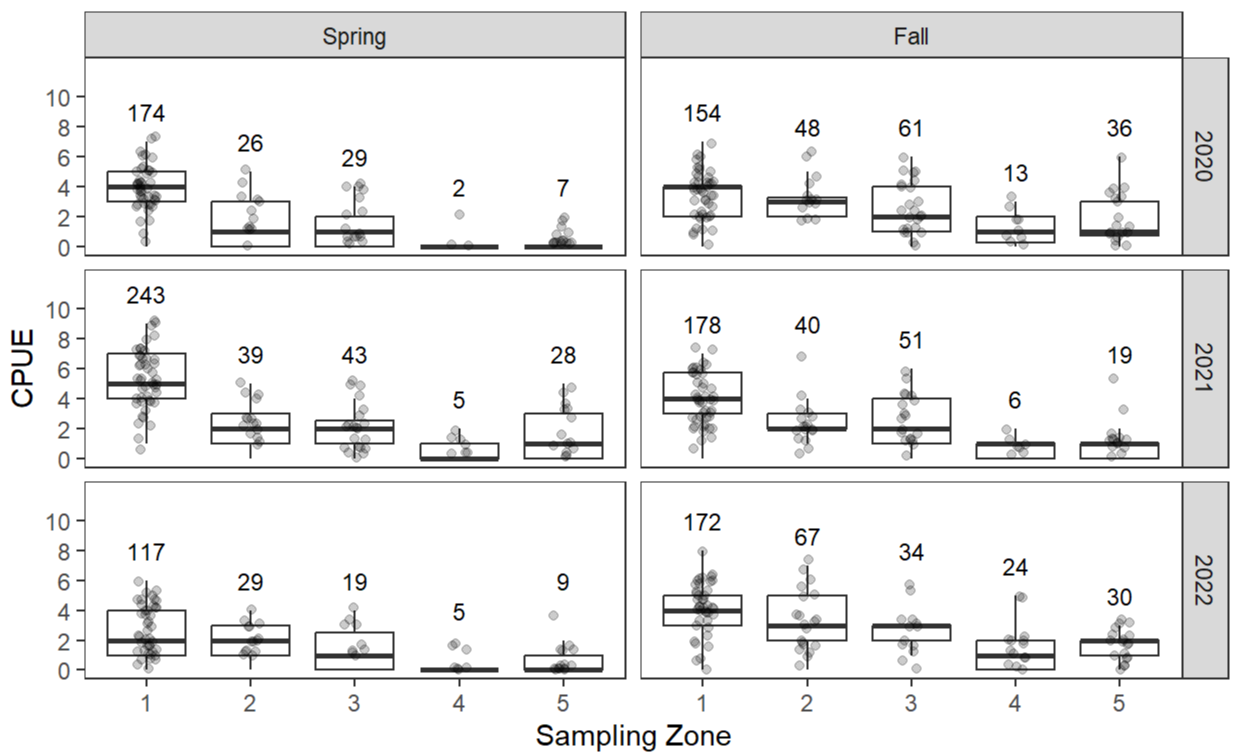

Figure 3.6: Catch per unit effort (CPUE; number of sturgeon per 24 hours) for hatchery-origin white sturgeon captured within the Canadian section of the Lower Columbia River during the 2020 – 2022 stock assessments. Results are separated by year, season, and sampling zone. Points represent CPUE for individual set lines. Labels represent total hatchery-origin sturgeon captured.

3.4.2 Fork Length, Weight, Relative Weight, and Growth

Fork Length

Mean fork length (FL) of juveniles captured within Canada during the 2020 – 2022 stock assessments was 96.6 ± 13.0 cm, 96.9 ± 13.6 cm, and 98.2 ± 12.6 cm respectively. Juvenile FL as a function of year class (Table 3.7; Figure 3.7) is provided below. In all sampling years, mean FL decreased as a function of year class (YrC). As seen in previous capture years, mean FL of YrC 2001 was larger than YrC 2002 (BC Hydro 2017). Wild juveniles were generally larger than hatchery-origin fish in 2020 – 2022 (Table 3.7; Figure 3.7).

Weight

Weight of juveniles captured within Canada during the 2020 – 2022 stock assessments was 6.0 ± 2.9 kg, 6.1 ± 3.2 kg, and 6.4 ± 3.2 kg respectively. Weight of juveniles as a function of year class (Table 3.8; Figure 3.8) is provided below. Generally, weight decreased as a function of YrC. Similar to previous years mean weight of YrC 2001 was larger than YrC 2002 (BC Hydro 2017). Juveniles of wild origin were generally larger than hatchery-origin fish in 2020 – 2022 (Table 3.8; Figure 3.8).

Relative Weight

Relative weight (W_r) for juveniles captured within Canada during the 2020 – 2022 stock assessments was 79.5 ± 8.0, 78.7 ± 8.3, and 80.0 ± 7.4 respectively. Generally, W_r was similar among all year classes (Table 3.9; Figure 3.9). Unlike the measurements of FL and weight, juveniles of wild origin had a similar W_r as hatchery-origin fish in 2020 – 2022 (Table 3.9; Figure 3.9).

Growth

Environmental conditions (by season and country) and competition had the greatest effects on growth. Growth, length-at-age, weight-at-age, and condition factor were higher for fish residing in reservoir habitats (US) compared to those in riverine habitat (Canada) (Figures 3.10 – 3.12). Growth declined over the study period but growth in length for larger fish remained higher in the US as fish >100 cm fork length in Canada were not growing. Small differences in growth among families indicate that differences in genetics among parents spawned in the hatchery had negligible effects on growth in the wild. Full results are provided in Crossman et al. (2023).

