Columbia River Project Water Use Plan

Columbia River White Sturgeon Management Plan

Implementation Year 10

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EXECUTIVE SUMMARY

The population of White Sturgeon (*Acipenser transmontanus*) in the lower Columbia River (LCR) Canada was listed as one of four endangered populations 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. Accordingly, the population was forecast to become functionally extinct by 2044 in the absence of effective recovery measures. Recovery was directly initiated in 2001 through the release of hatchery-reared juveniles as a stopgap measure until recruitment failure could be addressed. It was identified during the development of the Columba 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.

For early life stage monitoring, sampling was conducted passively using drift nets in order to determine the distribution of White Sturgeon yolk-sac larvae in the LCR and assist in identifying spawning locations and areas of habitat use. In 2017, drift net sampling was conducted at monitoring sites downstream of Arrow Lakes Generating Station (ALH; rkm 0.1), Kinnaird (rkm 13.4 – 18.2) and downstream of the Pend d'Oreille confluence (Waneta; rkm 56.0). Based on developmental stages of captured yolk-sac larvae, spawning was estimated to have occurred over a period between June 11 and July 5 at Waneta and on July 19 at ALH. No yolk-sac larvae captured at Kinnaird were able to be developmentally staged. While the majority of yolk-sac larvae samples captured in 2017 at both ALH and Waneta were at an early developmental stage (<40), samples collected in 2016 were further developed and some (19%) were transitioning to exogenous feeding. This suggests some suitable habitat exists for yolk-sac larvae to hide in until they reach developmental stages where drift would naturally occur.

Recent genetic work determined that the number of adults spawning 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) was developed in 2014 for the purpose of incubating naturally produced embryos collected in the LCR in order to increase number of adults contributing to stocked offspring to increase effective breeding numbers and maintain genetic diversity within the population. The program has been successful from 2014 through 2017 with wild embryos and larvae incubated in the SIF and subsequently reared at the Kootenay Trout Hatchery for release as juveniles the following spring.

An annual juvenile White Sturgeon program was initiated in 2008 to describe important parameters related to growth, survival, and distribution in the Canadian portion of the LCR. Monitoring is focused on hatchery origin juveniles as wild juvenile age classes are lacking. Releases of hatchery origin juveniles have

occurred from 2002-2018 with 148,464 individuals stocked into the lower Columbia River and into Lake Roosevelt in the United States. In 2018, 457 hatchery juveniles (year class 2017) were released in the spring with additional fish (~150) to be released in the fall once target size is reached. In 2013, juvenile monitoring was established as part of a five-year population assessment initiated to estimate survival rate and abundance of the White Sturgeon population within the transboundary reach of the LCR. Additionally, data from this program will be used to determine juvenile growth rates, fish condition, age class structuring, and density dependent responses. This program is standardized throughout the Transboundary Reach of the Columbia River, incorporating all habitats within Canada and the US. While wild juvenile sturgeon are encountered, captures from 2013-2017 have been predominantly hatchery-released fish with wild juveniles representing <1% of the total catch. Survival analyses completed using juvenile capture data have indicated that survival 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 6,000 individuals (BC Hydro 2018). Survival estimates have been used to modify release targets for wild origin progeny, with fish reared to a minimum 200 g prior to release into the LCR 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 Columbia River suggests that hiding habitat exists from the Canadian/US border downstream to North Port, Washington. - Juvenile Stage: Survival of hatchery origin juveniles has been higher than originally predicted. This has resulted in a large hatchery population estimated at more than 6,000 individuals in the Canadian section of the Transboundary Reach. 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 U.S. portions of the Transboundary Reach of the Columbia River. Unequal family representation presents a substantial genetic risk to the long term viability of the White Sturgeon population in the Transboundary Reach, and the UCWSRI TWG are working on conservation measures to 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. - Distribution of juveniles has been assessed extensively throughout the LCR, and is restricted primarily to slower moving habitats like eddy's and deeper runs. While these habitats

Management Question	Status
	are available primarily in the upper (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 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 in 2015, 2016 and 2017 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 Columbia River suggesting that hiding habitat exists from the Canadian/US border downstream to North Port, Washington. A specific Columbia Water Use Plan physical works program (CLBWORKS-27) is evaluating habitat conditions for early life stages at the three spawning locations in the lower Columbia River in 2018. 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 one of four endangered populations 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 United States border. An estimated 1,157 adult White Sturgeon (95% C.I. 414-1899; Irvine et al. 2007) reside within the Canadian reach, 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 2013).

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-reared 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 reared 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) to incorporate wild offspring into the stocking practices increasing representation of LCR spawning adults and levels of genetic diversity among stocked juvenile White Sturgeon (Jay et al. 2014). This has been successful for other sturgeon species (e.g. Lake Sturgeon *Acipenser fulvescens*, Crossman et al. 2011). Developing this facility 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, with 1,095 wild-origin juvenile White Sturgeon were successfully reared to release in the spring of 2015. In 2015, the broodstock program was suspended and all juvenile white sturgeon stocked as of 2015 year class have been of wild origin collected through the SIF program. Release criteria developed for these wild origin fish is a minimum of 200 grams in body weight to improve survival following release based on results of recent juvenile survival modeling (BC Hydro 2016c). A total of 63 and 800 wild progeny met the release size criteria and were released the following spring after capture for year classes 2015 and 2016, respectively. It was determined that the wild collection program would continue for the next several years. In total, the Conservation Aquaculture Program has been successful in releasing 148,464 hatchery reared juvenile sturgeon into the Transboundary Reach of the Columbia River; 108,132 of which were released in the lower Columbia River in Canada (as of the spring of 2017). In spring 2018, 457 individuals were released into the LCR with additional fish (~150) to be released in the fall once the target size is met.

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. 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 tenth (2017) year of monitoring in the LCR as a component of the WUP under the project: CLBMON-29 Lower Columbia River Juvenile Sturgeon Detection. Specific components of the study are to:

1. Monitor distribution of both larvae and juvenile life history stages.

2. Estimate growth and survival of both wild and hatchery origin White Sturgeon.

3. Describe sex and stage of maturity of hatchery origin White Sturgeon.

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 2017 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 scope of the juvenile program focuses on data collection to define yolk-sac larvae and juvenile habitat conditions, determine the effect of existing hydraulic conditions, and identify and assess the most suitable of several management responses to be considered in lieu of operational changes. 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. Wild Progeny: Collect naturally produced embryos and larvae for streamside incubation and Kootenay Sturgeon Hatchery (KSH) rearing for stocking purposes.

1.3.2 Larval Stage

1.3.2.1 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 Stage

1.3.3.1 Juvenile Population Assessment

1. Assess juvenile population abundance, growth, age structure, annual survival rates, and population trajectories.

2. Provide relative abundance and periodic updates to population estimates of the LCR juvenile White Sturgeon populations.

3. Periodically compare new data describing length/weight relationships to monitor growth and conditions of all age classes.

1.3.3.2 Sex and Stage of Maturity

1. Identify the sex of hatchery origin White Sturgeon in the Upper Columbia River using non-lethal methods.

2. Develop methods and a program to describe annual changes to the reproductive structure of the hatchery origin White Sturgeon. Reproductive structure can be defined as the proportion of females and males in the adult population that are capable of spawning in any given year.

1.3.4 Habitat Mapping

1. Assess availability and suitability of juvenile White Sturgeon habitat.

2. Quantify physical habitat that can be tied to early life stages and juvenile data collected as part of the Detection Program.

3. Describe and classify physical habitat in the LCR downstream of HLK to the Canada/US border.

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

1.4 Study Area

The study area for the 2017 monitoring program encompassed the 57 km stretch of the LCR from HLK to the Canada/US Border (Figure 1). The study area also included a small section (~2.5 km) of the Kootenay River below Brilliant Dam extending to its confluence with the LCR. Specific areas of the LCR sampled under the various components of the program are described below.

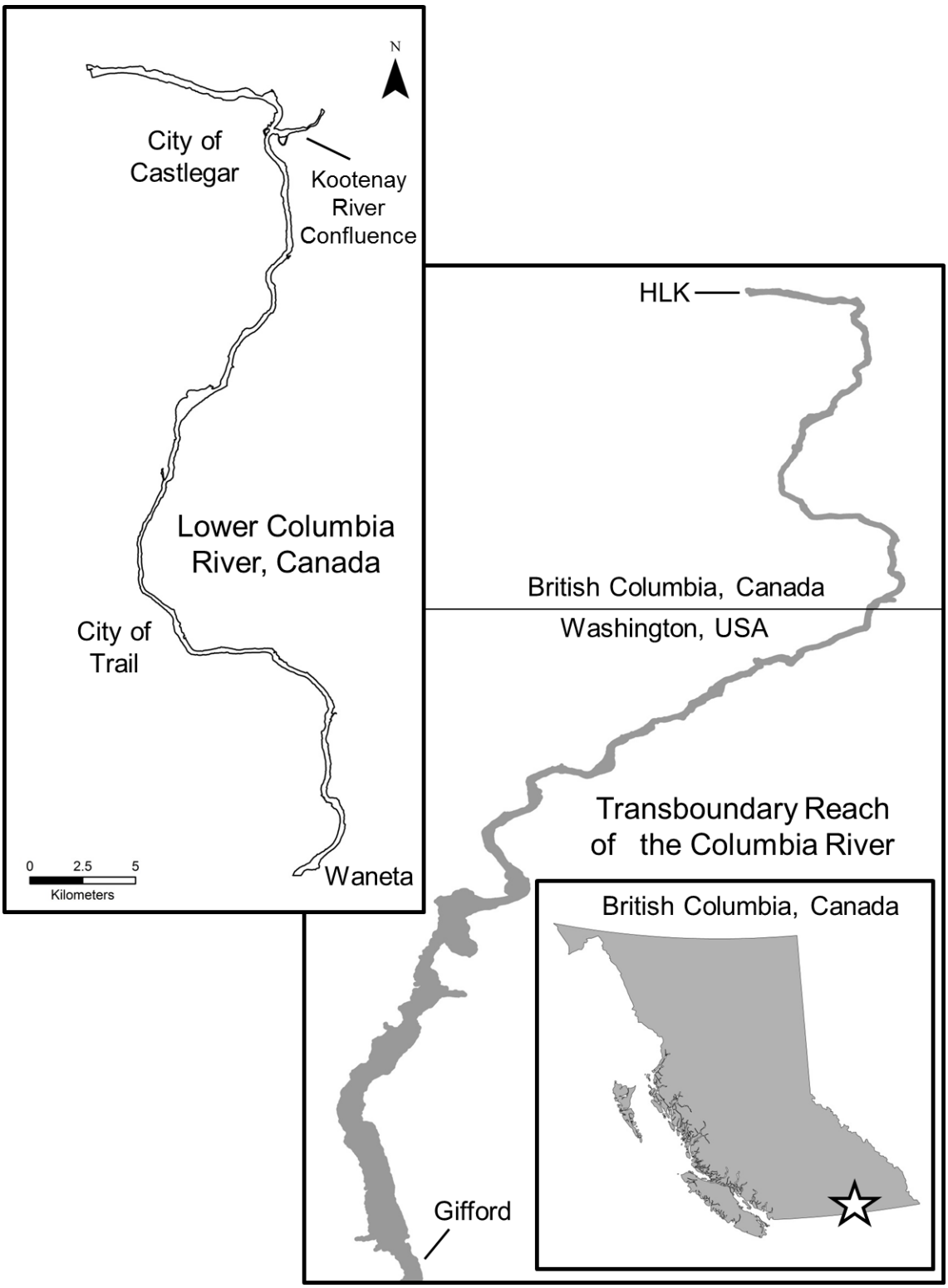

Figure 1. Overview of the study area in the lower Columbia River between Hugh L. Keenleyside Dam (HLK; rkm 0.1) and the Canada/US border (rkm 57.0).

2 METHODOLGY

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). The program is divided into data collection during spawn monitoring, yolk-sac larvae and juvenile assessments, and a suite of population characteristics. These are described separately below.

2.1 Physical Parameters

2.1.1 Discharge

In 2017, discharge records for the LCR at Arrow Reservoir (combined HLK and ALH discharges from Arrow Lakes Reservoir), 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), cubic feet per second (cfs), and in thousands of cubic feet per second (kcfs) of passage flow.

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

2.1.2 Water Temperature

For the 2017 study period, water temperatures were collected at several locations on the LCR including HLK (rkm 0.1), Kootenay River (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), 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).

2.2 Larval Stage

2.2.1 Larval Assessment

2.2.1.1 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 portion 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). 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 to rkm 18.2; Figure 2) based on previous studies (BC Hydro 2015a, 2015b), however location of exact egg deposition remains unknown.

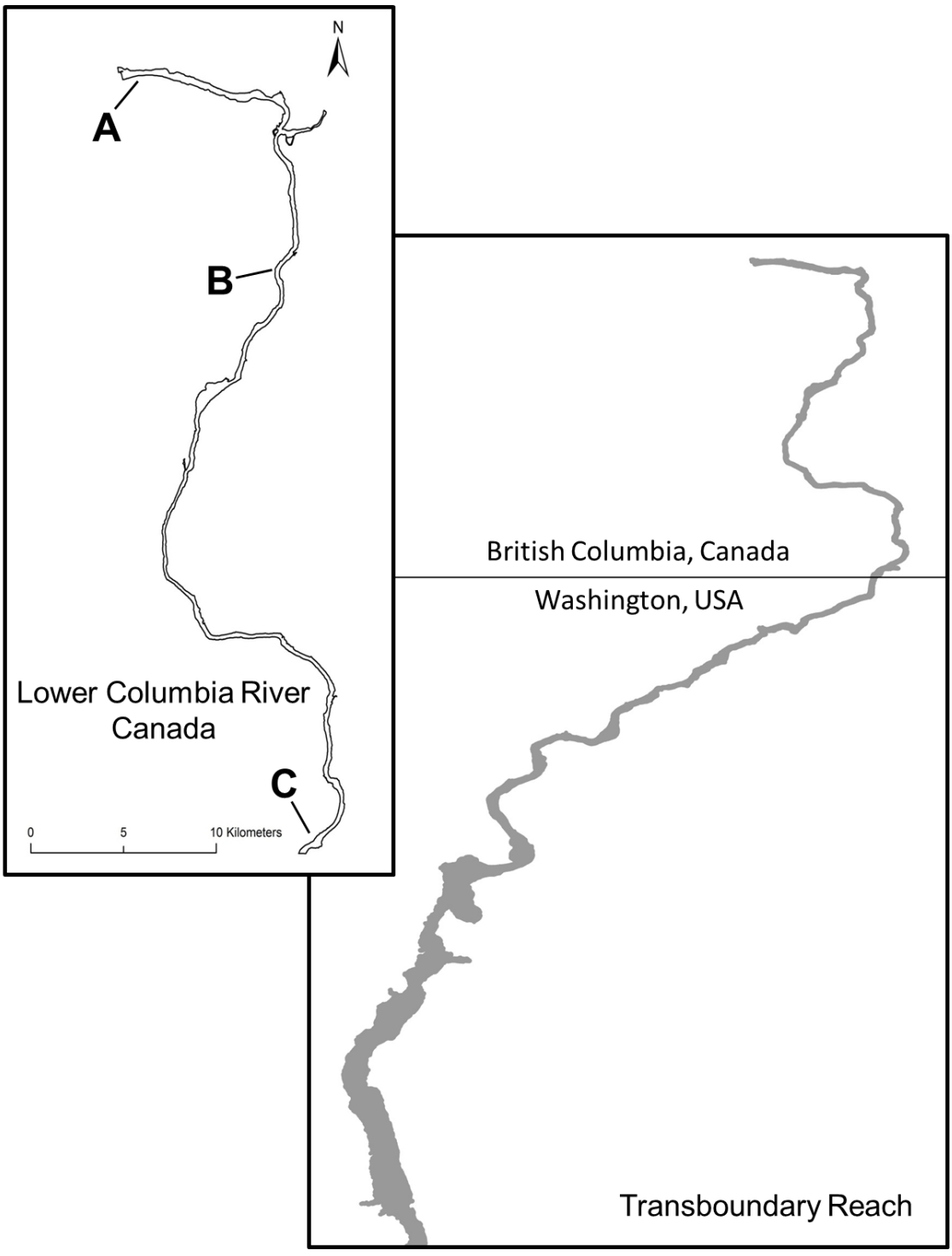

Figure 2. Drift net deployment sites in the lower Columbia River including: A) Arrow Lakes Generating Station (rkm 0.1), B) downstream of Kinnaird (rkm 13.4 to rkm 18.2), and C) Waneta (rkm 56.0).

2.2.1.2 Sampling Methods

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 (n=4), Kinnaird (n=10), and Waneta (n=6; Table 1). Drift net locations at ALH, Kinnaird (rkm 18.2), and Waneta have remained consistent 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 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 1. Number of drift nets deployed at each spawning site in 2016.

Spawning Site	rkm	n
Waneta	56.0	6
ALH	0.1	4
Kinnaird	13.4	3
Kinnaird	14.5	2
Kinnaird	16.9	1
Kinnaird	18.2	4

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.

2.2.1.3 Larval Sampling

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.

2.2.1.4 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 (BC hydro 2016b). 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).

2.3 Juvenile Stage

2.3.1 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 from. Embryos collected from the LCR were transferred to the SIF for incubation in hatching jars (MacDonald Type; J30, Dynamic Aqua-Supply Ltd., Surrey, BC). Five jars were available for each collection location (i.e., upstream, downstream) and embryos of similar developmental stages were grouped together. Water was flow through from the LCR and flows were maintained to ensure adequate embryo separation and oxygenation (~5 L/min). Upon hatch, 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 bags of ambient river water filled with oxygen. Juveniles were reared at the KSH until date of release into the LCR (see FFSBC 2017 and FFSBC 2018 for details). Temperature loggers inside the facility recorded air, LCR water, and facility tank water temperatures.

2.3.2 Juvenile Population Monitoring, Abundance, and Characteristics

From 2013 - 2017, a systematic stock assessment program to address uncertainties in the current population abundance and survival estimates was developed between Canadian and US recovery partners. This study represents the first systematic population estimate for the entire Transboundary Reach (TBR). 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 portions of the LCR.

2.3.2.1 Study Design

The study area for the stock assessment program started at HLK, Canada, and extended downstream to Gifford, Washington, USA (Figure 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 3. Study area for White Sturgeon stock assessment survey occurring from 2013-2017 in the Transboundary Reach of the Columbia River. Upstream extent of the study area is Hugh L. Keenleyside Dam in Canada, and the downstream extent of the study area ends at Gifford, Washington, USA.

2.3.2.2 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 a known to select for both adult and juvenile White Sturgeon. Hooks were systematically attached to the mainline in 3 sets of each hook size in descending order of size. The barbs on all hooks were removed to reduce the severity of hook-related injuries and to facilitate fish recovery and release. All set line hooks were baited with pickled squid obtained from Gilmore Fish Smokehouse, Dallesport, WA USA.