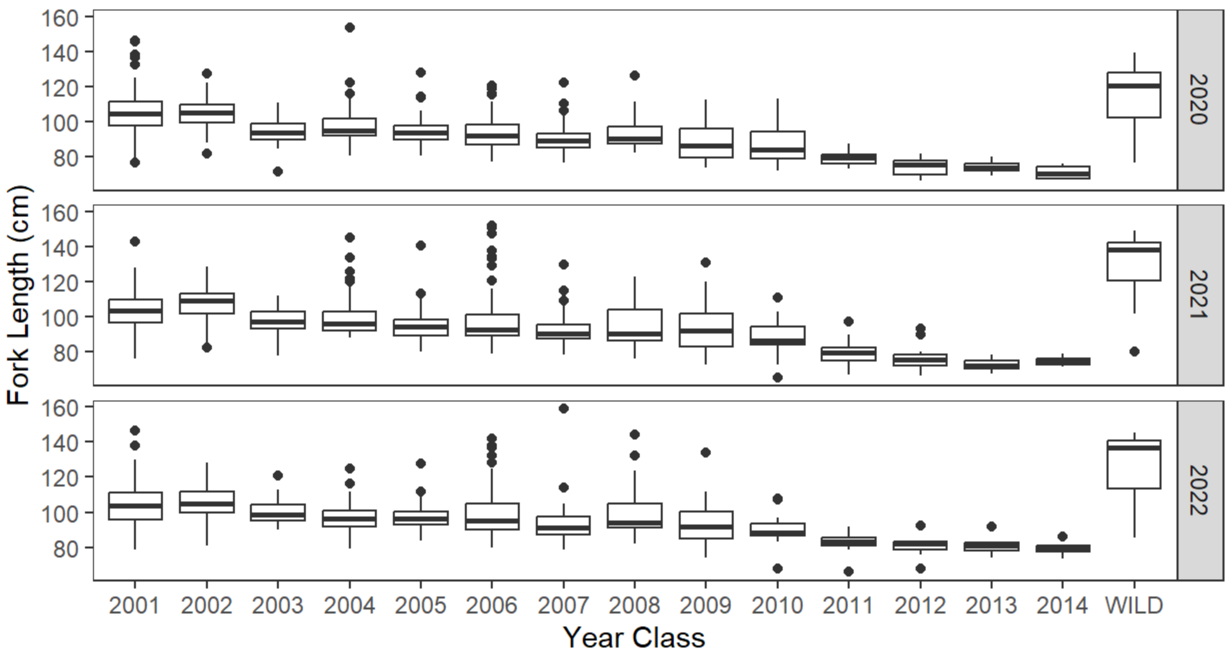

Figure 3.7: Fork length (cm) of juvenile white sturgeon captured in the Canadian section of the Lower Columbia River during the 2020 – 2022 stock assessments. Data is represented by year class. Wild-origin juveniles were of unknown age.

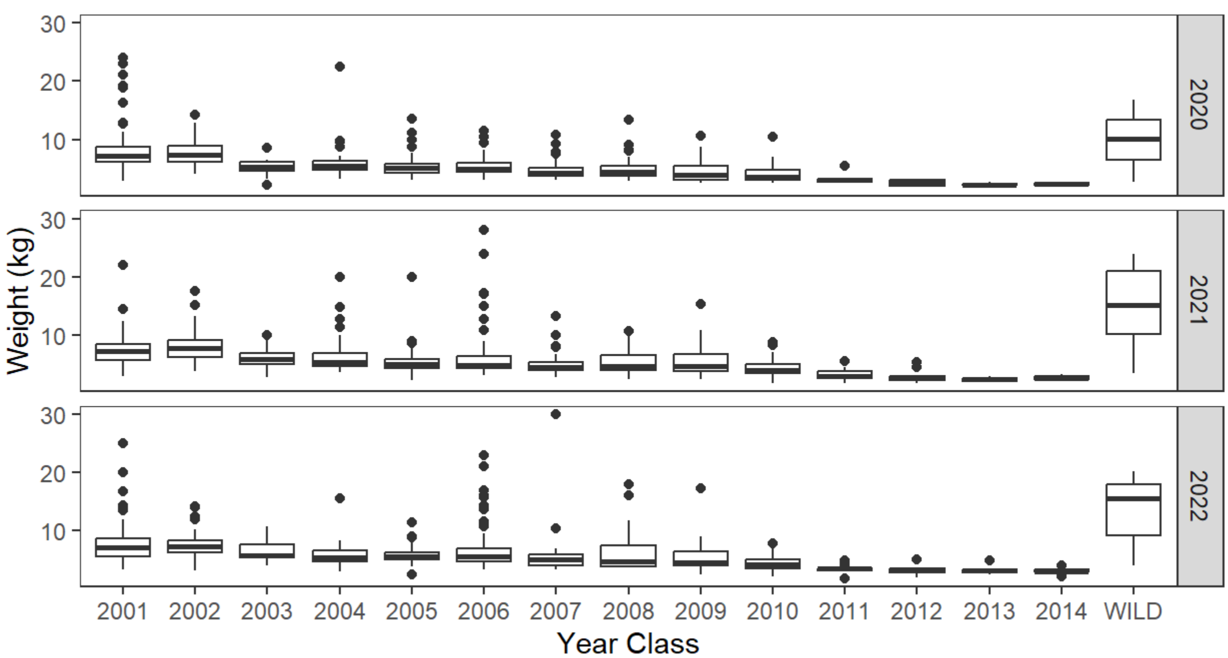

Figure 3.8: Weight (kg) of juvenile white sturgeon captured in the Canadian section of the Lower Columbia River during the 2020 – 2022 stock assessments. Data is represented by year class. Wild-origin juveniles were of unknown age.

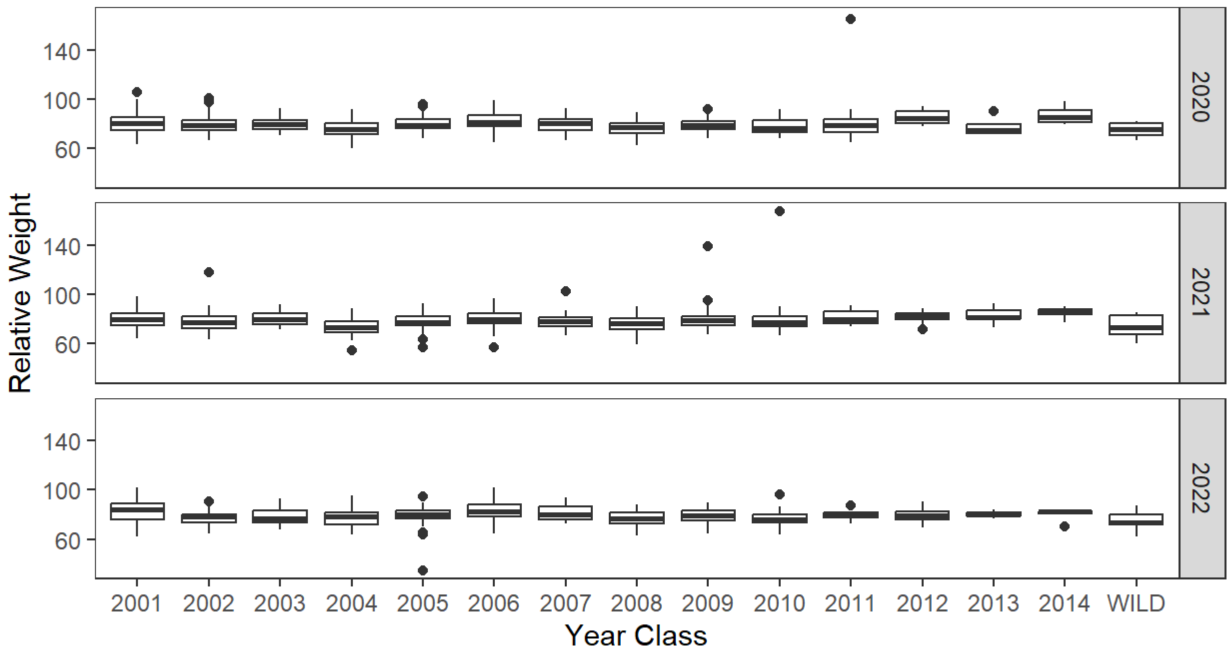

Figure 3.9: Relative weight of juvenile white sturgeon captured in the Canadian section of the Lower Columbia River during the 2020 – 2022 stock assessments. Data is represented by year class. Wild-origin juveniles were of unknown age.

Table 3.7: Mean ± SD fork length (cm) by year class of juvenile white sturgeon captured in the Canadian section of the Lower Columbia River during the 2020 – 2022 stock assessments. Data is represented by year class. Wild-origin juveniles were of unknown age.

Year Class	2020	2021	2022
2001	105.5 ± 12.6	103.2 ± 10.9	104.2 ± 11.6
2002	105.1 ± 9.0	107.4 ± 9.3	105.5 ± 9.2
2003	94.0 ± 7.7	96.7 ± 9.1	100.3 ± 8.6
2004	98.5 ± 12.2	100.2 ± 11.5	97.1 ± 8.9
2005	94.5 ± 8.2	95.1 ± 9.3	97.3 ± 7.2
2006	94.3 ± 10.3	98.2 ± 16.5	99.0 ± 14.1
2007	91.5 ± 10.2	92.5 ± 9.8	95.7 ± 16.5
2008	94.0 ± 10.3	95.2 ± 12.0	98.8 ± 15.4
2009	88.6 ± 10.3	94.4 ± 14.0	93.6 ± 12.2
2010	87.0 ± 10.2	88.5 ± 9.7	90.1 ± 8.5
2011	79.3 ± 4.0	80.0 ± 7.9	82.5 ± 6.9
2012	74.4 ± 5.5	76.5 ± 7.0	80.9 ± 7.5
2013	74.2 ± 4.5	72.8 ± 3.7	81.1 ± 5.2
2014	71.1 ± 4.1	74.7 ± 2.6	79.4 ± 3.8
WILD	113.9 ± 23.1	128.4 ± 23.3	125.1 ± 23.7

Table 3.8: Mean ± SD weight (kg) by year class of juvenile white sturgeon captured in the Canadian section of the Lower Columbia River during the 2020 – 2022 stock assessments. Data is represented by year class. Wild-origin juveniles were of unknown age.

Year Class	2020	2021	2022
2001	8.0 ± 3.6	7.3 ± 2.6	7.9 ± 3.4
2002	7.5 ± 2.0	8.0 ± 2.5	7.5 ± 2.3
2003	5.3 ± 1.3	5.9 ± 1.8	6.4 ± 1.7
2004	6.0 ± 2.9	6.2 ± 2.8	5.8 ± 2.0
2005	5.4 ± 1.8	5.4 ± 2.3	5.8 ± 1.4
2006	5.5 ± 2.0	6.8 ± 5.2	6.9 ± 4.0
2007	4.9 ± 1.9	5.0 ± 1.9	6.4 ± 5.6
2008	5.2 ± 2.1	5.4 ± 2.2	6.4 ± 3.8
2009	4.5 ± 1.9	5.6 ± 2.8	5.4 ± 2.7
2010	4.1 ± 1.7	4.4 ± 1.6	4.5 ± 1.4
2011	3.2 ± 0.8	3.2 ± 1.0	3.5 ± 0.8
2012	2.6 ± 0.5	2.8 ± 0.9	3.3 ± 1.0
2013	2.4 ± 0.3	2.4 ± 0.3	3.3 ± 0.7
2014	2.3 ± 0.4	2.6 ± 0.3	3.1 ± 0.6
WILD	10.0 ± 5.3	14.7 ± 7.3	13.5 ± 6.5

Table 3.9: Mean ± SD relative weight by year class of juvenile white sturgeon captured in the Canadian section of the Lower Columbia River during the 2020 – 2022 stock assessments. Data is represented by year class. Wild-origin juveniles were of unknown age.

Year Class	2020	2021	2022
2001	80.4 ± 7.5	79.9 ± 6.6	82.5 ± 8.2
2002	79.2 ± 6.9	77.8 ± 7.9	77.5 ± 5.8
2003	79.8 ± 6.2	80.0 ± 6.1	78.7 ± 7.1
2004	75.8 ± 7.2	74.1 ± 6.9	77.2 ± 6.9
2005	79.5 ± 6.0	77.5 ± 6.7	79.0 ± 8.1
2006	81.4 ± 7.2	80.5 ± 7.0	83.2 ± 7.3
2007	79.1 ± 6.4	78.4 ± 6.3	81.7 ± 6.8
2008	76.0 ± 5.8	75.8 ± 7.0	76.7 ± 6.7
2009	79.2 ± 5.5	80.3 ± 11.8	79.3 ± 6.3
2010	78.0 ± 6.9	80.3 ± 17.0	76.6 ± 7.4
2011	85.6 ± 27.6	81.1 ± 6.2	79.8 ± 3.7
2012	85.2 ± 6.4	81.6 ± 4.7	79.5 ± 6.7
2013	77.6 ± 8.8	83.2 ± 6.4	80.4 ± 2.3
2014	86.8 ± 7.7	85.1 ± 4.2	80.5 ± 4.8
WILD	75.0 ± 6.4	74.4 ± 9.8	75.3 ± 8.4

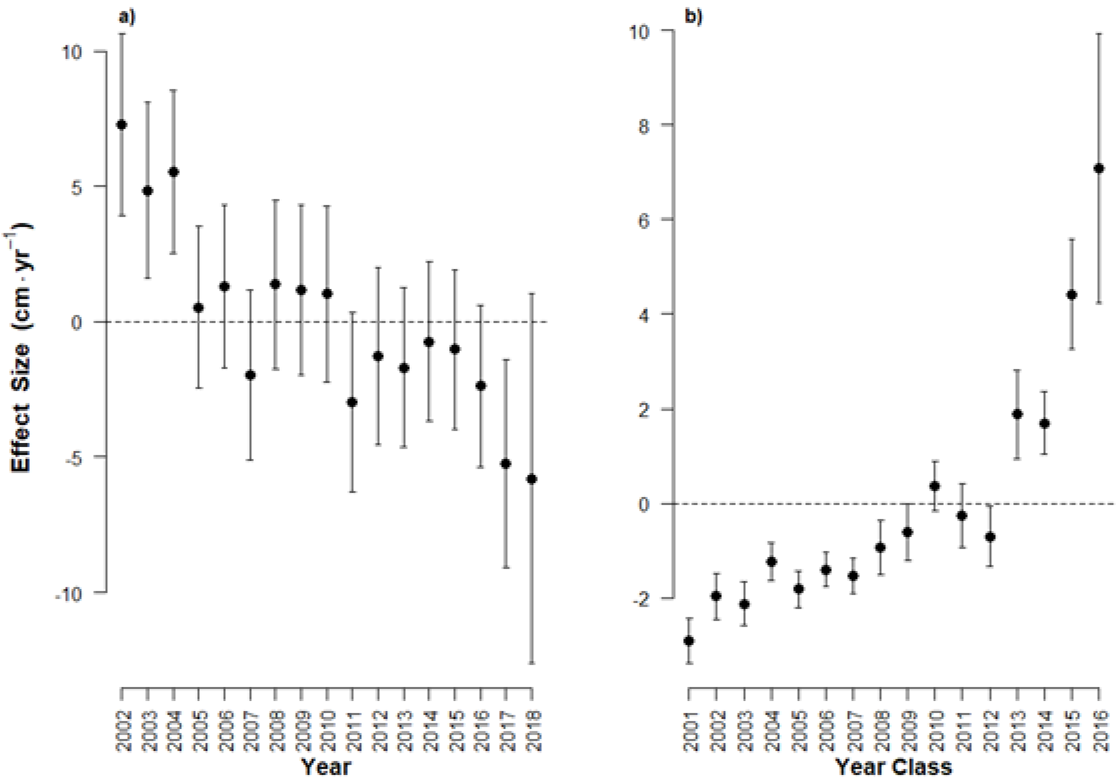

Figure 3.10: The effect of year (a) and year class (b) on the growth rate of an averaged sized hatchery-origin white sturgeon (67 cm) in the Lower Columbia River. Points and error bars show the most likely estimates and 95% confidence intervals, respectively. Reproduced from Crossman et al. (2023).