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

The set line retrieval procedure involved lifting the back anchor using the float line until the mainline was retrieved. The boat was then propelled along the mainline and each hook line was removed. If a fish was captured on a hook, the boat was stopped while the fish was removed. White Sturgeon removed from the set line were tethered between two anchor points to the port or starboard side of the boat. While tethered, the entire body of the fish was submerged. Once all fish were removed from the set line, the boat was idled into shore or anchored within a nearby back eddy and White Sturgeon were individually brought aboard for biological processing (described in Section 2.3.2.3 and Section 2.3.4). Catch per unit effort (CPUE) was calculated as the total number of fish captured per set line hour.

2.3.2.3 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, 2014, 2015, 2016, 2017, 2018 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.

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

The ploidy of White Sturgeon has been previously determined to be 8N (Hedrick et al. 1991). However, spontaneous autopolyploid (12N) females that successfully mated with normal (8N) males producing viable offspring of intermediate ploidy (putative 10N; Drauch Schreier et al. 2011) using artificial spawning techniques has recently been detected in the wild brood within the Kootenai River White Sturgeon Conservation Aquaculture Program (Schreier et al. 2013). This has raised concerns within the LCR White Sturgeon Conservation Aquaculture Program, as the hatchery reared offspring reproductive success and effects on the wild population are unknown. Due to these recent discoveries, blood samples were collected from all captured fish in 2014 through 2016 (BC Hydro 2015a, 2016a, 2017), to determine the incidence of 12N fish in the wild as well as hatchery-reared fish stocked in earlier years when ploidy levels were unknown. Blood samples were not collected in 2017 as new methods are being developed to provide additional confidence in the measurement of ploidy levels. It

is intended that starting in the fall of 2018, blood samples will be collected for ploidy analysis using revised methodology.

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

2.3.2.4 Data Analysis

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.

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).

Total and annual growth was calculated for each age class. We used an allometric growth model ($W = \alpha L^{\beta}$) to predict juvenile sturgeon weight from length and to develop a relationship for use in further sampling efforts. Prior to fitting the model, the equation was log-transformed on both sides to achieve a linear relationship:

$$\ln W_i = \ln(\alpha) + \beta*\ln(L_i)$$

where W_i is the predicted weight and L_i is the fork length of the individual juvenile sturgeon used to predict W_i. We fit the model by minimizing the residual sum of squares using the solver tool in excel. After fitting the model the estimates were back transformed using the equation:

$$W_i = EXP(\alpha)*EXP(L_i)^{\beta}$$

A von Bertalanffy growth model (Equation 9.9, Ricker 1975) was used to predict juvenile White Sturgeon length-at- age from age using the solver tool in excel to predict model parameters. The equation used was:

$$l_t = L_\infty \left(1 - e^{(-K(t-t_0))}\right)$$

where l is length at age t, L_∞ is the length that a fish would achieve if it continued to live and grow indefinitely, K is a constant determining the rate of increase or decrease in length, and t_0 is the age at which the fish would have been zero length if it grew according to the manner described in the equation (Ricker 1975). Von Bertalanffy growth curves were also developed for fish from Canada and the US using the 2013-2017 stock assessment dataset.

After the completion of the stock assessment study, mark recapture data will be used to estimate population abundance, age class 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.

2.3.3 Juvenile Survival and Abundance Analyses

A key component of the Upper Columbia White Sturgeon Recovery Initiative (UCWSRI) Recovery Plan is the supplementation of the existing White Sturgeon population through broodstock collections, hatchery rearing, and stocking of juvenile White Sturgeon. More than 148,464 hatchery-reared juvenile White Sturgeon have been released in the TBR from 2002 to 2018. These fish have been monitored annually by Canadian and US organizations providing data regarding distribution, abundance, growth, and condition. Recent work under this monitoring program has focused on refinements to both survival and population abundance estimates for both the hatchery and wild components of the population using data collected under the joint stock assessment implenmented throughout the Transboundary Reach. Preliminary models have been developed to estimate recapture probability, survival, and abundance. The methods and candidate models are described in BC Hydro (2018). In addition, preliminary abundance estimates, year class specific abundance estimates were produced using model results from BC Hydro (2018).

2.3.4 Sex and Stage of Maturity

A program to determine the sex and stage of maturity for juvenile 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 juvenile White Sturgeon that could initiate spawning with the existing wild adults. Knowledge of when hatchery-released fish reach reproductive maturity is important for recovery planning and confidence in assigning sex of White Sturgeon is critical for many of the LCR research projects including telemetry and population assessments. Accordingly, 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.

2.3.4.1 Background

Recruitment of White Sturgeon in the Transboundary Reach (TBR) of the Columbia River [Hugh L. Keenleyside Dam (HLK) to Grand Coulee Dam (GCD) in WA, USA] has not occurred at a rate sufficient over the past 40 years to maintain the population going forward. Conservation aquaculture has become a critical component of recovery programs, including for White Sturgeon in the lower Columbia River where extirpation has largely been avoided due to the success of hatchery-origin juveniles released into the wild. Survival of hatchery-origin juveniles in the lower Columbia River population has been higher than originally predicted, with more than 30,000 individuals estimated to be at large in the population (BC Hydro 2016a). Within the hatchery population, certain year classes are estimated to be in higher abundance than the existing wild population (~3,000 mature individuals), as a result of higher survival for year classes released at larger body size. Of further concern, within year class genetic diversity has been estimated to be reduced relative to the time of release from the hatchery (McLellan and Crossman unpublished data) as a result of disproportionate survival among maternal family groups. As a result of these findings, there is an urgent need to determine when the hatchery population will mature and begin contributing to natural spawning, as genetic swamping of the existing wild population is a risk given numbers of estimated annual breeders (121.5 ± 34.7 adults (mean ± SD); Jay et al. 2014).

In the wild, White Sturgeon begin maturing between the ages of 15-35 years for females and 10-12 years for males (PSMFC 1992; Billard and Lecointre 2001). When provided with conditions for maximum growth in captivity, sexual maturity can occur much earlier with males maturing as early as 3 years of age and females as early as 6 years of age (Doroshov et al. 1997) However, age at first maturity is not well documented for hatchery-origin fish in productive systems like the lower Columbia River, Canada, where growth rates are high following release into the wild and individuals are reaching a body size similar to mature adults by age 14 (BC Hydro 2016b). The hatchery population in the lower Columbia River, Canada, represents a unique opportunity to determine age and size at first maturity in hatchery-origin fish, whether the hatchery-origin fish differ in reproductive indices (Table 2) compared to wild fish, and how other variables (e.g. habitat use or environmental covariates) may influence when individuals become reproductive. This information, in combination with other ongoing monitoring, will help inform both long-term population targets and ongoing revisions to numbers of fish that are released annually from the conservation aquaculture program.

Sturgeon females and males are not sexually dimorphic (Billard and Lecointre, 2001). There are several available methods to assess sex and stage of maturity in sturgeons (Webb and Van Eenennaam 2015), though direct comparison among all methods (ultrasound, endoscopy, measurement of plasma sex steroids, and biopsy) in their efficiency and reliability in assigning sex and stage of maturity are limited. Additionally, certain methods are more invasive than others limiting what may be possible for threatened or endangered populations where permitting requirements focus only on noninvasive techniques, and the most accurate method(s) that may be applied to females to assess sex and stage of maturity may differ from those that may be applied to males. This further

supports the need for comparative assessments between available methods for females and males and, given the endangered status of sturgeon species globally, is applicable beyond White Sturgeon.

Table 2. Reproductive indices to be determined in hatchery-origin and wild White Sturgeon in the lower Columbia River, Canada.

Reproductive Index	Description
Sex	Biological criteria used to define female or male gametogenesis
Age at first maturity	Age at which puberty is initiated; onset of vitellogenesis in females and meiosis in males
Spawning periodicity	Length of time between spawning events

2.3.4.2 Objectives:

Knowledge pertaining to when hatchery-origin White Sturgeon become reproductively mature and contribute to spawning occurring in the wild population is critical to informing management decisions for the population. Accordingly, the objectives of this project are to:

1. Determine sex and stage of maturity using multiple methods, estimate age at first maturity and, if applicable, spawning periodicity of hatchery-origin White Sturgeon in the lower Columbia River, Canada.
2. Determine sex and stage of maturity using multiple methods and spawning periodicity of wild White Sturgeon in the lower Columbia River, Canada. Reproductive indices will be developed for the wild population through collection of biological samples during the course of the study as well as using a long-term sex and stage of maturity dataset developed based on multiple captures of adults over the past decade within the study area.
3. Determine accuracy across multiple methods used to assign sex and stage of maturity to hatchery-origin and wild White Sturgeon in the lower Columbia River, Canada. Methods tested will include ultrasound, endoscopy (otoscope and endoscope), and measurement of plasma sex steroids. Histological analysis of gonadal tissue collected by biopsy will be used to validate true sex and stage of maturity. In order to validate histological analysis of the gonad as a control for sex and stage at maturity in this study, the following sub-objectives will be evaluated:
    3.1. Determine homogeneity of stage of maturity across gonadal tissue in both female and male White Sturgeon of hatchery-origin in the lower Columbia River, Canada.
    3.2. Determine the accuracy of gonadal biopsy in assessing stage of maturity in hatchery-origin White Sturgeon in the lower Columbia River, Canada.
4. Compare reproductive indices for hatchery-origin White Sturgeon to the wild breeding population including sex ratio, estimated age at first maturity, and spawning periodicity.

5. Determine how age, size, and habitat influence growth and reproductive indices for hatchery-origin White Sturgeon.

2.3.4.3 Methods:

1. Fish Collection

Sampling for this project will be conducted during routine monitoring being implemented during the stock assessment program. Accordingly, methods for handling fish and collection of biological data were consistent with those described above in section 2.3.2.3. As per the stock assessment design, sampling within the lower Columbia River study area was randomly distributed with equal effort across all habitats as site fidelity has been demonstrated to be high for this population (BC Hydro 2016a, b). Specifically, fidelity is high to upstream (River kilometer 0-10), middle river (rkm 13-30), and downstream (rkm 45-57) habitats that differ in hydraulics and amount of available habitat. Samples for this project were distributed throughout all three habitats. Sampling sessions for fish capture occurred during both spring and fall of 2017 and are planned for 2018.

2. Sample Collection to Assess Methods to Determine Sex and Stage of Maturity (Objectives 1 and 2)

Samples from hatchery-origin White Sturgeon were distributed across different age classes, size classes, and habitats. Samples from wild White Sturgeon were distributed across reproductive classes of sex and stage of maturity. Multiple methods were used to assign sex and stage of maturity and are described below.

Plasma Sex Steroids

The pattern of steroid production in sturgeons allows for discrimination of sex and stage of maturity less-invasively with blood collection (Webb and Doroshov, 2011). Specifically, plasma testosterone (T) and estradiol-17B (E2) have been found to provide the best discrimination (i.e., least error) in classifying sex and stage of maturity in White Sturgeon (Webb et al., 2002). In general, the steroid 11-ketotesterone (KT) provided similar or higher error rates as T.

In sub-adult and adult White Sturgeon in the lower Columbia River below Bonneville Dam, plasma T and E2 were found to be the best predictors of sex and stage of maturity, with 88% of the non-reproductive females, 72% of the non-reproductive males, 98% of the reproductive (vitellogenic and ripe) females, and 96% of the reproductive (maturing and ripe) males correctly identified (Webb et al. 2002). When analyzing only the adult population (size at which first sexual maturity has already been reached) of White Sturgeon below Bonneville Dam in the Columbia River, 93% of the non-reproductive females, 100% of the non-reproductive males, 98% of the reproductive females, and 100% of the reproductive males were correctly identified using plasma T and E2 (Webb et al. 2002).

Over the years of analyzing plasma samples, the Webb Lab has set steroid values to attempt to decrease the error associated with using plasma sex

steroids to predict sex and stage of maturity in various sturgeon populations. A total of 41 paired gonadal tissue and plasma samples from hatchery-origin White Sturgeon in the TRA of the Columbia River have been analyzed to date (Webb et al. 2016). Using the Webb Lab pre-set steroid values, 100% of the non-reproductive females, 95% of the non-reproductive males, and 100% of the reproductive males were correctly classified. A concentration of 4 ng/ml of plasma T was used as the discriminating value between non-reproductive females and non-reproductive males. That T concentration resulted in only one male being misclassified as a non-reproductive female. Of these hatchery-origin fish, 16% of the males had reached puberty as determined histologically, 23% of the males had reached puberty as determined steroidogenically, and 0% of the females had reached puberty as determined histologically or steroidogenically (Webb et al. 2016).

Further work is needed to better define the plasma sex steroid concentrations that may be used to differentiate classes of sex and stage of maturity. Specifically, we need to better understand the sex steroid concentration profiles in non-reproductive males and reproductive males as well as how the plasma T concentration increases prior to initiation of vitellogenesis in females to avoid misclassifying these females (prior to the increase in E2) as reproductive males. This study will determine the most accurate tool(s) to assess sex and stage of maturity in White Sturgeon which will assist with management of the population.

Following length and weight measurements, blood samples will be collected from all fish via the caudal vasculature, taken midline just posterior of anal fin. A hypodermic needle (25 gauge) will be inserted slowly into the musculature perpendicular to the ventral surface until blood enters the syringe. Approximately 1 ml of blood will be extracted. Blood will be immediately centrifuged, and plasma collected and frozen for steroid analysis. Plasma T and E2 will be extracted from plasma following the method of Fitzpatrick et al. (1987) for analysis by radioimmunoassay (RIA). Plasma concentrations of T and E2 will be measured by RIA as described in Fitzpatrick et al. (1986) modified by Feist et al. (1990).

Ultrasound

Ultrasound is a non-invasive technique with relatively high accuracy in identifying sex of an individual sturgeon. Moghim et al. (2002) found that sex could be accurately determined in 97% of examined stellate sturgeon but that immature males were difficult to identify. Colombo et al. (2004) was able to identify shovelnose sturgeon males with 96% accuracy and females with 80% accuracy, but this study had difficulties correctly identifying post-spawned females (60% accuracy). Wildhaber et al. (2005) were able to correctly identify the sex in 68% of the shovelnose sturgeon examined in the field and 70% of the shovelnose sturgeon examined in the laboratory, but they reported that non-gravid females were difficult to identify. Masoudifard et al. (2011) reported 98% accuracy in determining sex of 3-year-old cultured beluga sturgeon. Stage of maturity may be assessed in females based on oocyte/ovarian follicle diameter, though the accuracy is not well described in the differentiation of various stages (i.e. pre-vitellogenic, vitellogenic, post-vitellogenic, post-spawn). Stage of maturity in males cannot yet be determined as size of testicular lobes does not confer stage

of maturity, but density of testicular tissue has been hypothesized as a means to determine stage of maturity in males and needs further evaluation.

For ultrasound, two project members will independently and blindly determine sex and stage of maturity for each fish based on the presence of ovigerous folds, oocytes, or ovarian follicles and their size in females (see Table 3) and the presence of testicular lobes and density of the lobes in males (see Table 4). It is hypothesized that density of testicular tissue may be used as an indicator of ripeness with density increasing as spermatozoa density increases within testicular cysts, and tissue density may be assessed through ultrasound.

One ultrasound (Sonosite Edge, P11x/10-5 MHz transducer) image per reader will be captured and saved for each individual fish. Fish will be positioned ventral side up in the stretcher with the transducer positioned lengthwise on the abdomen, 3-5 ventral scutes anterior from the pelvic fin, and directly above the gonad (i.e. frontal or longitudinal view of the gonad). We will attempt to develop a relationship between ultrasound and assigning sex and stage of maturity. Using image analysis software, we will determine if the contrast of testicular tissue reflects testicular density and stage of maturity by comparison of ultrasound images and histological analysis of testicular tissue collected from those individuals. Images will be catalogued by individual reader, fish, sex, and stage of maturity in females.

Endoscopy

For endoscopy, a 1.5 to 2.0 cm long incision will be made through the ventral body wall just off the mid-line using a sterile scalpel. Both sex and maturational stages for both males and females will be assessed using an otoscope and an endoscope. Fish will be assessed based on macroscopic observations (Webb and Van Eenennaam 2015). Females will be classified (Table 3) by the presence of ovarian tissue; bright white, yellow, or orange in colour with grainy ovigerous folds or the presence of oocytes/ovarian follicles, and the size and color of the oocytes/ovarian follicles. Males will be classified (Table 4) by the presence and size of testicular tissue; smooth, turgid, whitish in colour, and lobed or unlobed. The otoscope will be inserted into the body cavity and sex and stage of maturity will be assessed independently and blindly by the two project members. A handheld USB digital endoscope (Vividia 2.0MP) will be inserted into the body cavity to capture an image of the gonad. The image will be projected onto a computer screen, and the endoscope will be manipulated in the body cavity to ensure a clear image is obtained. Fish will again be classified for sex and stage of maturity independently and blindly by the two project members. Images will be saved directly on the computer and further edited to improve contrast and clarity. We will attempt to develop a relationship between endoscopy via otoscope and an endoscope and assigning sex and stage of maturity. Images will be catalogued by individual reader, fish, sex, and stage of maturity in females.

Table 3. Stage of female gonad development identified through visual examination.

Developmental Stage		Description
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

Table 4. Stage of male gonad development identified through visual examination.

Developmental Stage		Description
1	Differentiation	Testicular tissue is a thin white thread (≤ 1mm)
2	Pre-meiotic	Testicular tissue is a thicker white thread (1-4 mm)
3	Onset of meiosis	Testis have whitish colour and turgid texture ranging from 0.5-2 cm
4	Meiotic	Gonad is primarily testicular tissue (2-3 cm) with much less adipose tissue
5	Mature	Large milky-white testis (3-8 cm) with no adipose tissue
6	Spermiation	Release of milt
7	Post-spermiation	Classification requires histological methods

Biopsy

In order to collect a sample of gonad for histological analysis, a biopsy tool (Miltex Cup Jaw Biopsy Tool) will be inserted into the body cavity via the otoscope to collect a small (2 mm^3) sample. Each sample will be preserved in 10% phosphate buffered formalin for histology. Following endoscopy and biopsy, the incision will be closed using a half circle CP-2 reverse cutting-edge needle wedged to a 2-0 monofilament Polydioxanone suture. Sutures will be spaced approximately 0.75 cm apart with sufficient slack provided to prevent tissue damage caused by swelling during the healing process.

Gonadal tissue will be processed histologically by embedding in paraffin, sectioning at 5 µm, and staining by Periodic Acid Schiff stain (PAS; Luna 1968). Slides will be examined under a compound scope (5-100x, Leica DM2000), and

the germ cells will be scored for stage of maturation according to Webb and Van Eenennaam (2015).

3. Determination of Accuracy across Multiple Methods to Assign Sex and Stage of Maturity (Objective 3)

   The order of the methods to determine sex and stage of maturity will be randomized per sampling day to avoid bias of the project members. The sex and stage of maturity of each fish will compared among each method using data from when the method was used first to assess sex and stage of maturity. The accuracy of each method, including sex and stage of maturity as assessed by plasma sex steroid concentrations, will be determined as compared to histological analysis of sex and stage of maturity.