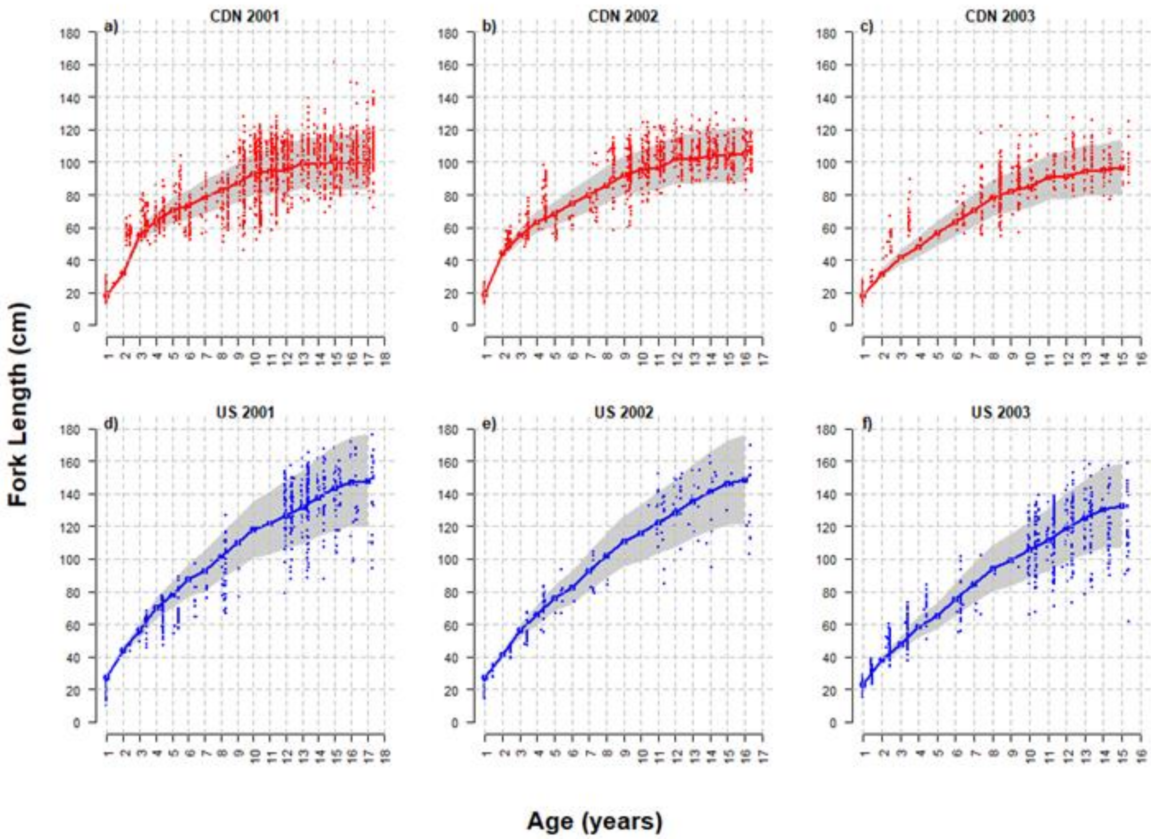

Figure 3.11: Observed (points) and predicted (lines) length-at-age for three years classes of hatchery-origin white sturgeon in Canada (CDN; a-c) and in the US (d-f). The shaded grey areas show the predicted 95% confidence intervals. Reproduced from Crossman et al. (2023).