4. Sample Collection for Homogeneity of Stage of Maturity (Objective 3.1) and Accuracy of Gonadal Biopsy (Objective 3.2)

   A total of 30 female and 30 male hatchery-origin White Sturgeon will be euthanized to assess homogeneity of stage of maturity across both lobes of the gonad and the accuracy of gonadal biopsy in assessing stage of maturity. In the 22 hatchery-origin male White Sturgeon previously analyzed, 16% of the males had reached puberty as determined histologically, while 23% of the males had reached puberty as determined steroidogenically (Webb et al. 2016). The small size of the gonadal biopsy in combination with these results suggests that, particularly in males, multiple biopsies may be needed to truly assess stage of maturity. Following euthanasia, the coelomic cavity will be opened, and 10 biopsy samples (anterior to posterior spaced equally across the gonad) from each gonadal lobe (n=20 total per individual) will be collected using the Miltex Cup Jaw Biopsy Tool. Macroscopic photos will be taken, and gonadosomatic index will be determined. Each biopsy will be labeled and stored independently in 10% phosphate buffered formalin for histological analysis.

   In order to evaluate the homogeneity of gonadal development in both females and males, we will develop a mixed model to predict stage at maturity based on multiple gonad samples from the same individual. Using the final complied dataset, we will take a random sample from the list of assigned stages (e.g. n=20 for males) for each individual and build a model where the response would be whether the true sex (determined from all samples for the individual) matches that determined from the subsample (i.e. a binary response and a logistic model). Predictors will be the number of subsamples and other covariates including size and age of the individual. We would then repeat this process sub sampling the data through multiple iterations (e.g. bootstrap) to address sampling variability. The end result would be a model to determine the number of biopsy samples that would be required to be collected to determine sex with a certain probability. This analysis will be further developed as the project proceeds.

5. Comparison of Hatchery-origin Reproductive Indices to the Wild Population (Objective 4) and Determine How Age, Size, and Habitat Influence Growth and Reproductive Indices (Objective 5)

   Following analyses of all samples collected in 2017 and 2018 and analysis of the BC Hydro database for White Sturgeon, sex ratio, age at first maturity, and spawning periodicity will be compared between the hatchery-origin and wild fish. The effects of age, size, and habitat on growth and reproductive indices for hatchery-origin White Sturgeon will be assessed to determine how variability in results is partitioned. Further development of these analyses will occur as year 1 samples are processed.

2.3.4.4 Expected Results:

The overall result of this work will describe the reproductive status of hatchery-origin White Sturgeon in the lower Columbia River. This will directly inform ongoing management actions for the population. In addition, this proposed work will 1) determine the most accurate method(s) to assess sex and stage of maturity in White Sturgeon, 2) allow for comparison of reproductive indices between hatchery-origin and wild White Sturgeon, 3) determine how age, size, and habitat influence growth and reproductive indices for hatchery-origin White Sturgeon, and 4) determine whether gonadal development is homogenous across the gonad in White Sturgeon, and whether it can accurately be assessed by a single biopsy. Overall, this information, in combination with other ongoing monitoring, will help facilitate recovery of not only the population in the lower Columbia River, but sturgeon species and populations across North America.

2.4 Habitat Mapping

To address questions regarding the use and availability of suitable habitat for larval or juvenile stages of White Sturgeon in the LCR, it is important to quantify physical habitat that can be tied to data collected as part of this program. It is believed that small substrate (e.g., gravel) with interstitial spacing is important for survival of larvae by providing hiding habitat that they can use to avoid predators (McAdam 2011) while age-0 and older juvenile White Sturgeon tend to prefer substrates of hard clay, mud, silt, and sand (Parsley and Beckman 1994). Uncertainties exist in the LCR as to how the quality and quantity of such habitat changes across different sections of the river. As such, physical habitat data are required to assess habitat use and suitability/availability for both wild and hatchery released juvenile sturgeon found in the LCR.

As part of this monitoring program, a habitat mapping program was developed for the LCR to describe and classify physical habitat in the LCR between HLK and the US border. Riverbed images were acquired in 2010 and 2011 with a Tritech Starfish sidescan sonar. Image editing, processing, and mapping of substrate classes were completed in 2012 (see BC Hydro 2015c for details).

3 MONITORING RESULTS

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

3.1 Physical Parameters

3.1.1 Discharge

Mean daily discharge (cms; cfs) measured from Arrow Reservoir, Kootenay River, Birchbank, and Canada/U.S. International Border for the 2017 study period is presented in Figure 4. Minimum and maximum discharge (cms; cfs) for each location is given in Table 5.

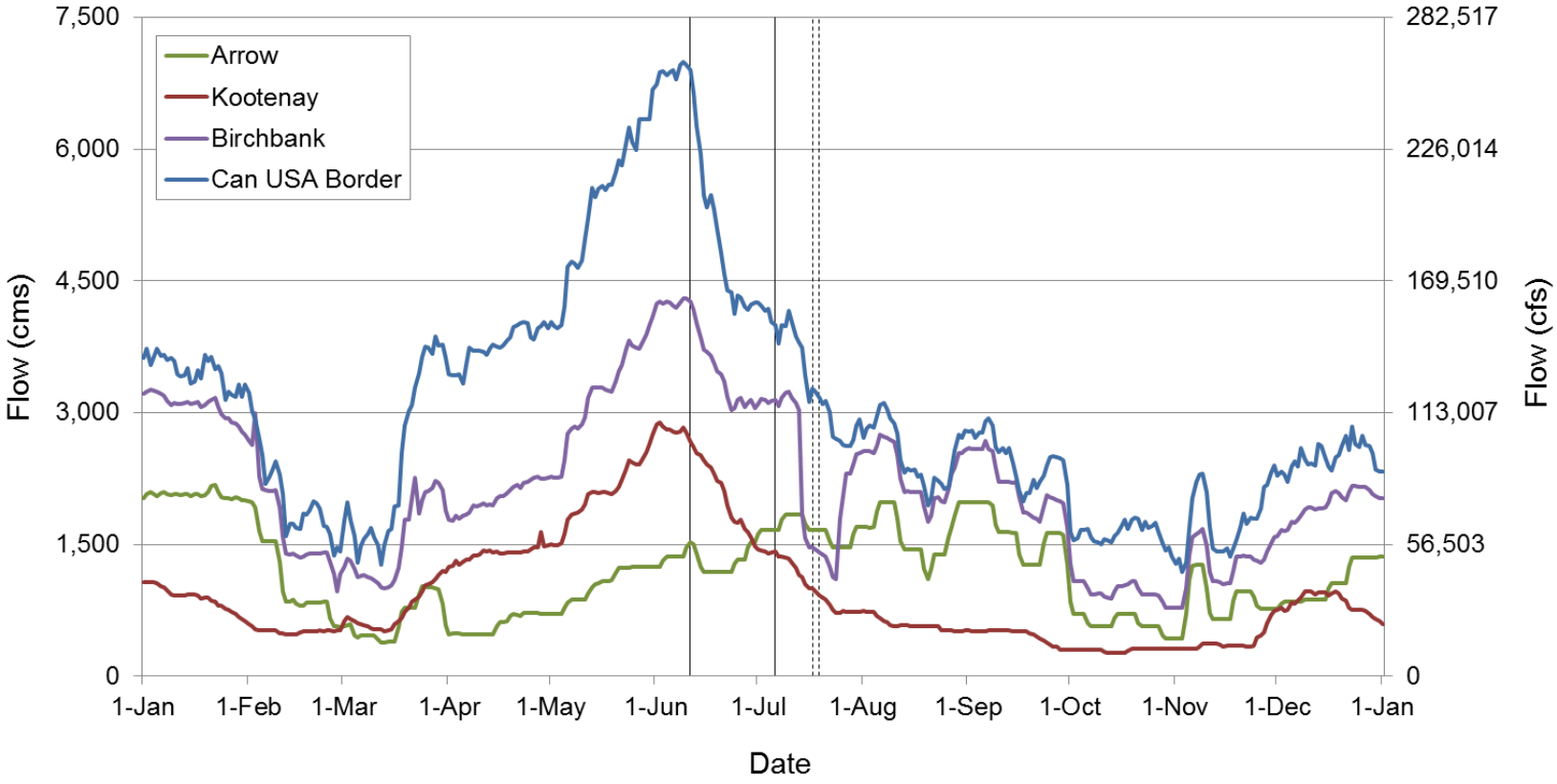

Figure 4. Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada/U.S. International Border on the Lower Columbia River from January 01, 2017 – December 31, 2017. The solid and dashed vertical bars represent the first and last estimated spawning dates detected at Waneta and ALH, respectively. Estimated spawning dates are based on the developmental stage of collected embryos (BC Hydro 2018) and/or larvae. One embryo was developmentally staged at Kinnaird and was estimated to have been fertilized July 10.

Table 5. Minimum and maximum discharge (cubic meters per second, cms; cubic feet per second, cfs) at four locations on the Lower Columbia River in 2017.

Location	Discharge			
	Minimum (cms)	Maximum (cms)	Minimum (cfs)	Maximum (cfs)
Arrow Reservoir	382.2	2,176.3	13,496	76,853
Kootenay River	267.6	2,892.6	9,450	102,150
Birchbank	778.6	4,301.4	27,497	151,903
Border	1,188.8	6,992.4	41,980	246,934

3.1.2 Water Temperature

Mean daily water temperatures (°C) in the LCR during 2017 are illustrated in Figure 5. Annual mean (± SD), minimum, and maximum water temperatures (°C) at locations HLK (rkm 0.1), Kootenay Eddy (rkm 10.5), Kinnaird (rkm 13.4), Genelle Eddy (rkm 26.0), and Waneta Eddy (rkm 56.0) are summarized in Table 6. The date of occurrence of spawning temperature threshold (14°C) at each location is provided in Table 6. Variations in water temperatures experienced during the study period can be attributed to warm/cold water influences caused in the Arrow Reservoir system (i.e., combined HLK and ALH discharges from Arrow Lakes Reservoir), and other cold-water tributary influences.

Table 6. Mean (± SD) daily, minimum, and maximum water temperatures (^{o}C) recorded within the Lower Columbia River during 2017. Data was recorded at locations of Hugh L. Keenleyside (rkm 0.1), Kootenay Eddy (rkm 10.5), Kinnaird (rkm 13.4), Genelle Eddy (rkm 26.0), Rivervale (rkm 35.8) and Waneta Eddy (rkm 56.0).

Location	RKM	Temperature			Date of Suspected Spawning Threshold (14°C)
		Mean ± SD	Minimum	Maximum	
HLK	0.1	8.56 ± 5.04	1.9	18.7	22-Jun
Kootenay	10.5	9.46 ± 5.84	2.1	20.2	25-Jun
Kinnaird	13.4	9.14 ± 5.34	2.0	19.7	29-Jun
Genelle	26	9.03 ± 5.25	1.9	19.4	24-Jun
Rivervale*	35.8	9.18 ± 5.71	1.9	19.5	24-Jun
Waneta*	56	12.72 ± 5.22	2.9	20.7	22-Jun

*Data incomplete due to lost or damaged temp loggers

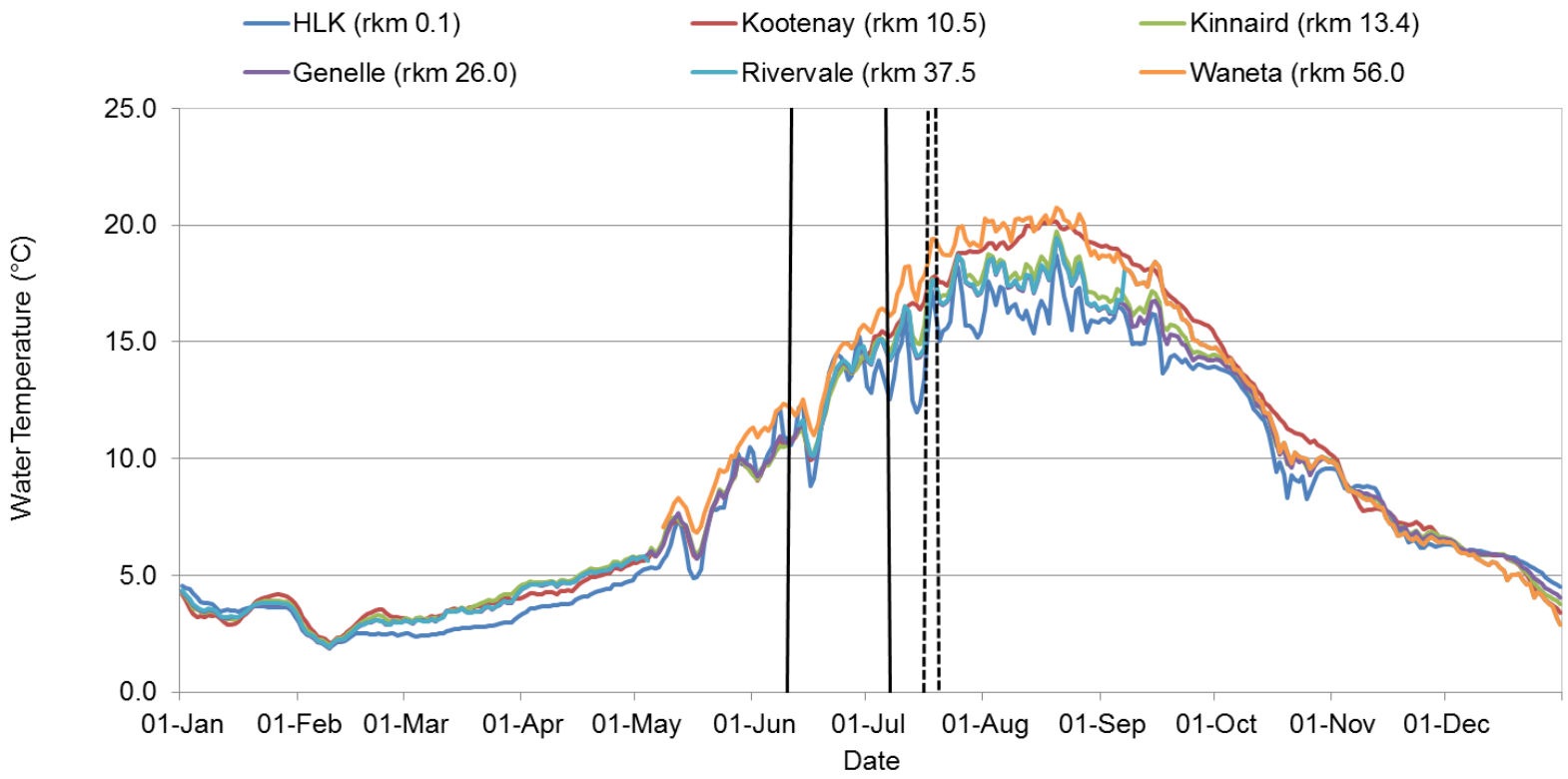

Figure 5. Mean daily water temperature (^{o}C) of the Lower Columbia River in 2017. Data was recorded at locations of HLK (rkm 0.1), Kootenay (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), Rivervale (rkm 35.8) and Waneta (rkm 56.0). Missing data is due to lost or damaged temperature loggers. Vertical solid and dashed lines represent estimated first and last spawning dates at Waneta and ALH, respectively. Estimated spawning duration is based on the developmental stage of collected embryos (BC Hydro 2018) and/or larvae. One embryo captured at Kinnaird was developmentally staged and estimated to have been fertilized on July 10.

3.2 Larval Stage

3.2.1 Larval Assessment

3.2.1.1 Larval Sampling Effort and Collection

Downstream Location – Waneta (rkm 56.0)

Sampling was conducted from May 31 to July 11 at depths of 5.4 ± 1.6 m (mean ± SD) and water temperatures ranging from 10.6 to 20.7°C (Figure 5). Drift nets were deployed for 10.5 ± 8.7 hours per sampling period with a total sampling effort of 913 hours (Table 7).

A total of 582 yolk-sac larvae were captured at Waneta between the dates of June 22 and July 11 (Table 7), however only 53 were alive and transported to the SIF. The largest daily sample was 49 larvae collected on July 6 representing 0.09 of total drift net sample collection. All live larvae were transported to the KSH for rearing purposes. For embryo collection details see BC Hydro (2018).

Upstream location – Kinnaird (rkm 12.8 to rkm 18.2)

Drift nets were deployed at rkm 13.4 (n=3), rkm 14.5 (n=2), rkm 16.9 (n=1), and rkm 18.2 (n=4) on July 12 and sampling continued until August 2. Water temperatures ranged from 14.6 to 18.9°C (Figure 5) and sampling water depth was 5.0 ± 2.2 m. Total sampling effort for drift nets were 1289hours (rkm 13.4, 416 h; rkm 14.5, 433 h; rkm 16.9, 78 h; rkm 18.2, 363 h; Table 7). Mean daily effort was 15.7 ± 10.8 hours.

A total of 14 larvae (rkm 13.4, n=2; rkm 14.5, n=8; rkm 18.2, n=4; Table 7; Figure 6) were collected between July 13 and July 27. All larvae were dead upon capture and preserved.

Upstream Location – ALH (rkm 0.1)

Drift nets (n=4) were deployed on July 12 and sampling continued until August 3 with water temperatures ranging from 11.7 to 18.4°C (Figure 5). Total drift net sampling effort was 2146 h (Table 7). Mean daily sampling water depth was 5.2 ± 1.7 m and daily effort for was 38.3 ± 22.7 h. A total of 159 larvae were collected between July 19 and July 27 (Table 7). All larvae were dead upon capture and preserved.

Table 7. White Sturgeon embryo and larval collection and sampling effort at Lower Columbia River monitoring locations of Waneta (rkm 56.0), downstream of Kinnaird (rkm 12.8 to rkm 19.2), Kootenay (rkm 10.5), downstream Arrow Lakes Generating Station (ALH; rkm 6.0), ALH (rkm 0.1), and HLK (rkm 0.1) for years 2008 through 2017.

Year	Location	Embryos	Larvae	Effort (hrs)	CPUE
2008	Waneta	494	220	72	9.92
	rkm 18.2	0	1	164	0.01
2009	Waneta	77	39	90	1.29
	rkm 18.2	0	5	976	0.01
	rkm 6.0	0	0	3,091	0.00
2010	Waneta	888	89	113	8.65
	rkm 18.2	1	8	2,104	<0.00
	ALH	30	115	2,084	0.07
2011	Waneta	234	15	50	4.98
	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
	HLK	0	0	461	0.00
	ALH	183	308	2,538	0.19
2012	Waneta	134	15	48	3.10
	rkm 18.2	0	0	197	0.00
	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	Waneta	33	62	43	2.21
	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
	ALH	0	0	857	0.00
2015	Waneta	8	55	275	0.23
	rkm 13.4	0	0	805	0.00
	rkm 14.5	0	1	272	<0.00
	rkm 16.9	0	4	186	0.02
	rkm 17.3	0	1	187	0.01
	rkm 18.2	0	2	1,767	<0.00
	rkm 19.2	0	0	91	0.00
	ALH	0	1	1,373	<0.00

Table 7 (continued). White Sturgeon embryo and larval collection and sampling effort at Lower Columbia River monitoring locations of Waneta (rkm 56.0), downstream of Kinnaird (rkm 12.8 to rkm 19.2), Kootenay (rkm 10.5), downstream Arrow Lakes Generating Station (ALH; rkm 6.0), ALH (rkm 0.1), and HLK (rkm 0.1) for years 2008 through 2017.