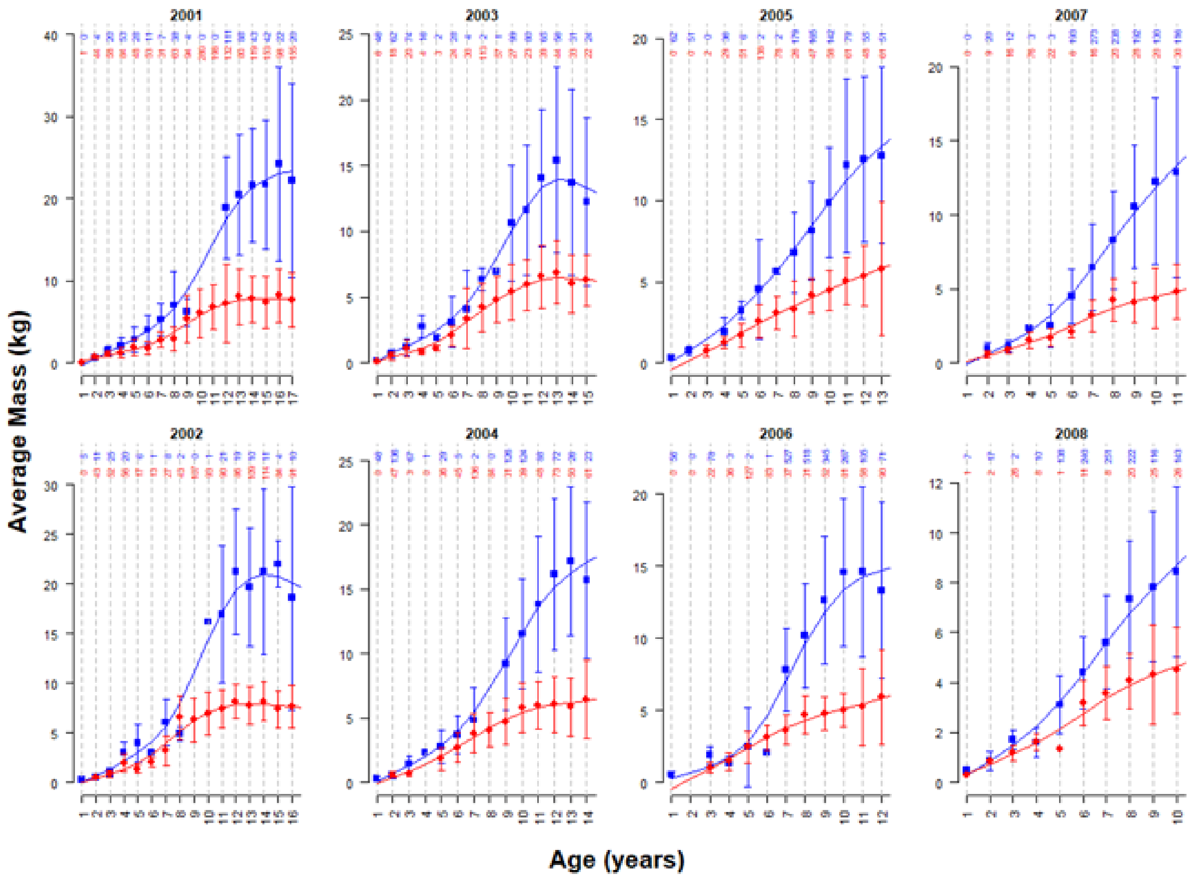

Figure 3.12: Average mass of hatchery-origin white sturgeon by age for 2001 – 2008 year classes (panels) in Canada (red circles) and the US (blue squares). Error bars show 1 standard deviation. The sample size is shown by text at the top of each panel. Reproduced from Crossman et al. (2023).

3.4.3 Survival and Abundance

The proportion of white sturgeon released in Canada that were captured in the US (relative to captures in both countries) increased from 0.2 for the 2001 year class to 1.0 for the 2010 year class. The proportion of fish released in the US that were captured in Canada increased from ~0.2 to 0.4 between 2001 and 2004 year classes, and then consistently declined until it reached zero for the 2011 and later year classes. These movement dynamics are predicted to be having important effects on the abundance trends, resulting in a relatively steep decline over time in Canada due to a combination of reduced stocking rates and greater emigration (Figure 3.13). In contrast, abundance in the US remains stable in spite of lower stocking rates and removal from fisheries due to immigration of fish released in Canada. Full results are provided in Crossman et al. (2023).

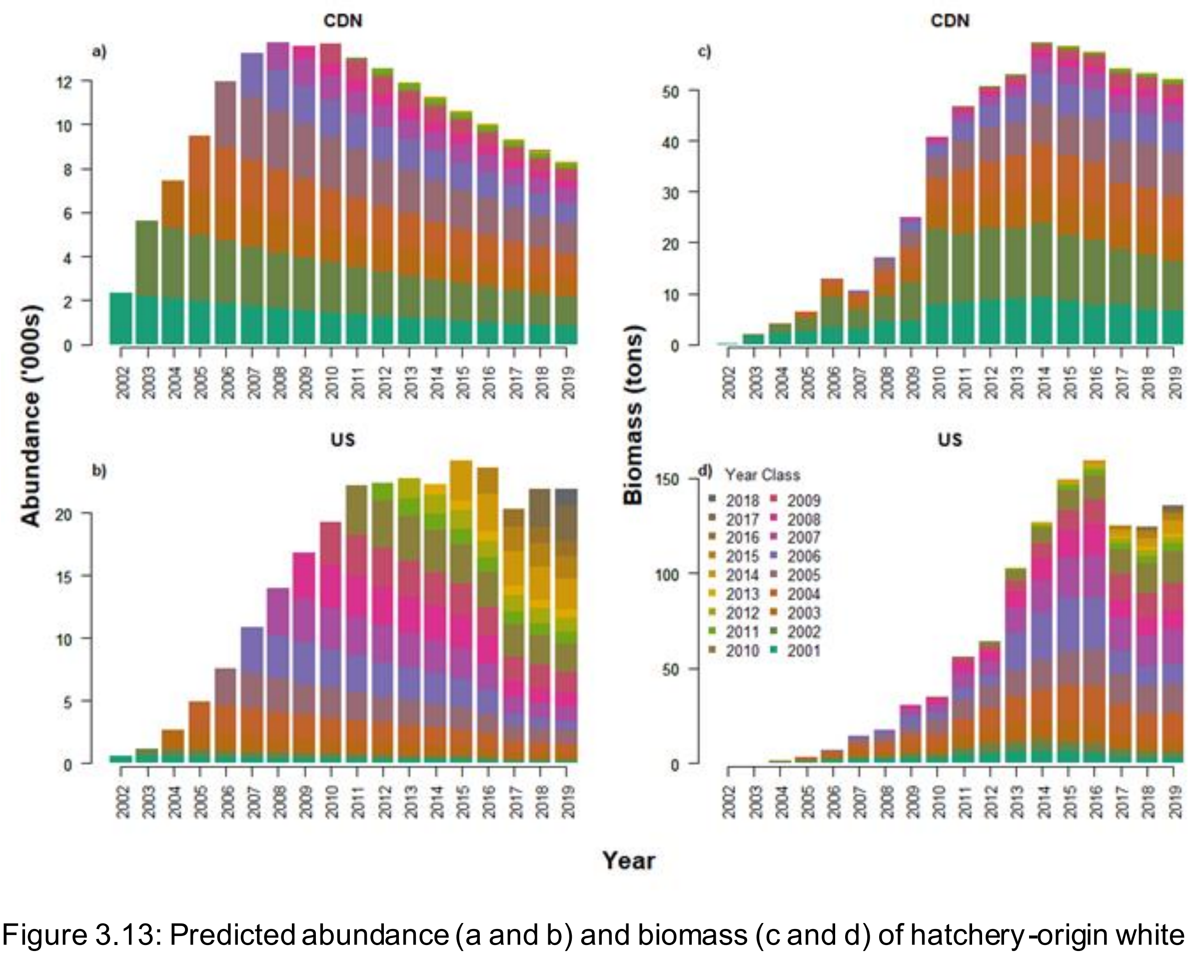

Figure 3.13: Predicted abundance (a and b) and biomass (c and d) of hatchery-origin white sturgeon in Canada and the US by calendar year. The total height of the bars is the total abundance or biomass, and the colors show the values for each year class. Reproduced from Crossman et al. (2023).

3.4.4 Sex and Stage of Maturation

From 2015 – 2018, no hatchery-origin white sturgeon within Canada were found to be reproductive, however, a portion of males were identified as spawning capable in the US (Table 3.10). From 2019 – 2020, 2 males captured in Canada near HLK were identified as spawning capable in the field. Histology is still needed to confirm the reproductive status of these fish. Pandemic restrictions limited export to our sturgeon physiologist during this period. Sample sizes of fish that have been assigned sex in Canada and the US between 2015 – 2022 are reported in Table 3.11. Full results of the comprehensive study on sex and stage of maturation of hatchery-origin white sturgeon in the Canadian section of the LCR are provided in Maskill (2020) and Maskill et al. (2022).

Table 3.10: Reproductive structure of hatchery-origin white sturgeon residing in the Canada and US sections of the Lower Columbia River (2015 – 2018). Results from samples from 2019 – 2022 are pending.

Stage of Maturation	Canada	USA
Pre-vitellogenic Females	100%	100%
Vitellogenic Females (Spawning Capable)	0%	0%
Pre-meiotic Males	100%	66%
Early Meiotic Males (Initiation of Puberty)	0%	7%
Meiotic Males (Spawning Capable)	0%	27%

Table 3.11: Sample sizes of hatchery-origin white sturgeon assigned sex in the Canada and US sections of the Lower Columbia River (2015 – 2022).