Year	Location	Embryos	Larvae	Effort (hrs)	CPUE
2016	Waneta	5203	955	965	6.38
	rkm 12.8	0	0	901	0.00
	rkm 13.4	0	0	118	0.00
	rkm 14.5	0	3	381	0.01
	rkm 16.9	0	5	121	0.04
	rkm 17.3	0	1	122	0.01
	rkm 18.2	0	8	990	0.01
	ALH	0	0	1006	0.00
2017	Waneta	1,914	582	913	2.73
	rkm 13.4	1	2	416	0.01
	rkm 14.5	0	8	433	0.02
	rkm 16.9	0	0	78	0.00
	rkm 18.2	0	4	363	0.01
	ALH	511	159	2,146	0.31

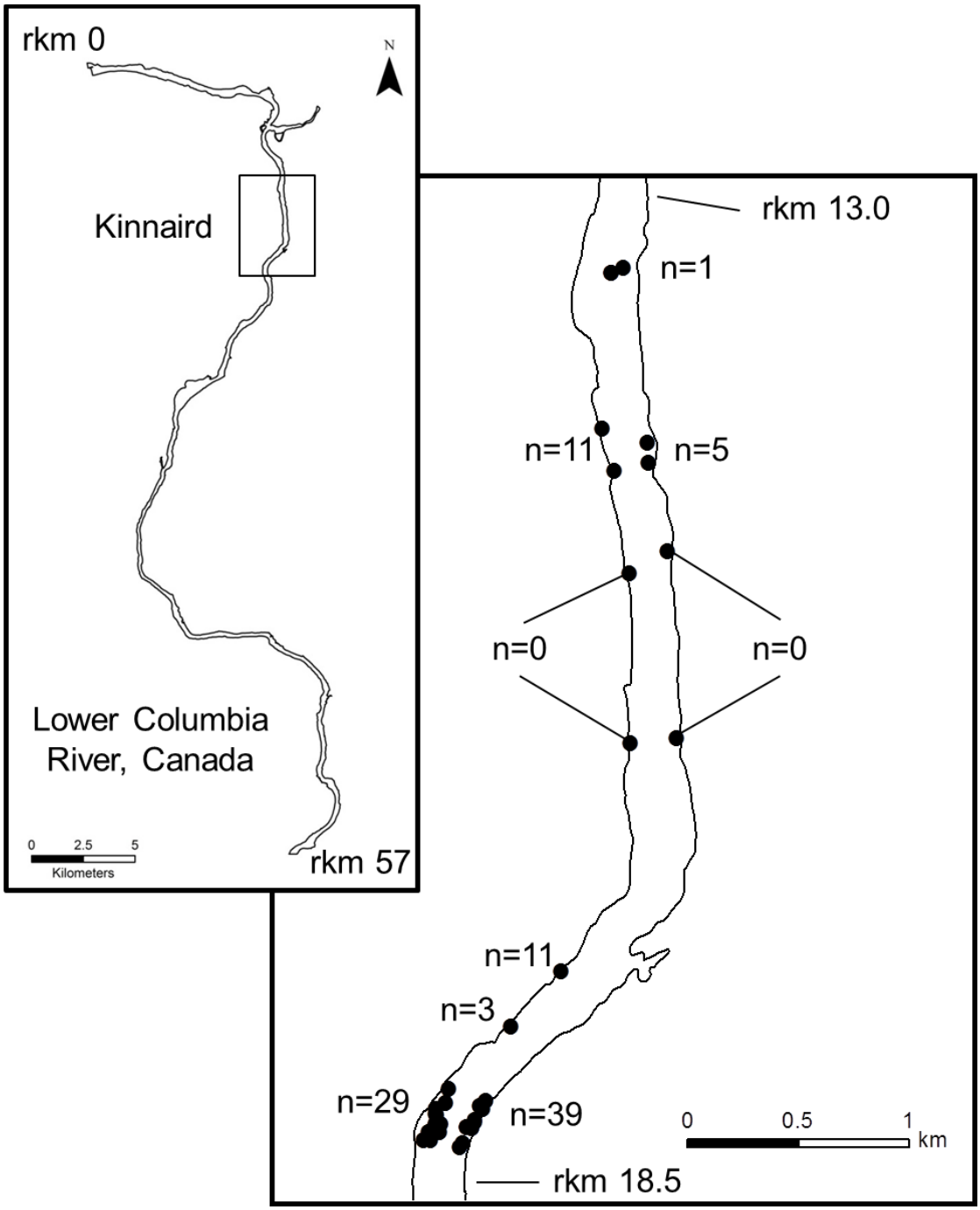

Figure 6. Drift net sampling locations and corresponding numbers of larvae collected downstream of Kinnaird (rkm 13.4 – 19.2) in the Lower Columbia River from 2010 through 2017 sampling seasons.

3.2.1.2 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. Based on 45 developmentally staged larvae (Table 8), twelve spawning days was estimated to have occurred between June 11 and July 5 at Waneta. Spawning was estimated to have occurred on July 19 at ALH (Table 8). No larvae were able to be developmentally staged at Kinnaird. For 2017 estimated spawning days via developmental staging of embryo samples see BC Hydro (2018).

Table 8. Developmental stages of White Sturgeon larvae collected at multiple locations (river kilometer, RKM) in the Lower Columbia River in 2017.

		Developmental Stage									
Location	n	36	37	38	39	40	41	42	43	44	45
ALH	3	0	3	0	0	0	0	0	0	0	0
Waneta	123	51	63	7	2	0	0	0	0	0	0

3.3 Juvenile Stage

3.3.1 Conservation Aquaculture Program

The Conservation Aquaculture Program has released a total of 148,464 juvenile White Sturgeon through 2002 to 2018 (Table 9). In the spring of 2018, 457 wild-origin juveniles (year class 2017) were released into the lower Columbia River. Additional fish (~150) will be released in the fall once target size is reached. A total of 228 and 229 juveniles were released at Millennium Park (rkm 10.5) and Beaver Creek (rkm 49.0), respectively. FL for released wild origin released was 31.5 and 32.4 cm for Millennium and Beaver Creek release sites, respectively (Figure 7). Weight for released wild origin released was 234 and 265 g for Millennium and Beaver Creek release sites, respectively (Figure 8).

Table 9. Numbers of hatchery-origin juvenile White Sturgeon released into the Transboundary Reach of the Columbia River [Hugh L. Keenleyside Dam (HLK) to Grand Coulee Dam (GCD) in WA, USA] from 2002-2018. Bolded numbers indicate releases of progeny collected in the wild as embryos or larvae and reared in the hatchery. Release numbers are presented by release year and indicated whether they occurred in the fall or spring.

Release Year	Year Class	Canada		USA		Total
		Spring	Fall	Spring	Fall	
2002	2001	8,671				8,671
2003	2002	11,803				11,803
2004	2003	9,695		1,881		11,576
2005	2004	12,748		3,755		16,503
2005	2005		5,039			5,039
2006	2005	10,828		4,351		15,179
2006	2006		4,042			4,042
2007	2006	8,123		3,422		11,545
2007	2007		4,029			4,029
2008	2007	6,448		3,821		10,269
2009	2008	4,141		3,537		7,678
2010	2009	3,947		3,873		7,820
2010	2010				**522**	522
2011	2010	4,010		3,869		7,879
2011	2011				**3,586**	3,586
2012	2011	4,000				4,000
2012	2012				**302**	302
2013	2012	4,037				4,037
2014	2013	1,800			**656**	2,456
2015	2014	2,800				2,800
2015	2014	**1,095**		**2,833**		3,928
2016	2015	**76**		**2,333**		2,409
2017	2016	**800**		**1,134**		1,934
2018	2017	**457**		N/A*		457
Total		95,479	13,110	34,809	5,066	148,464

*Release numbers not available at the present time for USA releases

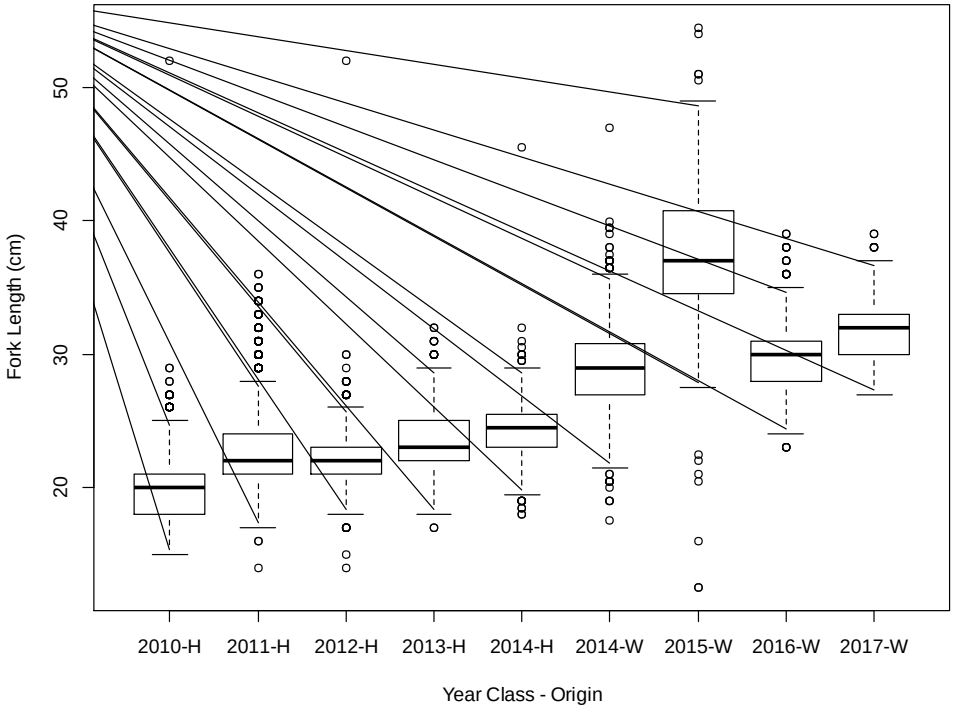

Figure 7. Fork length (cm) at release (approximately 9 months of age) of 2010 through 2017 year class juvenile White Sturgeon of hatchery (H) and wild (W) origins.

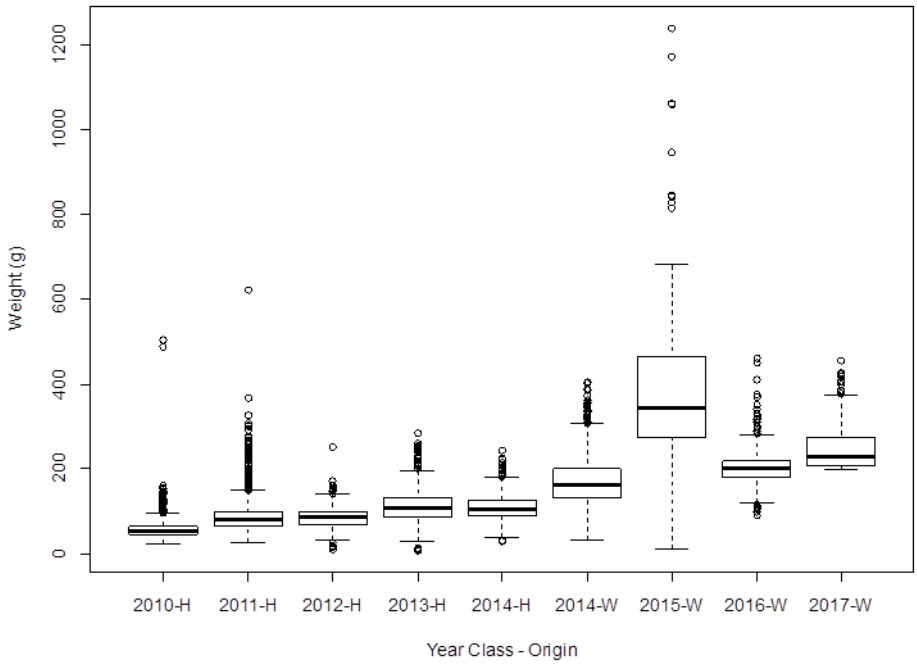

Figure 8. Weight (g) at release (approximately 9 months of age) of 2010 through 2017 year class juvenile White Sturgeon of hatchery (H) and wild (W) origins.

3.3.2 Juvenile Population Assessment

3.3.2.1 Juvenile Sampling Effort and Captures

The biannual stock assessment program was initiated in the spring of 2013. Sampling was continued twice a year (spring and fall) in the TRB extending from HLK in Castlegar British Columbia, Canada, to Gifford Washington, USA, until Fall 2017. Results are presented for data collected in the Canadian portion of the LCR.

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

Within Canada, total hatchery-origin White Sturgeon captures during the 2017 spring and fall stock assessments were 140 and 334, respectively (Table 10; Figure 9). Individuals 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. Over the stock assessments 5-year sampling period, 51 captured fish were identified as wild representing a 0.02 proportion of total capture across all sampling years (Table 10). See BC Hydro (2016c) for details on captures of fish to date in the US.

Table 10. Total hatchery-origin White Sturgeon capture during the 2013 through 2017 stock assessments in the Lower Columbia River Canada. 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.

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
Total		2,131	51	2,182

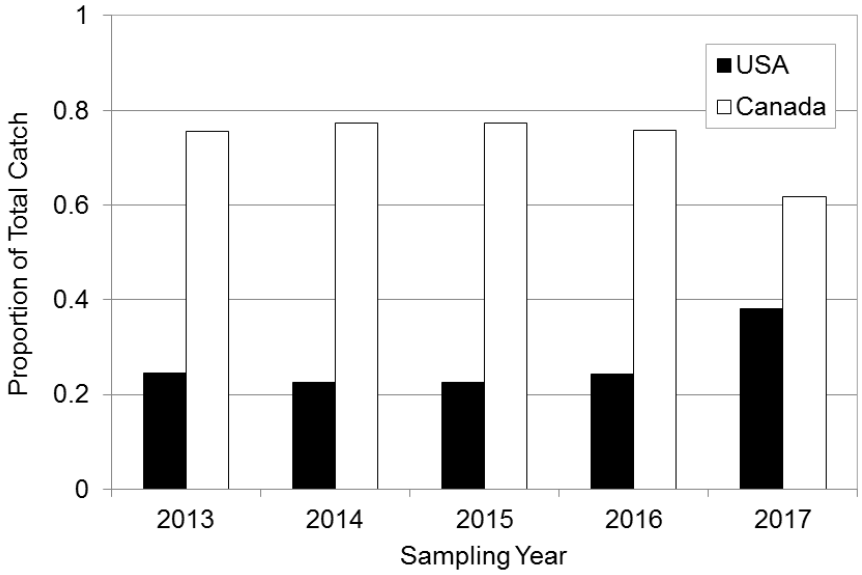

Figure 9. Percent of the total number of hatchery-origin White Sturgeon captured within the Lower Columbia River Canada that were originally released in either the US or Canada. The proportion of US and Canadian origin fish are presented for each of 2013 through 2017stock assessments.

Within Canada, total capture by brood year class (YrC) for sampling in 2017 is provided in Table 11 and Figure 10. The 2001 and 2002 year classes represented the largest proportion of total capture across all stock assessments (0.25 and 0.22, respectively; Figure 11). See BC Hydro (2016b; 2016c) for 2009 through 2015 juvenile capture data.

Total capture across 2017 stock assessments within each sampling zone included: zone 1, n=308; zone 2, n=60; zone 3, n=48; zone 4, n=7; and zone 5, n=27 (Table 11; Figure 12). Wild-origin fish were captured in zones 1, 2, and 3 (n=3). Year class 2001 represented the highest proportion of fish captured in zones 1, 3, 4, and 5; fish of year class 2004 and 2005 represented the highest proportion of fish captured in zone 2. Juveniles were distributed widely throughout zone 1 (Figure 13), and were caught in specific habitat types (e.g., eddies) in zone 2 (Figure 14), zone 3 (Figure 15), zone 4 (Figure 16), and zone 5 (Figure 17).

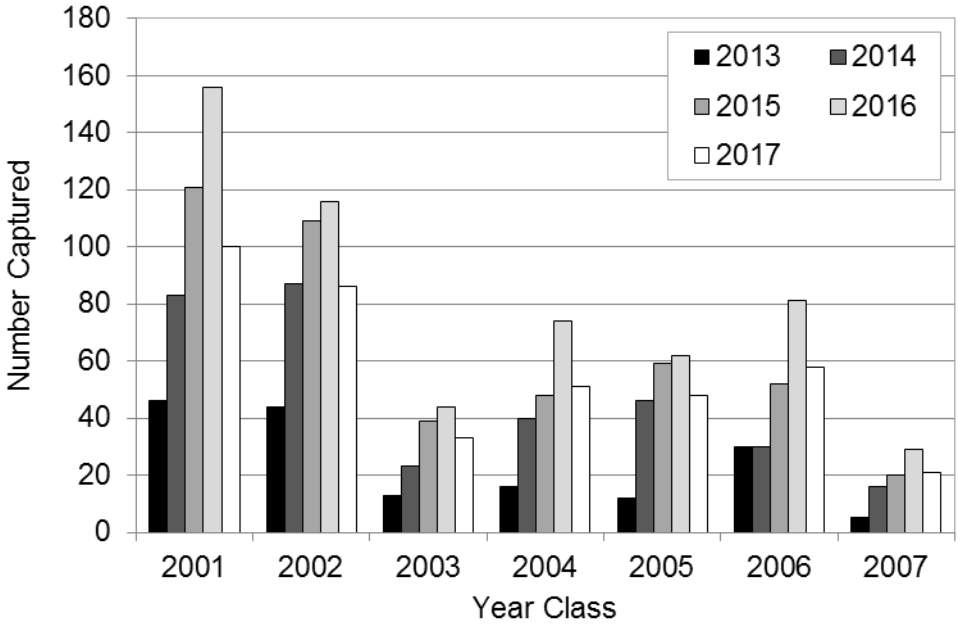

Figure 10. The total number of hatchery-origin White Sturgeon captured within the Lower Columbia River during the 2013 through 2017 stock assessments. Only the 7 most abundant year classes recaptured are presented.

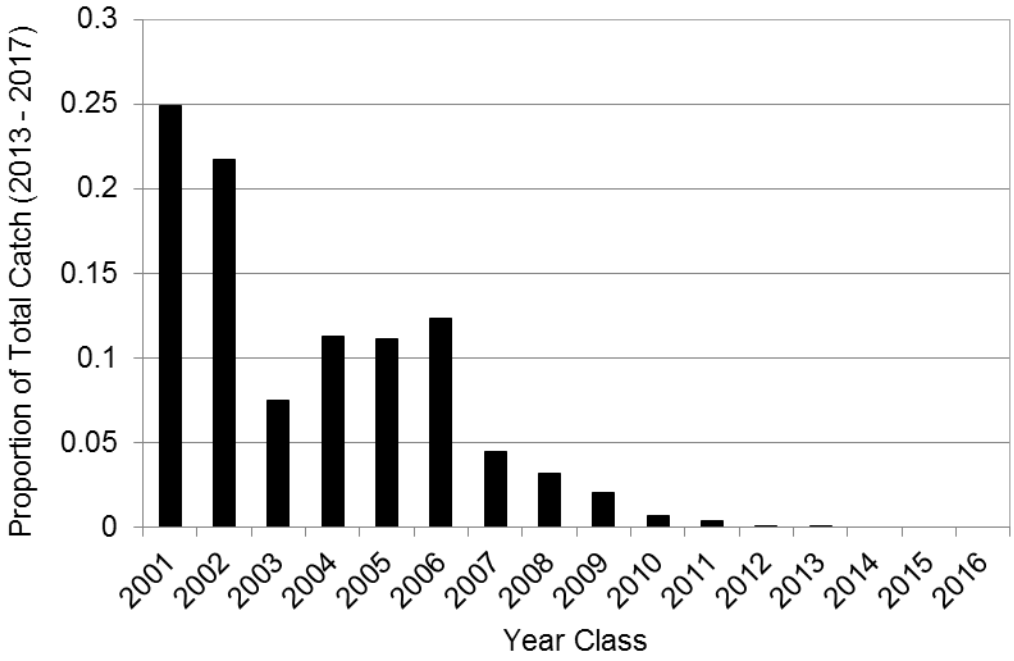

Figure 11. The proportion of the total catch of hatchery-origin White Sturgeon by year class within the Lower Columbia River during the 2013 through 2017 stock assessment surveys. Year class of hatchery origin fish was determined by external mark of removed lateral scutes and PIT tag.

Table 11. Total juvenile White Sturgeon captured by brood year class within the Lower Columbia River for each sampling zone during the 2017 spring and fall stock assessments. Year class of hatchery origin fish was determined by external mark of removed lateral scutes and PIT tag. Individuals 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. Sampling zones represent 11.2 km increments starting from Hugh L. Keenleyside Dam and moving downstream to the US Border.

Year Class	Zone					Total
	1	2	3	4	5	
2001	75	9	9	2	5	100
2002	72	8	6	0	0	86
2003	23	2	2	2	4	33
2004	28	12	6	1	4	51
2005	25	12	8	0	3	48
2006	47	5	4	0	2	58
2007	12	5	2	2	0	21
2008	17	3	4	0	1	25
2009	5	3	4	0	3	15
2010	2	0	1	0	3	6
2011	1	0	0	0	2	3
2012	0	0	1	0	0	1
2013	0	0	0	0	0	0
2014	0	0	0	0	0	0
2015	0	0	0	0	0	0
2016	0	0	0	0	0	0
Wild	1	1	1	0	0	3
Total	308	60	48	7	27	450*

*not all hatchery origin fish captured were assigned a brood year class

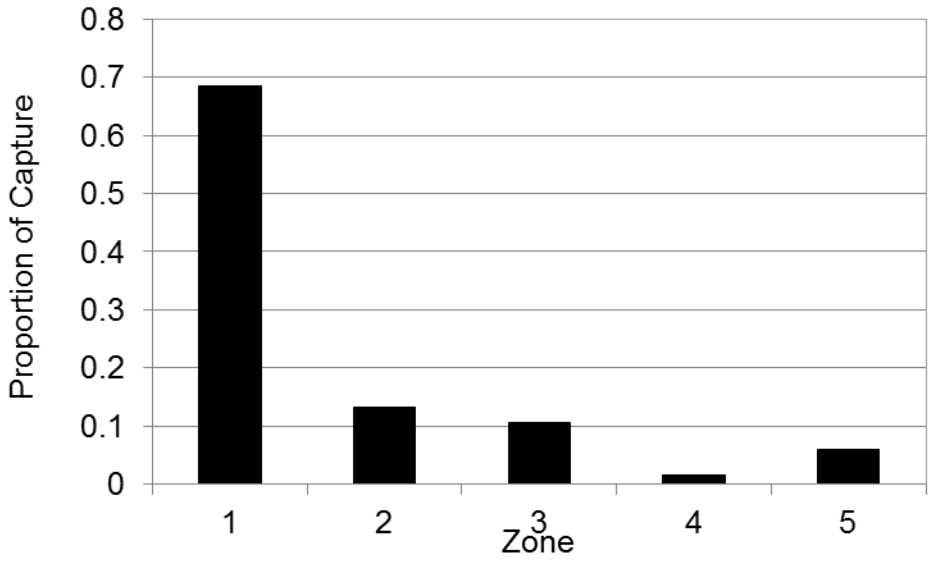

Figure 12. Proportion of total juvenile White Sturgeon captured within the Lower Columbia River for each sampling zone during the 2017 stock assessments. Sampling zones represent 11.2 km increments starting from Hugh L. Keenleyside Dam and moving downstream to the US Border.

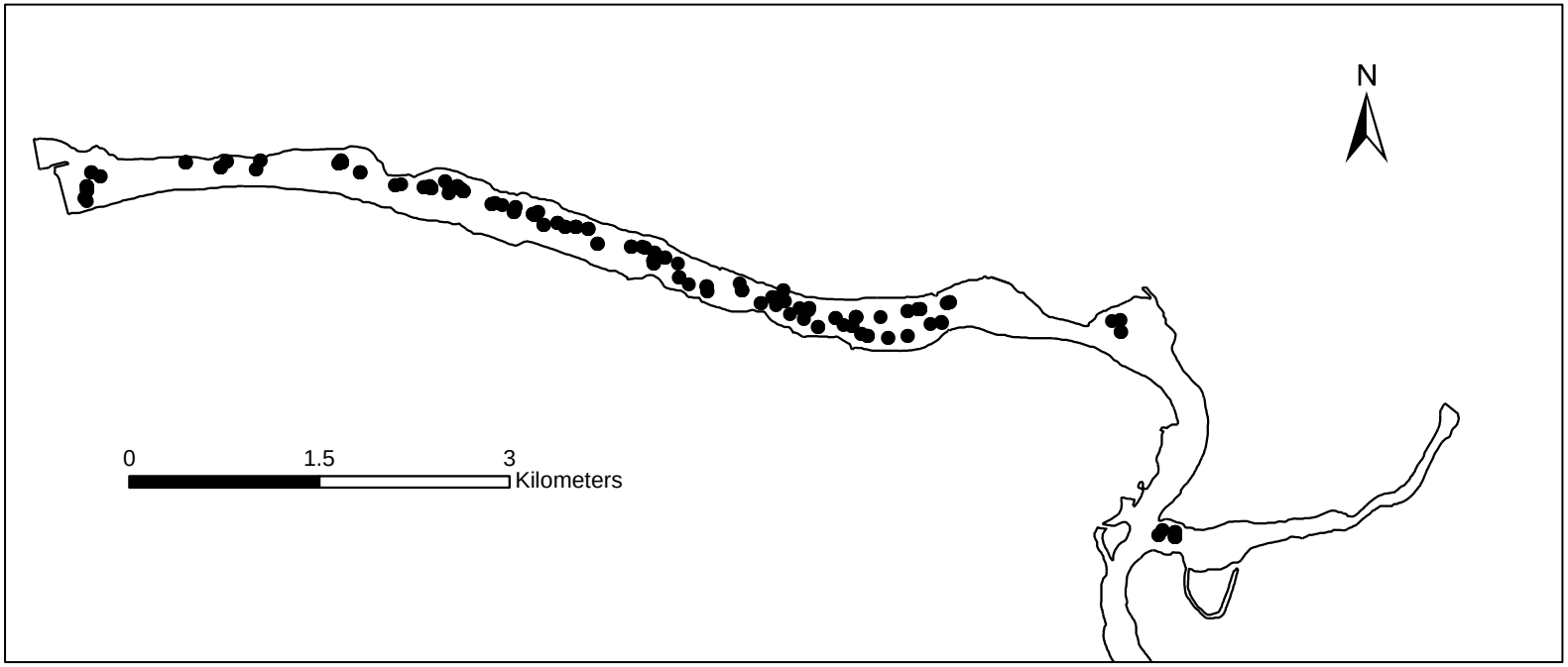

Figure 13. Juvenile White Sturgeon distribution in zone 1 of the Lower Columbia River based on locations of sampling effort and fish capture (n=324) during 2017. Sampling zones represent 11.2 km increments starting from Hugh L. Keenleyside Dam and moving downstream to the US Border.

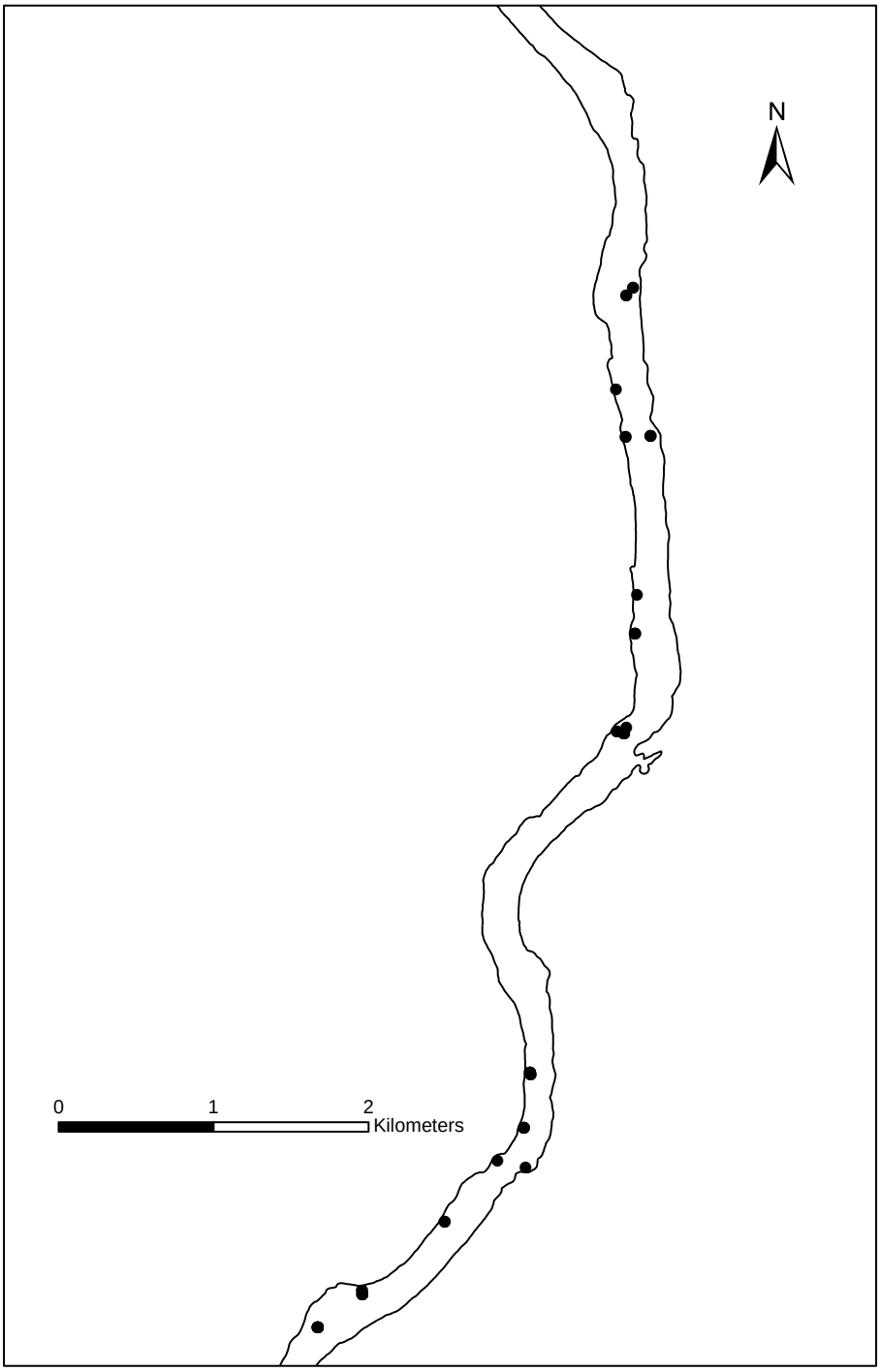

Figure 14. Juvenile White Sturgeon distribution in zone 2 of the Lower Columbia River based on locations of sampling effort and fish capture (n=62) during 2017. Sampling zones represent 11.2 km increments starting from Hugh L. Keenleyside Dam and moving downstream to the US Border.

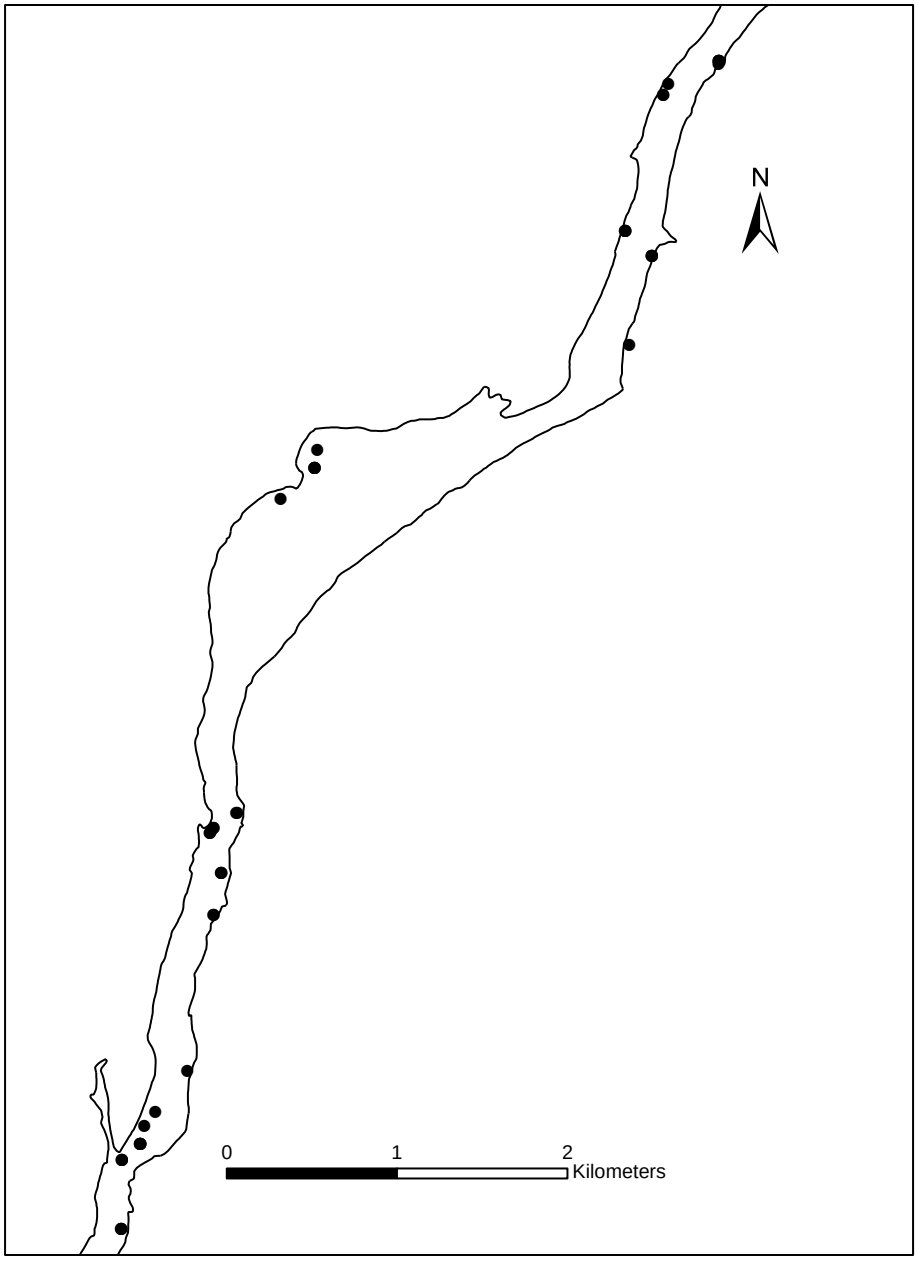

Figure 15. Juvenile White Sturgeon distribution in zone 3 of the Lower Columbia River based on locations of sampling effort and fish capture (n=52) during 2017. Sampling zones represent 11.2 km increments starting from Hugh L. Keenleyside Dam and moving downstream to the US Border.

Figure 16. Juvenile White Sturgeon distribution in zone 4 of the Lower Columbia River based on locations of sampling effort and fish capture (n=12) during 2017. Sampling zones represent 11.2 km increments starting from Hugh L. Keenleyside Dam and moving downstream to the US Border.

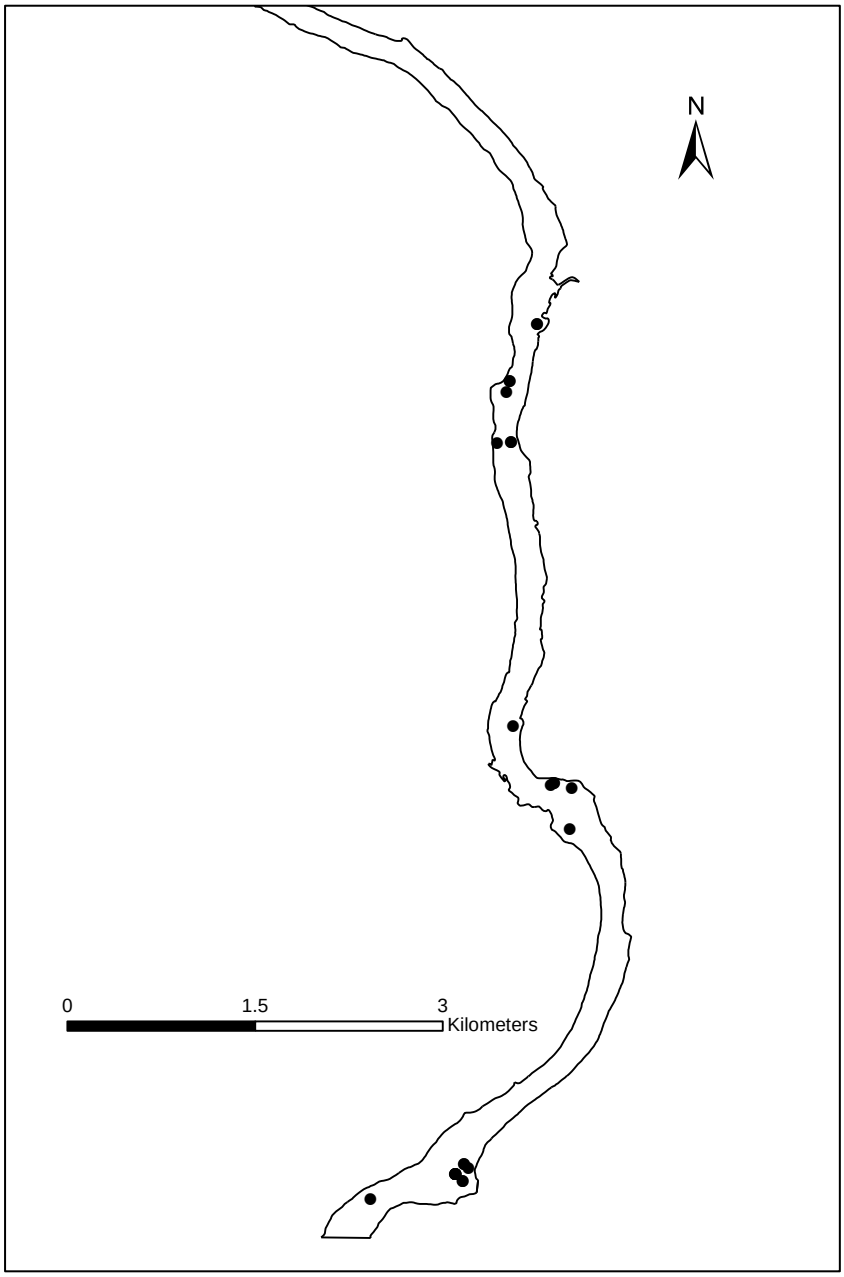

Figure 17. Juvenile White Sturgeon distribution in zone 5 of the Lower Columbia River based on locations of sampling effort and fish capture (n=27) during 2017. Sampling zones represent 11.2 km increments starting from Hugh L. Keenleyside Dam and moving downstream to the US Border.