Country	Year	Female	Male	Intersex
Canada				
	2015	11	17	1
	2016	35	32	0
	2017	113	165	0
	2018	63	64	3
	2019	28	41	0
	2020	10	10	0
	2021	16	14	0
	2022	10	14	0
USA				
	2015	20	23	0
	2016	28	28	0
	2017	5	1	0
	2018	15	18	0
	2019	8	17	0

3.5 Juvenile Movement Ecology

Distinct residential and transitory patterns in movement behaviour were identified from the acoustic telemetry dataset of hatchery-origin white sturgeon in the LCR between 2019 – 2020, with the former representing localized movement at a single receiver station and the latter representing directed and undirected movements between receiver stations. Overall, hatchery-origin white sturgeon moved very little and demonstrated strong site fidelity. Fish spent most of their time expressing residential behaviour and residing in a single river zone. In GLMM analyses, location (i.e. country, river zone), discharge, and water temperature had the greatest influence on behaviour probability and maximum displacement. Sturgeon moving within the United States, whose river zones can be characterized as more reservoir-like, exhibited maximum displacements far greater than fish moving within Canada (Figure 3.14). Discharge also interacted with fish location. Increases in discharge related to faster declines in maximum displacement in Canada compared to the United States, as well as fish in more channelized river zones (zones 3 – 6) having increased probabilities of expressing residential behaviour when previously in a transitory state (Figure 3.15). These channelized river zones often resided near the international border and all observed border-crossing fish were initially tagged from border adjacent zones. Warming water temperatures were related to increases in maximum displacement and decreases in the probability of residential behaviour when previously in a transitory state (Figure 3.15). Trends could be observed seasonally, with warmer waters in the summer and fall being associated with increased movement. Full results are provided in Jetter (2022).

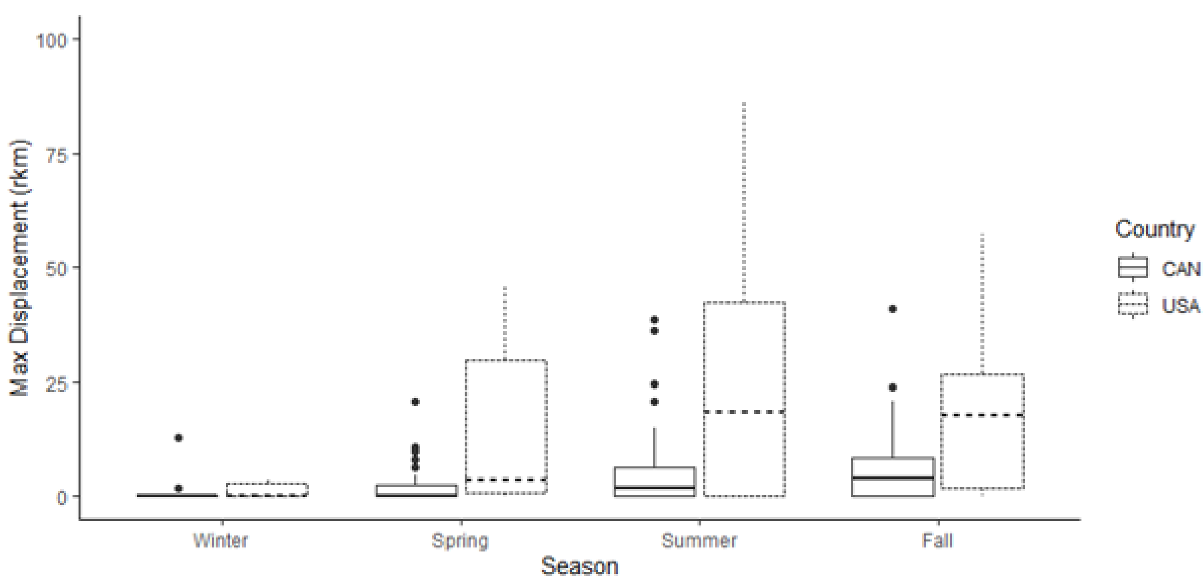

Figure 3.14: Maximum displacement (rkm) of tagged hatchery-origin white sturgeon by season and country where movement took place between May 2019 – August 2020. Reproduced from Jetter (2022).