3.3.2.2 Fork Length, Weight, Relative Weight, and Growth

3.3.2.2.1 Fork Length

Fork length (FL; cm; mean ±SD) of juveniles captured within Canada during the spring and fall 2017 stock assessments was 98.3 ± 14.2 cm and 97.8 ± 12.6 cm, respectively (Table 12). Juvenile FL as a function of year class (Table 12; Figure 18) and sampling zone (Table 13) is provided below. For 2017 capture, mean FL decreased as a function of YrC. Unlike previous capture years, mean FL of YrC 2001 was larger than YrC 2002. Wild juveniles were larger than hatchery-reared fish, with the exception of a few individuals of YrC 2001 and 2006 (Figure 18). FL was similar of fish captured in sampling zone 1 (98.4 ± 12.7 cm), zone 2 (96.5 ± 12.5 cm), zone 3 (98.9 ± 14.3 cm), and zone 5 (96.2 ± 15.2. Fork length of fish captured in zone 4 was 92.8 ± 15.2 cm.

3.3.2.2.2 Weight

Weight (kg) of juveniles captured within Canada during the spring and fall 2017 stock assessments was 6.4 ± 3.0 kg and 6.3 ± 2.9 kg, respectively. Weight of juveniles as a function of year class (Table 14; Figure 18) and sampling zone (Table 15) is provided below. Generally, weight decreased as a function of YrC. Unlike previous years, mean weight of YrC 2001 was larger than YrC 2002. Juveniles of wild origin were larger than all hatchery-reared fish, with the exception of a few individuals of YrC 2001 and 2006 (Figure 18). Weight of fish captured in sampling zone 3 (6.7 ± 3.1 kg) was larger than fish captured in zone 1 (6.3 ± 2.9 kg), zone 2 (6.2 ± 3.0 kg), zone 4 (5.8 ± 2.5kg), and zone 5 (6.4 ± 3.2 kg; Table 15).

3.3.2.2.3 Relative Weight

Relative weight (W_r) for juveniles captured within Canada during the spring and fall 2017 stock assessments was 80.6 ± 9.6 and 80.1 ± 9.4 (Table 16), respectively. Generally, W_r was similar among all year classes (Figure 18). Unlike the measurements of FL and weight, juveniles of wild origin had a similar W_r as hatchery-reared fish. Relative weight of juveniles were similar across zones (zone 1, 79.1 ± 10.1; zone 2, 82.4 ± 6.8; zone 3, 81.5 ± 7.3; zone 4, 86.3 ± 7.1; zone 5, 84.1 ± 6.5; Table 17).

Table 12. Mean ± SD fork length (cm) by brood year class of juvenile White Sturgeon captured in the Lower Columbia River during the 2013 through 2017 stock assessments. Year class of hatchery origin fish was determined by external mark of removed lateral scutes and PIT tag. Individuals 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.

Year Class	2013		2014		2015		2016		2017	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
2001	102.1 ± 11.7	98.9 ± 13.0	103.8 ± 10.0	104.4 ± 14.3	105.5 ± 10.3	103.1 ± 13.2	102.6 ± 12.5	100.4 ± 11.1	110.6 ± 15.5	105.2 ± 10.8
2002	104.4 ± 10.9	105.3 ± 10.1	109.5 ± 7.5	106.0 ± 7.9	104.8 ± 9.0	106.5 ± 6.6	106.9 ± 8.3	107.4 ± 7.9	103.6 ± 8.5	104.9 ± 8.8
2003	89.0 ± 15.6	91.6 ± 13.1	104.5 ± 16.9	95.2 ± 7.1	96.2 ± 8.7	101.8 ± 12.3	100.2 ± 9.1	100.8 ± 11.1	94.9 ± 8.4	98.2 ± 10.8
2004	85.6 ± 12.1	90.5 ± 11.1	94.8 ± 10.6	98.6 ± 10.8	93.4 ± 8.3	101.5 ± 8.4	98.8 ± 8.0	98.3 ± 11.7	95.8 ± 8.6	98.7 ± 12.0
2005	-	80.8 ± 9.6	86.8 ± 5.5	87.1 ± 7.8	88.3 ± 7.1	88.6 ± 8.1	92.1 ± 7.7	89.3 ± 8.0	94.5 ± 8.6	92.6 ± 10.1
2006	-	83.1 ± 8.0	82.3 ± 3.2	90.1 ± 7.9	86.8 ± 4.5	92.6 ± 6.7	90.0 ± 7.0	92.5 ± 6.8	88.5 ± 6.6	93.5 ± 10.7
2007	-	70.8 ± 4.0	80.3 ± 0.4	80.6 ± 9.3	82.3 ± 6.1	88.8 ± 8.4	87.9 ± 8.6	86.3 ± 9.3	94.8 ± 16.5	85.7 ± 7.8
2008	-	-	-	80.5 ± 7.1	77.2 ± 5.5	86.8 ± 8.0	86.0 ± 3.2	87.8 ± 10.1	78.9 ± 7.8	93.0 ± 9.8
2009	-	-	-	68.4 ± 7.1	-	77.3 ± 5.5	74.5 ± 9.0	79.4 ± 9.6	73.6 ± 3.5	90.7 ± 13.7
2010	-	-	-	-	-	77.7 ± 2.1	-	71.4 ± 4.3	-	87.3 ± 7.1
2011	-	-	-	-	-	-	-	67.5 ± 2.4	-	78.2 ± 8.6
2012	-	-	-	-	-	-	-	-	-	70.5 ± 0.0
2013	-	-	-	-	-	-	-	53.5 ± 0.0	-	-
Wild	131.0 ± 12.7	140.9 ± 5.7	145.0 ± 2.8	130.4 ± 13.4	142.7 ± 11.8	119.9 ± 34.9	134.8 ± 9.4	141.2 ± 4.2	139.0 ± 0.0	132.3 ± 8.1
Total	102.3 ± 14.7	93.4 ± 16.5	103.8 ± 13.0	97.1 ± 15.5	99.6 ± 14.5	98.2 ± 13.6	99.2 ± 12.5	96.6 ± 14.3	98.3 ± 14.2	97.8 ± 12.6

Table 13. Mean (±SD) fork length (FL; cm) of juvenile White Sturgeon captured in the 5 sampling zones of the Lower Columbia River during the 2013 through 2017 stock assessments. Sampling zones represent 11.2 km increments starting from Hugh L. Keenleyside Dam and moving downstream to the US Border.

Zone	2013		2014		2015		2016		2017	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
1	107.1 ± 13.1	99.1 ± 14.5	106.7 ± 12.4	100.1 ± 13.1	99.9 ± 13.7	100.5 ± 12.1	96.8 ± 13.1	99.4 ± 11.8	98.5 ± 13.7	98.3 ± 12.2
2	87.8 ± 10.6	89.3 ± 11.5	91.8 ± 7.9	97.3 ± 18.6	97.6 ± 16.7	96.1 ± 10.5	101.0 ± 15.1	97.2 ± 12.8	90.2 ± 11.4	99.1 ± 12.1
3	94.5 ± 22.6	81.2 ± 13.1	-	90.5 ± 13.9	108.9 ± 28.7	99.2 ± 15.0	100.0 ± 16.4	104.9 ± 10.0	112.1 ± 20.5	97.2 ± 12.6
4	95.5 ± 0.7	80.9 ± 15.3	-	88.0 ± 31.8	-	94.6 ± 21.6	88.2 ± 17.4	94.5 ± .7	109.5 ± 0.0	91.3 ± 15.0
5	94.3 ± 18.3	85.9 ± 19.6	90.2 ± 10.4	80.1 ± 10.7	83.3 ± 1.3	87.3 ± 14.6	86.3 ± 9.9	97.5 ± 21.7	111.3 ± 13.1	95.0 ± 14.9
Total	102.3 ± 14.7	93.4 ± 16.5	103.8 ± 13.0	97.1 ± 15.5	99.6 ± 14.5	98.2 ± 13.6	99.2 ± 12.5	96.6 ± 14.3	98.3 ± 14.2	97.8 ± 12.6

Table 14. Mean (±SD) weight (kg) of juvenile White Sturgeon captured in the Lower Columbia River during the 2013 through 2017 stock assessments. Year class of hatchery origin fish was determined by external mark of removed lateral scutes and PIT tag. Individuals 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.

Year Class	2013		2014		2015		2016		2017	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
2001	7.2 ± 2.0	6.9 ± 2.4	7.7 ± 2.4	8.2 ± 3.9	8.1 ± 2.3	7.6 ± 3.0	7.6 ± 3.6	7.1 ± 2.5	9.0 ± 4.2	7.9 ± 3.0
2002	7.7 ± 2.0	7.5 ± 2.1	8.6 ± 1.8	8.0 ± 1.8	7.7 ± 2.2	7.7 ± 1.5	8.1 ± 2.2	8.3 ± 2.1	7.3 ± 1.8	7.4 ± 1.9
2003	4.3 ± 2.2	5.3 ± 2.3	7.9 ± 3.6	5.5 ± 1.2	5.9 ± 1.8	7.0 ± 2.6	6.8 ± 2.0	7.0 ± 2.8	5.7 ± 1.7	6.3 ± 2.5
2004	4.2 ± 2.1	4.6 ± 1.9	5.5 ± 1.7	5.9 ± 2.0	5.4 ± 1.6	6.5 ± 1.9	6.1 ± 1.8	6.0 ± 2.7	5.5 ± 1.5	6.0 ± 2.5
2005	-	3.4 ± 1.3	4.5 ± 1.0	4.1 ± 1.1	4.5 ± 1.3	4.5 ± 1.2	5.3 ± 1.6	4.7 ± 1.5	5.5 ± 1.6	5.3 ± 2.0
2006	-	3.7 ± 1.1	3.8 ± 0.0	4.7 ± 1.3	4.4 ± 0.8	5.1 ± 1.2	4.8 ± 1.2	5.1 ± 1.1	4.4 ± 0.9	5.4 ± 2.9
2007	-	2.0 ± 0.2	3.2 ± 0.6	3.2 ± 1.1	3.6 ± 0.7	4.6 ± 1.6	4.3 ± 1.2	4.1 ± 1.6	5.7 ± 3.5	3.9 ± 1.1
2008	-	-	-	3.2 ± 0.9	3.0 ± 1.0	3.9 ± 1.0	3.9 ± .5	4.1 ± 1.4	3.0 ± 1.0	5.5 ± 2.6
2009	-	-	-	1.9 ± 0.6	-	2.8 ± 0.7	2.7 ± .8	3.3 ± 1.4	2.4 ± 0.3	5.0 ± 2.7
2010	-	-	-	-	-	2.8 ± 0.2	-	2.1 ± .3	-	4.1 ± 0.8
2011	-	-	-	-	-	-	-	1.8 ± .3	-	3.2 ± 1.1
2012	-	-	-	-	-	-	-	-	-	2.1 ± 0.0
2013	-	-	-	-	-	-	-	0.78 ± 0.0	-	-
Wild	19.2 ± 11.1	20.6 ± 6.3	20.5 ± 2.1	15.1 ± 4.8	21.5 ± 5.3	13.4 ± 7.5	16.3 ± 4.0	17.8 ± 1.9	19.1 ± 0.0	16.6 ± 6.2
Total	7.7 ± 4.2	5.8 ± 3.6	7.7 ± 3.1	6.3 ± 3.5	7.0 ± 3.9	6.4 ± 2.9	6.7 ± 3.0	6.2 ± 3.0	6.4 ± 3.0	6.3 ± 2.9

Table 15. Mean (±SD) weight (kg) of juvenile White Sturgeon captured in the sampling zones of the Lower Columbia River during the 2013 through 2017 stock assessments. Sampling zones represent 11.2 km increments starting from Hugh L. Keenleyside Dam and moving downstream to the US Border.

Zone	2013		2014		2015		2016		2017	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
1	8.8 ± 4.5	6.5 ± 2.8	8.3 ± 3.1	6.8 ± 3.2	7.0 ± 3.5	6.6 ± 2.5	6.6 ± 2.6	5.9 ± 2.6	6.3 ± 2.8	6.3 ± 2.9
2	4.6 ± 1.6	5.0 ± 2.1	5.5 ± 1.8	6.7 ± 4.6	6.7 ± 4.7	5.8 ± 2.0	6.7 ± 2.7	7.5 ± 3.5	5.0 ± 2.1	6.7 ± 3.1
3	6.5 ± 4.0	4.0 ± 2.3	-	5.2 ± 2.6	10.6 ± 9.5	6.9 ± 3.5	8.4 ± 2.6	7.3 ± 3.9	10.7 ± 5.3	6.1 ± 2.4
4	5.9 ± 0.3	3.7 ± 2.3	-	5.7 ± 6.9	-	6.7 ± 5.6	5.8 ± .1	5.1 ± 2.6	7.6 ± 0.0	5.6 ± 2.6
5	5.3 ± 3.2	5.2 ± 6.2	4.9 ± 1.7	3.4 ± 1.6	3.5 ± 0.2	4.9 ± 3.6	7.4 ± 7.1	4.4 ± 1.5	9.6 ± 4.7	6.2 ± 3.1
Total	7.7 ± 4.2	5.8 ± 3.6	7.7 ± 3.1	6.3 ± 3.5	7.0 ± 3.9	6.4 ± 2.9	6.7 ± 3.0	6.2 ± 3.0	6.4 ± 3.0	6.3 ± 2.9

Table 16. Mean (±SD) relative weight (W_r) of juvenile White Sturgeon by brood year class captured in the Lower Columbia River during the 2013 through 2017 stock assessments. Year class of hatchery origin fish was determined by external mark of removed lateral scutes and PIT tag. Individuals 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.

Year Class	2013		2014		2015		2016		2017	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
2001	83.4 ± 8.2	84.7 ± 9.3	83.7 ± 6.7	83.9 ± 8.4	83.0 ± 5.6	83.0 ± 7.2	84.1 ± 13.7	84.5 ± 8.4	82.8 ± 19.1	82.0 ± 8.4
2002	82.0 ± 8.0	77.9 ± 6.1	80.1 ± 7.3	81.6 ± 5.9	81.3 ± 7.3	78.6 ± 7.9	81.0 ± 11.5	80.9 ± 14.4	80.1 ± 5.4	77.8 ± 12.3
2003	75.4 ± 1.6	84.0 ± 5.3	83.1 ± 9.0	80.2 ± 6.6	81.6 ± 7.2	79.5 ± 5.9	82.5 ± 7.1	82.4 ± 7.8	81.6 ± 6.4	79.8 ± 6.4
2004	81.4 ± 8.6	76.1 ± 7.2	81.0 ± 6.2	75.5 ± 5.4	83.6 ± 8.9	75.8 ± 6.1	78.6 ± 14.0	75.3 ± 7.1	77.5 ± 4.2	76.0 ± 6.6
2005	-	82.7 ± 8.3	87.1 ± 2.5	79.3 ± 6.8	83.1 ± 10.9	81.1 ± 7.3	85.5 ± 15.6	82.5 ± 5.3	81.1 ± 3.5	82.6 ± 5.1
2006	-	83.6 ± 8.0	89.1 ± 11.0	81.1 ± 7.9	86.0 ± 10.0	81.3 ± 5.3	84.3 ± 6.9	81.8 ± 7.0	81.4 ± 7.9	81.0 ± 7.4
2007	-	76.1 ± 8.2	81.5 ± 17.4	77.4 ± 8.0	84.7 ± 5.3	82.4 ± 11.4	80.0 ± 3.7	80.1 ± 7.0	79.5 ± 4.0	79.1 ± 7.0
2008	-	-	-	77.9 ± 4.3	83.8 ± 10.9	76.4 ± 5.1	79.7 ± 5.4	76.3 ± 9.3	78.0 ± 7.7	83.6 ± 26.9
2009	-	-	-	80.6 ± 7.6	-	78.0 ± 4.8	86.8 ± 14.7	84.2 ± 5.4	81.3 ± 5.1	79.4 ± 7.9
2010	-	-	-	-	-	78.5 ± 4.9	-	79.3 ± 6.4	-	78.8 ± 5.7
2011	-	-	-	-	-	-	-	81.7 ± 7.6	-	87.2 ± 3.6
2012	-	-	-	-	-	-	-	-	-	82.4 ± 0.0
2013	-	-	-	-	-	-	-	74 ± 0.0	-	-
Wild	94.7 ± 27.8	84.0 ± 16.7	77.3 ± 3.1	78.0 ± 10.0	83.9 ± 7.0	77.3 ± 8.9	77.1 ± 8.6	73.3 ± 8.9	82.8 ± 0.0	82.5 ± 15.0
Total	83.1 ± 9.6	81.4 ± 8.7	82.2 ± 7.2	80.3 ± 7.4	83.0 ± 7.8	80.3 ± 7.4	82.6 ± 12.0	81.0 ± 9.4	80.6 ± 9.6	80.4 ± 10.0

Table 17. Mean relative weight (W_r) of juvenile White Sturgeon by sampling zone in the Lower Columbia River captured during the 2013 through 2017 stock assessment. Sampling zones represent 11.2 km increments starting from Hugh L. Keenleyside Dam and moving downstream to the US Border.