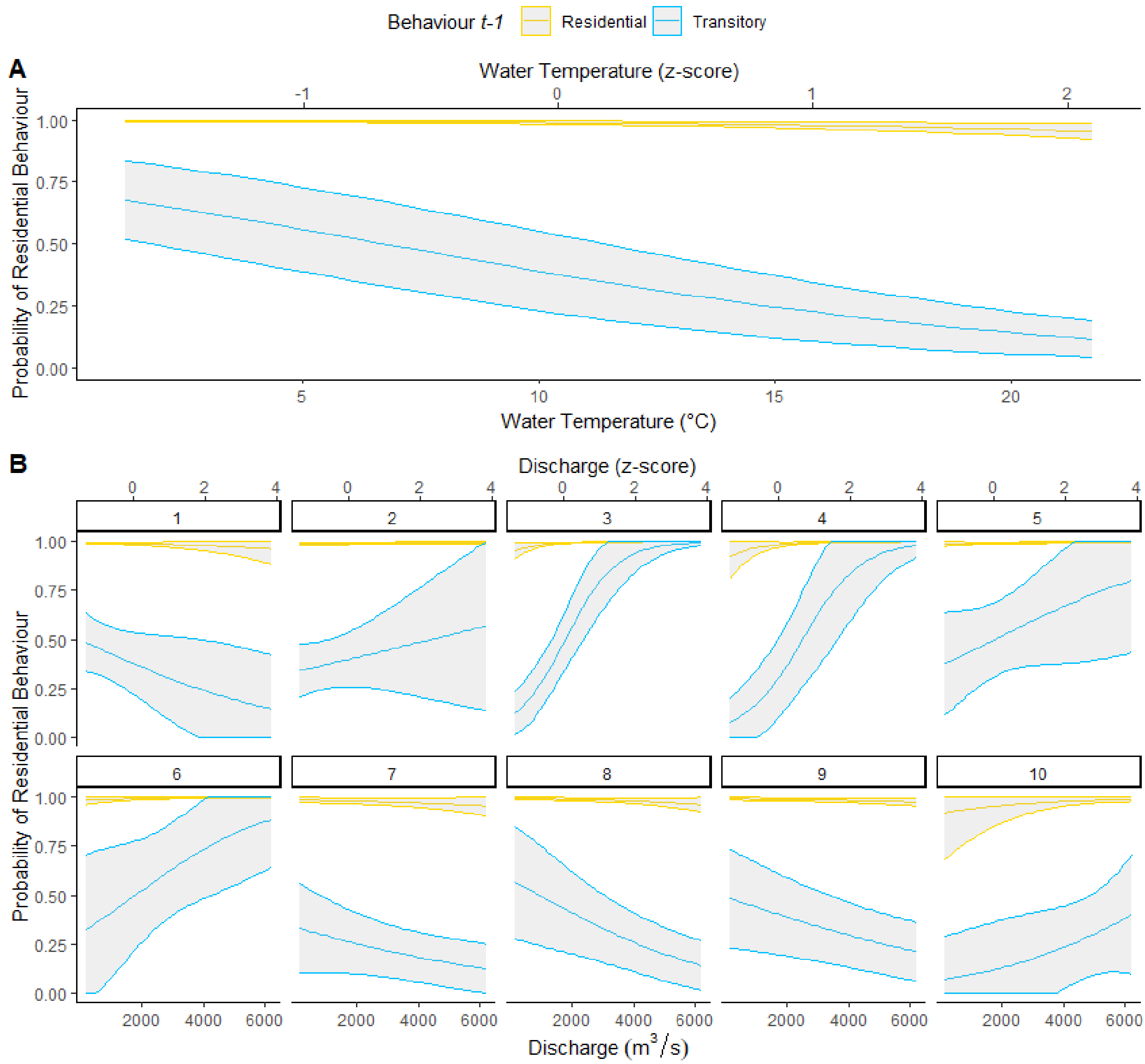

Figure 3.15: Model averaged predictions of the effect of water temperature (A), discharge (B), and river zone (B) on the probability of being in the residential behaviour state. Behaviour state at time *t-1* represented by colour with 95% confidence interval (shaded area). To isolate the effect, other numeric model covariates were fixed at their mean and the categorical covariates sex and river zone were set to Female and Zone 1 respectively. Reproduced from Jetter (2022).

4 Discussion

General discussion points are provided for each of the main areas of this monitoring program. While this monitoring program has contributed significant knowledge pertaining to larval and juvenile white sturgeon ecology and the overall success of the Conservation Aquaculture Program, additional years of data are required to assess trends (e.g. growth and survival for more recent year classes 2014 – present) and answer the management questions (e.g. river regulation and movement patterns) of this program.

4.1 Larval Assessment

For white sturgeon throughout their range, it has generally been observed that the spawning period is protracted and occurs in the late spring and early summer months (May through early August) with specific timing dependent on environmental cues (e.g., water temperature, flow; Parsley and Beckman 1994). Based on river conditions (water temperature) and developmental stages of yolk-sac larvae at time of collection (Jay et al. 2020), spawning was estimated to have occurred from mid-June to mid/late July downstream of Waneta and over only a few days in early/mid-July downstream of ALH in 2020. Importantly, developmental staging of both embryos and larvae is important when estimating spawning time as events can be missed solely through the staging of embryos. All of the estimated spawning days occurred after freshet flows had peaked which is consistent with the timing of spawning since 1993 in the LCR, where the majority of events have been on the descending limb of the hydrograph and at water temperatures above 14°C.

In 2020 – 2022, no larvae were collected within the vicinity of Kinnaird. These results differ from previous year where spawning has been documented annually since 2007. This area requires additional monitoring to further describe where spawning may be occurring (Fisheries and Oceans 2014). Since 2013 (BC Hydro 2016a; BC Hydro 2016b, BC Hydro 2016c), extensive sampling with drift nets has been conducted in an attempt to narrow down the location of embryo deposition and dispersing larvae. However, challenges remain to define the spawning area as low numbers of embryos and larvae have been collected to date, and smaller numbers of wild adults may be spawning in different locations within that reach annually. With an ageing wild population competing with a large number of hatchery-origin juveniles, fewer adults may be in spawning condition in recent years. While not evaluated yet for wild sturgeon, hatchery-origin sturgeon have reduced growth rates associated with high densities (Crossman et al. 2023), which may reduce the amount of resources fish can put towards reproductive development. Further work to evaluate trends in wild sturgeon growth and condition before and after hatchery supplementation began may provide insight into this question.

Reduced quality of early life stage habitat used for embryo incubation and early rearing of larvae is one of several recruitment failure hypotheses for this population (UCSWRI 2012). Larvae that are young in developmental stage (<40) have dominated the collections to date across all spawning locations in Canada, suggesting the substrates at the spawning locations are not adequate for hiding until they reach feeding age. However, increased larval monitoring efforts with drift nets at the Waneta spawning site has resulted in the capture of a percentage of later stage larvae close to feeding age. Describing spawning and early life stage habitat at known (e.g., Waneta, ALH) and suspected (e.g., Kinnaird) spawning locations is important to determine habitat suitability for yolk-sac larvae hiding behaviour and young-of-year rearing conditions and the potential effects of habitat on recruitment. This has been conducted recently as part of a substrate restoration feasibility study being conducted under the Columbia Water Use Plan. Results are described in West et al. (2020) and are expected to inform this program. Importantly, a spawning substrate restoration project will be completed downstream of ALH for the 2023 spawning season. Monitoring of spawning activity in 2023 and beyond will help describe the effectiveness of the enhanced substrate for embryo incubation and larval hiding.

Lastly, it will be important to incorporate results from larval monitoring programs in the US section of the LCR, as captures of larvae at feeding stages occur annually (Hildebrand and Parsley 2013) and are captured in much larger numbers in recent years (Jason McLellan, Colville Confederated Tribes, unpublished data). These results suggest that hiding habitat is present between the Waneta spawning location and the capture location downstream of Northport, WA. Genetic analyses in addition to those already completed (Jay et al. 2014) are underway in 2023 and will help determine the proportion of larvae that originated from the Waneta location.

4.2 Juvenile Population Assessment

For approximately the last 40 years, recruitment of white sturgeon in the LCR has not occurred at a rate sufficient to maintain the population. In response to this, a key component has been supplementation of the existing white sturgeon population through release of hatchery-origin individuals. Results from coordinated stock assessment efforts suggested that while survival of hatchery-origin fish has been high, certain year classes were in much higher abundance than others, including the wild population. In response to potential genetic risks of overrepresented year classes, a harvest program was initiated in the US. Removal of hatchery-origin white sturgeon has had a modest effect on abundance of the overrepresented year classes based on a combination of targeted removals and creel estimates from size slot-regulated harvest fisheries (Crossman and Korman 2021). Although some families may be overrepresented, genetic risks are characterized as low given the buffers in place against future inbreeding which include no relatedness among year classes produced through direct mating of broodstock, the transition to more genetically diverse wild-origin progeny, introgression with spawning wild adults, the time to reach puberty not simply being a function of age, and the multiple spawning locations used on an annual basis (Crossman and Korman 2021). The sex and stage of maturation component of this monitoring program (e.g., Maskill et al. 2022; Webb et al. 2018) will be important as it is critical to understand when these fish will start to reproduce with the existing wild adults due to genetic swamping being a critical risk given the number of hatchery-origin fish at large. Based on examination of samples collected from 2015 – 2018, both females and males were at early maturation stages in Canada and no fish had reached puberty. Conversely, samples collected in the US section showed that a portion of males are spawning capable and stress the importance of this aspect of the monitoring program. Data on sex and stage of maturation being collected under this program will directly inform discussions on next steps in the development of conservation measures to address this genetic risk.

Despite some of the potential genetic issues found through the standardized stock assessment program, hatchery-origin juveniles in the LCR represent a significant learning opportunity as juvenile age classes were lacking in the Columbia River in recent decades and remain lacking in many sturgeon populations throughout the world. Significant insights about habitat use, growth (Crossman et al. 2023), diet (Crossman et al. 2016), and survival (BC Hydro 2016c; BC Hydro 2020) have been made that not only inform recovery for LCR white sturgeon, but other species in North America. One of the management questions of this work is to evaluate how normal river operations affect juvenile habitat conditions in the LCR. In the first 10 years of this program, we have used a spatially balanced and randomly assigned sampling design and documented habitat use throughout the entire LCR. Results suggest that habitat is characterized primarily by deep, slow-moving water and smaller substrates (e.g., sand, gravel, cobbles). These habitats are available throughout the upper section of the LCR and become more isolated further downstream (e.g., Kootenay River confluence to the Canada–US border). These deeper, slow-moving habitats are not limited by the current operational regime of the LCR. Importantly, juvenile habitat distribution is similar to, and overlaps with, adult habitat use (BC Hydro 2013b, 2015a, and 2015b).

4.3 Juvenile Movement Ecology

Recent results from sex and stage of maturation work in the LCR have identified that a portion of hatchery-origin males are mature and could be contributing to wild spawning events. These are predominantly larger fish (>130 cm FL) residing in the US, and it is unknown if they make movements to spawn at sites in Canada. Capture data collected during spring and fall population assessments (2013 – 2018) has found that the probability of movement between major habitats (e.g., riverine (Canada) to reservoir (USA) or vice versa) is very low (approximately 1%; BC Hydro 2020) for hatchery-origin white sturgeon. This behavior is similar to adults, where fish spend >90% of their time within a specific river zone (10 km of river habitat), only making movements during the summer months to feed or reproduce (BC Hydro 2020). For hatchery-origin fish that are starting to become mature, it is unknown if they also make larger movement during the summer months as capture data is limited to spring and fall periods. The primary objective of our telemetry study was to determine the seasonal movements of larger (maturing if possible) hatchery-origin white sturgeon in the LCR. This includes determining movements between Canada and the US and identifying spawning related movements to known spawning areas.

The telemetry study found that while water temperature, discharge, and fish location (country, river zone) were influential in predicting movement, in general hatchery-origin white sturgeon expressed strong site fidelity with movement typically not extending beyond two river zones. A total of three hatchery-origin white sturgeon moved across the Canada–US border, however, these fish were all initially tagged in border adjacent river zones. One fish (a 10-year old male) resided in a spawning area outside their country of initial tagging. Understanding the rates of movement between countries is important as legislative protections differ for the LCR population. While white sturgeon are federally protected in Canada, there is an active fishery in the US where they can be harvested when they reach a larger size (135–160 cm slot limit). Current data suggests there is minimal movement between countries, however, continued monitoring will help inform stocking numbers from the Conservation Aquaculture Program required to meet recovery targets in Canada.

Determining movements of hatchery-origin white sturgeon to known spawning locations during the spawning period (June–July) is critical to determine interactions with wild breeding adults. The current Conservation Aquaculture Program is dependent on collections of embryos and larvae from the river that are a product of wild spawning events (BC Hydro 2020; FFSBC 2020). Increasing numbers of hatchery-origin fish at the known spawning locations would trigger the need to further evaluate the genetic composition of progeny collected for the aquaculture program as some progeny would be from individuals that are already well represented in the population. Our telemetry study observed that long-distance migrations by hatchery-origin sturgeon to spawning areas were uncommon. Of the fish that resided in spawning areas during the spawning period, most spent a majority of their time in a given year within a spawning area or moved less than one river zone to reach a spawning area. While males were of interest due to their earlier sexual maturity and greater likelihood of spawning activity, the sex ratio of fish present in spawning areas was similar to the ratio of the entire study population. The average age of both female and male hatchery-origin sturgeon occupying spawning areas was around 15 years. This age is below average for expected female spawning in the LCR (~25 years) and on par for expected male spawning (~15 years), with the youngest age of a sexually mature hatchery-origin surgeon in the LCR being a 9-year old male (Maskill et al. 2022). As spawning areas in the LCR can also overlap with productive feeding habitat (Hildebrand et al. 2013), incorporating supporting empirical data in future studies, such as time-stamped embryo/larvae collection and reproductive staging, will help better determine spawning activity in relation to sturgeon movement.

5 Recommendations

5.1 Larval Assessment

- Larval sampling should continue to occur annually at the ALH and Kinnaird spawning areas to determine spawning timing and frequency at this area and if habitat allows for larvae to develop to later developmental stages prior to dispersing downstream.
  - Sampling should start in early July and continue through the middle of August, as the timing of spawning in the upper parts of the LCR is still uncertain.
- Drift nets have been shown to maximize catch per unit effort of embryos and larvae from spawning locations upstream of the sampling equipment and should be used as the primary collection method in areas where the exact geographical boundary of the spawning location remains unknown.
  - Additional drift net stations should be deployed downstream of Kinnaird to determine where larvae may be originating from.

- If hydrology permits, drift net sampling should be attempted in the lower Kootenay River to determine if larval captures near Kinnaird could be originating from this location.

- Tissue samples should be collected from as many larval captures as possible to determine how many adults are contributing using molecular methods. If possible, genetic analyses should address if larval captures near Kinnaird are genetically similar to upstream spawning locations (e.g., ALH spawning area).

5.2 Juvenile Population Assessment

- Continue to approach juvenile sampling programs in a spatially balanced random design, to acknowledge variability in growth between habitat types and year classes.
- Survival estimates should be revised as additional data is collected going forward. Results from survival estimates should be used to continually update abundance estimates for hatchery-origin white sturgeon in the LCR. This information can be used to revise the Conservation Aquaculture Program and help guide long-term population targets.
- Sampling effort should continue to be focused using set lines as they minimize harm to the individual and can be fished for longer time periods throughout all areas that juveniles have been identified to use in the LCR.
- Continue to describe the diet of juvenile white sturgeon in the LCR using non-lethal methods such as gastric lavage or stable isotopes.
- Continue to describe the sex and stage of maturation of hatchery-origin white sturgeon in the LCR, and describe variability attributable to year class and habitats if possible.
- Continue to monitor habitat use and distribution of juveniles under varying operational scenarios over the life of the monitoring program.

5.3 Juvenile Movement Ecology

- Continue to monitor the seasonal movements of the acoustically tagged population of hatchery-origin white sturgeon to understand habitat use and movement between Canada and US.
- As hatchery-origin sturgeon mature, time-stamped embryo/larvae collection and reproductive staging data should be incorporated in movement analyses to better identify spawning related movements.
- Determine centers of attraction (e.g., spawning and overwintering habitat) and investigate how movement between or displacement from these centers is influenced

spatially (between countries) and temporally (between seasons), and by environmental (water temperature, discharge) and biological (age, sex) factors.

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