Zone	2013		2014		2015		2016		2017	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
1	83.5 ± 9.8	79.1 ± 6.2	81.1 ± 6.8	79.7 ± 7.0	83.3 ± 7.7	78.5 ± 6.5	81.0 ± 12.7	78.4 ± 9.5	80.3 ± 10.1	78.4 ± 10.1
2	85.7 ± 11.4	84.9 ± 9.1	87.2 ± 7.8	81.2 ± 8.8	81.3 ± 9.4	80.5 ± 8.9	87.9 ± 8.2	84.9 ± 8.2	81.6 ± 7.8	82.7 ± 6.4
3	91.7 ± 10.1	89.6 ± 7.7	-	83.7 ± 7.3	82.1 ± 9.3	83.1 ± 6.8	87.2 ± 6.4	84.4 ± 7.5	84.7 ± 4.3	81.1 ± 7.6
4	86.0 ± 2.1	81.7 ± 9.6	-	81.2 ± 8.9	-	83.6 ± 11.6	88.1 ± .4	85.3 ± 9.2	70.7 ± 0.0	87.7 ± 5.4
5	73.5 ± 2.4	83.8 ± 12.1	84.3 ± 5.8	81.3 ± 7.3	79.4 ± 2.0	85.4 ± 6.7	85.2 ± 6.2	84.8 ± 7.0	81.5 ± 10.2	84.3 ± 6.3
Total	83.1 ± 9.6	81.4 ± 8.7	82.2 ± 7.2	80.3 ± 7.4	83.0 ± 7.8	80.3 ± 7.4	82.6 ± 12.0	81.0 ± 9.4	80.6 ± 9.6	80.1 ± 9.4

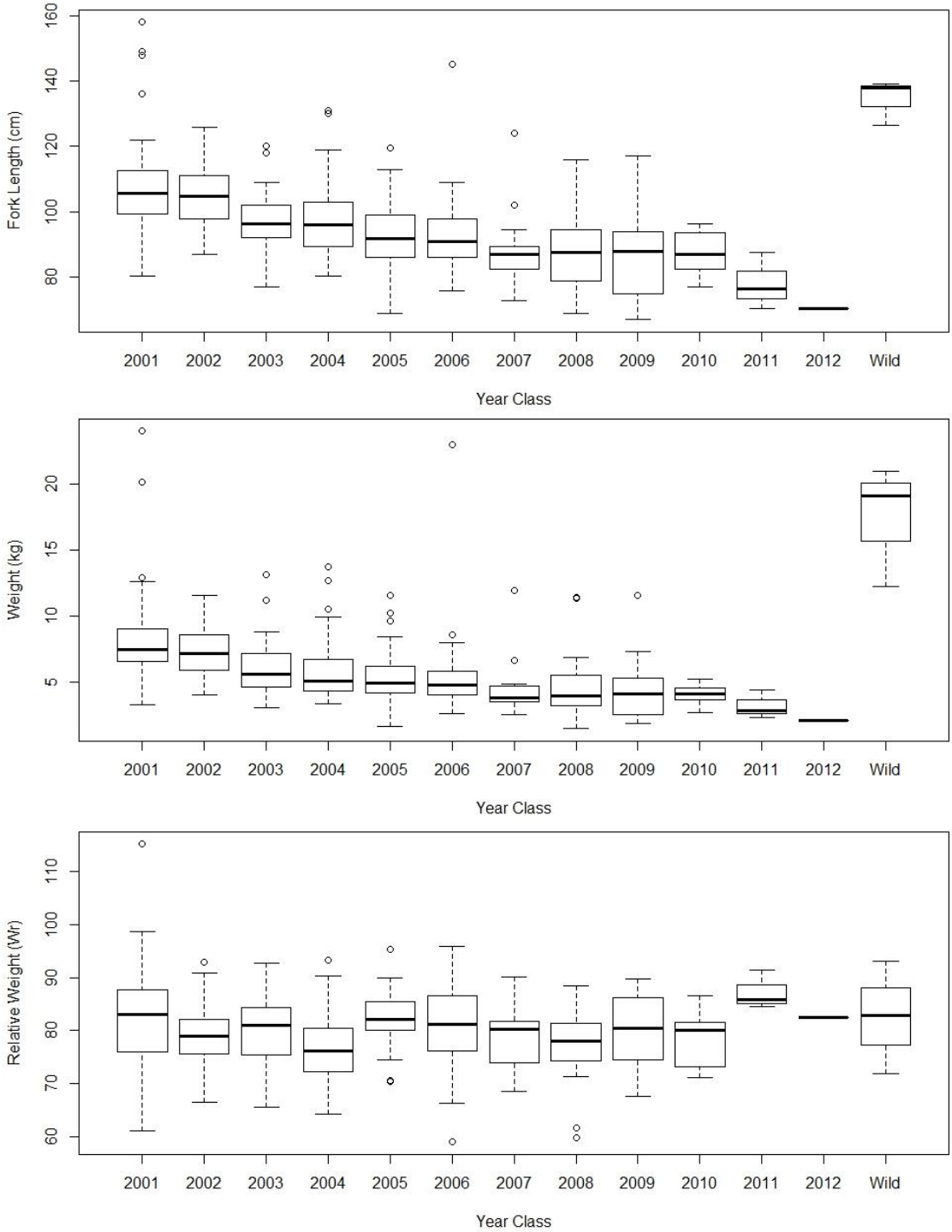

Figure 18. Fork length (cm), weight (kg) and relative weight (W_r) of juvenile White Sturgeon captured during stock assessments conducted in 2017. Biological data are presented as a function of year class in the Canadian portion of the Lower Columbia River. Year class of hatchery origin fish was determined by external mark of removed lateral scutes and PIT tag. Individuals 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.

3.3.2.2.4 Growth

The relationship that best described juvenile White Sturgeon length-at-age is shown in Figure 19, with length highly variable by age. Using the 2013-2017 stock assessment dataset, von Bertalanffy curves for length-at-age were developed for fish caught in Canada and the US, with US fish growing faster (Figure 20).

As with the length-at-age relationship, the weight-length relationship (Figure 21) predicted faster growth in fork length at younger ages (Figure 22) and faster growth in weight at later ages (Figure 23). The model results are similar to relationships present for the LCR in previous years (BC Hydro 2013a, BC Hydro 2015c, BC Hydro 2016c, BC Hydro 2017) and other White Sturgeon populations (Beamesderfer 1993).

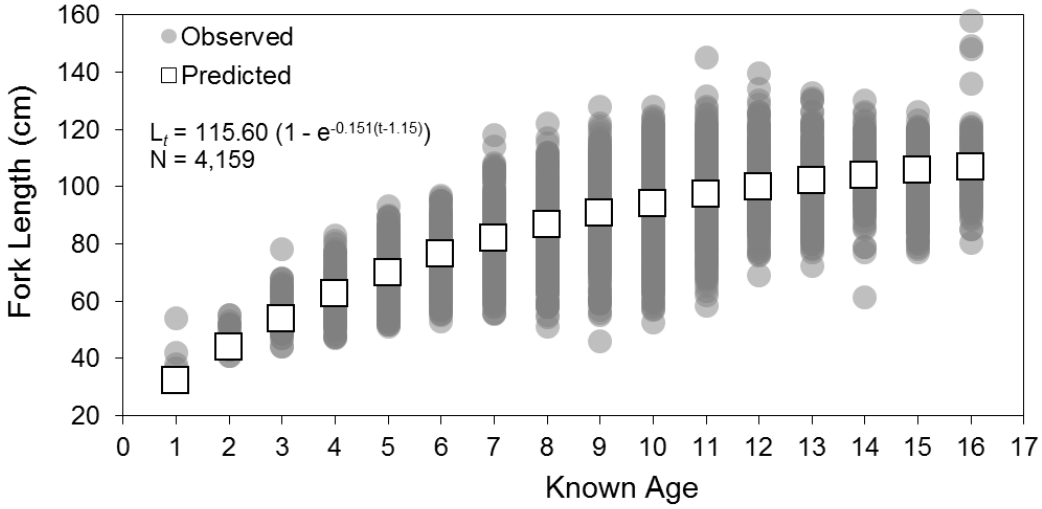

Figure 19. Length-at-age relationship and von Bertalanffy growth equation for known age hatchery-origin White Sturgeon captured in the Lower Columbia River from 2009 to 2017.

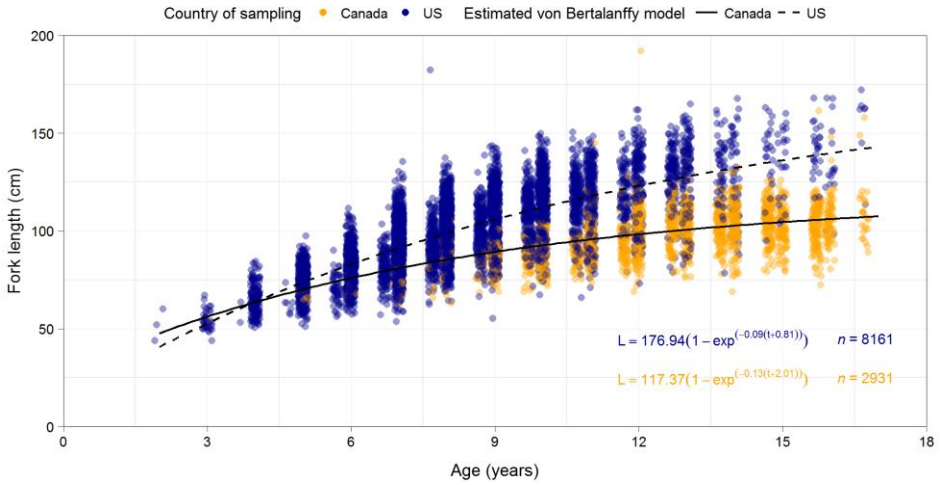

Figure 20. Fork length vs age of hatchery fish, with fitted von Bertalanffy curves by country of sampling. Data collected as part of the stock assessment program, 2013-2017.

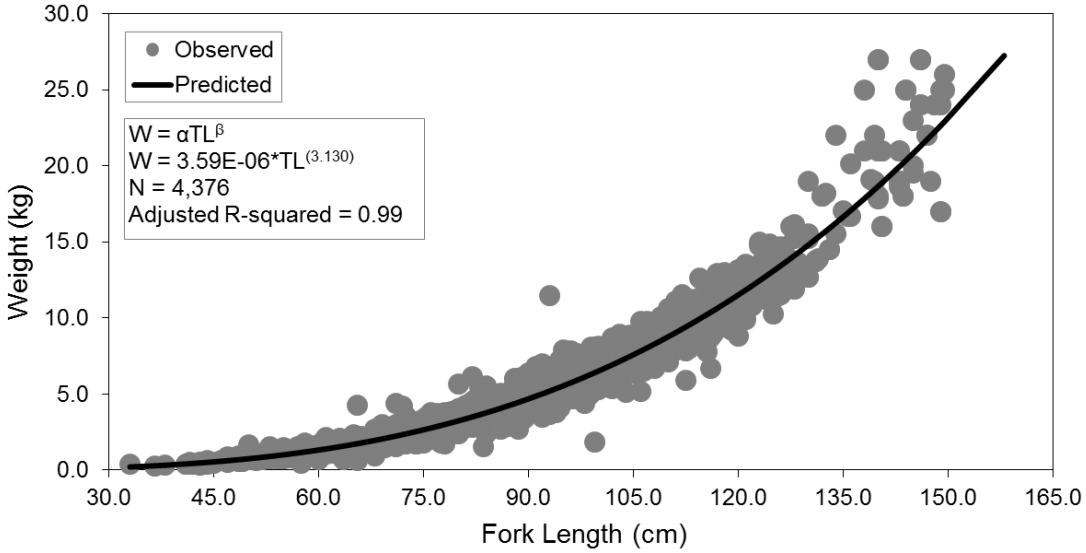

Figure 21. Observed and predicted weight-length relationship and equation for juvenile White Sturgeon captured in the Lower Columbia River from 2009 through 2017.

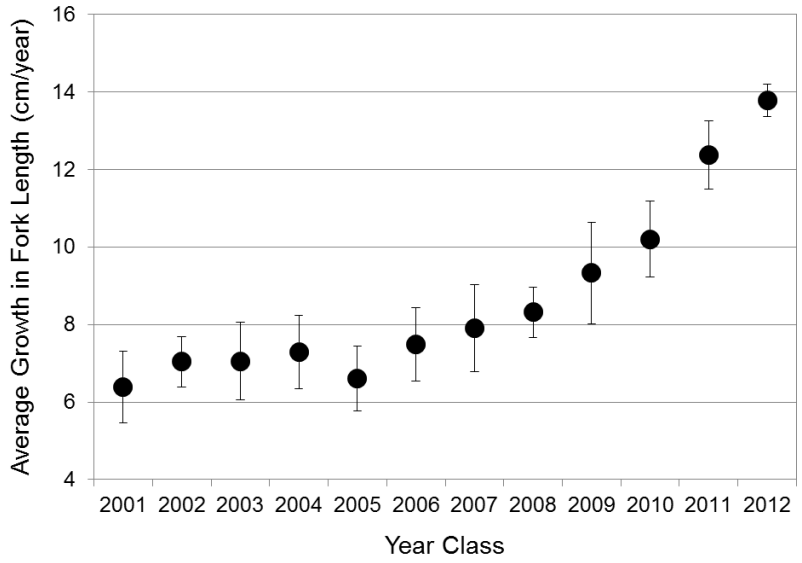

Figure 22. Fork length growth (cm/year) since release by brood year class for juvenile White Sturgeon captured in the Lower Columbia River in 2017. Year class of hatchery origin fish was determined by external mark of removed lateral scute and PIT tag. Insufficient captures for year classes greater than 2012 precluded calculations of growth.

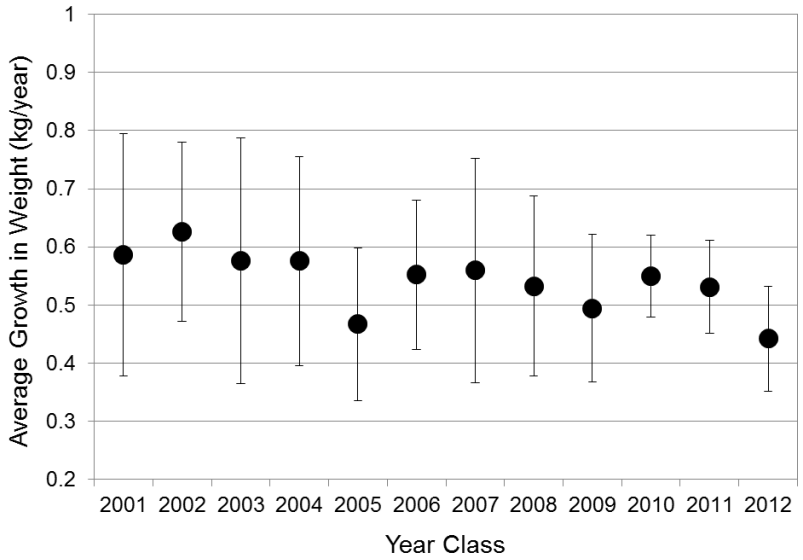

Figure 23. Growth (kg/year) in weight since release by brood year class for juvenile White Sturgeon captured in the Lower Columbia River in 2017. Year class of hatchery origin fish was determined by external mark of removed lateral scute and PIT tag. Insufficient captures for year classes greater than 2012 precluded calculations of growth.

3.3.3 Juvenile Survival and Abundance Estimates

The stock assessment data has been used to develop survival and abundance estimates for hatchery-origin and wild white sturgeon, though further refinements to the analyses are required. Results presented in BC Hydro 2018 found that the abundance of hatchery-origin sturgeon residing in the lower Columbia River was >6,000. The oldest year classes (2001 and 2002) are captured in higher numbers than all other year classes in Canada and have been diminishing in US captures over the past several years (Table 18; Figure 24). The effect of age of hatchery-reared fish age on recapture probability suggested that recapture probabilities increased with age in the spring in both US and Canada-released fish, across all five sampling years (Figure 25). In the fall, however, recapture probabilities were greater for younger fish in 2015-2017, but not in 2013-2014. Year class specific abundance estimates developed from models presented in BC Hydro 2018 show that the 2001 and 2002 year classes are increasing in estimated abundance over the period of the stock assessment while the remaining year classes are stable (Figure 26).

Table 18: Counts of hatchery-released year classes captured in the US and Canada during the stock assessment program by sampling year (values shown in Figure 24).

Country	Year class	Sampling year				
		2013	2014	2015	2016	2017
US	2001	113	90	37	42	23
US	2002	19	19	9	11	4
US	2003	94	83	67	57	31
US	2004	122	126	88	72	26
US	2005	177	168	142	79	55
US	2006	544	544	354	274	107
US	2007	188	276	239	195	132
US	2008	133	245	253	225	122
US	2009	45	94	121	118	79
US	2010	24	101	229	192	219
US	2011	1	5	8	16	21
US	2012	-	-	6	10	26
US	2013	-	-	2	2	5
Canada	2001	46	84	123	156	101
Canada	2002	46	88	109	116	88
Canada	2003	13	23	39	44	33
Canada	2004	16	40	48	74	51
Canada	2005	12	47	59	62	48
Canada	2006	30	31	52	81	59
Canada	2007	5	16	20	29	21
Canada	2008	1	11	8	20	26
Canada	2009	1	7	9	11	15
Canada	2010	-	-	3	6	6
Canada	2011	-	-	1	4	3
Canada	2012	-	-	-	-	1
Canada	2013	-	-	-	1	-

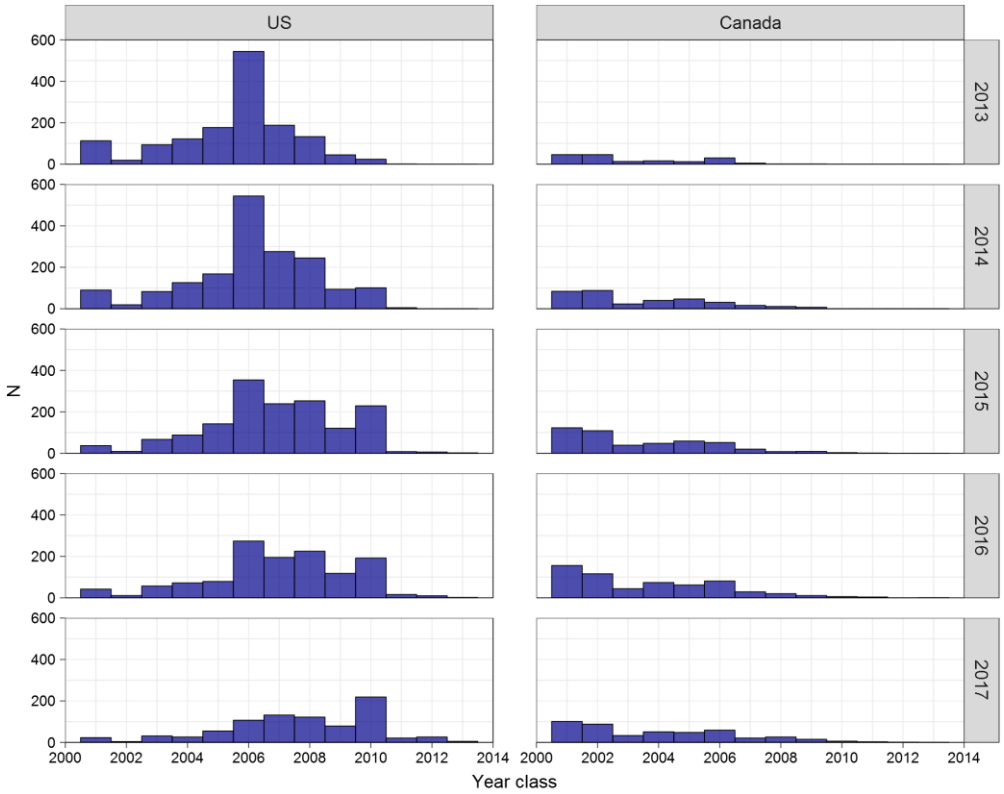

Figure 24: Distribution of year class information of hatchery-reared sturgeon, by year and country of sampling.

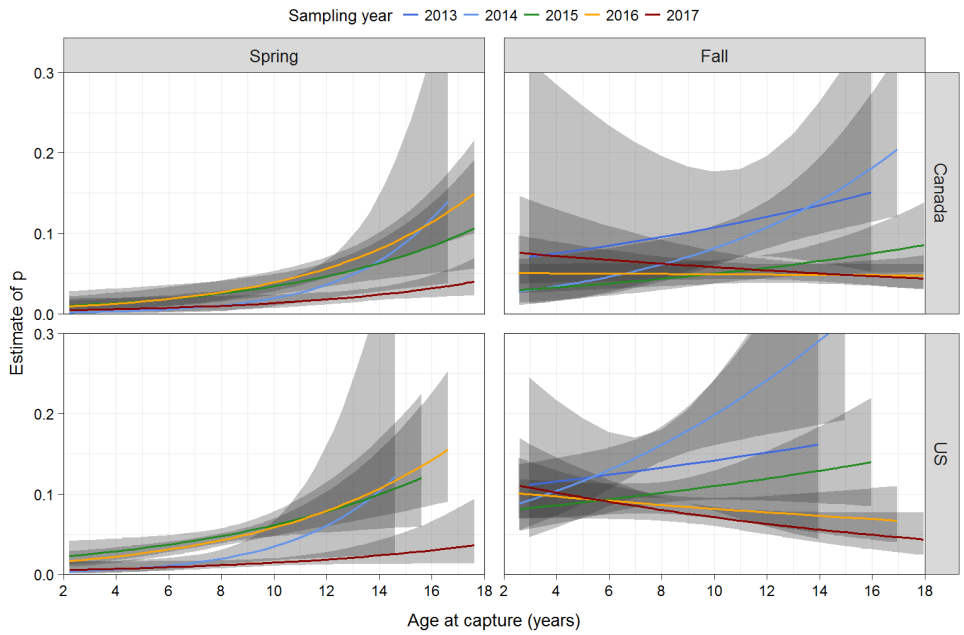

Figure 25: The effect of fish age on recapture probabilities between countries of original release (panels) and sampling years and seasons

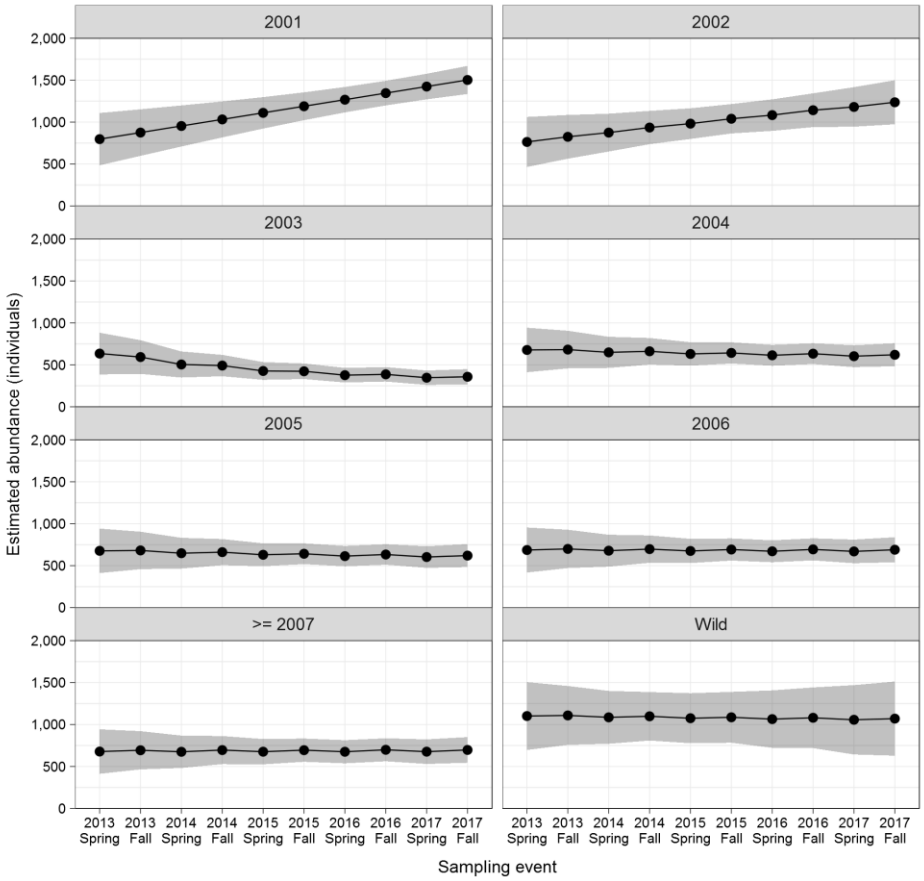

Figure 26: Estimated abundance of hatchery-origin white sturgeon in the Lower Columbia River, Canada by year class and wild. Abundances were developed using model results presented in BC Hydro (2018). Fish younger than 2007 year class had to be combined due to low recaptures.

3.3.4 Sex and Stage of Maturity

3.3.4.1 Fish Capture and Sampling

In 2017, juvenile sex assignment and biopsy sampling was completed in concurrence with the spring and fall stock assessments. Since fall 2015, assignment of sex has been conducted on 283 hatchery-origin white sturgeon across a range of age classes (Table 19). Sex was successfully assigned to 250 individuals resulting in 118 females and 132 males and one unknown based on visual examination and histology (Table 20; Figure 27 and 28). The sex ratio of 1.1 males to 1 female is slightly higher than reported for the wild population (1:1; BC Hydro 2015) in the lower Columbia River, Canada. For comparison, samples were also collected in the US portion of the Transboundary Reach. Sample sizes are reported in Table 21.

Table 19. Samples collected from 2015-2017 for hatchery-origin White Sturgeon for assignment of sex and stage of maturity including gonad biopsies and plasma for plasma sex steroid work.

Year	Year Class	Age	Gonad Biopsy Sample	Plasma
2015	2001	14	20	0
	2002	13	10	0
	2003	12	0	0
	2004	11	0	0
	2005	10	0	0
	2006	9	4	0
2016	2001	15	16	16
	2002	14	14	14
	2003	13	14	14
	2004	12	24	24
	2005	11	10	10
	2006	10	7	7
	2007	9	2	2
	2008	8	2	2
	2009	7	2	2
2017	2001	16	28	28
	2002	15	20	20
	2003	14	21	21
	2004	13	27	27
	2005	12	26	26
	2006	11	21	21
	2007	10	16	16

Table 20. Assignment of sex for hatchery-origin White Sturgeon by year class. Fish were captured in the Lower Columbia River in 2015 (fall), 2016 (spring and fall), and 2017. Year class of hatchery origin fish was determined by external mark of removed lateral scutes and PIT tag.

Year Class	Total	Assigned Sex	
		Female	Male
2001	54	25	29
2002	39	13	26
2003	33	18	15
2004	45	16	29
2005	30	18	12
2006	28	18	10
2007	17	8	9
2008	2	1	1
2009	2	1	1
Total	250	118	132

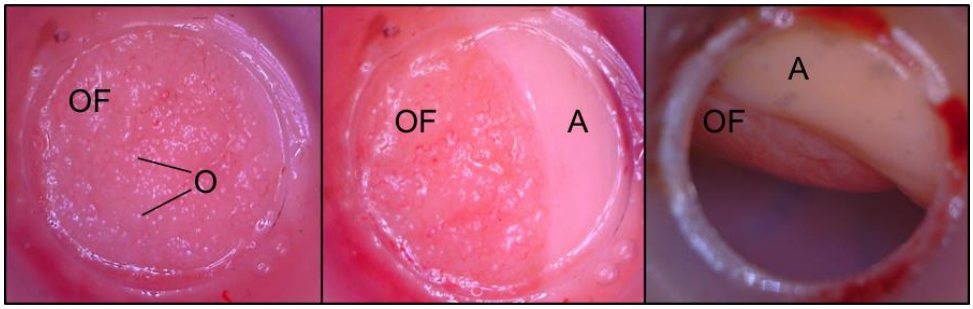

Figure 27. Endoscopic images of adipose tissue (A), ovigerous folds (OF) and small translucent oocytes (O) in pre-vitellogenic female juvenile White Sturgeons.

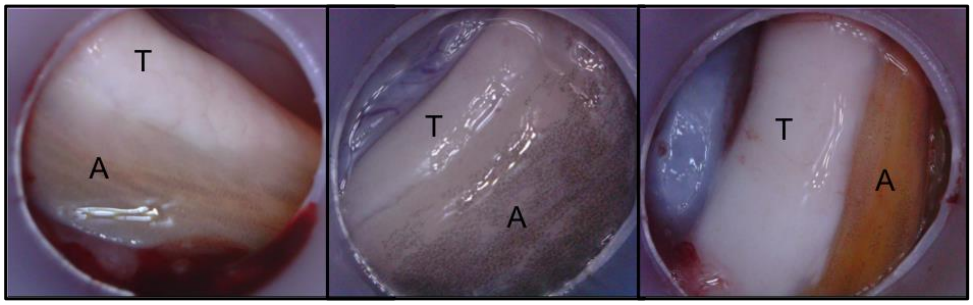

Figure 28. Endoscopic images of testicular tissue (T) and adipose tissue (A) in male juvenile White Sturgeon. Stage of maturity cannot be determined through visual examination.

In Canada, fork length and weight for all individuals sexed was 97.5 ± 11.3 cm and 6.2 ± 2.3 kg, respectively. Individuals assigned sex were similar in mean size with females (FL: 95.6 ± 11.2 cm; W: 5.9 ± 2.3 kg) being slightly smaller than males (FL: 99.4 ± 11.4 cm; W: 6.6 ± 2.4 kg). Samples collected from fish residing in the US for comparison were larger (Figure 29), though the difference in size wasn't related to the assigned sex of the individual (Figure 30).

Table 21. Samples collected for assignment of sex for hatchery-origin White Sturgeon in both Canada and the US, 2015-2017. Samples for both histology and plasma sex steroids (PSS) were collected.

Year	Location	Total	Spring	Fall	PSS	Histology	Females	Males	Intersex
2015	Canada	29		29	0	29	11	17	1
2016		67	63	4	67	67	35	32	
2017		129	63	66	129	129	64	65	
2015	US	43	12	31	43	43	20	23	
2016		56	15	41	56	56	28	28	
2017		6		6	6	6	5	1	
Total							163	166	1

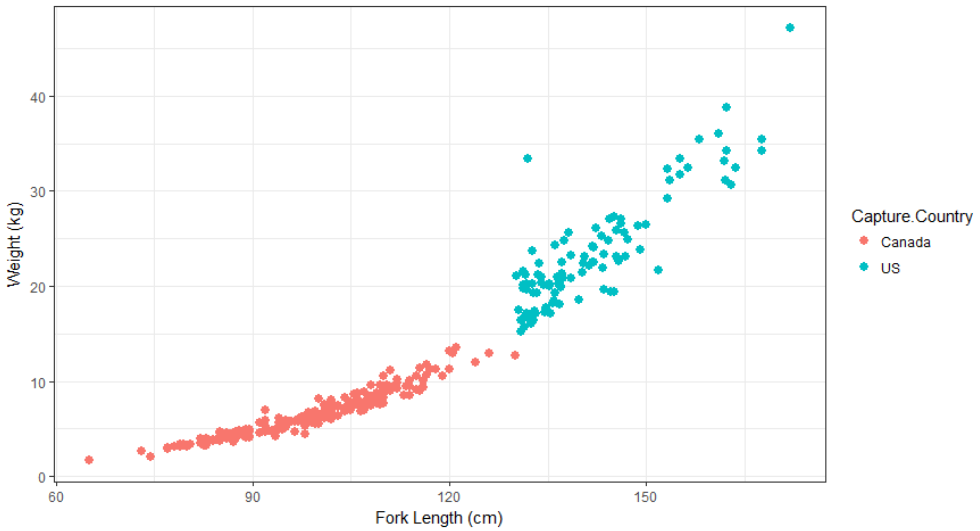

Figure 29. Weight-length for hatchery-origin collected in both Canada and the US for assignment of sex and stage of maturity, 2015-2017.

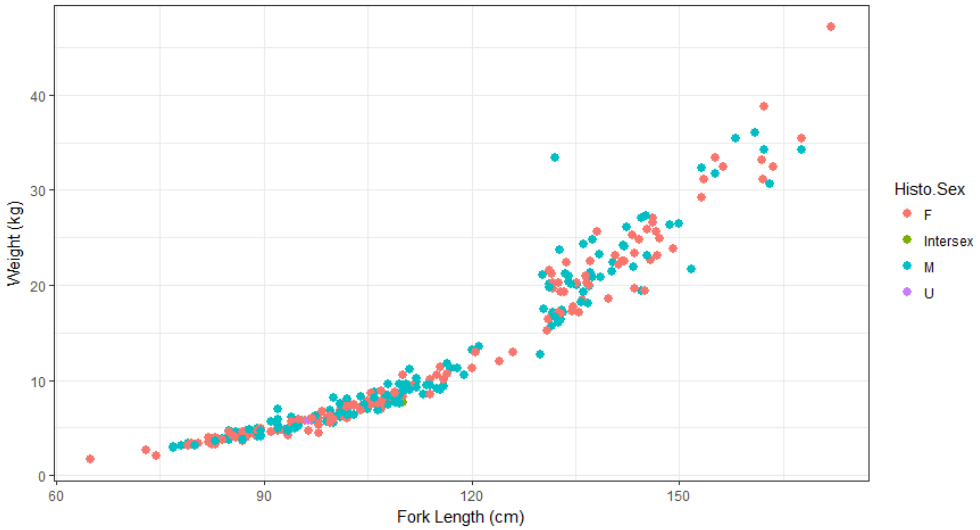

Figure 30. Weight-length by assigned sex for hatchery-origin white sturgeon collected in both Canada and the US for assignment of sex and stage of maturity, 2015-2017. Sex was assigned using histology as either female (F), Intersex, male (M), and unknown (U).

3.4 Habitat Mapping

Recorded images have been edited and processed identifying ten acoustic substrate classes. Detailed results of analyses are provided in Appendix 1 of BC Hydro 2015c. Image processing identified ten acoustic substrate classes. Ground truthing will be required to identify specific riverbed sediment types (e.g., cobble, gravel, sand) represented by each acoustic class. It is expected that results from CLBWORKS-27, underway in 2018, will help inform habitat mapping.

4 DISCUSSION

While this report is primarily a data report, general discussion points are provided for each of the main areas of this monitoring program. Results are discussed in the context of the monitoring program objectives; however they should be interpreted with caution as they represent ongoing analyses. 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 and answer the management questions 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., temperature, flows; Parsley and Beckman 1994). Based on developmental stages of collected yolk-sac larvae, spawning was

estimated to have occurred over a 3 week period in mid-June to early July downstream of Waneta and over only a few days in mid-July downstream of ALH and Kinnaird in 2017. 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 14ºC.

In 2017, larvae were again collected within the vicinity of Kinnaird, which has now had spawning documented annually since 2007 and is an area that requires additional monitoring to further describe where spawning may be occurring (Fisheries and Oceans 2014). Despite annual monitoring since 2007, the exact location of the spawning area (embryo deposition and larval hiding habitat) remains unknown and is the focus of this component of the program. 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 where larvae are dispersing from (Figure 6). .

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 (<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 is being conducted in 2018 as part of new substrate restoration feasibility study being conducted under the Columbia Water Use Plan. Results are expected to inform this program. Lastly, it will be important to incorporate results from larval monitoring programs in the US section of the TBR, 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) could determine the proportion of larvae that originated from the Waneta location and should be considered if data are available in future years.

4.2 Juvenile Assessment

For approximately the last 40 years, recruitment of White Sturgeon in the Transboundary Reach (TBR) of the Columbia River (Hugh L. Keenleyside Dam (HLK) to Grand Coulee Dam (GCD) in WA, USA) 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 White Sturgeon. While survival of hatchery-origin fish has been high, certain year classes are in higher abundance than others, including the wild population. Many of these year classes represent relatively few wild parents, resulting in reduced genetic diversity relative to the original goals. The sex and stage of maturity component of this monitoring program will be important as results are finalized as it is critical to understand when these fish will start to reproduce with the existing wild spawners as genetic swamping is a critical risk given the number of hatchery fish at large. Based on visual examination in 2015, 2016, and 2017, both females and males were at early developmental stages in Canada and no fish are expected to spawn in the coming year. However, this will be confirmed with histology of collected gonadal tissue and measurement of plasma sex steroids. Importantly, the development of non-invasive methods to determine sex of hatchery origin fish will be an important monitoring component going forward to track when they enter the breeding population. Data on sex and stage of maturity 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 in recent decades and remain lacking in many sturgeon populations throughout the world. Significant learnings about habitat use, growth, diet (details in Crossman et al. 2016), and survival (BC Hydro 2016c; BC Hydro 2018) have been made that not only inform recovery for Upper Columbia White Sturgeon, but other species in North America. While this program serves as a means of detecting wild juveniles, they remain rarely encountered and represent < 1% of the total catch in the stock assessment program to date. 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 river and become more isolated further downstream (e.g., Kootenay River confluence to the 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 (described in BC Hydro, 2013b, 2015a, and 2015b).

5 RECCOMENDATIONS

The following recommendations are based on sampling results from the first five years of project implementation. Specific recommendations are provided for larval, juvenile, and habitat sampling.

5.1 Larval Sampling

- Larval sampling should continue to occur annually at the HLK/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., HLK/ALH spawning area).

5.2 Juvenile Sampling

- 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 White Sturgeon of hatchery origin 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 setlines 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.

- Determine sex and stage of maturity for the hatchery population, 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 Habitat Mapping

- Continue to develop a habitat map for the entire LCR. Validate side scan sonar data collected in years 2 and 3 of this study using videography or physical substrate collection (e.g., ponar grabs).

- Describe the spawning and early life stage habitat at key spawning locations (e.g., HLK/ALH and Kinnaird locations). Focus should be given to determining the suitability of the immediate larval hiding habitat and downstream rearing habitat.

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